

N00174.AR.001468  
NSWC INDIAN HEAD  
5090.3a

FINAL TIER 2 SAMPLING AND ANALYSIS PLAN (FIELD SAMPLING PLAN AND QUALITY  
ASSURANCE PROJECT PLAN) REMEDIAL INVESTIGATION SITE 67 HOG OUT FACILITY  
NSWC INDIAN HEAD MD  
07/01/2013  
TETRA TECH INC

## TITLE AND APPROVAL PAGE

(UFP-QAPP Manual Section 2.1 and UFP-QAPP Workbook Worksheet [WS] #1)

**Final**

### **Tier 2 Sampling and Analysis Plan** (Field Sampling Plan and Quality Assurance Project Plan)

#### **Remedial Investigation**

#### **Site 67 – Hog-Out Facility**

#### **Naval Support Facility Indian Head Indian Head, Maryland**

**Prepared for:**

Naval Facilities Engineering Command Washington  
1314 Harwood Street, S.E.  
Washington Navy Yard, D.C. 20374-5018

**Prepared by:**

Tetra Tech, Inc.  
234 Mall Boulevard, Suite 260  
King of Prussia, Pennsylvania 19406

**Prepared under:**

Contract No. N62470-08-D-1001  
Contract Task Order JU11

Approval Signatures:

\_\_\_\_\_  
Ed Corack, P.E. – PM, Tetra Tech

\_\_\_\_\_  
Date

\_\_\_\_\_  
Tom Johnston, Ph.D. – QAM, Tetra Tech

\_\_\_\_\_  
Date

\_\_\_\_\_  
Joe Rail, P.E. – Navy RPM

\_\_\_\_\_  
Date

\_\_\_\_\_  
Jan Nielsen – Navy QAO/Chemist

\_\_\_\_\_  
Date



## TITLE AND APPROVAL PAGE

(UFP-QAPP Manual Section 2.1 and UFP-QAPP Workbook Worksheet [WS] #1)

**Pre-Draft**

### **Tier 2 Sampling and Analysis Plan** (Field Sampling Plan and Quality Assurance Project Plan)

### **Remedial Investigation**

### **Site 67 – Hog-Out Facility**

### **Naval Support Facility Indian Head** Indian Head, Maryland

**Prepared for:**

Naval Facilities Engineering Command Washington  
1314 Harwood Street, S.E.  
Washington Navy Yard, D.C. 20374-5018

**Prepared by:**

Tetra Tech, Inc.  
234 Mall Boulevard, Suite 260  
King of Prussia, Pennsylvania 19406

**Prepared under:**

Contract No. N62470-08-D-1001  
Contract Task Order JU11

**Approval Signatures:**

\_\_\_\_\_  
Ed Corack, P.E. – PM, Tetra Tech

\_\_\_\_\_  
Date

\_\_\_\_\_  
Tom Johnston, Ph.D. – QAM, Tetra Tech

\_\_\_\_\_  
Date

\_\_\_\_\_  
Joe Rail, P.E. – Navy RPM

\_\_\_\_\_  
Date

NIELSEN.JANICE.L.106994  
3540

Digitally signed by NIELSEN.JANICE.L.1069943540  
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI,  
ou=USN, cn=NIELSEN.JANICE.L.1069943540  
Date: 2012.11.26 07:08:05 -05'00'

\_\_\_\_\_  
Jan Nielsen – Navy QAO/Chemist

\_\_\_\_\_  
Date



## EXECUTIVE SUMMARY

This Uniform Federal Policy (UFP) Sampling and Analysis Plan (SAP) (Navy "Tier 2" format) has been prepared for Naval Facilities Engineering Command (NAVFAC) Washington by Tetra Tech, Inc. (Tt) under the *Comprehensive Long-Term Environmental Action Navy (CLEAN)* Contract No. N62470-08-D-1001, Contract Task Order (CTO) JU11. This UFP-SAP provides the site/project-specific work plan components for the Remedial Investigation (RI) at *Site 67 – Hog-Out Facility* (the site) at Naval Support Facility (NSF) Indian Head (NSF-IH) (the base or facility) in Indian Head, Maryland. This SAP will be accompanied in the field by the *Health and Safety Plan (HASP)* and the *NSF-IH Master UFP-SAP* (Tt, 2009).

Site 67 – Hog-Out Facility is located on the southeast side of Naval Support Facility (NSF) Indian Head (NSF-IH) bordered by Mattawoman Creek ([Figures 1 and 2](#)). NSF-IH is on the U.S. Environmental Protection Agency's (EPA's) National Priorities List (NPL). The site is described as having perchlorate-contaminated groundwater resulting from historical site practices at Building 1419 ([Figure 3](#)), which consisted of cleaning out (hogging out) solid propellant from various devices, including rockets and Jet-Assisted Take-Off (JATO) ejection seat motors (Tetra Tech, 2011 and 2012). The 2-acre grassy site contains a small drum storage building (Building 1861) ([Figures 3 and 4](#)). Direct dumping of the hog-out wastewater occurred from the 1960s to 1996 (Tt, 2009). Hog-out operations continue, but wastewaters now are drummed, characterized, handled, and disposed appropriately (NSF-IH, 2006). Operations at Building 1219 can also include some ordnance handling and storage.

The water table of the unconfined surficial aquifer at Site 67 varies seasonally from 6 to 10 feet (ft) below ground surface (bgs) in response to precipitation and evapotranspiration, and generally slopes similarly to the land surface topography toward Mattawoman Creek. Upland areas serve as groundwater recharge areas and low areas and the creek serve as groundwater discharge areas. Groundwater flow follows the surface topography at the site.

Site 67 has been studied previously several times by the Department of Defense (DoD) in order to research the impacts of perchlorate contamination to aquifer systems and receiving bodies, as well as means and methods of remediating said contamination. The studies were not conducted under the Navy's Environmental Restoration Program. However, they consisted of groundwater sampling and analysis for perchlorate and several other parameters to support study objectives, sediment, and surface water sampling, macrocosm (in situ) and microcosm (laboratory) studies of microbial communities, etc. Perchlorate mass flux and groundwater discharge evaluations were performed. Based in part on these studies, DoD published a guidance document on / protocol for monitored natural attenuation (MNA) of perchlorate in groundwater (Environmental Security Technology Certification Program [ESTCP], 2008).

Based on the research, lab results, field results, conclusions, and guidance presented in the previous studies, it is expected that perchlorate concentrations at Site 67 will decline via multiple natural attenuation mechanisms (e.g., biodegradation and dilution). However, groundwater concentrations of perchlorate may not reach an appropriate cleanup level<sup>1</sup> in a reasonable timeframe (not considering land use) via natural attenuation only.

While perchlorate contamination in the surficial aquifer is evident at the site, the lateral limits of the plume have not been delineated, and other potential site-related contaminants (e.g., phthalates, metals, and polycyclic aromatic hydrocarbons [PAHs]) have not been investigated. Further, the soil, sediment, and surface water media require Remedial Investigation (RI)-level study, and respective human health and

---

<sup>1</sup> The site-specific cleanup level for perchlorate (and any other contaminants) will be developed in the Feasibility Study (FS). The default groundwater perchlorate cleanup level is 15 µg/L in accordance with DoD and Navy policy (Navy, 2010) and the U.S. Environmental Protection Agency (EPA) January 2009 perchlorate Interim Drinking Water Health Advisory of 15 µg/L.

ecological risk assessments are required. Therefore, an RI is under way as described herein. A Feasibility Study (FS) likely will be performed to evaluate remedial alternatives for site cleanup.

The objectives of the investigation are as follows:

- Determine the nature and extent of perchlorate contamination and other site-related contaminants in groundwater, soil, sediment, and surface water.
- Determine if unacceptable risks to human health or ecological receptors are presented by site contaminants.
- Gather required information to complete the RI and support the follow-on FS.

Meeting these objectives and completing the RI fieldwork will require several field tasks and the use of multiple subcontractors as describe throughout this SAP. Field tasks include the following: utility clearance, soil borings, monitoring well installations, monitoring well groundwater sampling, surface and subsurface soil sampling, sediment and surface water sampling, surveying, management of investigation-derived waste (IDW), decontamination activities, and other related ancillary tasks. The following subcontractors will be required to complete the RI: utility clearance, drilling / direct push technology (DPT), survey, IDW management, and offsite laboratory services. Following offsite laboratory analysis of the various samples, the data will be validated, evaluated, and presented in the RI Report. The RI Report will be prepared consistent with Navy and EPA guidance and recent RI Reports for NSF-IH.

Data Quality Objectives (DQOs) have been identified or developed herein, including decision action limits and risk-based screening levels for each analyte. Samples in all media will be analyzed for perchlorate and other potential site-related contaminants, which have been selected via research on rocket motor materials: phthalates, PAHs, select metals, and select energetics/explosives (Tt, 2011). Other parameters and analyses (e.g., total organic carbon) detailed in this SAP will support the risk assessments and an evaluation of geochemical conditions at the site. In addition, groundwater will be tested for microbial genetic material indicative of conditions favorable for perchlorate biodegradation.

## TABLE OF CONTENTS

<b>TITLE AND APPROVAL PAGE</b> .....	<b>1</b>
<b>EXECUTIVE SUMMARY</b> .....	<b>3</b>
<b>TABLE OF CONTENTS</b> .....	<b>5</b>
<b>ACRONYMS AND ABBREVIATIONS</b> .....	<b>9</b>
<b>1 PROJECT ORGANIZATIONAL CHART</b> .....	<b>13</b>
<b>2 COMMUNICATION PATHWAYS</b> .....	<b>15</b>
<b>3 PROJECT PLANNING SESSION PARTICIPANTS SHEET(S)</b> .....	<b>17</b>
3.1 Partnering Team Scoping Session No. 1 .....	17
3.2 Tetra Tech Team Charter Meeting.....	19
3.3 Partnering Team Scoping Session No. 2.....	20
3.4 Partnering Team Scoping Session No. 3.....	21
<b>4 CONCEPTUAL SITE MODEL</b> .....	<b>23</b>
4.1 Site Description and History.....	23
4.2 Potential Sources of Contamination.....	26
4.3 Potential Contaminant Migration Mechanisms .....	27
4.4 Land Uses and Potential Exposure.....	29
<b>5 DATA QUALITY OBJECTIVES / SYSTEMATIC PLANNING PROCESS STATEMENTS</b> .....	<b>31</b>
5.1 Identification of Study Goals .....	31
5.2 Information/Decision Inputs .....	31
5.3 Boundaries of the Study.....	34
5.4 Analytic Approach .....	35
5.5 Performance Criteria .....	35
5.6 Plan for Obtaining Data.....	35
<b>6 FIELD QUALITY CONTROL SAMPLES</b> .....	<b>37</b>
<b>7 SAMPLING DESIGN AND RATIONALE</b> .....	<b>39</b>
7.1 Sampling Schedule .....	39
7.2 Sample Selection .....	39
7.3 Monitoring Well Construction Details.....	39
7.4 Sample Collection .....	39
7.5 Sample Rationale Table.....	41
<b>8 FIELD PROJECT IMPLEMENTATION</b> .....	<b>47</b>
8.1 Field Project Tasks.....	47
8.1.1 Mobilization/Demobilization .....	47
8.1.2 Utility Clearance .....	48
8.1.3 Field Monitoring / Equipment Calibration / Inspection .....	48
8.1.4 Surface Water Sampling .....	48

TABLE OF CONTENTS

8.1.5 Sediment Sampling .....	49
8.1.6 Surface Soil Sampling .....	49
8.1.7 Soil Borings and Subsurface Soil Sampling .....	49
8.1.8 Monitoring Well Installation.....	49
8.1.9 Water Level Measurements.....	50
8.1.10 Monitoring Well Sampling.....	50
8.1.11 IDW Management.....	50
8.1.12 Surveying.....	50
8.1.13 Field Equipment Decontamination Procedures .....	50
8.1.14 Field Documentation Procedures .....	51
8.1.15 Sample Custody and Shipment Tasks .....	51
8.2 Field SOPs Reference Table.....	51
8.3 Sample Details Table .....	52
8.4 Analytical SOP Requirements Table .....	55
8.5 Additional Project-Related Tasks .....	57
8.5.1 Analytical Tasks.....	57
8.5.2 Data Management .....	57
8.5.3 Project Reports.....	59
<b>9 REFERENCE LIMITS AND EVALUATION TABLES.....</b>	<b>61</b>
<b>10 ANALYTICAL SOP REFERENCES .....</b>	<b>71</b>
<b>11 LABORATORY QC SAMPLES TABLE .....</b>	<b>73</b>
<b>12 DATA VERIFICATION AND VALIDATION (STEPS I AND IIa/IIb) PROCESS TABLE .....</b>	<b>81</b>
12.1 Validation Summary .....	83
<b>REFERENCES .....</b>	<b>85</b>

*Sections in this document correspond to Navy Tier 2 SAP Section numbers as amended by Tetra Tech. Sections consisting of tabular content are not listed as individual tables in the Table of Contents. For formatting purposes, even-numbered pages at the end of a section may be blank such that the next section starts on an odd-numbered page. Any purposeful blank page is labeled, "This page left blank intentionally." Figures are provided at the end of the document. Exhibits (inset mini-figures and/or tabulated content) are provided throughout the text as indicated. Appendices are provided electronically, only. The entire document is provided as a bookmarked Portable Document Format (PDF) file on the accompanying disc.*

*Virtually all references are available for review in the Administrative Record for Naval Support Facility Indian Head; however, subject documents that may not be readily available are provided as an appendix or can be made available by request.*

**APPENDICES**

- A Supporting Information / Historical Documents
- B Fieldwork SOPs
- C Laboratory DoD ELAP Certifications

## **FIGURES**

- 1 Facility Location Map
- 2 Site Location
- 3 Site Plan – Aerial
- 4 Site Plan – Topography
- 5 Interpretive Three-Dimensional Conceptual Site Model
- 6 Exposure Pathway Analysis Conceptual Site Model
- 7 Proposed RI Sample Locations



## ACRONYMS AND ABBREVIATIONS

#	number
%	percent
°C	degree Celsius
°F	degree Fahrenheit
a.k.a.	also known as
AA	Atomic Absorption
amu	atomic mass unit
ANSI/ASQ	American National Standards Institute/American Society for Quality
ASTM	American Society for Standards and Materials
BERA	Baseline Ecological Risk Assessment
bgs	below ground surface
BTAG	[EPA Region 3] Biological Technical Assistance Group
c/o	care of
CAS	Chemical Abstract Service [Number]
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CD	chlorite dismutase
CFR	Code of Federal Regulations
CLEAN	Comprehensive Long-Term Environmental Action Navy
CLP	Contract Laboratory Program
CoC	chain-of-custody [form]
COC	Chemical of Concern
COMAR	Code of Maryland Regulations
COPC	Chemical of Potential Concern
COPEC	Chemical of Potential Ecological Concern
CRDL	Contract-Required Detection Limit
CSM	Conceptual Site Model
CTO	Contract Task Order
DAF	Dilution Attenuation Factor
DL	Detection Limit
DoD	Department of Defense
DCN	Document Control Number
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DPT	Direct Push Technology (a.k.a. Geoprobe®)
DQI	Data Quality Indicator
DQO	Data Quality Objective
DV	data validation
DVM	Data Validation Manager
eco	ecological
EDD	electronic data deliverable
ELAP	[DoD] Environmental Laboratory Accreditation Program
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ERA	ecological risk assessment
ERP	[Navy] Environmental Restoration Program
ESTCP	Environmental Security Technology Certification Program
FCR	Field Change Request
FID	flame ionization detector

ACRONYMS AND ABBREVIATIONS

---

FOL	Field Operations Leader
FS	Feasibility Study
FSP	Field Sampling Plan
ft	feet or foot
FTMR	Field Task Modification Request
g	gram(s)
GC	Gas Chromatograph
GC/MS	Gas Chromatograph/Mass Spectrometer
GC-FID	Gas Chromatograph – Flame Ionization Detector
GIS	Geographic Information System
GPC	Gel Permeation Chromatography
GPS	Global Positioning System
H&S	health and safety
HASP	Health and Safety Plan
HH	human health
HHRA	human health risk assessment
HI	Hazard Index
HMX	His/Her Majesty's Explosive (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)
HQ	Hazard Quotient
HPLC	High Pressure Liquid Chromatograph
IC	Ion Chromatograph
ICB	initial calibration blank
ICP	Inductively Coupled Plasma
ID	identification
IDQTF	Intergovernmental Data Quality Task Force
IDW	investigation-derived waste
ILCR	Incremental Lifetime Cancer Risk
IRP	[Navy] Installation Restoration Program
ITRC	Interstate Technology and Regulatory Council
JATO	Jet-Assisted Take-Off [motor]
kg	kilogram(s)
L	liter(s)
LANL	Los Alamos National Laboratory
LCS	Laboratory Control Sample
LFB	Laboratory Fortified Blank
LIMS	Laboratory Information Management Systems
LOD	Limit of Detection
LOQ	Limit of Quantification
MCL	Maximum Contaminant Level
µg	microgram(s)
µg/kg	microgram(s) per kilogram
µg/L	microgram(s) per liter
mg	milligram(s)
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
MCL	[federal] Maximum Contaminant Level
MDE	Maryland Department of Environment
mL	milliliter(s)
MS	Mass Spectrometry

MS	Matrix Spike
MSD	Matrix Spike Duplicate
msl	[above] mean sea level
mV	millivolt(s)
MPC	Measurement Performance Criteria
MQO	Measurement Quality Objectives
MDL	Method Detection Limit
MNA	monitored natural attenuation
MS	Matrix Spike
MSD	Matrix Spike Duplicate
MSR	Management Systems Review
NA or N/A	not applicable
NAVFAC	Naval Facilities Engineering Command
NEDD	NIRIS Electronic Data Deliverable
NIRIS	Navy Installation Restoration Information Solution
NIST	National Institute of Standards and Technology
No.	number
NOAA	National Oceanic and Atmospheric Administration
NOSSA	Naval Ordnance Safety and Security Activity
NPL	National Priorities List
NSF	Naval Support Facility
NSF-IH	Naval Support Facility Indian Head
NTU	Nephelometric Turbidity Unit
ORNL	Oak Ridge National Laboratory
ORP	oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency and Response
oz	ounce(s)
PAL	Project Action Limit
PAH	polycyclic aromatic hydrocarbon (or polynuclear aromatic hydrocarbon)
PARCC	Precision, Accuracy, Representativeness, Completeness, and Comparability
PDF	Portable Document Format
P.E.	Professional Engineer
P.G.	Professional Geologist
PID	photoionization detector
PM	Project Manager
PPE	personal protective equipment
PQL	Project Quantitation Limit
PQLG	Project Quantitation Limit Goal
PQO	Project Quality Objective
PRAP	Proposed Remedial Action Plan
PRP	Potentially Responsible Party
PRQL	Project-Required Quantitation Limit
PSL	Project Screening Limit
PT	Proficiency Testing (previously known as performance evaluation (PE) sample)
PVC	polyvinyl chloride
QA	Quality Assurance
QAM	Quality Assurance Manager
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QC	Quality Control
QL	Quantitation Limit

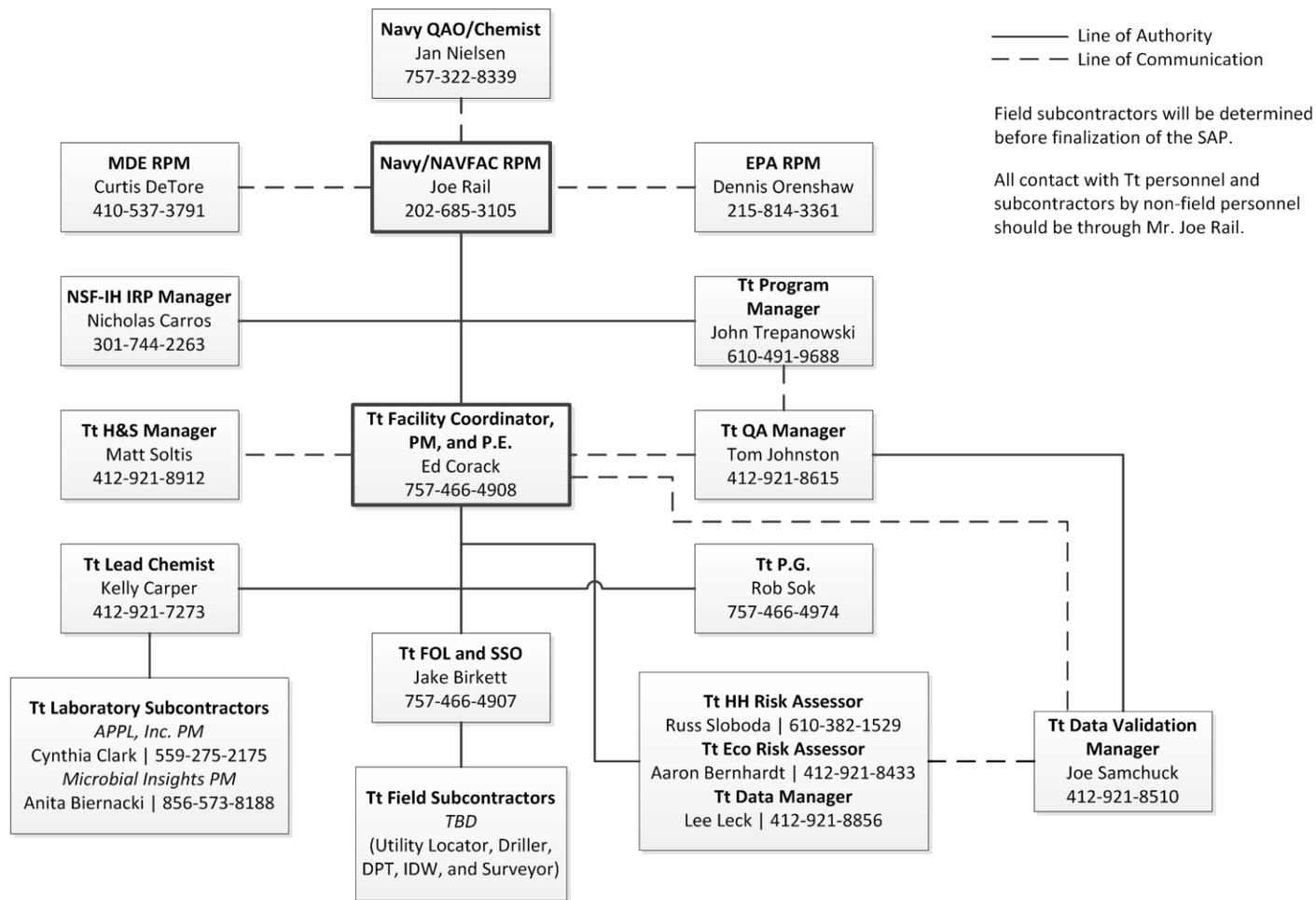
## ACRONYMS AND ABBREVIATIONS

---

qPCR	quantitative polymerase chain reaction
QS	Quality System
QSM	Quality Systems Manual
RAGS	[U.S. EPA] Risk Assessment Guidance for Superfund
RDX	Royal Demolition Explosive (hexahydro-1,3,5-trinitro-1,3,5-triazine)
RI	Remedial Investigation
RIC	Reconstructed Ion Chromatogram
RME	Reasonable Maximum Exposure
ROD	Record of Decision
RPD	Relative Percent Difference
RPM	Remedial Project Manager
RSD	Relative Standard Deviation
RSL	[EPA] Regional Screening Level
RT	Retention Time
SAP	Sampling and Analysis Plan
SDG	Sample Delivery Group
SERA	Screening Ecological Risk Assessment
SERDP	Strategic Environmental Research and Development Program
SOP	Standard Operating Procedure
SOW	scope of work (or statement of work)
SQL	Sample Quantitation Limit
SSL	Soil Screening Level
SVOC	semivolatile organic compound
TCLP	Toxicity Characteristic Leaching Procedure
TBD	To Be Determined
TOC	total organic carbon
Tt	Tetra Tech
UCL	upper confidence limit
U.S.	United States
UFP	Uniform Federal Policy
WS	worksheet

# 1 PROJECT ORGANIZATIONAL CHART

(UFP-QAPP Manual Section 2.4.1 and UFP-QAP Workbook WS #5)



———— Line of Authority  
 - - - - Line of Communication

Field subcontractors will be determined before finalization of the SAP.

All contact with Tt personnel and subcontractors by non-field personnel should be through Mr. Joe Rail.

**Notes:**

QA – Quality Assurance  
 RPM – Remedial Project Manager  
 H&S – Health and Safety  
 SSO – Site Safety Officer

QAO – Quality Assurance Officer  
 EPA – U.S. Environmental Protection Agency [Region 3]  
 PM – Project Manager  
 HH – Human Health  
 Eco – Ecological

MDE – Maryland Department of Environment  
 NSF-IH – Naval Support Facility Indian Head  
 P.E. – Professional Engineer  
 DPT – Direct Push Technology

NAVFAC – Naval Facilities Engineering Command  
 IRP – Installation Restoration Program  
 P.G. – Professional Geologist  
 IDW – Investigation-Derived Waste  
 TBD – To Be Determined

FOL – Field Operations Lead  
 Tt – Tetra Tech



## 2 COMMUNICATION PATHWAYS

(UFP-QAPP Manual Section 2.4.2 and UFP-QAPP Workbook WS #6)

Communication Drivers	Responsible Affiliation	Name	Phone Number	Procedure
Changes in schedule	Tetra Tech (Tt) PM Navy RPM	Ed Corack Joe Rail	757-466-4908 202-685-3105	Tt PM informs the Navy RPM via telephone within 1 day. Navy RPM informs Regulatory RPMs via email within 7 days.  Tt PM will document the changes within 5 days and send the Navy RPM a concurrence letter (or equivalent) within 7 days of identifying the need for change. Navy RPM will send scope change approval to Tt Program office before work is started.
Issues in the field that result in minor modifications of field methodology or sampling protocol	Tt FOL Tt PM	Jake Birkett Ed Corack	757-466-4907 757-466-4908	Tt FOL informs Tt PM/P.E. as soon as possible via phone, and Tt PM informs Navy RPM and Tt P.G. via email within 1 day Tt FOL documents in field log book. Navy RPM informs Regulatory RPMs via email within 7 days..
Field conditions that result in changes in scope of field work or major modifications in field methodology or sampling protocol	Tt FOL Tt PM	Jake Birkett Ed Corack	757-466-4907 757-466-4908	Tt FOL informs Tt PM/P.E. as soon as possible via phone. Tt PM informs the Navy RPM and Tt P.G. as soon as possible via phone. Tt FOL and PM prepare a field task modification request (FTMR) within 2 days, and Navy RPM provides request to Regulatory RPMs within 2 days via email.
Recommendation to stop work and initiate work upon corrective action	Tt FOL Tt PM Tt QA Manager Tt H&S Manager Navy RPM	Jake Birkett Ed Corack Tom Johnston Matt Soltis Joe Rail	757-466-4907 757-466-4908 412-921-8615 412-921-8912 202-685-3105	Responsible party immediately informs subcontractors, Navy, and Tt PM via phone and email. Navy RPM informs Regulatory RPMs via email.  Tt PM will inform Navy RPM (verbally or via email) by close of the next working day. Navy RPM will issue scope change approval (verbally or via email at RPM discretion). If warranted (as determined by the Navy RPM), scope change will be documented before work is executed. The Tt FOL will document the changes on a FTMR form within 2 days of identifying the need for change and obtain required approvals within five days of initiating the form.  If Tt is the responsible party for a stop work command, the Tt FOL will inform onsite personnel, subcontractor(s), the Navy RPM, and the Facility POC (NSF-IH IRP Manager) within 1 hour (verbally or by email). The Navy RPM will notify the Regulatory RPMs within 1 day. If a subcontractor is the responsible party, the subcontractor PM must inform the Tt FOL within 15 minutes, and the Tt FOL will then follow the procedure listed above.
Corrective Action for field program	Tt QA Manager Tt PM	Tom Johnston Ed Corack	412-921-8615 757-466-4908	Tt QA Manager will notify Tt PM via email within 1 day that the corrective action has been completed. Tt PM will then notify the Navy RPM via email within 1 day.
Field data quality issues	Tt FOL Tt PM	Jake Birkett Ed Corack	757-466-4907 757-466-4908	Tt FOL will inform Tt PM via phone or by email (at FOL discretion) on the same day that a field data quality issue is discovered.

2. COMMUNICATION PATHWAYS

Communication Drivers	Responsible Affiliation	Name	Phone Number	Procedure
Analytical data quality issues	APPL PM Microbial Insights PM Tt Project Chemist Tt DVM Tt PM Navy RPM	Cynthia Clark Anita Biernaki Kelly Carper Joe Samchuck Ed Corack Joe Rail	559-275-2175 865-573-8188 412-921-7273 412-921-8510 757-466-4908 202-685-3105	The Laboratory PM will notify (via phone or email) the Tt Project Chemist within 1 day of when an issue related to laboratory data is discovered.  The Tt Project Chemist will notify (via phone or or via email) the data validation staff and the Tt PM within 1 day.  Tt DVM or Project Chemist notifies Tt PM via phone or email within 48 hours of validation completion that a non-routine and significant laboratory quality deficiency has been detected that could affect this project and/or other projects. The Tt PM verbally advises the Navy RPM within 24 hours of notification from the Project Chemist or DVM. The Navy RPM takes corrective action that is appropriate for the identified deficiency. Examples of significant laboratory deficiencies include data reported that has a corresponding failed tune or initial calibration verification. In the event of a significant laboratory deficiency, the navy RPM should contact the Navy Chemist/QA Officer.

**Notes:**

Tt – Tetra Tech      PM – Project Manager      RPM – Remedial Project Manager      FOL – Field Operations Lead      QA – Quality Assurance      DV – Data Validation  
P.E. – Professional Engineer      P.G. – Professional Geologist      FTMR – Field Task Modification Request (or Field Change Request [FCR])  
APPL – Agriculture and Priority Pollutants Laboratory (Tt subcontractor analytical laboratory along with Microbial Insights)      DVM – Data Validation Manager      NAVFAC – Naval Facilities Engineering Command

### 3 PROJECT PLANNING SESSION PARTICIPANTS SHEET(S)

(UFP-QAPP Manual Section 2.5.1 and UFP-QAPP Workbook WS #9)

#### 3.1 Partnering Team Scoping Session No. 1

<b>Project Name:</b>	Site 67 Remedial Investigation (RI)	<b>Site Name:</b>	Site 67 – Hog-Out Facility		
<b>Projected Date(s) of Sampling:</b>	Fall 2011	<b>Site Location:</b>	Naval Support Facility Indian Head (NSF-IH)		
<b>Project Manager:</b>	Ed Corack, Tetra Tech (Tt)				
<b>Date of Session:</b>	May 11, 2011				
<b>Scoping Session Purpose:</b>	Initial scoping session for the RI at Site 67 c/o the Navy-format Uniform Federal Policy (UFP) Sampling and Analysis Plan (SAP) work plan.				
Name	Title	Affiliation	Phone #	E-mail Address	Project Role
Dennis Orenshaw	RPM	EPA Region 3	215-814-3361	orenshaw.dennis@epa.gov	Regulatory oversight
Curtis DeTore	RPM	MDE	410-537-3791	cdetore@mde.state.md.us	Regulatory oversight
Joe Rail	RPM	NAVFAC Washington	202-685-3105	joseph.rail@navy.mil	Navy RPM
Nate DeLong	RPM	NAVFAC Washington	202-685-3297	nathan.delong@navy.mil	NTR
Nicholas Carros	IRP Manager	NAVFAC Washington	301-744-2263	nicholas.carros@navy.mil	Onsite/Facility IRP Manager
Ed Corack	PM	Tt	757-466-4908	ed.corack@tetratech.com	Navy Contractor
Scott Nesbit	Facility Coordinator	Tt	412-921-7134	scott.nesbit@tetratech.com	Navy Contractor
Margaret Kasim	Activity Manager	CH2M HILL	703-376-5154	margaret.kasim@ch2m.com	Navy Contractor
Vicki Waranoski	Meeting Scribe	CH2M HILL	703-376-5049	victoria.waranoski@ch2m.com	Navy Contractor

First scoping session for the RI at Site 67.

The Team agreed the Tier 2 UFP-SAP format should be used for this project. [Jon Tucker/NAVFAC LANT Chemist provided a presentation to the Team on the new Tier 2 format at this Partnering Meeting].

PowerPoint presentation provided onscreen and via handouts.

New IR Program site. Previously studied by DoD for perchlorate research. Reviewed Desktop Evaluation material.

Comments/Decisions:

Historical documents summarized in desktop review tech memo (Tt, 2011). There is unacceptable risk from at least perchlorate in one or more media (definitely in groundwater). A focused RI/FS effort is appropriate.

Team reviewed conceptual site model (CSM).

Team discussed likely receptors: ecological receptors (tbd); human health receptors –construction worker, industrial worker, visitor, and trespasser. Future residential scenario also will be evaluated to be conservative.

Team used judgmental approach to place sample locations in order to bound the perchlorate groundwater plume previously partially identified. Similarly, Team selected biased sample locations to investigate soils, sediments, and surface water. Sediments will be sampled for perchlorate because of the high perchlorate concentrations in groundwater and the degree of historical release(s).

Team developed the initial problem statement as follows:

Based on site history and previous studies, releases occurred to soil and groundwater from hog-out activities. Based on Desktop Audit, the chemicals likely associated with hog-out activities are ammonium perchlorate, nitrate/nitrite, select metals

### 3. PROJECT PLANNING SESSION PLANNING SHEET(S)

---

and explosives, PAHs, and phthalates. Additional data are needed to determine the nature and extent of contamination and risks to human health and ecological receptors.

The proposed sampling approach for the Site 67 will be comprised of the following:

- Installation of nine new monitoring wells, including one upgradient well. Surface and subsurface soil samples will be collected during installation at each location.
- Groundwater monitoring of the new and existing monitoring wells; existing wells were last sampled in 2005 and will need to be re-developed.
- 19 surface soil and 9 subsurface soil samples collected across the site (9 of the surface soil samples are collocated with the subsurface soil samples and the 9 new monitoring wells). Data will be assessed for the potential for soils to be an ongoing source of groundwater contamination.
- Six each collocated sediment and surface water samples collected from Mattawoman Creek.

#### Action Items:

Tt to complete proposed sampling scheme and refine CSM and exposure pathway analysis for next scoping session. Tt to develop/refine decision rules with/from problem statement for next scoping session.

#### Consensus Decisions:

Considering the previous investigations and documentation, a focused RI/FS effort is appropriate for Site 67.

### 3.2 Tetra Tech Team Charter Meeting

<b>Project Name:</b>	Site 67 Remedial Investigation (RI)	<b>Site Name:</b>	Site 67 – Hog-Out Facility
<b>Projected Date(s) of Sampling:</b>	Fall 2011	<b>Site Location:</b>	Naval Support Facility Indian Head (NSF-IH)
<b>Project Manager:</b>	Ed Corack, Tetra Tech (Tt)		
<b>Date of Session:</b>	June 15, 2011		
<b>Scoping Session Purpose:</b>	RI charter and kickoff meeting following first scoping with the Tier 1 Partnering Team.		

Name	Title	Affiliation	Phone #	E-mail Address	Project Role
Ronnie Britto	Senior Consultant	Tt	901-849-0193	Ronnie.Britto@tetrattech.com	Senior Consultant
Ann Cognetti	Chemist	Tt	412-921-8862	Ann.Cognetti@tetrattech.com	Chemist
Kelly Carper	Project Chemist	Tt	412-921-7273	Kelly.Carper@tetrattech.com	Project Chemist
Tom Johnston	QAM	Tt	412-921-8615	Tom.Johnston@tetrattech.com	QAM
Ed Corack	PM	Tt	757-466-4908	ed.corack@tetrattech.com	PM
Scott Nesbit	Facility Coordinator	Tt	412-921-7134	scott.nesbit@tetrattech.com	Facility Coordinator
Lee Ann Sinagoga	Risk Assessment Manager	Tt	412-921-8887	LeeAnn.Sinagoga@tetrattech.com	Risk Assessment Manager
Suzanne Paxton	GIS Tech	Tt	412-921-8817	Suzanne.Paxton@tetrattech.com	GIS Tech

QAM – Quality Assurance Manager

PM – Project Manager

This was a conference call meeting.

Comments/Decisions:

The PM provided an overview of the project via PowerPoint presentation.

- The overview identified organizational info, including Navy and regulator members of the Tier 1 Partnering Team, as well as Tt personnel and roles for the SAP through the RI Report.
- Required subcontractors for the RI will include laboratory, survey, IDW, utility, and driller/DPT.
- Milestones (including intermediate, workable tasks) were defined from the SAP through the RI fieldwork and report.

PM set up and identified a project share folder on Pittsburgh server.

Action Items:

Lee Ann to assign lead human health and ecological risk assessors through the RI risk assessments. By 6/16.

Consensus Decisions:

None.

### 3.3 Partnering Team Scoping Session No. 2

<b>Project Name:</b>	Site 67 Remedial Investigation	<b>Site Name:</b>	Site 67 – Hog-Out Facility
<b>Projected Date(s) of Sampling:</b>	Winter 2012	<b>Site Location:</b>	Naval Support Facility Indian Head (NSF-IH)
<b>Project Manager:</b>	Ed Corack, Tetra Tech (Tt)		
<b>Date of Session:</b>	August 3, 2011		
<b>Scoping Session Purpose:</b>	Follow-on scoping session for the RI at Site 67.		

Name	Title	Affiliation	Phone #	E-mail Address	Project Role
Dennis Orenshaw	RPM	EPA Region 3	215-814-3361	orenshaw.dennis@epa.gov	Regulatory oversight
Curtis DeTore	RPM	MDE	410-537-3791	cdetore@mde.state.md.us	Regulatory oversight
Joe Rail	RPM	NAVFAC Washington	202-685-3105	joseph.rail@navy.mil	Navy RPM
Nate DeLong	RPM	NAVFAC Washington	202-685-3297	nathan.delong@navy.mil	NTR
Nicholas Carros	IRP Manager	NAVFAC Washington	301-744-2263	nicholas.carros@navy.mil	Onsite/Facility IRP Manager
Ed Corack	PM	Tt	757-466-4908	ed.corack@tetrattech.com	Navy Contractor
Scott Nesbit	Facility Coordinator	Tt	412-921-7134	scott.nesbit@tetrattech.com	Navy Contractor
Margaret Kasim	Activity Manager	CH2M HILL	703-376-5154	margaret.kasim@ch2m.com	Navy Contractor
Vicki Waranoski	Meeting Scribe	CH2M HILL	703-376-5049	victoria.waranoski@ch2m.com	Navy Contractor

Presentation via PowerPoint onscreen and handouts.

Comments/Decisions:

Team reviewed updated problem statement and individual DQOs/decision rules. Team reviewed updated CSM, including 3-d figure and Exposure Pathway Analysis matrix.

Team reviewed and modified the RI sampling approach (locations). Discussion of whether additional sediment/surface water locations are needed; no, previous ESTCP study determined groundwater discharges prior to reaching tidal mudflats.

Team reviewed and revised the analytes for Groundwater, Soil, Sediment, and Surface Water.

Action Items:

None.

Consensus Decisions:

RI analytes will consist of those noted above. These should capture all likely potential contaminants and support the baseline human health and screening ecological risk assessments.

Analytes for Groundwater, Soil, Sediment, and Surface Water	
<b>SVOCs</b>	<b>Metals (Total &amp; Dissolved)</b>
<b>Phthalates</b>	Aluminum
Bis(2-ethylhexyl)phthalate	Boron
Butyl benzyl phthalate	Lithium
Diethyl phthalate	Zinc
Dimethyl phthalate	<b>Explosives</b>
Di-n-butyl phthalate	2,4-Dinitrotoluene
Di-n-octyl phthalate	2,6-Dinitrotoluene
<b>PAHs</b>	HMX
2-Methylnaphthalene	RDX
Acenaphthene	Nitroglycerin
Acenaphthylene	Tetryl
Anthracene	<b>Oxidizers</b>
Benzo(a)anthracene	Perchlorate
Benzo(a)pyrene	
Benzo(b)fluoranthene	
Benzo(g,h,i)perylene	
Benzo(k)fluoranthene	
Chrysene	
Dibenzo(a,h)anthracene	
Fluoranthene	
Fluorene	
Indeno(1,2,3-c,d)pyrene	
Naphthalene	
Phenanthrene	
Pyrene	

Miscellaneous / Other
<b>Groundwater</b>
Nitrate, Nitrite, and Chloride
TOC
Sulfate
Methane
qPCR
<b>Sediment</b>
TOC
<b>Surface Soil</b>
TOC
pH
<b>Surface Water</b>
Hardness

### 3.4 Partnering Team Scoping Session No. 3

<b>Project Name:</b>	Site 67 Remedial Investigation	<b>Site Name:</b>	Site 67 – Hog-Out Facility
<b>Projected Date(s) of Sampling:</b>	Winter 2012	<b>Site Location:</b>	Naval Support Facility Indian Head (NSF-IH)
<b>Project Manager:</b>	Ed Corack, Tetra Tech (Tt)		
<b>Date of Session:</b>	February 8, 2012		
<b>Scoping Session Purpose:</b>	Site visit.		

Name	Title	Affiliation	Phone #	E-mail Address	Project Role
Dennis Orenshaw	RPM	EPA Region 3	215-814-3361	orenshaw.dennis@epa.gov	Regulatory oversight
Curtis DeTore	RPM	MDE	410-537-3791	cdetore@mde.state.md.us	Regulatory oversight
Joe Rail	RPM	NAVFAC Washington	202-685-3105	joseph.rail@navy.mil	Navy RPM
Nate DeLong	RPM	NAVFAC Washington	202-685-3297	nathan.delong@navy.mil	NTR
Nicholas Carros	IRP Manager	NAVFAC Washington	301-744-2263	nicholas.carros@navy.mil	Onsite/Facility IRP Manager
Ed Corack	PM / Facility Coordinator	Tt	757-466-4908	ed.corack@tetrattech.com	Navy Contractor
Scott Nesbit	Engineer	Tt	412-921-7134	scott.nesbit@tetrattech.com	Navy Contractor
John Trepanowski	Program Manager	Tt	610-382-1532	john.trepanowski@tetrattech.com	Navy Contractor
Margaret Kasim	Activity Manager	CH2M HILL	703-376-5154	margaret.kasim@ch2m.com	Navy Contractor
Vicki Waranoski	Meeting Scribe	CH2M HILL	703-376-5049	victoria.waranoski@ch2m.com	Navy Contractor

Team visited site to truth sample locations, terrain and vegetation, and the presence of existing wells.

Comments/Decisions:

Some sample locations adjusted to accommodate assumed utilities and terrain/vegetation.

Action Items:

None.

Consensus Decisions:

None.



## 4 CONCEPTUAL SITE MODEL

(UFP-QAPP Manual Section 2.5.2 and UFP-QAPP Workbook WS #10)

This section summarizes the currently understood Conceptual Site Model (CSM) for Site 67 – Hog-Out Facility based on previous studies at the site. See [Section 5](#) for the Data Quality Objective (DQO) / Project Quality Objective process. Background information, including site location and description, site history, and a brief summary of the site geology and hydrogeology are included below. Further, a summary of environmental investigations and the limitations of previously collected data are provided below. Several historical documents in [Appendix A](#) provide more details on site conditions and CSM development.

### 4.1 Site Description and History

Naval Support Facility Indian Head (NSF-IH) is located approximately 25 miles southwest of Washington, D.C., in northwestern Charles County, Maryland ([Figure 1](#)), positioned along the Potomac River at the confluence of Mattawoman Creek. NSF-IH has been active since 1890 and assumed its current name in 2005. As shown on [Figures 1 and 2](#), the Main Area of the facility is bounded by the Potomac River on the northwest, west, and south, Mattawoman Creek to the south and east, and the Town of Indian Head to the northeast.

The Indian Head peninsula is located in the Atlantic Coastal Plain Physiographic Province, approximately 8 to 10 miles east of the Fall Line that marks the western extent of the physiographic province. Indian Head has gently rolling to undulating topography with elevations ranging from sea level to more than 100 feet (ft) above mean sea level (msl). The higher elevations are on the eastern portion of the facility, and the land surface generally slopes to the southwest and southeast. The portion of NSF-IH along the Potomac River is characterized by 20- to 100-ft bluffs. The portion along Mattawoman Creek is more gently sloping.

Site 67 is located on the southeast side of NSF-IH bordering Mattawoman Creek ([Figure 2](#)). The site is described as having perchlorate-contaminated groundwater resulting from historical site practices at Building 1419 ([Figure 2](#)), which consisted of cleaning out (hogging out) solid propellant from various devices, including rockets and Jet-Assisted Take-Off (JATO) ejection seat motors (Tt, 2011 and 2012). The 2-acre grassy site contains a small drum storage building (Building 1861) ([Figures 3 and 4](#)). Direct dumping of the hog-out wastewater occurred from the 1960s to 1996 (Tt, 2009). Hog-out operations continue, but wastewaters now are drummed, characterized, handled, and disposed appropriately (NSF-IH, 2006). Operations at Building 1219 can also include some ordnance handling and storage.

Previous environmental investigations/efforts are indicated by the following documents, which are summarized in the Tt (2011) *Desktop Audit* technical memorandum ([Appendix A](#)):

- **Activity: 2002 Pilot Test.**  
**Document:** Naval Ordnance Safety and Security Activity (NOSSA) (2004) *Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419*.
- **Activity: 2006 Technology Demonstration Plan.**  
**Document:** Environmental Security Technology Certification Program (ESTCP) (2006a) *Evaluation of Potential for Monitored Natural Attenuation of Perchlorate in Groundwater: Technology Demonstration Plan for Building 1419 Site, Naval Surface Warfare Center, Indian Head, MD*.
- **Activity: 2008 Perchlorate Attenuation Guidance.**  
**Document:** ESTCP (2008) *Natural Attenuation of Perchlorate in Groundwater: Processes, Tools, and Monitoring Techniques*.

4. CONCEPTUAL SITE MODEL

The previous studies were performed in an effort by the Department of Defense (DoD) c/o the Strategic Environmental Research and Development Program (SERDP), NOSSA, and ESTCP (among others) to gain an understanding of fate and transport of and treatment options for perchlorate in various aquifer systems. They were not performed under the Navy Environmental Restoration Program. The CSM herein is supported largely by the information and data collected and evaluated previously. No risk evaluations have been performed to date.

Mattawoman Creek and the Potomac River are tidal estuaries of the Chesapeake Bay estuary system. The unconfined surficial aquifer at Site 67 consists of more recent saturated alluvial soil resting on top of the Patapsco clay that is encountered at approximately 16 ft bgs site-wide. The water table varies seasonally from 6 to 10 ft bgs in response to precipitation and evapotranspiration, and generally slopes similarly to the land surface topography. Upland areas serve as groundwater recharge areas and low areas and the creek serve as groundwater discharge areas. Groundwater flow follows the surface topography at the site.

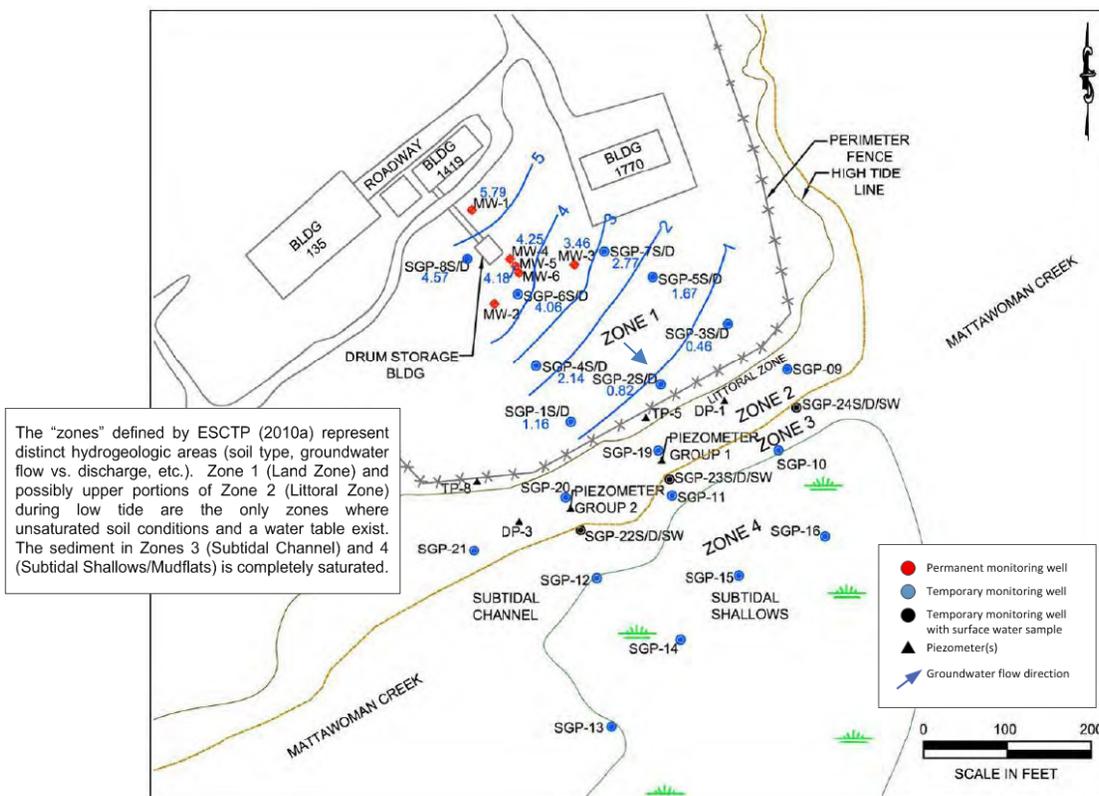


Exhibit: Water Table Contour Map—April 2008 (ESTCP, 2010a)

NOSSA (2004) reported an average hydraulic gradient at 0.023 (between wells MW01 and MW03) and an average hydraulic conductivity (determined by slug tests) at 0.012 ft/min (17 ft/day). Low-tide mudflats lie just offshore. Mattawoman Creek is tidally influenced with daily fluctuations in this area between 1 and 2 ft, causing reversal in groundwater flow in and out of the sediments. [Figure 5](#) provides a three-dimensional CSM for the site. [Figure 6](#) provides an exposure route pathway CSM for the site, which will be utilized to conduct the Baseline Human Health Risk Assessment (HHRA) and Screening-level Ecological Risk Assessment (ERA) (SERA).

The ESTCP (2006 and 2010a) reports provide multiple hydrogeologic interpretive cross-sections and discussion of local hydrogeology. The reports also provide tabular data and figures detailing perchlorate concentrations and distribution, along with presentation and evaluation of secondary data indicators. This information will be considered and/or incorporated into the forthcoming RI Report for Site 67.

Estimated perchlorate isoconcentration contours in surficial aquifer groundwater from 2005 are shown on the exhibits below (ESTCP, 2006).

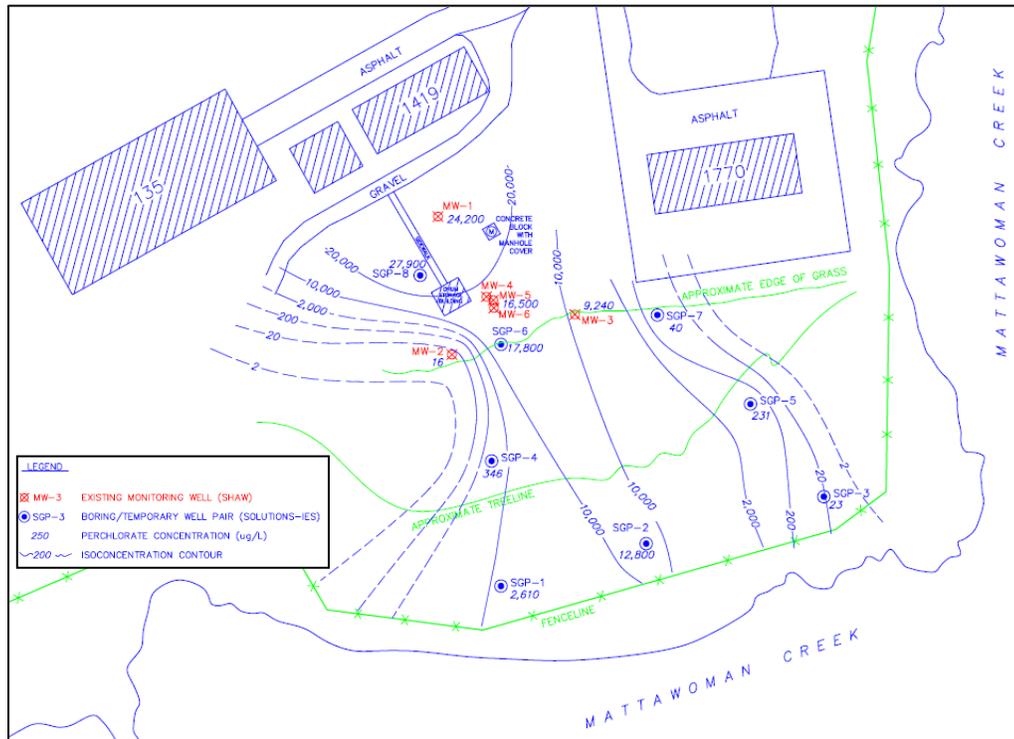


Exhibit: 2005 Groundwater Perchlorate Isoconcentration Map – “Shallow” Wells | Surficial Aquifer (µg/L) (ESTCP, 2006)

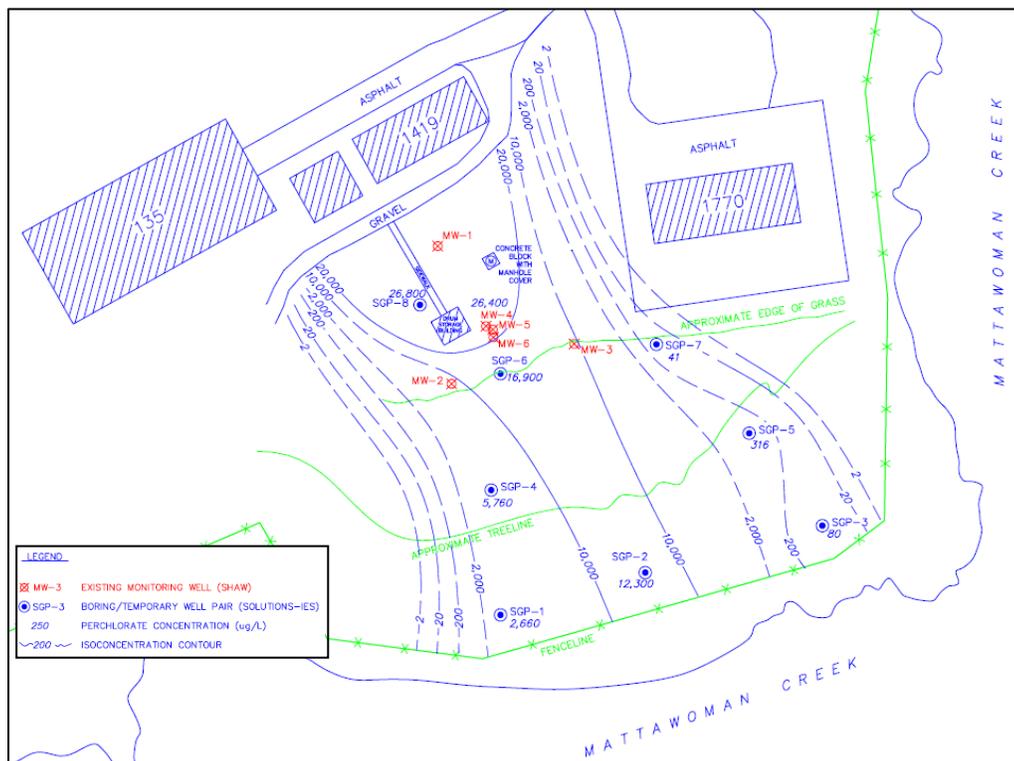


Exhibit: 2005 Groundwater Perchlorate Isoconcentration Map – “Deep” Wells | Surficial Aquifer (µg/L) (ESTCP, 2006)

The purpose of the previous studies at Site 67 was to understand the environmental fate and mechanics of perchlorate contamination and develop better ways to evaluate the natural attenuation of perchlorate. The results of the previous studies at Site 67 led to the creation of DoD's perchlorate monitored natural attenuation (MNA) guidance (ESTCP, 2008). This guidance provides a three-tier assessment to evaluate optimal perchlorate attenuation (Tetra Tech [Tt], 2011; ESTCP, 2008):

**Tier 1** – Perchlorate concentrations decrease with time and distance due to biodegradation, dilution, and dispersion.

**Tier 2** – Most ideal geochemical conditions coincide with greatest perchlorate reduction.

**Tier 3** – Greatest perchlorate reduction occurs where highest population of perchlorate-reducing bacteria indicators are measured.

Considering this three-tier assessment, MNA is a likely an acceptable final remedy for Site 67. However, additional sampling should be performed during the RI to obtain a more robust temporal dataset for the Tier 1 assessment. Further, additional sampling locations are necessary to fully delineate the perchlorate plume, define the source area, determine if other contaminants are present, and calculate associated risks.

#### **4.2 Potential Sources of Contamination**

Historical discharges of hog-out wastewater directly onto the ground surface resulted in the current perchlorate contamination ([Figures 5 and 6](#)). This process is thought to have resulted in the discharge of solid perchlorate and/or water containing perchlorate on the soil surface in the general vicinity of Building 1419. Perchlorate present in the soils would then be carried vertically into the shallow water table aquifer by infiltrating rainwater. Sorption of perchlorate to the aquifer matrix is believed to be minimal, so perchlorate could be flushed from the aquifer relatively easily by ambient groundwater flow. The exact location of the historical hog-out activities is not known, but is believed to have occurred in the general vicinity of Building 1419 and a drum storage building (1861). The estimated perchlorate isoconcentration contours support this expectation. Other specific contamination is unknown, but probable hog-out items and probable contaminants include explosive compounds / energetics (e.g., hexahydro-1,3,5-trinitro-1,3,5-triazine [RDX] and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine [HMX]), nitrate, and sulfate (ESTCP, 2008; ITRC, 2002). Other contaminants may originate from specific types of rocket motors (e.g., PAHs from jet-assisted takeoff [JATO] motors) (Maryland Department of Environment [MDE], 2010).

In addition to perchlorate, the following are probable contaminants in one or more media at Site 67 based on a review of known or probable materials released during hog-out operations. Therefore, perchlorate and the compounds listed below are the target analytes / contaminants for the Site 67 RI. Note that phthalates and PAHs are subsets of the semivolatile organic compounds (SVOCs) analytical group.

**Exhibit: Specific Analytes for Site 67 RI**

SVOCs		
Phthalates	PAHs	
Bis(2-ethylhexyl)phthalate	2-Methylnaphthalene	Chrysene
Butyl benzyl phthalate	Acenaphthene	Dibenzo(a,h)anthracene
Diethyl phthalate	Acenaphthylene	Fluoranthene
Dimethyl phthalate	Anthracene	Fluorene
Di-n-butyl phthalate	Benzo(a)anthracene	Indeno(1,2,3-c,d)pyrene
Di-n-octyl phthalate	Benzo(a)pyrene	Naphthalene
	Benzo(b)fluoranthene	Phenanthrene
	Benzo(g,h,i)perylene	Pyrene
	Benzo(k)fluoranthene	
Metals	Energetics/Explosives	
Aluminum	2,4-Dinitrotoluene	RDX
Boron	2,6-Dinitrotoluene	Nitroglycerin
Lithium	HMX	Tetryl
Zinc		

A Contaminated Water Shed Document has not been prepared for this area. There are no probable non-Navy sources in this area of Mattawoman Creek, and no non-Navy sources of perchlorate or explosives. This site borders the subject water body. The area upland from the site will be sampled to confirm perchlorate contamination does not also result from another Navy source/site on NSF-IH (not likely based on known historical operations at this site and previous study findings). Perchlorate can be a contaminant in nitrate fertilizers -- but nitrate fertilizers are not expected to be measurable or significant contributors to observed perchlorate contamination levels. The CSM is relatively well understood based on data collected during previous studies and the pilot test. The upland soil and upgradient groundwater will be sampled as a standard, qualitative confirmation of non-site-related conditions.

Only site-related contaminants will be analyzed in sediment, and ultimately no to low detections are expected, especially little to no perchlorate. Sediment is being sampled for perchlorate due to the nature and size of the perchlorate release(s) at the site (as evidenced by previous study findings) (sediment often forgoes perchlorate analysis otherwise). Sediment and at-depth surface water samples (at sediment horizon) will be collected to support the ecological risk assessment.

Any subsequent remedial decisions for sediment (not anticipated) will follow the Navy's (2002) *Policy on Sediment Site Investigation and Response Action*, which details identification and control of the source prior to any sediment response actions, risk-based and site-specific cleanup goals, and established monitoring criteria prior to sampling. Although the RI is just starting, based on previous studies, and in accordance with Navy sediment investigation policy, the sediment investigations are "directly linked to Navy CERCLA contaminated releases..." and the sediment contamination (magnitude unknown, but anticipated to be low to none due to the fate and transport of perchlorate) "...is scientifically connected to the Navy Site."

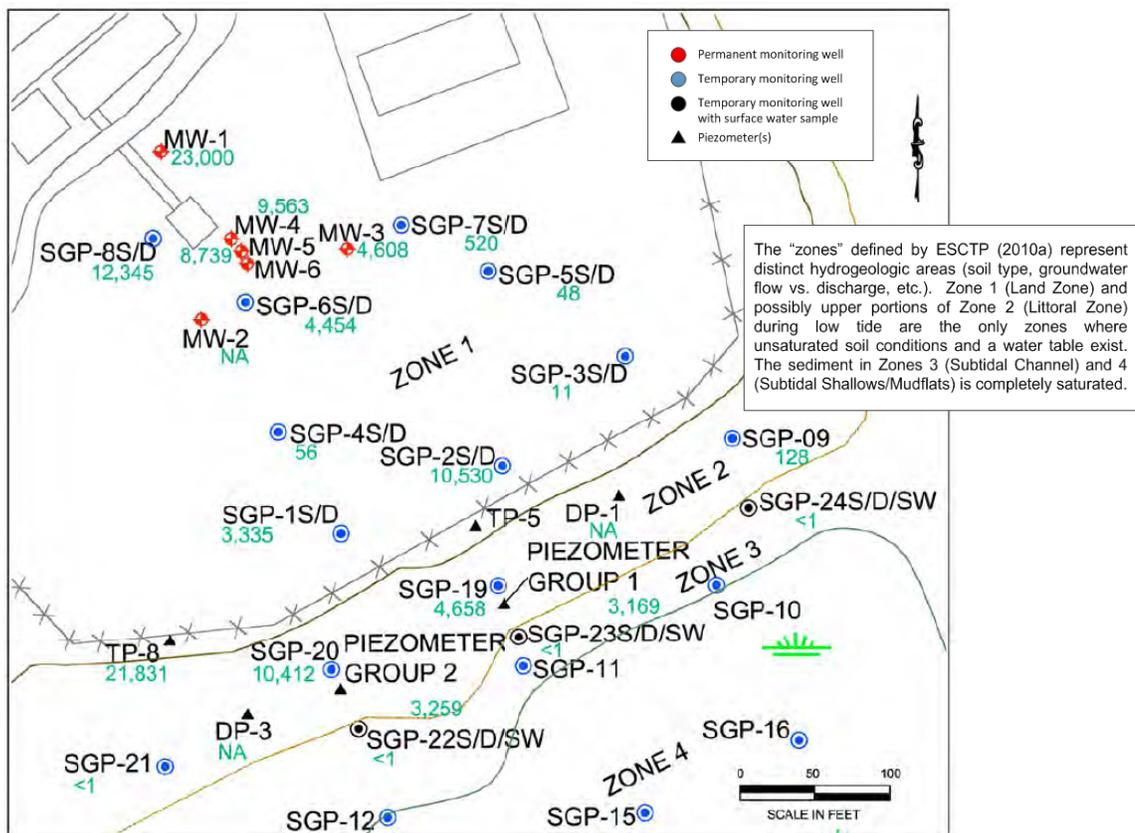
### 4.3 Potential Contaminant Migration Mechanisms

Refer to [Figures 5 and 6](#) for primary and secondary contaminant sources, migration mechanisms, and exposure routes. Groundwater is believed to enter the unconfined shallow surficial aquifer as diffuse recharge in the upland areas. Discharges to the soil of solid perchlorate and/or aqueous perchlorate solutions (and related contaminants if present) occurred from hog-out operations in the general vicinity of Building 1419 and the drum storage building (1861). Perchlorate in soils would be carried vertically to the surficial aquifer by

infiltrating rainwater or snowmelt. Sorption of perchlorate to the aquifer matrix is believed to be minimal, so perchlorate could be flushed from the aquifer relatively easily by ambient groundwater flow (ESTCP, 2010a).

Perchlorate (an oxidizer) and explosives/energetics (e.g., nitramines) and some metal salts are relatively soluble compared to other environmental contaminants and generally do not adsorb strongly to soils or sediments. Phthalates, PAHs, and metals of environmental interest used at this site tend to preferentially adsorb to soils and sediments rather than dissolve into water. Vapor intrusion is not a concern at this site due to the [apparent] lack of volatile contaminants. Underground utilities (potable water, sewer, telecommunications, etc.) are present at the site and may offer preferential contaminant migration pathways. Current plume geometry from historical data does not show a discernible correlation of contaminant distributions with known underground utilities. More detailed information can be found in [Appendix A](#).

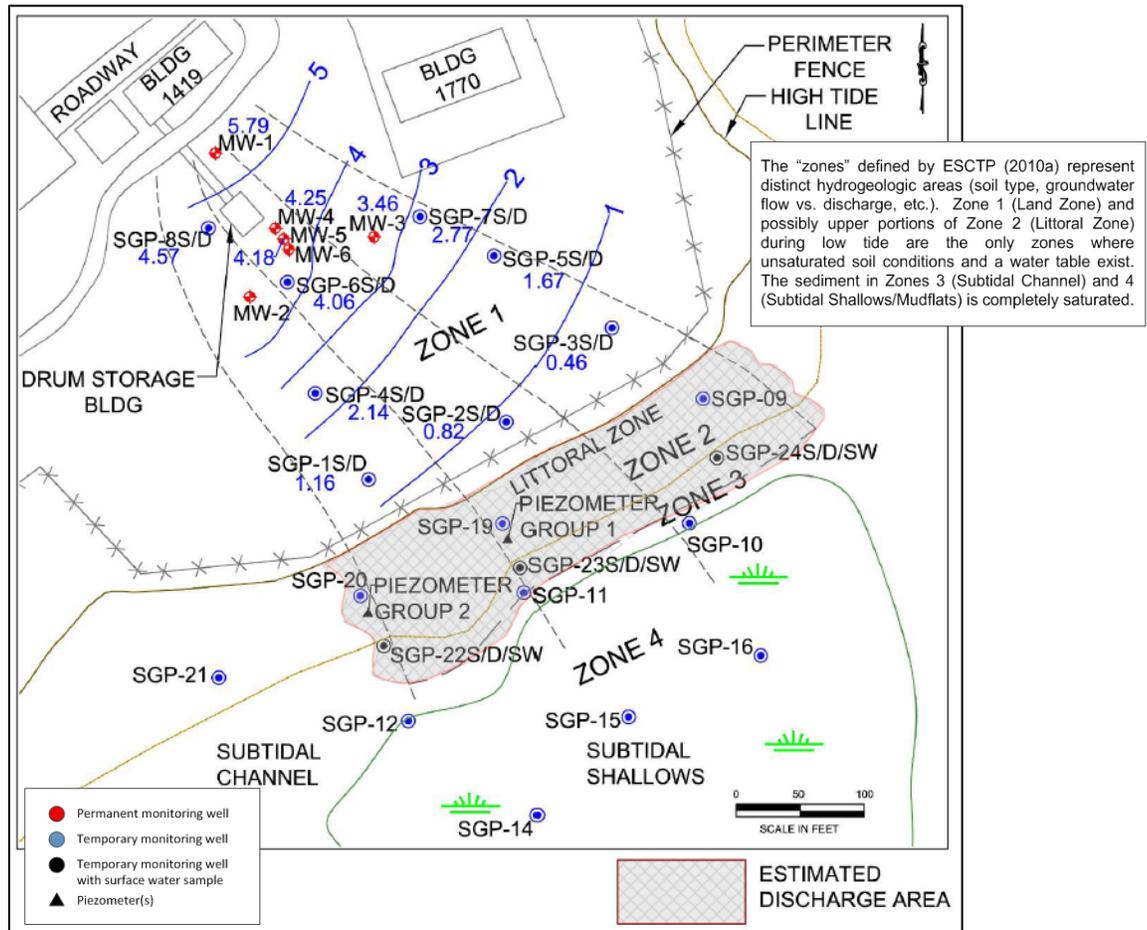
April 2008 perchlorate detections in groundwater are shown in the exhibit below (ESTCP, 2010a). The previous studies determined that the perchlorate plume geometry has changed very little over time.



**Exhibit: Perchlorate Concentrations (µg/L)—April 2008 (ESTCP, 2010a).** Perchlorate extends over 450 feet from Building 1419 to the Subtidal Channel (Zone 3) (see flow net on next exhibit).

Flux meters used during a 2001 ESTCP study at Site 67 showed perchlorate flux did not change over time from 2002 through 2005, indicating the presence of a persistent source of perchlorate near well MW01 (ESTCP, 2010a). Vertical perchlorate flux measurements suggested the possibility of a vadose zone source that continuously releases perchlorate to the aquifer by recharge induced by precipitation. The ESTCP (2010a) presented the discerned discharge zone for groundwater via the flow net shown in the exhibit below. Groundwater flowing through the site flows up through the creek sediments prior to reaching the low-tide mudflats. A significant conclusion in the previous studies was that perchlorate completely attenuates in

groundwater by the time it discharges through the high-organic-content sediments in the Mattawoman Creek (Tt, 2011).



**Exhibit: Flow Net for Study Area (ESTCP, 2010a).** Site groundwater discharges into creek prior to the subtidal shallows, as indicated by perchlorate concentrations and geochemical indicators (not shown). This is due to biodegradation and dilution with surface water.

#### 4.4 Land Uses and Potential Exposure

Hog-Out operations at Site 67 are based out of Building 1419. NSF-IH is a military facility with restricted access. Current land use at Site 67 is commercial/industrial and is anticipated to remain as such for the foreseeable future. In addition to hog-out operations, some explosives and equipment are occasionally stored in Building 1419. The site lies within K18 explosive arcs set from Buildings 1419, 1770, and 1861. [Figure 6](#) presents the potential exposure routes to be evaluated in the RI.



## 5 DATA QUALITY OBJECTIVES / SYSTEMATIC PLANNING PROCESS STATEMENTS

(UFP-QAPP Manual Section 2.6.1 and UFP-QAPP Workbook WS #11)

### 5.1 Identification of Study Goals

Based on site history and past data collection, chemical releases are known to have occurred to soil from hog-out operations at Site 67. The chemicals potentially, or known to be, associated with that operation are ammonium perchlorate and nitrate used as oxidizers; nitrite, a potential degradation product of nitrate; select metals or metalloids used as fuels, nitramine explosives used as binders; and PAHs and plasticizers (phthalates) that were major components of binders used in the rocket fuel mixtures.

Previous studies indicate that perchlorate is a chemical of potential concern (COPC). However, the Team must determine if other potential operations-related contaminants are present (previous studies only looked at perchlorate), and, if so, if they contribute to unacceptable risk(s), so the risks can be mitigated as necessary. The human and ecological receptors representing potentially exposed organisms corresponding to each exposure medium are identified in [Figure 6](#). The Team also must delineate the detected contamination and characterize site geochemical conditions sufficiently to support the risk assessments and possible actions such as conducting an FS in response to the site characterization.

### 5.2 Information/Decision Inputs

To resolve the problem stated in the Study Goals above, concentrations of the following target analytes (site-related contaminants) must be measured in soil, sediment, surface water, and groundwater.

- Perchlorate
- Phthalates, representing plasticizers
- PAHs, from JATO rocket motors
- Energetics (e.g., nitramine, HMX, and RDX) (explosives potentially used as binders)
- Metals (i.e., aluminum, lithium, and zinc) and boron (a metalloid)

A list of target analytes and analyte groups considered to be site-related or potentially site-related contaminants is provided in [Section 4.2](#). Lists of individual target analytes are presented in [Section 9](#). The analytical methods used to generate concentration data for these target analytes must be of sufficient sensitivity to allow detection and quantitation of the contaminants in support of project objectives. The analyses at an offsite fixed-base laboratory will be possible after sample collection in accordance with [Section 7.4](#) and shipment to the laboratory.

Numerical screening criteria, or Project Screening Limits (PSLs), are needed to which measured chemical concentrations can be compared to establish the extent of contamination, to select suitable analytical methods, and to make initial estimates of human health and ecological risk for selecting chemicals of potential concern (COPCs) and Chemicals of Potential Ecological Concern (COPECs) that are evaluated further in the HHRA and SERA. These criteria, in addition to established NSF-IH background values, must be consistent with criteria used for other NSF-IH Environmental Restoration Program (ERP)<sup>2</sup> investigations. The criteria are presented in [Section 9](#). Established NSF-IH background data values for soil and groundwater are available from the *NSF-IH Background Report* (Tt, 2002). The background criteria are needed to screen out concentrations of inorganics that are naturally occurring after the initial risk assessment is conducted. For the SERA, some of the PSLs can be considered Project Action Limits (PALs), because an exceedance requires

---

<sup>2</sup> The Navy ERP comprises both the Installation Restoration Program (IRP) and the Munitions Response Program (MRP).

performing the next ERA steps beyond this current effort (i.e., a BERA); however, for simplicity they will be referred to as PSLs.

PALs are needed by which human health and ecological risks can be estimated to determine whether mitigation of risks is necessary. The PSLs are utilized in the first step of the HHRA to determine COPCs, and PSLs/PALs are used for the SERA to determine initial COPECs. The PALs are as follows:

- An Incremental Lifetime Cancer Risk (ILCR) of  $1 \times 10^{-5}$  for carcinogens, which, if exceeded in any of the environmental media, indicates an unacceptable level of human health risk. EPA's acceptable *risk range* is  $1 \times 10^{-4}$  to  $1 \times 10^{-6}$ ; however, cleanup levels for other IRP sites at NSF-IH typically are based on a target cancer risk of  $1 \times 10^{-5}$ .
- Hazard Index (HI) equal to unity (1.0) based on common target organs and effects for non-carcinogens, which, if exceeded in any of the environmental media, also indicates an unacceptable level of human health risk.
- The ecological risk-related PSLs, which, if exceeded, indicates a BERA may be necessary (see Section 5.4).

To conduct comparisons of site data to screening values for surface soil, subsurface soil, sediment, surface water, and groundwater and to complete delineation of potential contamination, the selected laboratory(s) should be able to achieve Limits of Quantitation (LOQs) that are low enough to measure constituent concentrations that are less than the PSLs. Analytical data reported by the laboratory use the following reporting conventions: All results below the Detection Limit (DL) will be considered nondetects; positive results reported at concentrations between the DL and LOQ will be reported with a "J" qualifier; and analytes not found (not detected) in a sample will be reported at the Limit of Detection (LOD) with a "U" qualifier.

Several target analytes have PSLs that fall between the LOD and the LOQ. "J"-flagged data will be accepted to achieve project goals; however, greater scrutiny will be applied in these cases. Additionally, the inability to quantify select analytes to PSL levels with confidence will be addressed in the risk screening uncertainty analysis. In cases where the laboratory LODs are greater than the PSLs, consistent with the *EPA Risk Assessment Guidance for Superfund, Part A* (EPA, 1989), if the analyte is not detected, the LOD will be reported and "U" qualified. An evaluation of these analytes will be also presented in the uncertainty section of the risk screening in the RFI Report."

For the HHRA, the exposure point concentration (EPC) is statistically determined to summarize the data and to support the risk calculations. For each of the environmental media, this statistic is the upper confidence level (UCL) of the mean chemical concentration for each analyte/medium. Chemical-specific UCLs will be calculated using EPA's latest ProUCL software. If the UCL is greater than the maximum detected concentration for that medium, the maximum detected concentration will represent the EPC. EPCs established in this manner represent a reasonable maximum exposure (RME). Subareas can be established if warranted by the spatial distribution of the data. If fewer than 10 detections are observed (or fewer than 10 samples collected) for a particular target analyte in a particular environmental medium, the maximum observed concentration must be used as the EPC.

Soil and groundwater data from location S01, which is topographically and hydraulically upgradient from the perceived source area, will provide qualitative site-specific background information as a separate line of evidence. That is, the data can be used to revise the CSM, will provide limited confirmation of metals concentrations prior to groundwater flowing through the source area, and limited confirmation of the northern boundary of contamination (i.e., confirm the source is on the south side of Building 1419) and of the contaminant migration direction (i.e., confirm contaminants are moving with groundwater flow). Side-gradient

samples also may serve these qualitative purposes, but only if it is determined that they are located outside of any contaminant plume(s).

**Perchlorate Sampling.** Perchlorate sample collection will be performed in accordance with Appendix F of the 2007 *DoD Perchlorate Handbook* ([Appendix B](#)). Groundwater samples will be field filtered prior to cold storage and shipment of the perchlorate samples (not required for surface water samples). Discrete soil samples will be collected instead of composite samples. Composite, multi-incremental samples will not be necessary for soil or sediment, as perchlorate is expected to be distributed relatively homogeneously due to the nature of hog-out activities, no propellant matrices are expected to be encountered, and all perchlorate is expected to have immediately dissolved after previous release(s). Sediment samples will be analyzed for perchlorate because of the quantity of the historical release(s) and the evident elevated groundwater concentrations.

**Perchlorate Action Levels.** Maryland’s generic cleanup level for perchlorate in Type I aquifers is 2.6 µg/L (MDE, 2008). Maryland’s generic residential soil cleanup level for perchlorate is 4.4 mg/kg. DoD’s perchlorate action level in groundwater is 15 µg/L (Navy, 2010), based on EPA’s Interim Drinking Water Health Advisory corresponding to 15 µg/L in January 2009.

**Metals.** Both total and dissolved (field filtered) metals samples must be collected for analysis of aluminum, boron, lithium, and zinc. Total metals results are used in the HHRA as a conservative measure per EPA’s Risk Assessment Guidelines. However, the dissolved metals results can provide an additional perspective to the exposure scenario (simulating results from a constructed, operating as intended drinking well), and can be used for risk management decisions and discussed in the risk uncertainty section when metals results may be attributable to sample turbidity. Dissolved metals results are preferred over total metals results for the ERA.

**Secondary Indicator Data.** In addition to the target analytes, the following secondary indicators/analytes will be included in Site 67 RI in one or more media (also see Sample Details Table in [Section 8.3](#)). These data are needed to evaluate aquifer conditions (as they affect the fate and transport of contaminants), possible MNA remedy (three-tier assessment for perchlorate MNA), and to support the risk assessments. Detailed rationale for each of these is provided in [Section 7.5](#).

Exhibit: Other Analyses Per Medium

Groundwater	Surface Soil	Subsurface Soil	Sediment	Surface Water
Nitrate, Nitrite, & Chloride	TOC	(none)	TOC	Hardness
TOC Sulfate	pH			
Methane qPCR				

TOC – total organic carbon

qPCR – quantitative polymerase chain reaction

- TOC in surface soil and sediment and pH in surface soil provide information on metals solubility and bioavailability, and subsequently toxicity, to support the ERA. Hardness in surface water provides information to the ecological risk assessor about the potential need to adjust PSLs/PALs (some ERA PSLs/PALs are directly related to hardness).
- Aquifer Condition Indicators and Well Stabilization Parameters: pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), Specific Conductance, Temperature, and Turbidity. These indicators/parameters will be measured in groundwater and surface water with a field water quality meter. For groundwater samples, the samples are not collected until these parameters stabilize. These indicators parameters along with nitrate/nitrite, sulfate, and methane provide an indication as to whether conditions are favorable to anaerobic biodegradation and can thus support natural attenuation (Perchlorate MNA Tier 2 assessment). If the aquifer conditions are outside of a range that is supportive of anaerobic biodegradation, then the success of natural attenuation may be limited.

- qPCR via CENSUS (Microbial Insights Laboratory): Based on qPCR, CENSUS is a nucleic acid-based approach to quantify specific microorganisms, groups of microorganisms, or functional genes involved in bioremediation or other biological processes. CENSUS targets include bacteria and functional genes responsible for biodegradation of chlorinated compounds and petroleum products among others. For the Site 67 RI, the qPCR analysis is used to quantify perchlorate reducing bacteria / functional genes / enzymes such as, in this case, the enzymes chlorite dismutase (CD) and perchlorate reductase, to support the Perchlorate MNA Tier 3 assessment.

**Physical Data.** The following physical data also must be collected:

- Horizontal and vertical location data for sampling locations and monitoring wells as described in [Section 8.1.12](#).
  - Horizontal measurements (coordinates) shall be accurate to 0.1 ft.
  - Vertical elevation measurements shall be accurate to 0.01 ft.
  - Each of the locations must be surveyed in the North American Datum (NAD) of 1983, State Plane Coordinate System of Maryland (feet) relative to the coordinates of established site benchmarks or the nearest United States Geological Survey (USGS) benchmark.
- Depth to groundwater as described in [Section 8.1.9](#) (used to compute groundwater elevations and flow direction)
- Groundwater level measurement times and groundwater sample collection times that can be used to control the timing of sample collection and water level measurements to prevent or minimize adverse effects on data interpretation due to tidal fluctuations.

**Quality Assurance (QA) and Quality Control (QC) Samples.** Selected QA/QC samples are required to ensure data quality. New disposable polyethylene tubing must be used to purge and sample each well. Therefore, no rinse blank is needed. One duplicate sample from one must be analyzed for the site-related contaminants (perchlorate, select metals, select energetics, PAHs, phthalates, and nitrate/nitrite) and TOC (see [Section 8.3](#)). All sample containers must be new and supplied directly from the laboratory. They must be labeled immediately upon filling, preserved appropriately (see [Section 8.4](#)), stored on ice, and submitted to the laboratory under chain-of-custody (CoC) control.

### 5.3 Boundaries of the Study

Two populations of each medium (soil, sediment, surface water, and groundwater) are of interest. One population is the population of material contaminated by site operations. The other is the population of uncontaminated material that helps to bound the extent of contamination. As shown in [Section 4](#) (CSM), the extent of perchlorate is known to some degree, but not the full extent, and there are no data available for other potential site contaminants. In addition, a contamination source area has not been definitively identified in soil.

Therefore, the investigative approach must be sufficient to establish whether an identifiable soil contaminant source area is likely to exist. Surface soil measures from 0 to 1 ft bgs. Subsurface soil measures from 1 ft bgs to the water table; subsurface soil samples will target the 1-ft interval above the encountered water table (possibly unique for each location). The maximum depth of interest in soil is the unsaturated depth to the water table. For delineating the extent of subsurface contamination and potential for contaminants leaching to groundwater, the maximum extent of investigation is currently assumed to be 10 ft bgs (to be confirmed during the RI). For sediment, the maximum depth of investigation is limited to 1 ft below the sediment surface to support the evaluations of human health and ecological risk and to estimate the extent of contamination.

For surface water, the depth of investigation is limited to the 0 to 1 ft horizon above the sediment surface to support the evaluations of human health and ecological risk and to estimate the extent of contamination nearest the sediment pore water.

Initial groundwater plume data indicate that the data collection pattern must be expanded in all directions to bound the extent of contamination.

Site 67 groundwater levels near Mattawoman Creek fluctuate in response to tidal elevation changes. It is expected that groundwater levels in wells to be installed at locations S15 (MW13), S17 (MW14), and S19 (MW15) will be affected. Data collection times must be coordinated to minimize adverse effects of tides on the data interpretation and adverse effects that could be caused by a precipitation event. This means gauging the wells and collecting samples to be analyzed within 1 hour of the bottom of the groundwater elevation / 6-hour tidal cycle, and no sooner than 1 day after a major precipitation event. Groundwater level gauging must be completed at all site wells within the 1-hour period.

Surface water samples must be collected prior to collecting sediment samples to prevent entrainment of disturbed sediment in the surface water samples.

#### **5.4 Analytic Approach**

The following decision rule must be applied to the new and existing data to resolve the problem statement:

If the extent of measured perchlorate and other contaminant concentrations in soil, sediment, surface water, and groundwater at Site 67 has been determined by the Team sufficiently well to conduct a human health and ecological risk assessments, and values are above established applicable background levels, then conduct these risk assessments; otherwise, recommend additional data collection to support the risk assessment(s).

#### **5.5 Performance Criteria**

Sampling locations were selected based on the need to characterize the nature and extent of contamination and groundwater flow directions but also to provide enough data, when combined with previously collected data, to support a risk assessment. The data collected under this SAP are anticipated to be sufficient to achieve these goals. Particular scrutiny will be applied to analytical results less than the LOQ when PSLs/PALs are less than the LOQ. The data verification, validation, and usability evaluation processes are described in more detail in [Section 12](#). These processes will be used to assess the data quality and whether the data meet project objectives

If any significant data gaps (i.e., quality deficiencies) are identified, the Project Team will document the deficiencies and determine the next appropriate step (e.g., additional data collection to fill the data gap).

#### **5.6 Plan for Obtaining Data**

The sampling design is a judgmental, or biased, design: sampling locations were selected to supplement existing information about Site 67. In areas that have limited accessibility, the Project Team attempted to select sampling locations in accessible areas as close as possible to what would be considered to be an ideal location for achieving project objectives. See [Figure 7](#) and [Section 7](#) for a detailed sampling design.



## 6 FIELD QUALITY CONTROL SAMPLES

(UFP-QAPP Manual Section 2.6.2 and UFP-QAPP Workbook WS #12)

**Measurement Performance Criteria (MPC) Table – Field Quality Control (QC) Samples <sup>(1)</sup>**

QC Sample	Analytical Group	Frequency	Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample Assesses Error for Sampling, Analytical, or Both
Equipment Rinsate Blanks	Energetics, Perchlorate, and Metals	One per day per matrix per sampling equipment. <sup>(1)</sup>	Accuracy/Bias/Contamination	No analytes $\geq \frac{1}{2}$ Limit of Quantitation (LOQ), except common lab contaminants, which must be $<$ LOQ.	Sampling and Analytical
Field Duplicate	All Fractions	One per 10 field samples collected for fixed-base laboratory analysis.	Precision	Values $>$ 5X LOQ: Relative Percent Difference (RPD) $\leq 30\%$ <sup>(2)</sup> (aqueous); $\leq 50\%$ <sup>(2)(3)</sup> (solid).	Sampling
Cooler Temperature Blank	All Fractions	One per cooler.	Representativeness	Temperature must be less than 6 degrees Celsius ( $^{\circ}$ C).	Sampling

**Notes:**

1. Equipment rinsate blanks will be collected if non-dedicated sampling equipment is used. For disposable equipment, one sample per batch of disposable equipment will be collected for target analytes (site-related contaminants).
  2. If duplicate values for non-metals are  $<$  5x LOQ, the absolute difference should be  $<$  2x LOQ.
  3. If duplicate values for metals are  $<$  5x LOQ, the absolute difference should be  $<$  4x LOQ.
- No ambient field blanks will be collected (no volatiles analysis, site is not dusty, no nearby emissions, etc.).  
 No trip blanks will be collected (no volatiles analysis).



## 7 SAMPLING DESIGN AND RATIONALE

(UFP-QAPP Manual Section 3.1.1 and UFP-QAPP Workbook WS #17)

### 7.1 Sampling Schedule

Due to explosives operations in Building 1419 and vicinity, fieldwork likely will be conducted on weekends only. The sampling schedule likely will vary and will be determined on a weekly basis.

### 7.2 Sample Selection

The biased proposed sample locations are shown on [Figure 7](#). Data from these locations and media will supplement existing information about Site 67 and allow for evaluating the full nature and extent of contamination, completing the human health and ecological risk assessments, and preliminary remedial action planning. Sample locations and analyses were selected by consensus by the Tier 1 Partnering Team to fill data gaps from previous investigations and to provide ample information to complete the risk assessments and RI ([Section 7.5](#)). Detailed sample rationale is summarized/tabulated in [Section 7.5](#).

### 7.3 Monitoring Well Construction Details

The five existing monitoring wells to be sampled (MW01 through MW05) are 2-inch inner-diameter, Schedule 40 PVC with 0.010-inch slot 10-ft well screens. Pertinent monitoring well construction details are provided below. Each screen is keyed into or just above the basal clay layer.

Well ID	Top PVC (ft above ground surface)	Depth from Top PVC to Bottom of Well (ft)	Well Screen Interval (ft bgs)
MW01	2.5	17.7	5-15
MW02	2.6	18.7	6-16
MW03	2.7	17.6	5-15
MW04	0.8	17.9	7-17
MW05	2.6	19.5	7-17

### 7.4 Sample Collection

Sampling for each analysis/matrix will be performed in accordance with [Section 7.5](#) (sample rationale), [Section 8.1](#) (field tasks), [Section 8.3](#) (sample details), and the field Standard Operating Procedures (SOPs) provided in [Appendix B](#). Notable information also is summarized in [Section 5.2](#).



## 7.5 Sample Rationale Table

**Matrix:** Monitoring well groundwater

**Depth of Samples:** Middle of well screen

- Refer to Figure 7 for wells and other sample locations.
- Well MW06 will not be sampled, because it will not provide actionable data beyond that of adjacent wells MW04 and MW05.
- All well samples will provide current conditions data for the human health risk assessment. Number of samples and spatial locations will provide for ample calculation(s) of exposure point concentration(s) (EPC[s]).

Analysis	Method	No. of Samples	Monitoring Well	Rationale	Sampling Strategy
Perchlorate	SW846 6850	14 monitoring wells (14 groundwater samples not including QA/QC)	5 Existing Wells: S67MW01 through MW05 9 To-Be-Installed Wells: S67MW07 through MW15	<b>Target analytes / site contaminants.</b> 5 Existing Wells: <ul style="list-style-type: none"> <li>• These wells are placed in close vicinity within and around the old pilot test area.</li> <li>• Determine current conditions (concentrations) and add to the temporal data set to evaluate MNA. Compare data from these five wells to historical [perchlorate only] data to evaluate degradation of the and migration of the perchlorate contaminant plume.</li> <li>• Use data for human health risk assessment calculations.</li> <li>• Confirmation of source area plume configuration and concentration order(s) of magnitude.</li> </ul> 9 To-Be-Installed Wells: <ul style="list-style-type: none"> <li>• Utilize data from the additional wells to supplement previous investigation data.</li> <li>• Determine upgradient aquifer condition via wells MW07 and MW08.</li> <li>• Determine lateral (MW09, MW10, MW11, MW12, MW13, MW15) and downgradient (MW13, MW14, MW15) plume configuration and boundaries.</li> <li>• Provide current conditions snapshot of perchlorate and other probable site contaminants in the surficial aquifer for risk assessment calculations.</li> <li>• Determine aquifer geochemical conditions to evaluate F&amp;T of contaminants and potential remedies.</li> </ul>	Also see <a href="#">Section 8</a> . Fieldwork SOPs are provided in <a href="#">Attachment B</a> . All existing and to-be-installed monitoring wells in the site vicinity are shown on <a href="#">Figure 7</a> . Existing wells are, and to-be-installed wells will be, 2-inch inner-diameter, Schedule 40 PVC with 0.010-inch slot 10-ft well screens. The screens are, and will be, keyed into the underlying clay unit approximately 6 inches. Screen intervals for five existing wells are as follows (place pump sample intake at middle of screen): MW01 – 5-15 ft bgs MW02 – 6-16 ft bgs MW03 – 5-15 ft bgs MW04 – 7-17 ft bgs MW05 – 7-17 ft bgs Perchlorate groundwater samples will be field-filtered prior to containerization.
Select SVOCs: Phthalates & PAHs (see <a href="#">Section 9</a> )	SW846 3510C & 8270D SIM	(same as above)	(same as above)	<b>Target analytes / site contaminants.</b> (same as above)	(same as above)
Select Metals (Total & Dissolved) (see <a href="#">Section 9</a> )	SW846 3010A / 6020A	(same as above)	(same as above)	<b>Target analytes / site contaminants.</b> (same as above)	(same as above) Dissolved metals samples will be field-filtered prior to preservation.
Select Energetics (see <a href="#">Section 9</a> )	SW846 8330B	(same as above)	(same as above)	<b>Target analytes / site contaminants.</b> (same as above)	(same as above)
TOC	SW846 9060	(same as above)	(same as above)	<ul style="list-style-type: none"> <li>• Evaluate aquifer characteristics for carbon/energy source to drive biodegradation via reductive dechlorination.</li> <li>• Can be natural or anthropogenic.</li> <li>• Establish baseline conditions. Future monitoring: Compare to baseline data to evaluate electron donor (which is a carbon source) distribution, longevity, and migration.</li> </ul>	(same as above)
Methane	RSK175	(same as above)	(same as above)	<ul style="list-style-type: none"> <li>• Evaluate aquifer characteristics for baseline methanogenesis. Establish baseline conditions.</li> <li>• Future monitoring: Compare to baseline data to evaluate biodegradation steps and progress. Elevated levels of methane indicate fermentation is occurring in a highly anaerobic environment.</li> </ul>	(same as above)
Nitrate, Nitrite, Chloride, & Sulfate	USEPA 353.2 / 300.0	(same as above)	(same as above)	<ul style="list-style-type: none"> <li>• Nitrate and nitrite can be a direct result of the perchlorate salts release(s) if part of the salt (i.e., if the perchlorate itself was contaminated with nitrate/nitrite). Potential contaminants.</li> <li>• Evaluate aquifer characteristics for sulfanogenesis, denitrification, and electron acceptors (biodegradation steps).</li> <li>• At higher concentrations, sulfate may compete with the reductive dechlorination pathway.</li> <li>• Chloride concentrations can be tracked as an indicator of perchlorate degradation (dechlorination)</li> </ul>	(same as above)
Dissolved Oxygen	CHEMetrics® Test Kit	(same as above)	(same as above)	<ul style="list-style-type: none"> <li>• Evaluate aquifer characteristics for favorable reducing conditions at baseline and post-injection. DO below 0.5 mg/L suggests ideal conditions. Iron II concentrations indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese.</li> <li>• Ferrous iron above 1 mg/L suggests ideal conditions.</li> </ul>	(same as above)
Ferrous Iron	HACH® Field Test Kit	(same as above)	(same as above)		
qPCR	CENSUS for Perchlorate Reductase and Chloride Dismutase	2 monitoring wells (2 groundwater samples) (no QA/QC)	1 Existing Well: S67MW04 1 To-Be-Installed Well: S67MW14	<ul style="list-style-type: none"> <li>• Indicator of degrading microbial behavior (anaerobic dechlorination of perchlorate in this case).</li> <li>• MW04 is in the source area and MW14 is at the end of the plume.</li> </ul>	Biotrap samplers.

**Matrix:** Surface Water**Depth of Samples:** 0-1 ft horizon above sediment bottom

Refer to Figure 7 for sample locations.

Analysis	Method	No. of Samples	Rationale	Sampling Strategy
Perchlorate	SW846 6850	6 locations (6 surface water samples not including QA/QC)	<p><b>Target analytes / site contaminants.</b></p> <ul style="list-style-type: none"> <li>Surface water samples to be collected at depth to obtain the most representative sample of any groundwater contaminant discharge into creek (without performing pore water sampling).</li> <li>Determine spatial distribution along shoreline in discharge zone for any contamination if detected in surface water.</li> <li>Provide current conditions snapshot of perchlorate and other probable site contaminants in surface water for risk assessment calculations.</li> </ul>	<p>Also see <a href="#">Section 8</a>. Fieldwork SOPs are provided in <a href="#">Attachment B</a>.</p> <p>Surface water samples are collocated with sediment samples.</p> <p>Surface water to be collected at depth using a pole-mounted sample tubing intake—at 0-1 ft above sediment horizon. (Sediment samples are to be collected at 0-1 ft beneath the sediment horizon—see next table).</p>
Select SVOCs: Phthalates & PAHs (see <a href="#">Section 9</a> )	SW846 3510C & 8270D SIM	(same as above)	<p><b>Target analytes / site contaminants.</b></p> <p>(same as above)</p>	(same as above)
Select Metals (Total & Dissolved) (see <a href="#">Section 9</a> )	SW846 3010A / 6020A	(same as above)	<p><b>Target analytes / site contaminants.</b></p> <p>(same as above)</p>	(same as above) Dissolved metals samples will be field-filtered prior to preservation.
Select Energetics (see <a href="#">Section 9</a> )	SW846 8330B	(same as above)	<p><b>Target analytes / site contaminants.</b></p> <p>(same as above)</p>	(same as above)
Hardness	SM2340B	2 locations (2 surface water samples) (no QA/QC)	Some water quality criteria are hardness-dependent (as hardness increases, the criteria increases). The ecological risk assessor uses equation(s) to adjust the criteria based on hardness values.	(same as above)
Nitrate, Nitrite, Chloride	USEPA 300.0	(same as above)	<ul style="list-style-type: none"> <li>Nitrate and nitrite can be a direct result of the perchlorate salts release(s) if part of the salt (i.e., if the perchlorate itself was contaminated with nitrate/nitrite). Potential contaminants.</li> <li>Chloride concentrations can be tracked as an indicator of perchlorate degradation (dechlorination)</li> </ul>	(same as above)

**Matrix:** Sediment

**Depth of Samples:** 0-1 ft below top of sediment

Refer to Figure 7 for sample locations.

Analysis	Method	No. of Samples	Rationale	Sampling Strategy
Perchlorate	SW846 6850	6 locations (6 sediment samples not including QA/QC)	<p><b>Target analytes / site contaminants.</b></p> <ul style="list-style-type: none"> <li>Surficial sediment samples to be collected to obtain the most representative sample of any effects of groundwater contaminant discharge into creek.</li> <li>Determine spatial distribution along shoreline in discharge zone for any contamination if detected in sediment.</li> <li>Provide current conditions snapshot of perchlorate and other probable site contaminants in sediment for risk assessment calculations.</li> </ul>	<p>Also see <a href="#">Section 8</a>. Fieldwork SOPs are provided in <a href="#">Attachment B</a>.            Sediment samples are collocated with surface water samples.            Sediment to be composited from the first foot of sediments (benthic invertebrate habitat).</p>
Select SVOCs: Phthalates & PAHs (see <a href="#">Section 9</a> )	SW846 3550C & 8270D SIM	(same as above)	<p><b>Target analytes / site contaminants.</b> (same as above)</p>	(same as above)
Select Metals (see <a href="#">Section 9</a> )	SW846 3050B / 6020A	(same as above)	<p><b>Target analytes / site contaminants.</b> (same as above)</p>	(same as above)
Select Energetics (see <a href="#">Section 9</a> )	SW846 8330B (no grinding)	(same as above)	<p><b>Target analytes / site contaminants.</b> (same as above)</p>	(same as above)
TOC	Walkely Black	(same as above)	<ul style="list-style-type: none"> <li>Provide information on metals solubility and bioavailability, and subsequently toxicity, for ecological risk assessment.</li> <li>Can be used to adjust ERA-related criteria due to equilibrium partitioning.</li> </ul>	(same as above)

**Matrix:** Surface Soil**Depth of Samples:** 0-1 ft bgs

Refer to Figure 7 for sample locations.

Analysis	Method	No. of Samples	Rationale	Sampling Strategy
Perchlorate	SW846 6850	19 locations (19 sediment samples not including QA/QC)	<p><b>Target analytes / site contaminants.</b></p> <ul style="list-style-type: none"> <li>Determine spatial distribution throughout site to correlate with groundwater concentrations when examining spatial contaminant distributions—to determine source area and locations of historical releases. Upgradient (site-specific background) and downgradient locations included. Site-specific background data can provide information on natural conditions in the area to rule out impacts from the release(s).</li> <li>Evaluate overland flow and/or erosive transport of contaminants when updating the CSM and evaluating future risks.</li> <li>Provide current conditions snapshot of perchlorate and other probable site contaminants in surface soil for both human health and ecological risk assessment calculations.</li> </ul>	<p>Also see <a href="#">Section 8</a>. Fieldwork SOPs are provided in <a href="#">Attachment B</a>.</p> <p>Nine of the surface soil samples are collocated with subsurface soil samples and the nine new monitoring wells, which will benefit the evaluation of the presence of continuing source(s). Remaining 10 surface soil samples placed uniformly across topography to evaluate overland transport of mainly perchlorate and explosives.</p> <p>Discrete sample locations (not multi-incremental). Soil to be composited from 0 to 1 ft bgs at each discrete location (ecological habitat and human health exposure unit).</p>
Select SVOCs: Phthalates & PAHs (see <a href="#">Section 9</a> )	SW846 3550C & 8270D SIM	(same as above)	<p><b>Target analytes / site contaminants.</b> (same as above)</p>	(same as above)
Select Metals (see <a href="#">Section 9</a> )	SW846 3050B / 6020A	(same as above)	<p><b>Target analytes / site contaminants.</b> (same as above)</p>	(same as above)
Select Energetics (see <a href="#">Section 9</a> )	SW846 8330B (no grinding)	(same as above)	<p><b>Target analytes / site contaminants.</b> (same as above)</p>	(same as above)
pH	N/A	(same as above)	<ul style="list-style-type: none"> <li>Provide information on metals solubility and bioavailability, and subsequently toxicity, for ecological risk assessment.</li> <li>If pH is in the neutral range, then some metals are not necessary for evaluation in the ERA due to pH-dependent bioavailability relationships.</li> </ul>	(same as above) / N/A
TOC	Walkely Black	(same as above)	Provide information on metals solubility and bioavailability, and subsequently toxicity, for the ERA.	(same as above) / N/A

**Matrix:** Subsurface Soil

**Depth of Samples:** Exposure unit ranges from 1 ft bgs to water table; Anticipate sample collection above water table at approximately 7 ft bgs.

Refer to Figure 7 for sample locations.

Analysis	Method	No. of Samples	Rationale	Sampling Strategy
Perchlorate	SW846 6850	9 locations (9 subsurface soil samples not including QA/QC)	<p><b>Target analytes / site contaminants.</b></p> <ul style="list-style-type: none"> <li>Determine spatial distribution throughout site to correlate with groundwater concentrations—to determine source area and locations of historical releases. Upgradient (background) and downgradient locations included.</li> <li>Provide current conditions snapshot of perchlorate and other probable site contaminants in subsurface soil for human health risk assessment calculations.</li> </ul>	<p>Also see <a href="#">Section 8</a>. Fieldwork SOPs are provided in <a href="#">Attachment B</a>.</p> <p>The nine subsurface soil sample locations are collocated with surface soil samples and new monitoring wells. Having groundwater data at the same location as subsurface soil data will benefit the evaluation of the presence of continuing source(s).</p> <p>Samples will be collected from the 1-ft interval above the water table (depth possibly unique at each location; ranges between 6 and 10 ft bgs). However, if staining or PID responses are encountered, the impacted soil must be sampled, too (in addition to planned sample). A PID response greater than 100 parts per million would indicate unanticipated volatiles contamination. If this occurs, the Partnering Team will have to be consulted to scope new analyses, etc.</p> <p>oil to be composited from the 1-ft interval above the water table at each of the 9 locations. This will provide representative concentrations for use in the human health risk assessment for the subsurface soil exposure unit.</p>
Select SVOCs: Phthalates & PAHs (see <a href="#">Section 9</a> )	SW846 3550C & 8270D SIM	(same as above)	<p><b>Target analytes / site contaminants.</b> (same as above)</p>	(same as above)
Select Metals (see <a href="#">Section 9</a> )	SW846 3050B / 6020A	(same as above)	<p><b>Target analytes / site contaminants.</b> (same as above)</p>	(same as above)
Select Energetics (see <a href="#">Section 9</a> )	SW846 8330B (no grinding)	(same as above)	<p><b>Target analytes / site contaminants.</b> (same as above)</p>	(same as above)



## 8 FIELD PROJECT IMPLEMENTATION

### (Field Project Instructions)

The field tasks are summarized below. A short description of each task is also provided.

- Mobilization/Demobilization
- Utility Clearance
- Field Monitoring / Equipment Calibration
- Surface Water Sampling
- Sediment Sampling
- Surface Soil Sampling
- Soil Borings and Subsurface Soil Sampling
- Monitoring Well Installation
- Water Level Measurements
- Monitoring Well Sampling
- IDW Management
- Surveying
- Field Equipment Decontamination Procedures
- Field Documentation Procedures
- Sample Custody and Shipment Tasks

Additional project-related tasks include:

- Analytical Tasks
- Data Management
- Project Reports

### 8.1 Field Project Tasks

(UFP-QAPP Manual Section 2.8.1 and UFP-QAPP Workbook WS #14)

This section provides a brief narrative for each field task, referencing the respective SOP(s) tabulated in [Section 8.3](#) and provided in [Appendix B](#). The SOPs are from the *Master UFP-SAP for NSF-IH* (Tt, 2009)—any deviations are marked on the SOPs (red-line edits).

#### 8.1.1 Mobilization/Demobilization

Mobilization shall consist of the delivery of all equipment, materials, and supplies to the site, the complete assembly in satisfactory working order of all such equipment at the site, and the satisfactory storage at the site of all such materials and supplies. It will coordinate with the facility to identify locations for the storage of equipment and supplies. Site-specific H&S training will be provided to all Tt subcontractors as part of the site mobilization.

The sample locations are shown on [Figure 7](#). New monitoring well and sample locations ([Figure 7](#)) will be placed according to their pre-determined GPS coordinates (e.g., Maryland State Plane, feet; see Physical Data subsection in [Section 5.2](#)) using a sub-foot accuracy GPS unit. All locations will be staked or pin-flagged during mobilization, and then reconciled with utilities (i.e., moved as necessary) during the follow-on utility clearance task.

Demobilization shall consist of the prompt and timely removal of all equipment, materials, and supplies from the site following completion of the work. Demobilization includes the cleanup and removal of IDW generated during the investigation.

### 8.1.2 Utility Clearance

Prior to the commencement of any intrusive activities, the Tt FOL will coordinate with the utility subcontractor to identify and mark-out utilities that may be present within the proposed drilling areas. Subsurface utilities also will be cleared by the drilling/DPT subcontractor by notifying the utility clearing service. See Facility SOP HS-1.0 for conducting subsurface soil investigations for further information.

### 8.1.3 Field Monitoring / Equipment Calibration / Inspection

Field equipment will be inspected and calibrated as indicated in the table below.

Field Equipment	Activity	Frequency	Acceptance Criteria	Corrective Action	Responsible Person	Facility SOP Reference <sup>(1)</sup>
PID	Visual Inspection, Calibration	Daily, before use	Manufacturer's Guidance	Replace	Tetra Tech (Tt) FOL or designee	SA-2.2, Manufacturer's Guidance
DPT/Drill Rig	Inspection	Daily	Equipment inspection sheet criteria	Replace	Tt FOL or designee	GH-1.3, GH-1.5, GH-2.8, SA-2.5
Disposable Hand Trowel	Inspection	Per use	N/A	Replace	Tt FOL or designee	SA-1.3
Water Level Meter	Visual Inspection	Daily	Manufacturer's Guidance	Replace	Tt FOL or designee	Manufacturer's Guidance
Multi-Parameter Water Quality Meter (pH, Temp., Sp. Cond., D.O., ORP)	Visual Inspection, Calibration	Daily, before use	Manufacturer's Guidance	Replace	Tt FOL or designee	SA-1.1, Manufacturer's Guidance
Turbidity Meter	Visual Inspection, Calibration	Daily, before use	Manufacturer's Guidance; Calibrations must bracket expected values. Initial Calibration Verification (ICV) must be + or -10 Nephelometric Turbidity Units (NTUs) of target value.	Replace	Tt FOL or designee	SA-1.1, Manufacturer's Guidance
Groundwater sampling pumps and tubing	Inspect pumps, tubing and air/sample line quick-connects	Regularly	Maintained in good working order per manufacturer's recommendations	Replace	Tt FOL or designee	SA-1.1, Manufacturer's Guidance

### 8.1.4 Surface Water Sampling

Surface water samples will be collected prior to any site disturbance to minimize any impacts from runoff. Surface water samples also are to be taken prior to collecting the collocated sediment samples to eliminate potential effects of sediment particle entrainment. Field personnel will access each location using a boat.

The six surface water samples will be collected as grab samples using a peristaltic pump with dedicated-per-location, disposable tubing. The tube intake will be attached to a pole (that can reach the sediment bottom) such that the surface water sample can be collected from the 0 to 1 ft horizon above the sediment. Water

quality measurements will be taken using a water quality meter with flow-through cell (same as used during groundwater sampling). Surface water sample procedures are described in Facility SOP SA-1.2.

#### **8.1.5 Sediment Sampling**

Field personnel will access each location using a boat. The six sediment samples will be taken following collection of all six collocated surface water samples. A stainless steel Ekman or Ponar dredge (or similar device) will be utilized to collect sediment samples from 0 to 1 ft beneath the sediment horizon in accordance with Facility SOP SA-1.2. Reusable equipment will be decontaminated between sample locations.

#### **8.1.6 Surface Soil Sampling**

Surface soil samples will be collected from 19 locations. The samples will be collected from 0 to 1 ft bgs in accordance with Facility SOP SA-1.3. Discrete grab samples are appropriate for all analyses at each location during this RI. Reusable equipment will be decontaminated between sample locations.

#### **8.1.7 Soil Borings and Subsurface Soil Sampling**

Subsurface soil samples will be obtained from nine soil borings during new monitoring well installations using DPT methods. The proposed soil boring and soil sample locations are presented on [Figure 7](#). With a truck- or track-mounted DPT (depending on weather/terrain conditions), continuous soil cores will be obtained to the target depth at each location by advancing a macrocore (4- or 5-foot) to the basal clay layer/aquitard (expected at 15 ft bgs). The core barrel assembly will be withdrawn and the soils will be screened, described, and sampled.

The soil will be described by Tt field personnel and a boring log will be developed. Soil cores will be screened along their entire length with a photoionization detector (PID) for evidence of potential contamination. Any visual signs of potential contamination (such as soil staining) will be noted and [additional] samples will be collected.

Soil samples will be collected from the macrocores as described herein and outlined in [Section 7.5](#). Soil sampling, soil logging, sample handling, and DPT work procedures are discussed in Facility SOPs GH-1.3, GH-1.4, GH-1.5, SAQ-1.3, and SA-2.5. The use of the PID is described in the manufacturer's instructions. Reusable equipment will be decontaminated between sample locations.

#### **8.1.8 Monitoring Well Installation**

The nine new monitoring wells ([Figure 7](#)) will be constructed using the same materials and methods as the existing monitoring wells, with the 10 ft screen of each installed approximately 1 ft into the basal clay layer at the bottom of the surficial aquifer (expected at 15 ft bgs). Each new well will be finished with a stick-up riser and protective bollards.

Soil borings will be drilled at the proposed monitoring well locations to confirm the subsurface lithology and depths to ensure proper depths for well installation (to be screened just above the clay layer). The soil cores will be screened visually and along their entire length with a PID in accordance with the PID manufacturer's instructions. The boring information will be recorded in accordance with Facility SOP SA-6.3. The monitoring wells will be installed using hollow-stem auger (HSA) drilling methods. Monitoring well installation procedures are discussed in Facility SOP GH-2.8 and each of the new monitoring wells will be developed in accordance with this SOP.

### **8.1.9 Water Level Measurements**

Prior to groundwater sampling, a synoptic round of groundwater level measurements will be made. Depth to groundwater will be measured at each monitoring well, per Facility SOP GH-1.2. Along with the subsequent survey effort, this will provide for generation of groundwater elevation contour maps and provide information on groundwater flow patterns and gradients. Water-level measurements will be completed within the shortest time possible on the same day, and no sooner than 24 hours after a significant precipitation event to minimize the precipitation effects on the data. Water levels will be collected from the wells closest to the creek first so as to minimize tidal impacts on measurements. Water level measurements will be recorded to the nearest 0.01 foot and referenced to a top of casing notch or north side of the well casing. The measurement instrument will be decontaminated prior to conducting the measurement and between each monitoring well.

### **8.1.10 Monitoring Well Sampling**

Groundwater sampling will be conducted at each monitoring well using low-flow sampling procedures, per Facility SOP SA-1.1. Old monitoring wells MW01 through MW05 will be re-developed prior to sampling (Facility SOP GH-2.8). A peristaltic pump with dedicated-per-well, disposable tubing will be used for groundwater sample purging and collection activities, in combination with a continuous flow-through cell suitable for taking water quality measurements. Groundwater samples collected for perchlorate and dissolved metals will be field filtered. Reusable equipment will be decontaminated between sample locations.

### **8.1.11 IDW Management**

Based on previous investigations, all IDW is assumed to be nonhazardous.

Waste soils will be generated during the installation of the soil borings and monitoring wells. The soil IDW consists of the excess soil cuttings from the soil borings that were not collected for laboratory analyses, and the soils produced during the drilling of the boreholes for monitoring well installations. The waste soil will be collected and placed in 55-gallon drums for waste characterization sampling and analysis. Waste water will be generated during well installation, development, and sampling, and during all decontamination procedures for other sampling. Similar to waste soils, all aqueous IDW will be containerized in 55-gallon drums for waste characterization sampling and analysis.

All drums will be labeled and moved to be stored inside the diked area next to Building 289 that has secondary containment (near NSF-IH IRP Manager's office). The driller/DPT subcontractor is responsible for safely moving and handling the drums. Pending the results of the waste characterization(s), and upon Navy approval, the waste soil and water will be appropriately transported and disposed at a Navy-approved disposal facility(ies) by the IDW subcontractor.

### **8.1.12 Surveying**

A surveyor subcontractor licensed in the state of Maryland will survey the horizontal location and vertical elevation of each of the monitoring wells (existing and to-be-installed). The horizontal measurements shall be accurate to 0.1 ft. The vertical elevation measurements shall be accurate to 0.01 ft at the top-of-riser at each monitoring well. Each of the locations will be surveyed in the North American Datum (NAD) of 1983, State Plane Coordinate System of Maryland (feet) relative to the coordinates of established site benchmarks or the nearest United States Geological Survey (USGS) benchmark.

### **8.1.13 Field Equipment Decontamination Procedures**

Decontamination of equipment will be conducted in accordance with Facility SOP SA-7.1. Decontamination fluids will be containerized and characterized for appropriate disposal with other IDW.

### 8.1.14 Field Documentation Procedures

Field documentation will be performed in accordance with Facility SOP SA-6.3. A summary of all field activities will be properly recorded in a bound logbook with consecutively numbered pages that cannot be removed. Logbooks will be assigned to field personnel and will be stored in a secured area when not in use. At a minimum, the following information will be recorded in the site logbook:

- Name of the person to whom the logbook is assigned.
- Project name.
- Project start date.
- Names and responsibilities of onsite project personnel including subcontractor personnel.
- Arrival/departure of site visitors.
- Arrival/departure of equipment.
- Sampling activities and sample log sheet references.
- Description of subcontractor activities.
- Sample pick-up information, including CoC numbers, air bill numbers, carrier, time, and date.
- Description of borehole or monitoring well installation activities and operations.
- H&S issues.

All entries will be written in ink and no erasures will be made. If an incorrect entry is made, striking a single line through the incorrect information will make the correction; the person making the correction will initial and date the change. Boring logs, sampling forms, and other field forms will be used to document field activities.

### 8.1.15 Sample Custody and Shipment Tasks

Data management and sample tracking tasks are described in [Section 8.5.2](#) and in Facility SOP CT-05. Sample nomenclature is detailed in [Section 8.3](#).

## 8.2 **Field SOPs Reference Table**

(UFP-QAPP Manual Section 3.1.2 – WS #21)

The SOPs tabulated below for the RI effort are from Appendix D of the *NSF-IH Master SAP* (Tt, 2009). Project-specific versions of the SOPs are provided in [Appendix B](#) herein. Minor deviations (or exclusions of portions) of SOPs are indicated by direct mark-up of the SOP. This section lists the SOPs to be used/referenced during the RI effort. Partial exclusions are not noted as deviations. Note that the sampling SOPs for all media for perchlorate are supplemented by the DoD (2007) perchlorate sampling SOP(s) (also provided in [Appendix B](#)).

SOP Reference Number	Title/Author and Revision Date/Number	Equipment Type	Any planned deviation for Project Work
CT-04	Sample Nomenclature, 02/04, Rev. 0	N/A	Yes
GH-1.1	Site Reconnaissance, 02/04, Rev. 0	N/A	No
GH-1.2	Evaluation of Existing Monitoring Wells and Water Level Measurement, 02/04, Rev. 0	Water level indicator	No
GH-1.3	Soil and Rock Drilling Methods, 02/04, Rev. 0	Drilling rig and accessories	No
GH-1.5	Borehole and Sample Logging, 02/04, Rev. 0	N/A	No
GH-2.8	Groundwater Monitoring Well Installation, 02/04, Rev. 0	Drilling rig, accessories, and well supplies	No

8. FIELD PROJECT IMPLEMENTATION

SOP Reference Number	Title/Author and Revision Date/Number	Equipment Type	Any planned deviation for Project Work
SA-1.6	Natural Attenuation Parameter Collection, 03/08, Rev. 0	Water Quality Meter and Field test kits	No
SA-1.1	Groundwater Sample Acquisition and Onsite Water Quality Testing, 03/08, Rev. 1 <i>*Also see included DoD (2007) Perchlorate Sampling SOP.</i>	Pump, tubing, water quality meter, and accessories	No
SA-1.2	Surface Water and Sediment Sampling, 03/08, Rev. 1 <i>*Also see included DoD (2007) Perchlorate Sampling SOP.</i>	Pump, tubing, pole-mount, boat, water quality meter, Ponor dredge, and accessories	No
SA-1.3	Soil Sampling, 03/08, Rev. 1 <i>*Also see included DoD (2007) Perchlorate Sampling SOP.</i>	Trowel, shovel, hand auger, and/or macrocore/split-barrel sampler	No
SA-2.5	Direct Push Technology (Geoprobe/Hydropunch), 02/04, Rev. 0	Drilling equipment and accessories	No
SA-2.2	Air Monitoring and Sampling, 02/04, Rev. 0	Air sampling pump and accessories, photoionization detector (PID), and/or flame ionization detector (FID)	No
SA-6.1	Non-Radiological Sample Handling, 02/04, Rev. 0	Sample bottleware, packaging material, shipping materials, field filtration equipment	No
SA-6.3	Field Documentation, 02/04, Rev. 0	Field logbook, field sample forms, boring logs	No
SA-7.1	Decontamination of Field Equipment, 03/08, Rev. 1	Decontamination equipment, phosphate-free detergent, deionized water	No
HS-1.0	Utility Locating and Excavation Clearance, 02/04, Rev. 0	Remote subsurface sensing equipment, magnetometer, ground-penetrating radar	No

### 8.3 Sample Details Table

(UFP-QAPP Manual Sections 3.1.1 and 3.5.2.3 – WSs #18, 19, 20 and 30)

The table below provides the sample IDs, analyses, and QA/QC for all samples to be collected during the RI. Also see the Analytical SOP Requirements Table in [Section 8.4](#) for bottleware and preservation requirements, etc.

Sample Details Table

Site	Station ID	Matrix	Sample ID	Depth/ Sampling Interval	Analyses <sup>(1)</sup>									Comments	
					Phthalates	PAHs	Select Metals (total & dissolved)	Select Energetics	Perchlorate	Nitrate/ Nitrite	Additional Ecological Risk Parameters <sup>(2)</sup>	Other MNA Parameters <sup>(3)</sup>	qPCR		
Site 67	S67MW01	groundwater	S67-MW001-mmddy	middle of screen	x	x	x	x	x	x		x		"MW-1" installed by Navy (NOSSA) in 2002.	
	S67MW02	groundwater	S67-MW002-mmddy	middle of screen	x	x	x	x	x	x		x		"MW-2" installed by Navy (NOSSA) in 2002.	
	S67MW03	groundwater	S67-MW003-mmddy	middle of screen	x	x	x	x	x	x		x		"MW-3" installed by Navy (NOSSA) in 2002.	
	S67MW04	groundwater	S67-MW004-mmddy	middle of screen	x	x	x	x	x	x		x	x	"MW-4" installed by Navy (NOSSA) in 2002.	
	S67MW05	groundwater	S67-MW005-mmddy	middle of screen	x	x	x	x	x	x		x		"MW-5" installed by Navy (NOSSA) in 2002.	
		groundwater	S67-MW005P-mmddy	middle of screen	x	x	x	x	x	x		x		Field duplicate	
	S67S01	surface soil	S67-SS001-0001	0 - 1 foot	x	x	x	x	x			x			
		surface soil	S67-SS001P-0001	0 - 1 foot	x	x	x	x	x			x			Field duplicate
		subsurface soil	S67-SB001-xyy	interval above water table	x	x	x	x	x						
		groundwater	S67-MW007-mmddy	middle of screen; tbd	x	x	x	x	x	x			x		Note "MW-6" installed by Navy (NOSSA) in 2002; Start new well number at MW07.
	S67S02	surface soil	S67-SS002-0001	0 - 1 foot	x	x	x	x	x			x			
	S67S03	surface soil	S67-SS003-0001	0 - 1 foot	x	x	x	x	x			x			
	S67S04	surface soil	S67-SS004-0001	0 - 1 foot	x	x	x	x	x			x			
		subsurface soil	S67-SB004-xyy	interval above water table	x	x	x	x	x						
		subsurface soil	S67-SB004P-xyy	interval above water table	x	x	x	x	x						Field duplicate
		groundwater	S67-MW008-mmddy	middle of screen; tbd	x	x	x	x	x	x			x		
	S67S05	surface soil	S67-SS005-0001	0 - 1 foot	x	x	x	x	x			x			
	S67S06	surface soil	S67-SS006-0001	0 - 1 foot	x	x	x	x	x						
		subsurface soil	S67-SB006-xyy	interval above water table	x	x	x	x	x						
		groundwater	S67-MW009-mmddy	middle of screen; tbd	x	x	x	x	x	x			x		
	S67S07	surface soil	S67-SS007-0001	0 - 1 foot	x	x	x	x	x						
		subsurface soil	S67-SB007-xyy	interval above water table	x	x	x	x	x						
		groundwater	S67-MW010-mmddy	middle of screen; tbd	x	x	x	x	x	x			x		
	S67S08	surface soil	S67-SS008-0001	0 - 1 foot	x	x	x	x	x						
	S67S09	surface soil	S67-SS009-0001	0 - 1 foot	x	x	x	x	x						
	S67S10	surface soil	S67-SS010-0001	0 - 1 foot	x	x	x	x	x						
		subsurface soil	S67-SB010-xyy	interval above water table	x	x	x	x	x						
		groundwater	S67-MW011-mmddy	middle of screen; tbd	x	x	x	x	x	x			x		
S67S11	surface soil	S67-SS011-0001	0 - 1 foot	x	x	x	x	x							
	subsurface soil	S67-SB011-xyy	interval above water table	x	x	x	x	x							
	groundwater	S67-MW012-mmddy	middle of screen; tbd	x	x	x	x	x	x			x			
	groundwater	S67-MW012P-mmddy	middle of screen; tbd	x	x	x	x	x	x			x		Field duplicate	
S67S12	surface soil	S67-SS012-0001	0 - 1 foot	x	x	x	x	x			x				
	surface soil	S67-SS012P-0001	0 - 1 foot	x	x	x	x	x			x			Field duplicate	
S67S13	surface soil	S67-SS013-0001	0 - 1 foot	x	x	x	x	x			x				
S67S14	surface soil	S67-SS014-0001	0 - 1 foot	x	x	x	x	x			x				

Sample Details Table (continued)

Site	Station ID	Matrix	Sample ID	Depth/ Sampling Interval	Analyses <sup>(1)</sup>									Comments
					Phthalates	PAHs	Select Metals (total & dissolved)	Select Energetics	Perchlorate	Nitrate/ Nitrite	Additional Ecological Risk Parameters <sup>(2)</sup>	Other MNA Parameters <sup>(3)</sup>	qPCR	
Site 67	S67S15	surface soil	S67-SS015-0001	0 - 1 foot	x	x	x	x	x					
		subsurface soil	S67-SB015-xyyy	interval above water table	x	x	x	x	x					
		groundwater	S67-MW013-mmddyy	middle of screen; tbd	x	x	x	x	x	x		x		
	S67S16	surface soil	S67-SS016-0001	0 - 1 foot	x	x	x	x	x		x			
	S67S17	surface soil	S67-SS017-0001	0 - 1 foot	x	x	x	x	x		x			
		subsurface soil	S67-SB017-xyyy	interval above water table	x	x	x	x	x					
		groundwater	S67-MW014-mmddyy	middle of screen; tbd	x	x	x	x	x	x		x	x	
	S67S18	surface soil	S67-SS018-0001	0 - 1 foot	x	x	x	x	x					
	S67S19	surface soil	S67-SS019-0001	0 - 1 foot	x	x	x	x	x					
		subsurface soil	S67-SB019-xyyy	interval above water table	x	x	x	x	x					
		groundwater	S67-MW015-mmddyy	middle of screen; tbd	x	x	x	x	x	x		x		
	S67S20	sediment	S67-SD20-0001	0 - 1 foot	x	x	x	x	x		x			
		surface water	S67-SW20-mmddyy	at depth / just above sediment	x	x	x	x	x	x	x			
	S67S21	sediment	S67-SD21-0001	0 - 1 foot	x	x	x	x	x		x			
		surface water	S67-SW21-mmddyy	at depth / just above sediment	x	x	x	x	x	x	x			
	S67S22	sediment	S67-SD22-0001	0 - 1 foot	x	x	x	x	x		x			
		sediment	S67-SD22P-0001	0 - 1 foot	x	x	x	x	x		x			Field duplicate
		surface water	S67-SW22-mmddyy	at depth / just above sediment	x	x	x	x	x	x	x			
	S67S23	sediment	S67-SD23-0001	0 - 1 foot	x	x	x	x	x		x			
		surface water	S67-SW23-mmddyy	at depth / just above sediment	x	x	x	x	x	x	x			
surface water		S67-SW23P-mmddyy	at depth / just above sediment	x	x	x	x	x	x	x			Field duplicate	
S67S24	sediment	S67-SD24-0001	0 - 1 foot	x	x	x	x	x		x				
	surface water	S67-SW24-mmddyy	at depth / just above sediment	x	x	x	x	x	x	x				
S67S25	sediment	S67-SD25-0001	0 - 1 foot	x	x	x	x	x		x				
	surface water	S67-SW25-mmddyy	at depth / just above sediment	x	x	x	x	x	x	x				

**Notes:**

tbd – to be determined

mmddyy – two digit month, two-digit date, two-digit year of sample collection.

xyyy – two digit top depth and two digit bottom depth of sample interval.

1. See specific analytes in [Section 9](#) (e.g., all the phthalates and PAHs).

2. Other Ecological Risk Parameters:
- surface soil (0-1 ft): pH and TOC
  - sediments (0-1 ft) - TOC (subset of samples if needed)
  - surface water (at depth) – Hardness; only for samples SW20 and SW24; ERA also needs total & dissolved metals.

3. Other MNA Parameters: To evaluate aquifer geochemistry and biodegradation via reductive dechlorination, analyze for Total Organic Carbon (TOC), Sulfate, Chloride, and Dissolved Methane.

4. See field QA/QC details in [Section 6](#). Equipment blank IDs shall be as follows: S67-EB01-mmddyy. MS/MSDs will retain same sample ID as parent sample (“do MS/MSD” will be noted on the chain-of-custody form).

## 8.4 Analytical SOP Requirements Table

(UFP-QAPP Manual Section 3.1.1)

Matrix	Analytical Group	Analytical and Preparation Method / SOP Reference <sup>(1)</sup>	Sample Size	Containers <sup>(2)</sup> (number, size, and type)	Preservation Requirements	Maximum Holding Time <sup>(3)</sup> (preparation / analysis)
Soil and Sediment	Phthalates and PAHs	SW-846 3550C, 8270D SIM/ANA8270DSIM	One 4-oz glass jar	40 gram (g)	Cool to 0 to 6 °C	14 days until extraction, 40 days to analysis
Groundwater, Surface water, and Aqueous QC samples	Phthalates and PAHs	SW-846 3510C, 8270D SIM/ANA8270DSIM	Two 1-L glass amber bottles	1,000 milliliter (mL)	Cool to 0 to 6 °C	7 days until extraction, 40 days to analysis
Soil and Sediment	Energetics	SW-846 8330B no grinding / HPL8330	One 4-oz glass jar	30 g	Cool to 0 to 6 °C	14 days until extraction, 40 days to analysis
Groundwater, Surface water, and Aqueous QC samples	Energetics	SW-846 8330B / HPL8330	Two 1-L glass amber bottles	1000 mL	Cool to 0 to 6 °C	7 days until extraction, 40 days to analysis
Soil and Sediment	Perchlorate	SW-846 6850 APPL SOP	One 4-oz glass jar	5 g	Cool to 0 to 6 °C	28 days to analysis
Groundwater, Surface water, and Aqueous QC samples	Perchlorate	SW-846 6850 / HPL6850	500 mL plastic	100 mL	Cool to 0 to 6 °C	28 days to analysis
Soil and Sediment	Metals	SW-846 3050B/ 6020A/ ANA6020	One 4-oz glass jar	1 to 2 g	Cool to 0 to 6 °C	180 days to analysis except mercury, 28 days for mercury
Groundwater, Surface water, and Aqueous QC samples	Metals (total and dissolved) and hardness	SW-846 3010A / 6020A / SM2340B APPL ANA6020	One 500-mL plastic bottle	50 mL	Nitric acid to pH <2; Cool to 0 to 6 °C	180 days to analysis except mercury, 28 days for mercury
Groundwater	Anions (nitrate, nitrite, chloride and sulfate)	USEPA 300.0 / ANA300.0	One 500-mL plastic bottle	5 mL for each analyte	Cool to 0 to 6 °C	Nitrate & Nitrite – 48 hours from sampled time to analysis. Chloride & Sulfate – 28 days from sampled date to analysis
Groundwater	Nitrate/Nitrite	USEPA 353.2 / ANA353.2	One 500-mL plastic bottle	5 mL for each analyte	Cool to 0 to 6 °C	48 hours from sampled time to analysis
Soil and Sediment	TOC	Walkely Black / ANAWALKLEY	One 4-oz glass jar	30 g	Cool to 0 to 6 °C	14 days to analysis
Groundwater	TOC	SW-846 9060/9060A / ANA9060A	One 500-mL plastic bottle	250 mL	Sulfuric acid to pH <2; Cool to 0 to 6 °C	28 days to analysis
Groundwater	Dissolved Methane	RSK SOP 175 / ANARSK-175	Three 40-mL glass vials	15 mL	Hydrochloric acid to pH <2; Cool to 0 to 6 °C	14 days from sampled date to analyze

8. FIELD PROJECT IMPLEMENTATION

Matrix	Analytical Group	Analytical and Preparation Method / SOP Reference <sup>(1)</sup>	Sample Size	Containers <sup>(2)</sup> (number, size, and type)	Preservation Requirements	Maximum Holding Time <sup>(3)</sup> (preparation / analysis)
Solid IDW <sup>(4)</sup>	TCLP – SVOCs	SW-846 1311 & 8270D / 11-PRE1311, ANA8270D	25 g	One 8-oz wide-mouth glass jar	Cool to 0 to 6 °C	14 days from sampled date to leaching, 14 days from leaching to analysis
Aqueous IDW <sup>(4)</sup>	TCLP – SVOCs	SW-846 1311 & 8270D / 11-PRE1311, ANA8270D	500 mL	One 1-L amber glass bottle	Cool to 0 to 6 °C	14 days from sampled date to leaching, 14 days from leaching to analysis
Solid IDW <sup>(4)</sup>	TCLP – Metals	SW-846 1311, 6010C & 7470A / 11-PRE1311, ANA6010, ANA7470A	100 g	One 8-oz wide-mouth glass jar	Cool to 0 to 6 °C	28 days from sampled date to leaching, 28 days from leaching to analysis
Aqueous IDW <sup>(4)</sup>	TCLP – Metals	SW-846 1311, 6010C & 7470A / 11-PRE1311, ANA6010, ANA7470A	500 mL	One 1-L High Density Polyethylene (HDPE) bottle	Cool to 0 to 6 °C	28 days from sampled date to leaching, 28 days from leaching to analysis
Solid IDW <sup>(4)</sup>	Ignitability	SW-846 1010A	20 g	One 4-oz wide-mouth glass jar	Cool to 0 to 6 °C	As soon as possible after laboratory receipt
Aqueous IDW <sup>(4)</sup>	Ignitability	SW-846 1010A	100 mL	One 100mL HDPE bottle	Cool to 0 to 6 °C	As soon as possible after laboratory receipt
Aqueous IDW <sup>(4)</sup>	Corrosivity (towards steel)	SW-846 1110A	425mL	One 1Liter HDPE bottle	Cool to 0 to 6 °C	As soon as possible after laboratory receipt
Microbial <sup>(4)</sup>	Perchlorate reductase gene (pcrA)	Laboratory proprietary Methods, MI SOP DNA-qPCR, MI SOP DNA Ext	1L	Bio-Trap samplers	Cool to 0 to 6 °C	Extract within 28 hours and freeze at -20°C until analysis
	Chlorite dismutase gene (cld)	Laboratory proprietary Methods, MI SOP DNA-qPCR, MI SOP DNA Ext	1L	Bio-Trap samplers	Cool to 0 to 6 °C	Extract within 28 hours and freeze at -20°C until analysis

**Notes:**

- mL – milliliter      g – gram    L – liter    oz – ounce      °C – Degrees Celsius      TCLP – Toxicity Characteristic Leaching Procedure      TOC – total organic carbon
- Laboratory SOPs are subject to revision and updates during duration of the project, the laboratory will use the most current revision of the SOP at the time of analysis.
  - Sample size is a minimum; the containers listed will be filled to compensate for any required re-analysis or re-extractions. For samples requiring Matrix Spike (MS)/Matrix Spike Duplicate (MSD), containers listed should be tripled.
  - Maximum holding time is calculated from the time the sample is collected to the time the sample is prepared/extracted.
  - IDW sample analyses and Microbial sample analyses are presented in this section for the utilization of field personnel. Quality control information is not presented in any of the remaining WSs for these samples.

## 8.5 Additional Project-Related Tasks

Additional project-related tasks include the following:

- Analytical tasks
- Data management
- Assessment and oversight
- Data review
- Project reports

### 8.5.1 Analytical Tasks

Chemical analyses will be performed by APPL. APPL is Department of Defense (DoD) Environmental Laboratory Program (ELAP) accredited. A copy of the laboratory accreditation is located in Appendix C. Analyses will be performed in accordance with the analytical methods specified in Section 8.2. APPL will meet most of the PSLs/PALs as shown in [Section 9](#). APPL will perform chemical analysis following laboratory-specific SOPs ([Section 10](#)).

All soil results will be reported by the laboratory on a dry-weight basis. Results of percent moisture will be reported in each analytical data package and electronic data deliverable (EDD). This information will also be captured in the project database which will eventually be uploaded to Naval Installation Restoration Information Solution (NIRIS).

The analytical data packages provided by APPL will be in a Contract Laboratory Program (CLP)-like format, contain raw data capable of full data validation, contain summary forms for all sample and laboratory method blank data, and contain summary forms showing all method-specific QC information [results, recoveries, relative percent differences (RPDs), relative standard deviation (RSDs), and/or percent differences (%Ds), etc.].

### 8.5.2 Data Management

The principal data generated for this project will be from field and laboratory analytical data. Field sampling log sheets will be organized by date and medium, and filed in the project files. The field logbooks for this project will be used only for this site and will also be categorized and maintained in the project files after the completion of the field program. Project personnel completing concurrent field sampling activities may maintain multiple field logbooks. When possible, logbooks will be segregated by sampling activity. The field logbooks will be titled based on date and activity.

The data handling procedures to be followed by APPL will meet the requirements of the technical specifications. Electronic data results will be automatically downloaded into the Tt database in accordance with the proprietary Tt processes.

The Tt PM (or designee) is responsible for the overall tracking and control of data generated for the project.

**Data Tracking.** Data are tracked from generation to archiving in the Tt project-specific files. The Tt Project Chemist (or designee) is responsible for tracking the samples collected and shipped to APPL. Upon receipt of the data packages from APPL, the Tt Project Chemist will monitor the data validation effort, which includes verifying that the data packages are complete and results for all samples have been delivered by APPL.

**Data Storage, Archiving, and Retrieval.** The data packages received from APPL are tracked in the data validation logbook. After the data are validated, the data packages are entered into the Tt Navy CLEAN file system and archived in secure files. The field records, including field log books, sample logs, chain-of-custody records, and field calibration logs, will be submitted by the Tt FOL to be entered into the Navy CLEAN file system prior to archiving in secure project files. Project files are audited for accuracy and completeness. At the completion of the Navy contract, the records will be stored by Tt.

**Data Security.** Access to Tt project files is restricted to designated personnel only. Records can only be borrowed temporarily from the project file using a sign-out system. The Tt Data Manager maintains the electronic data files, and access to the data files is restricted to qualified personnel only. File and data backup procedures are routinely performed.

**Electronic Data.** All electronic data will be compiled into a NIRIS Electronic Data Deliverable (NEDD) and loaded into NIRIS.

**Data Review.** This review comprises data verification, validation, and usability assessment. The data verification and validation processes and requirements are described in [Section 12](#). The data usability assessment will, at a minimum, constitute evaluation of the following characteristics to ensure that the amount, type, and quality of data are sufficient to achieve project objectives. The means of conducting these evaluations will vary depending on the nature of the data. For example, soil borings and well construction logs will generally be evaluated qualitatively or semi-quantitatively whereas precision, accuracy, and sensitivity of analytical data will generally be evaluated quantitatively and may be based on, or may supplement, data validation findings. Examples include the following:

- Comparing actual to intended sampling locations and verifying that the correct datum was used to delineate contamination.
- Looking for trends across sample delivery groups or sampling events.
- Identifying potential errant or outlier data points.
- Assessing planning assumption validity.
- Evaluating the potential for contamination of samples by samplers.

Data quality indicators to be evaluated during this assessment include the following:

1. **Precision.** A semi-quantitative estimate of the uncertainty in contaminant concentrations as a function of location will be made.
2. **Accuracy.** Accuracy data will be evaluated to ensure sampling and measurement accuracy is within or exceeds analytical method specifications and may depend in part on the data validation findings.
3. **Representativeness.** This evaluation will assess whether the data are adequately representative of intended populations based on the sample collection and data generation requirements specified in this SAP.
4. **Completeness.** Failure to obtain critical data from planned locations will be documented. Minor variations in actual versus intended sampling locations (or depths) that do not adversely affect the attainment of project objectives will not be documented.

5. **Comparability.** This will be accomplished by verifying that the planned analysis was used and that the data quality indicators reviewed during data validation indicate no significant data quality deficiencies.
6. **Sensitivity.** The Tt Project Chemist will determine whether project sensitivity goals were achieved by comparing non-detect values to PSLs/PALs.
7. **Other quantitative characteristics.** These may include quantities such as verification of soil volume calculations, soil disposal cost estimates, etc., that are used to determine whether the contaminants are sufficiently well delineated to estimate remediation costs.

If significant data quality deficiencies are detected that prevent the attainment of project objectives, the limitations on the affected data will be described in the project report. The Tt PM will bring these deficiencies to the attention of the project team for their evaluation and the team will determine an appropriate corrective action depending on the circumstances.

### 8.5.3 Project Reports

A Draft RI Report will be prepared in accordance with the EPA (1998) RI/FS guidance and submitted to the Navy and regulators (i.e., the Partnering Team) for review. The report will include a summary of the work performed in the approved UFP-SAP, field modifications as documented by the Tt FOL, summary and analysis of the analytical results, updated CSM, baseline HHRA, screening ERA, and conclusions and/or recommendations for the site. Tt will respond to comments received on the draft report. The final version of the report will be submitted in hardcopy and electronic format to the project stakeholders.

The RI report will contain a *results and data quality* section, which will present the analytical data and identify site-related contamination, and include an evaluation of the data as they relate to the nature and extent of contamination and both human health and ecological risk evaluations. It also will include a summary of quantitative analytical performance indicators such as completeness, precision, bias, and sensitivity and qualitative indicators such as representativeness and comparability. There will be a reconciliation of project data with the DQOs and an identification of deviations from this UFP-SAP. A data usability assessment will be used to identify significant deviations in analytical performance that could affect the ability to meet project objectives.

The Partnering Team will be updated throughout the RI fieldwork via email, conference call, and/or Partnering meetings. At least one summary presentation will be provided at a Partnering meeting prior to or just after submission of the draft report.



## 9 REFERENCE LIMITS AND EVALUATION TABLES

(UFP-QAPP Manual Section 2.8.1 and UFP-QAPP Workbook WS #15)

### Matrix: Soil

Chemical / Analyte	CAS Number	PSL/PAL (mg/kg)	PSL/PAL Reference <sup>(1)</sup>	PQLG (mg/kg) <sup>(2)</sup>	APPL, Inc.		
					LOQ (mg/kg)	LOD (mg/kg)	DL (mg/kg)
<b>Phthalates - 8270D</b>							
<b>Bis(2-ethylhexyl)phthalate</b>	<b>117-81-7</b>	<b>0.017</b>	<b>EPA SSL</b>	<b>0.006</b>	<b>0.66</b>	<b>0.167</b>	<b>0.062</b>
<b>Butyl benzyl phthalate</b>	<b>85-68-7</b>	<b>0.2</b>	<b>EPA SSL</b>	<b>0.067</b>	<b>0.33</b>	<b>0.167</b>	<b>0.056</b>
Diethyl phthalate	84-66-2	4.7	EPA SSL	1.57	0.33	0.167	0.066
Dimethyl phthalate	131-11-3	734	ORNL	244.67	0.33	0.167	0.058
<b>Di-n-butyl phthalate</b>	<b>84-74-2</b>	<b>0.15</b>	<b>NOAA</b>	<b>0.05</b>	<b>0.33</b>	<b>0.167</b>	<b>0.062</b>
Di-n-octyl phthalate	117-84-0	709	NOAA	236.33	0.33	0.167	0.063
<b>PAHs - 8270D SIM</b>							
2-Methylnaphthalene	91-57-6	0.14	EPA SSL	0.05	0.005	0.0017	0.0009
Acenaphthene	83-32-9	0.1	R3 BTAG	0.033	0.005	0.0017	0.0010
Acenaphthylene	208-96-8	0.1	R3 BTAG	0.033	0.005	0.0017	0.0009
Anthracene	120-12-7	0.1	R3 BTAG	0.033	0.005	0.0017	0.0008
Benzo(a)anthracene	56-55-3	0.1	R3 BTAG	0.033	0.005	0.0017	0.0009
<b>Benzo(a)pyrene</b>	<b>50-32-8</b>	<b>0.0035</b>	<b>EPA SSL</b>	<b>0.0012</b>	<b>0.005</b>	<b>0.0017</b>	<b>0.0009</b>
Benzo(b)fluoranthene	205-99-2	0.035	EPA SSL	0.012	0.005	0.0017	0.0011
Benzo(g,h,i)perylene	191-24-2	0.1	R3 BTAG	0.033	0.005	0.0017	0.0013
Benzo(k)fluoranthene	207-08-9	0.1	R3 BTAG	0.033	0.005	0.0017	0.0010
Chrysene	218-01-9	0.1	R3 BTAG	0.033	0.005	0.0017	0.0008
Dibenzo(a,h)anthracene	53-70-3	0.011	EPA SSL	0.004	0.005	0.0017	0.0009
Fluoranthene	206-44-0	0.1	R3 BTAG	0.033	0.005	0.0017	0.0012
Fluorene	86-73-7	0.1	R3 BTAG	0.033	0.005	0.0017	0.0010
Indeno(1,2,3-c,d)pyrene	193-39-5	0.1	R3 BTAG	0.033	0.005	0.0017	0.0009
<b>Naphthalene</b>	<b>91-20-3</b>	<b>0.00047</b>	<b>EPA SSL</b>	<b>0.00016</b>	<b>0.005</b>	<b>0.0017</b>	<b>0.0009</b>
Phenanthrene	85-01-8	0.1	R3 BTAG	0.033	0.005	0.0017	0.0011
Pyrene	129-00-0	0.1	R3 BTAG	0.033	0.005	0.0017	0.0012

## 9. REFERENCE LIMITS AND EVALUATION TABLES

Chemical / Analyte	CAS Number	PSL/PAL (mg/kg)	PSL/PAL Reference <sup>(1)</sup>	PQLG (mg/kg) <sup>(2)</sup>	APPL, Inc.		
					LOQ (mg/kg)	LOD (mg/kg)	DL (mg/kg)
<b>Metals - 6010C</b>							
Aluminum	7429-90-5	50	ORNL	16.67	10.0	2.00	1.02
Boron	7440-42-8	0.5	ORNL	0.17	5.0	TBD	0.35
Lithium	7439-93-2	2	ORNL	0.67	TBD	TBD	TBD
Zinc	7440-66-6	46	Eco SSL	15.33	5.0	2.00	1.15
<b>Select Energetics - 8330B</b>							
<b>2,4-DINITROTOLUENE</b>	<b>121-14-2</b>	<b>0.00028</b>	<b>EPA SSL</b>	<b>0.000093</b>	<b>0.50</b>	<b>0.200</b>	<b>0.083</b>
<b>2,6-DINITROTOLUENE</b>	<b>606-20-2</b>	<b>0.02</b>	<b>EPA SSL</b>	<b>0.0067</b>	<b>0.50</b>	<b>0.200</b>	<b>0.083</b>
HMX	2691-41-0	0.99	EPA SSL	0.33	0.50	0.200	0.080
TETRYL	479-45-8	0.59	EPA SSL	0.2	0.50	0.200	0.091
<b>RDX</b>	<b>121-82-4</b>	<b>0.00023</b>	<b>EPA SSL</b>	<b>0.000077</b>	<b>0.50</b>	<b>0.200</b>	<b>0.080</b>
<b>NITROGLYCERIN</b>	<b>55-63-0</b>	<b>0.00066</b>	<b>EPA SSL</b>	<b>0.00022</b>	<b>0.50</b>	<b>0.200</b>	<b>0.085</b>
<b>Oxidizer</b>							
PERCHLORATE- Method 6850	14797-73-0	5.5	EPA RSL	1.83	0.006	0.004	0.002
<b>Miscellaneous</b>							
pH	NA	NA	NA	NA	NA	NA	NA
Total Organic Carbon	NA	NA	NA	NA	200.0	100.0	100.0

**Notes:**

**Bold rows indicate that the Project Screening Limit (PSL) and/or Project Action Limit (PAL) is between the laboratory Limit of Quantitation (LOQ) and the Limit of Detection (LOD).**

**Bold and shaded rows indicate that the PSL/PAL is less than the LOD.**

1. Selected PSL/PAL is the lowest (most conservative) of the evaluated PSLs/PALs.

2. Project Quantitation Limit Goal (PQLG) is set at 1/3 the PSL/PAL.

CAS – Chemical Abstract Service DL – Detection Limit mg/kg – milligrams per kilogram LOQ – Limit of Quantitation LOD – Limit of Detection

HMX - His/Her Majesty's Explosive (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)

RDX - Royal Demolition Explosive (Hexahydro-1,3,5-trinitro-1,3,5-triazine)

PAL References (may be updated appropriately at time of data evaluation / RI Report preparation):

- EPA RSL – EPA (May 2012) residential soil RSL. RSLs based on non-carcinogenic effects have been divided by 10 to account for exposure to multiple constituents. The residential screening level for carcinogens (not adjusted) is equivalent to an Incremental Lifetime Cancer Risk (ILCR) of  $1 \times 10^{-6}$ .
- EPA SSL – EPA (May 2012) SSL using a Dilution Attenuation Factor (DAF) of 20.
- LANL – Los Alamos National Laboratory, 2009 (December). ECORISK Database (Release 2.4). LA-UR-04-7834. ER ID 107524. Environmental Programs Directorate, Los Alamos National Laboratory, Los Alamos, NM.
- ORNL - Oak Ridge National Laboratory Screening Benchmarks (Efroymson et al., 1997a,b)
- R3 BTAG – EPA Region 3 Biological Technical Assistance Group (EPA, 1995)
- Eco SSL – Ecological Soil Screening Level. USEPA, February 2005. Guidance for Developing Ecological Soil Screening Level. Office of Solid Waste and Emergency and Response. OSWER Directive 92857-55. February. Separate documents are available for each chemical at <http://www.epa.gov/ecotox/ecoss/>.

- NOAA (National Oceanic and Atmospheric Administration) – Buchman, M. F., 2008. NOAA Screening Quick Reference Tables, NOAA OR&R Report 08-1, Seattle, WA, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, 34 pages. <http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html>.
- MDE SSL – MDE Cleanup Standards for Soil and Groundwater, Interim Final Guidance (Update No. 2.1), June 2008.

**Matrix: Sediment**

Chemical / Analyte	CAS Number	PSL/PAL (mg/kg)	PSL/PAL Reference <sup>(1)</sup>	PQLG (mg/kg) <sup>(2)</sup>	APPL, Inc.		
					LOQ (mg/kg)	LOD (mg/kg)	DL (mg/kg)
<b>Phthalates - 8270D</b>							
<b>Bis(2-ethylhexyl)phthalate</b>	<b>117-81-7</b>	<b>0.18</b>	<b>R3 BTAG FW</b>	<b>0.06</b>	<b>0.66</b>	<b>0.167</b>	<b>0.062</b>
Butyl benzyl phthalate	85-68-7	10.90	R3 BTAG FW	3.63	0.33	0.167	0.056
<b>Diethyl phthalate</b>	<b>84-66-2</b>	<b>0.006</b>	<b>NOAA MA</b>	<b>0.002</b>	<b>0.33</b>	<b>0.167</b>	<b>0.066</b>
Dimethyl phthalate	131-11-3	60.00	NOAA MA	20.0	0.33	0.167	0.058
Di-n-butyl phthalate	84-74-2	1.16	R3 BTAG MA	0.39	0.33	0.167	0.062
<b>Di-n-octyl phthalate</b>	<b>117-84-0</b>	<b>0.061</b>	<b>NOAA MA</b>	<b>0.020</b>	<b>0.33</b>	<b>0.167</b>	<b>0.063</b>
<b>PAHs - 8270D SIM</b>							
2-Methylnaphthalene	91-57-6	0.020	R3 BTAG FW	0.0067	0.005	0.0017	0.0009
Acenaphthene	83-32-9	0.0067	R3 BTAG FW	0.0022	0.005	0.0017	0.0010
Acenaphthylene	208-96-8	0.0059	R3 BTAG MA	0.0020	0.005	0.0017	0.0009
Anthracene	120-12-7	0.047	R3 BTAG MA	0.016	0.005	0.0017	0.0008
Benzo(a)anthracene	56-55-3	0.075	R3 BTAG MA	0.025	0.005	0.0017	0.0009
Benzo(a)pyrene	50-32-8	0.089	R3 BTAG MA	0.030	0.005	0.0017	0.0009
Benzo(b)fluoranthene	205-99-2	0.13	NOAA MA	0.043	0.005	0.0017	0.0011
Benzo(g,h,i)perylene	191-24-2	0.067	NOAA MA	0.022	0.005	0.0017	0.0013
Benzo(k)fluoranthene	207-08-9	0.070	NOAA MA	0.023	0.005	0.0017	0.0010
Chrysene	218-01-9	0.11	R3 BTAG MA	0.037	0.005	0.0017	0.0008
Dibenzo(a,h)anthracene	53-70-3	0.0062	R3 BTAG MA	0.0021	0.005	0.0017	0.0009
Fluoranthene	206-44-0	0.113	R3 BTAG MA	0.038	0.005	0.0017	0.0012
Fluorene	86-73-7	0.021	R3 BTAG MA	0.007	0.005	0.0017	0.0010
Indeno(1,2,3-c,d)pyrene	193-39-5	0.017	R3 BTAG FW	0.0057	0.005	0.0017	0.0009
Naphthalene	91-20-3	0.0346	R3 BTAG MA	0.012	0.005	0.0017	0.0009
Phenanthrene	85-01-8	0.0867	R3 BTAG MA	0.029	0.005	0.0017	0.0011
Pyrene	129-00-0	0.153	R3 BTAG MA	0.051	0.005	0.0017	0.0012
<b>Metals - 6010C</b>							
Aluminum	7429-90-5	7700	EPA RSL	2566.67	10.0	2.00	1.02
Boron	7440-42-8	1600	EPA RSL	533.33	5.0	TBD	0.35
Lithium	7439-93-2	16	EPA RSL	5.33	TBD	TBD	TBD

Chemical / Analyte	CAS Number	PSL/PAL (mg/kg)	PSL/PAL Reference <sup>(1)</sup>	PQLG (mg/kg) <sup>(2)</sup>	APPL, Inc.		
					LOQ (mg/kg)	LOD (mg/kg)	DL (mg/kg)
Zinc	7440-66-6	121	R3 BTAG FW	40.3	5.0	2.00	1.15
<b>Select Energetics - 8330B</b>							
<b>2,4-DINITROTOLUENE</b>	<b>121-14-2</b>	<b>0.0416</b>	<b>R3 BTAG FW</b>	<b>0.014</b>	<b>0.50</b>	<b>0.200</b>	<b>0.083</b>
<b>2,6-DINITROTOLUENE</b>	<b>606-20-2</b>	<b>0.0416</b>	<b>R3 BTAG FW</b>	<b>0.014</b>	<b>0.50</b>	<b>0.200</b>	<b>0.083</b>
HMX	2691-41-0	126	Sunahara	42	0.50	0.200	0.080
<b>TETRYL</b>	<b>479-45-8</b>	<b>0.1</b>	<b>Sunahara</b>	<b>0.033</b>	<b>0.50</b>	<b>0.200</b>	<b>0.091</b>
<b>RDX</b>	<b>121-82-4</b>	<b>0.013</b>	<b>R3 BTAG FW</b>	<b>0.0043</b>	<b>0.50</b>	<b>0.200</b>	<b>0.080</b>
NITROGLYCERIN	55-63-0	0.61	EPA RSL	0.20	0.50	0.200	0.085
<b>Oxidizer</b>							
PERCHLORATE- Method 6850	14797-73-0	5.5	EPA RSL	1.83	0.006	0.004	0.002
<b>Miscellaneous</b>							
Total Organic Carbon	NA	NA	NA	NA	200.0	100.0	100.0

**Notes:**

**Bold rows indicate that the Project Screening Limit (PSL) and/or Project Action Limit (PAL) is between the laboratory LOQ and the LOD.**

**Bold and shaded rows indicate that the PSL/PAL is less than the LOD.**

1. Selected PSL/PAL is the lowest (most conservative) of the evaluated PALs. 2. Project Quantitation Limit Goal (PQLG) is set at 1/3 the PSL/PAL.

CAS – Chemical Abstract Service DL – Detection Limit mg/kg – milligrams per kilogram LOQ – Limit of Quantitation LOD – Limit of Detection

HMX - His/Her Majesty's Explosive (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) RDX - Royal Demolition Explosive (Hexahydro-1,3,5-trinitro-1,3,5-triazine)

PAL References (may be updated appropriately at time of data evaluation / RI Report preparation):

- EPA RSL – EPA (May 2012) residential soil RSL. RSLs based on non-carcinogenic effects have been divided by 10 to account for exposure to multiple constituents. The residential screening level for carcinogens (not adjusted) is equivalent to an ILCR of  $1 \times 10^{-6}$ .
- R3 BTAG – EPA Region 3 (1995) Biological Technical Assistance Group (USEPA, 1995); MA – Marine, FW- Freshwater.
- NOAA – Buchman, M. F., 2008. NOAA Screening Quick Reference Tables, NOAA OR&R Report 08-1, Seattle, WA, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration, 34 pages. <http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html>; MA-Marine
- Sunahara - Ecotoxicology of Explosives (Sunahara et al., 2009)

**Matrix: Groundwater**

Chemical / Analyte	CAS Number	PSL/PAL (µg/L) <sup>(1)</sup>	PSL/PAL Reference <sup>(2)</sup>	PQLG (µg/L)	APPL, Inc.		
					LOQ (µg/L)	LOD (µg/L)	DL (µg/L)
<b>Phthalates - 8270D</b>							
<b>Bis(2-ethylhexyl)phthalate</b>	<b>117-81-7</b>	<b>0.071</b>	<b>EPA RSL</b>	<b>0.024</b>	<b>20.0</b>	<b>5.00</b>	<b>2.90</b>
Butyl benzyl phthalate	85-68-7	14	EPA RSL	4.67	10.0	5.00	2.80
Diethyl phthalate	84-66-2	1100	EPA RSL	367	10.0	5.00	3.00
Dimethyl phthalate	131-11-3	1100	EPA RSL	367	10.0	5.00	2.90
Di-n-butyl phthalate	84-74-2	67	EPA RSL	22.3	10.0	5.00	3.20
Di-n-octyl phthalate	117-84-0	67	EPA RSL	22.3	10.0	5.00	2.60
<b>PAHs - 8270D SIM</b>							
2-Methylnaphthalene	91-57-6	2.4	MDE GW Std.	0.8	0.2	0.10	0.06
Acenaphthene	83-32-9	37	MDE GW Std.	12.33	0.2	0.10	0.06
Acenaphthylene	208-96-8	37	MDE GW Std.	12.33	0.2	0.10	0.06
Anthracene	120-12-7	130	EPA RSL	43.3	0.2	0.10	0.05
<b>Benzo(a)anthracene</b>	<b>56-55-3</b>	<b>0.029</b>	<b>EPA RSL</b>	<b>0.0097</b>	<b>0.2</b>	<b>0.10</b>	<b>0.07</b>
<b>Benzo(a)pyrene</b>	<b>50-32-8</b>	<b>0.0029</b>	<b>EPA RSL</b>	<b>0.00097</b>	<b>0.2</b>	<b>0.10</b>	<b>0.07</b>
<b>Benzo(b)fluoranthene</b>	<b>205-99-2</b>	<b>0.029</b>	<b>EPA RSL</b>	<b>0.0097</b>	<b>0.2</b>	<b>0.10</b>	<b>0.06</b>
Benzo(g,h,i)perylene	191-24-2	18	MDE GW Std.	6	0.2	0.10	0.08
Benzo(k)fluoranthene	207-08-9	0.29	EPA RSL	0.097	0.2	0.10	0.07
Chrysene	218-01-9	2.9	EPA RSL	0.97	0.2	0.10	0.05
<b>Dibenzo(a,h)anthracene</b>	<b>53-70-3</b>	<b>0.0029</b>	<b>EPA RSL</b>	<b>0.00097</b>	<b>0.2</b>	<b>0.10</b>	<b>0.05</b>
Fluoranthene	206-44-0	63	EPA RSL	21	0.2	0.10	0.08
Fluorene	86-73-7	22	EPA RSL	8	0.2	0.10	0.06
<b>Indeno(1,2,3-c,d)pyrene</b>	<b>193-39-5</b>	<b>0.029</b>	<b>EPA RSL</b>	<b>0.0097</b>	<b>0.2</b>	<b>0.10</b>	<b>0.07</b>
<b>Naphthalene</b>	<b>91-20-3</b>	<b>0.14</b>	<b>EPA RSL</b>	<b>0.047</b>	<b>0.2</b>	<b>0.10</b>	<b>0.05</b>
Phenanthrene	85-01-8	180	MDE GW Std.	60	0.2	0.10	0.07
Pyrene	129-00-0	8.7	EPA RSL	6	0.2	0.10	0.08
<b>Metals - 6010C</b>							
Aluminum	7429-90-5	50	MDE GW Std.	16.67	100.0	20.00	19.30
Boron	7440-42-8	310	EPA RSL	103.3	100.0	TBD	29.4
Lithium	7439-93-2	3.1	EPA RSL	1.03	TBD	TBD	TBD

Chemical / Analyte	CAS Number	PSL/PAL (µg/L) <sup>(1)</sup>	PSL/PAL Reference <sup>(2)</sup>	PQLG (µg/L)	APPL, Inc.		
					LOQ (µg/L)	LOD (µg/L)	DL (µg/L)
Zinc	7440-66-6	470	EPA RSL	156.7	50.0	5.00	2.30
<b>Select Energetics - 8330B</b>							
<b>2,4-DINITROTOLUENE</b>	<b>121-14-2</b>	<b>0.2</b>	<b>EPA RSL</b>	<b>0.067</b>	<b>0.50</b>	<b>0.300</b>	<b>0.125</b>
2,6-DINITROTOLUENE	606-20-2	1.5	EPA RSL	0.5	0.50	0.300	0.125
HMX	2691-41-0	78	EPA RSL	26	0.50	0.300	0.115
TETRYL	479-45-8	6.3	EPA RSL	2.1	0.50	0.300	0.133
RDX	121-82-4	0.61	EPA RSL	0.20	0.50	0.300	0.123
<b>NITROGLYCERIN</b>	<b>55-63-0</b>	<b>0.15</b>	<b>EPA RSL</b>	<b>0.05</b>	<b>0.50</b>	<b>0.300</b>	<b>0.130</b>
<b>Oxidizer</b>							
PERCHLORATE- Method 6850	14797-73-0	1.1	EPA RSL	0.4	0.60	0.400	0.200
<b>Miscellaneous</b>							
Chloride – EPA 300.0	NA	500	Other	167	1.0 mg/L		0.08 mg/L
Nitrate – EPA 300.0	14797-55-8	500	Other	167	0.5 mg/L		0.01 mg/L
Nitrite – EPA 300.0	14797-65-0	500	Other	167	0.3 mg/L		0.03 mg/L
Total Organic Carbon – 9060	NA	10,000	Other	3333	0.5		0.13
Sulfate – EPA 300.0	14808-79-8	500	Other	167	1.0 mg/L		0.09 mg/L
Methane – RSK 175	74-82-8	10	Other	3.33	1.0	0.45	0.25

**Notes:**

**Bold rows indicate that the Project Screening Limit (PSL) and/or Project Action Limit (PAL) is between the laboratory LOQ and the LOD.**

**Bold and shaded rows indicate that the PSL/PAL is less than the LOD.**

1. Selected PSL/PAL is the lowest (most conservative) of the evaluated PALs. 2. Project Quantitation Limit Goal (PQLG) is set at 1/3 the PSL/PAL.

CAS – Chemical Abstract Service µg/L – micrograms per Liter LOQ – Limit of Quantitation LOD – Limit of Detection DL – Detection Limit

HMX - His/Her Majesty's Explosive (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) RDX - Royal Demolition Explosive (Hexahydro-1,3,5-trinitro-1,3,5-triazine)

PAL References (may be updated appropriately at time of data evaluation / RI Report preparation):

- EPA RSL – U.S. EPA (May 2012) tap water RSL. RSLs based on non-carcinogenic effects have been divided by 10 to account for exposure to multiple constituents. The residential screening level for carcinogens (not adjusted) is equivalent to an ILCR of  $1 \times 10^{-6}$ .
- Other – Less than the Federal Maximum Contaminant Level (MCL) for nitrate (10,000 µg/L as nitrogen) and nitrite (1,000 µg/L as nitrogen), and less than the Secondary MCLs for chloride and sulfate (250,000 µg/L). EPA (April 2012) Drinking Water Standards & Health Advisories. EPA 822-S-12-001. Office of Water. Washington, D.C. PSLs for Total Organic Carbon and methane based on professional judgment.
- MDE GW Std – MDE Cleanup Standards for Soil and Groundwater, Interim Final Guidance (Update No. 2.1), June 2008.

**Matrix: Surface Water**

Chemical / Analyte	CAS Number	PSL/PAL (µg/L) <sup>(1)</sup>	PSL/PAL Reference <sup>(2)</sup>	PQLG (µg/L)	APPL, Inc.		
					LOQ (µg/L)	LOD (µg/L)	DL (µg/L)
<b>Phthalates - 8270D</b>							
<b>Bis(2-ethylhexyl)phthalate</b>	<b>117-81-7</b>	<b>0.071</b>	<b>EPA RSL</b>	<b>0.024</b>	<b>20</b>	<b>5</b>	<b>2.9</b>
Butyl benzyl phthalate	85-68-7	14	EPA RSL	4.7	10	5	2.8
Diethyl phthalate	84-66-2	75.9	R3 BTAG MA	25.3	10	5	3
Dimethyl phthalate	131-11-3	580	R3 BTAG MA	190	10	5	2.9
<b>Di-n-butyl phthalate</b>	<b>84-74-2</b>	<b>3.4</b>	<b>R3 BTAG MA</b>	<b>1.1</b>	<b>10</b>	<b>5</b>	<b>3.2</b>
<b>Di-n-octyl phthalate</b>	<b>117-84-0</b>	<b>3.4</b>	<b>NOAA MA</b>	<b>1.1</b>	<b>10</b>	<b>5</b>	<b>2.6</b>
<b>PAHs - 8270D SIM</b>							
2-Methylnaphthalene	91-57-6	2.7	EPA RSL	0.9	0.2	0.1	0.06
Acenaphthene	83-32-9	6.6	R3 BTAG MA	2.2	0.2	0.1	0.06
Acenaphthylene	208-96-8	306.9	EPA SQB	102.3	0.2	0.1	0.06
<b>Anthracene</b>	<b>120-12-7</b>	<b>0.18</b>	<b>R3 BTAG MA</b>	<b>0.06</b>	<b>0.2</b>	<b>0.1</b>	<b>0.05</b>
<b>Benzo(a)anthracene</b>	<b>56-55-3</b>	<b>0.029</b>	<b>EPA RSL</b>	<b>0.01</b>	<b>0.2</b>	<b>0.1</b>	<b>0.07</b>
<b>Benzo(a)pyrene</b>	<b>50-32-8</b>	<b>0.0029</b>	<b>EPA RSL</b>	<b>0.001</b>	<b>0.2</b>	<b>0.1</b>	<b>0.07</b>
<b>Benzo(b)fluoranthene</b>	<b>205-99-2</b>	<b>0.029</b>	<b>EPA RSL</b>	<b>0.01</b>	<b>0.2</b>	<b>0.1</b>	<b>0.06</b>
Benzo(g,h,i)perylene	191-24-2	0.4391	EPA SQB	0.14	0.2	0.1	0.08
<b>Benzo(k)fluoranthene</b>	<b>207-08-9</b>	<b>0.18</b>	<b>MDE SW Std.</b>	<b>0.06</b>	<b>0.2</b>	<b>0.1</b>	<b>0.07</b>
<b>Chrysene</b>	<b>218-01-9</b>	<b>0.18</b>	<b>MDE SW Std.</b>	<b>0.06</b>	<b>0.2</b>	<b>0.1</b>	<b>0.05</b>
<b>Dibenzo(a,h)anthracene</b>	<b>53-70-3</b>	<b>0.0029</b>	<b>EPA RSL</b>	<b>0.001</b>	<b>0.2</b>	<b>0.1</b>	<b>0.05</b>
Fluoranthene	206-44-0	1.6	R3 BTAG MA	0.53	0.2	0.1	0.08
Fluorene	86-73-7	2.5	R3 BTAG MA	0.8	0.2	0.1	0.06
<b>Indeno(1,2,3-c,d)pyrene</b>	<b>193-39-5</b>	<b>0.029</b>	<b>EPA RSL</b>	<b>0.01</b>	<b>0.2</b>	<b>0.1</b>	<b>0.07</b>
<b>Naphthalene</b>	<b>91-20-3</b>	<b>0.14</b>	<b>EPA RSL</b>	<b>0.05</b>	<b>0.2</b>	<b>0.1</b>	<b>0.05</b>
Phenanthrene	85-01-8	1.5	R3 BTAG MA	0.5	0.2	0.1	0.07
Pyrene	129-00-0	0.24	R3 BTAG MA	0.08	0.2	0.1	0.08
<b>Metals - 6010C</b>							
<b>Aluminum</b>	<b>7429-90-5</b>	<b>87</b>	<b>R3 BTAG FW</b>	<b>0.53</b>	<b>100</b>	<b>20</b>	<b>19.3</b>
<b>Boron</b>	<b>7440-42-8</b>	<b>1.6</b>	<b>R3 BTAG FW</b>	<b>0.53</b>	<b>100</b>	<b>TBD</b>	<b>29.4</b>
<b>Lithium</b>	<b>7439-93-2</b>	<b>3.1</b>	<b>EPA RSL</b>	<b>1</b>	<b>TBD</b>	<b>TBD</b>	<b>TBD</b>

Chemical / Analyte	CAS Number	PSL/PAL (µg/L) <sup>(1)</sup>	PSL/PAL Reference <sup>(2)</sup>	PQLG (µg/L)	APPL, Inc.		
					LOQ (µg/L)	LOD (µg/L)	DL (µg/L)
Zinc	7440-66-6	81	MDE WQS MA	27	50	5	2.3
<b>Select Energetics - 8330B</b>							
<b>2,4-DINITROTOLUENE</b>	<b>121-14-2</b>	<b>0.2</b>	<b>EPA RSL</b>	<b>0.07</b>	<b>0.5</b>	<b>0.3</b>	<b>0.125</b>
2,6-DINITROTOLUENE	606-20-2	1.5	EPA RSL	0.5	0.5	0.3	0.125
HMX	2691-41-0	78	EPA RSL	26	0.5	0.3	0.115
TETRYL	479-45-8	6.3	EPA RSL	2.1	0.5	0.3	0.133
RDX	121-82-4	0.61	EPA RSL	0.2	0.5	0.3	0.123
<b>NITROGLYCERIN</b>	<b>55-63-0</b>	<b>0.15</b>	<b>EPA RSL</b>	<b>0.05</b>	<b>0.5</b>	<b>0.3</b>	<b>0.13</b>
<b>Oxidizer</b>							
PERCHLORATE- Method 6850	14797-73-0	1.1	EPA RSL	0.4	0.6	0.4	0.2
<b>Miscellaneous</b>							
Total Hardness	NA	NA	NA	NA	NA	NA	NA

**Notes:**

**Bold rows indicate that the Project Screening Limit (PSL) and/or Project Action Limit (PAL) is between the laboratory LOQ and the LOD.**

**Bold and shaded rows indicate that the PSL/PAL is less than the LOD.**

1. Selected PSL/PAL is the lowest (most conservative) of the evaluated PALs. 2. Project Quantitation Limit Goal (PQLG) is set at 1/3 the PSL/PAL.

CAS – Chemical Abstract Service µg/L – micrograms per Liter LOQ – Limit of Quantitation LOD – Limit of Detection DL – Detection Limit

HMX - His/Her Majesty's Explosive (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) RDX - Royal Demolition Explosive (Hexahydro-1,3,5-trinitro-1,3,5-triazine)

PAL References (may be updated appropriately at time of data evaluation / RI Report preparation):

- EPA RSL – EPA (May 2012) tap water RSL. RSLs based on non-carcinogenic effects have been divided by 10 to account for exposure to multiple constituents. The residential screening level for carcinogens (not adjusted) is equivalent to an incremental lifetime cancer risk (ILCR) of 1×10<sup>-6</sup>.
- MDE WQS – Maryland Department of the Environment Water Quality Standards, Chronic value (MDE, 2010)
- R3 BTAG – EPA Region 3 Biological Technical Assistance Group (EPA, 2006a,b); MA- Marine, FW- Freshwater
- MDE SW Std. – COMAR 26.08.02.03-2 Numerical Criteria for Toxic Substances in Surface Waters, Maryland Department of the Environment Water Quality Standards, human health consumption, organism only.
- EPA SQB - EPA Sediment Quality Benchmarks: PAH Mixtures (EPA, 2003)



## 10 ANALYTICAL SOP REFERENCES

(UFP-QAPP Manual Section 3.2.1 and UFP-QAPP Workbook WS #23)

**Laboratory point of contact, e-mail address, and phone number:** Cynthia Clark, cclark@applinc.com, 559-275-2175

**Address:** APPL Inc. | 908 N. Temperance Ave. | Clovis, CA 93611

**Data Package Turnaround Time:** 21 days

**Tentative Sampling Dates:** Winter 2012 (TBD)

**Microbial Analysis:** Anita Biernacki, abiernacki@microbe.com, 865.573.8188 ext 108

**Address:** Microbial Insights, Inc. | 2340 Stock Creek Blvd. | Rockford, TN 37853-3044

**Data Package Turnaround Time:** 21 days

**Tentative Sampling Dates:** Winter 2012 (TBD)

Lab SOP Number	Title, Revision Date, and / or Number	Definitive or Screening Data	Matrix and Analytical Group	Instrument	Organization Performing Analysis	Variance to QSM? Y/N	Modified for Project Work? <sup>(1)</sup>
ANA8270 DSIM	Polynuclear Aromatic Hydrocarbons by SIM, Rev. 2, 2/2011	Definitive	Soil, Sediment, Surface water, Groundwater, and Aqueous QC samples/ Phthalates and PAHs	Gas Chromatography/Mass Spectrometry (GC-MS)	APPL Inc.	N	N
SEP004	625/8270 Separatory Funnel Extraction; Rev. 19; 06/2011	Definitive	Surface water, Groundwater, and Aqueous QC samples/ Phthalates and PAHs Extraction	NA	APPL Inc.	NA	N
SON009	BNA, SIM, PAH 8270 Sonication; Rev. 7; 10/2011	Definitive	Soil and Sediment/ Phthalates and PAHs	NA	APPL Inc.	NA	N
HPL8330	Explosives by EPA 8330A & 8330B, Rev 0, 10/2011	Definitive	Soil, Sediment, Surface water, Groundwater, and Aqueous QC samples/Energetics	High Performance Liquid Chromatography – Ultra Violet detector (HPLC-UV)	APPL Inc.	N	N
MWE3535	Extraction of Explosives by Method 3535A; Rev. 11; 07/2011	Definitive	Surface water, Groundwater, and Aqueous QC samples/ Energetics Extraction	NA	APPL Inc.	NA	N
MSE018	Mechanical orbital shaker extraction for solid explosive samples by method 8330; Rev. 17; 07/2011	Definitive	Soil and Sediment/ Energetics Extraction	NA	APPL Inc.	NA	N
HPL6850	Perchlorate by EPA 6850, Rev. 12, 05/2011	Definitive	Soil, Sediment, Surface water, Groundwater, and Aqueous QC samples/Perchlorate	HPLC	APPL Inc.	N	N

10. ANALYTICAL SOP REFERENCES

Lab SOP Number	Title, Revision Date, and / or Number	Definitive or Screening Data	Matrix and Analytical Group	Instrument	Organization Performing Analysis	Variance to QSM? Y/N	Modified for Project Work? <sup>(1)</sup>
ANA6020	ICP-MS by Method 6020; Rev. 0; 10/2011	Definitive	Soil, Sediment, Surface water, Groundwater, and Aqueous QC samples/Metals	Inductively Coupled Plasma/Mass Spectrometry (ICP/MS)	APPL Inc.	N	N
PRE3010 A	Digestion of Aqueous Samples by EPA Method 3010A; Rev. 8; 07/2011	Definitive	Surface water, Groundwater, and Aqueous QC samples/ Metals Digestion	NA	APPL Inc.	NA	N
PRE3050 B	Digestion of Soils by EPA Method 3050B; Rev. 13; 07/2011	Definitive	Soil and Sediment/ Metals Digestion	NA	APPL Inc.	NA	N
ANA300.0	Inorganic Anion, EPA Method 300.0; Rev. 19; 04/2011	Definitive	Groundwater: Anions (nitrate, nitrite, chloride and sulfate)	Ion Chromatography (IC)	APPL Inc.	N	N
ANA353.2	TOXN, NO2-N, NO3-N, EPA Method 353.2; Rev. 0; 10/2011	Definitive	Groundwater: Nitrate/Nitrite	IC	APPL Inc.	N	N
ANAWAL KLEY	TOC in soil by Walkley-Black, modified; Rev. 1; 06/2011	Definitive	Soil and Sediment: TOC	NA	APPL Inc.	NA	N
ANA9060 A	TOC, EPA Method 9060; Rev. 8; 10/2011	Definitive	Groundwater: TOC		APPL Inc.	NA	N
ANARSK-175	Dissolved gas analysis in water by headspace GC; Rev. 3; 10/2011	Definitive	Groundwater: Dissolved Methane	GC	APPL Inc.	NA	N
MI SOP-DNA EXT	Extraction of DNA from Environmental Samples (matrix-water, soil, biofilm, bio-Sep beads) (Revision 1, 01/05/06)	Screening	Groundwater/DNA Extraction	Incubator	Microbial Insights	NA	N
MI SOP-DNA qPCR	Quantitative Polymerase Chain Reaction (qPCR) (Revision 1, 01/05/06)	Screening	Groundwater/ qPCR	Applied Biosystems	Microbial Insights	NA	N

**Notes:**

Lab Accreditation or Certification requirements for the work of this project have been verified. Copies are provided in [Appendix C](#).

## 11 LABORATORY QC SAMPLES TABLE

(UFP-QAPP Manual Section 3.4 and UFP-QAPP Workbook WS #28)

**Matrix:** Soil, Sediment, Groundwater, Surface water, and Aqueous QC Blanks

**Analytical Group:** Phthalates and PAHs

**Analytical Method/SOP Reference:** SW-846 8270D, 8270D SIM / ANA8270DSIM-

QC Sample	Frequency / Number	Method / SOP QC Acceptance Limits	Corrective Action	Person(s) Responsible for CA	DQI	MPC
Method Blank	One per preparation batch of twenty or fewer samples of similar matrix.	No target compounds should be > ½ the LOQ except common lab contaminants, which should be, no target compounds should be > the LOQ.	(1) Investigate source of contamination. (2) Re-prepare and analyze method blank and all samples processed with the contaminated blank.	Analyst, Supervisor	Bias / Contamination	Same as QC Acceptance Limits.
Surrogates	6 per sample (scan): 2-Fluorophenol Phenol-d6 Nitrobenzene-d5 2-Fluorobiphenyl 2,4,6-Tribromophenol Terphenyl-d14 3 per sample (SIM) 2-Fluorobiphenyl, Terphenyl-d14, Nitrobenzene-D5	%Rs must meet the DoD QSM Version 4.2 limits as per Appendix G. SIM surrogate recoveries with in laboratory control limits.	(1) Check chromatogram for interference; if found, then flag data. (2) If not found, then check instrument performance; if problem is found, then correct and reanalyze. (3) If still out, then re-extract and analyze sample. (4) If reanalysis is out, then flag data.	Analyst, Supervisor	Accuracy / Bias	Same as QC Acceptance Limits.
LCS	One per batch of 20 or less.	%Rs must meet the DoD QSM Version 4.2 limits as per Appendix G. RPD must be ≤ 30% (for LCS/LCSD, if LCSD is performed). In-house statistical laboratory limits are used when DoD QSM v. 4.2 does not specify.	Correct problem, then re-prepare and reanalyze the LCS and all samples in the associated preparatory batch for failed analytes, if sufficient sample material is available  Contact Client if samples cannot be reanalyzed within hold time.	Analyst, Supervisor	Precision / Accuracy / Bias	Same as QC Acceptance Limits.
IS	Six per sample – 1,4-Dichlorobenzene-d4 Naphthalene-d8 Acenaphthene-d10 Phenanthrene-d10 Chrysene-d12 Perylene-d12	Retention times for internal standards must be ± 30 seconds and the responses within -50% to +100% of last calibration verification (12 hours) for each IS.	Reanalyze affected samples.	Analyst, Supervisor	Precision / Accuracy / Bias	Same as QC Acceptance Limits.

11. LABORATORY QC SAMPLEs

QC Sample	Frequency / Number	Method / SOP QC Acceptance Limits	Corrective Action	Person(s) Responsible for CA	DQI	MPC
MS/MSD	One per SDG or every 20 samples.	%Rs should meet the DoD QSM Version 4.2 limits as per Appendix G. RPD should be $\leq 30\%$ . In-house statistical laboratory limits are used when DoD QSM v. 4.1 does not specify.	Corrective Action will not be taken for samples when recoveries are outside limits and surrogate and LCS criteria are met. If both the LCS and MS/MSD are unacceptable re-prepare the samples and QC.	Analyst, Supervisor	Precision/Accuracy/ Bias	Same as QC Acceptance Limits.
Results between DL and LOQ	NA	Apply "J" qualifier to results between DL and LOQ.	NA	Analyst, Supervisor	Accuracy	Same as QC Acceptance Limits.

**Matrix:** Soil, Sediment, Groundwater, Surface water, and Aqueous QC Blanks

**Analytical Group:** Energetics

**Analytical Method/SOP Reference:** SW-846 8330B / HPL8330

QC Sample	Frequency / Number	Method / SOP QC Acceptance Limits	Corrective Action	Person(s) Responsible for CA	DQI	MPC
Method Blank	One per preparation batch of 20 or fewer samples of similar matrix.	All target analytes must be $\leq \frac{1}{2}$ LOQ.	(1) Investigate source of contamination. (2) Re-prepare and analyze method blank and all samples processed with the contaminated blank. (3) Qualify results if re-extraction/re-analysis not feasible.	Analyst, Supervisor	Contamination / Bias	Same as Method/SOP QC Acceptance Limits.
Soil sample triplicate	At the subsampling step, one sample per batch.	The %RSD for results above the LOQ must not exceed 20%.	Corrective action must be taken if this is not met. The grinding process must be investigated to make sure the samples are being reduced to the appropriate particle size.	Analyst, Supervisor	Accuracy / Bias Precision	Same as QC Acceptance Limits
LCS	One per preparatory batch of 20 or fewer samples of similar matrix.	%Rs must meet the DoD QSM Version 4.2 limits as per Appendix G of the DoD QSM.	Correct problem, then re-prepare and reanalyze the LCS and all samples in the associated preparatory batch for failed analytes, if sufficient sample material is available. Contact Client if samples cannot be reanalyzed within hold time.	Analyst, Supervisor	Accuracy / Bias	Same as Method/SOP QC Acceptance Limits.
MS/MSD	One per preparatory batch of 20 or fewer samples of similar matrix.	%Rs must meet the DoD QSM Version 4.2 limits as per Appendix G of the DoD QSM. The RPD between MS and MSD should be $\leq 30\%$ .	Corrective action will not be taken for samples when recoveries are outside limits and surrogate and LCS criteria are met, unless RPDs indicate obvious extraction/analysis difficulties, then re-prepare and reanalyze MS/MSD.	Analyst, Supervisor	Accuracy / Precision	Same as Method/SOP QC Acceptance Limits.
Surrogate Spikes	All field and QC samples - one per sample. One surrogate added: 1,2-Dinitrobenzene	%Rs must meet the DoD QSM Version 4.2 limits as per Appendix G of the DoD QSM.	If surrogate recovery falls outside acceptance criteria, the sample should be re-extracted and re-analyzed.	Analyst, Supervisor	Accuracy / Bias	Same as Method/SOP QC Acceptance Limits.
Second Column Confirmation	All positive results must be confirmed.	RPD must be $<40\%$ from primary concentration.	None. Apply flag if RPD $>40\%$ and discuss in the case narrative.	Analyst, Supervisor	Presence / Precision	Same as Method/SOP QC Acceptance Limits.
Results between DL and LOQ	NA.	Apply "J" qualifier to results detected between DL and LOQ.	NA	Analyst, Supervisor	Accuracy	Same as QC Acceptance Limits.

**Matrix:** Groundwater, and Aqueous QC Blanks

**Analytical Group:** Nitrate/Nitrite

**Analytical Method/SOP Reference:** EPA 353.2 / ANA353.2

QC Sample	Frequency / Number	Method / SOP QC Acceptance Limits	Corrective Action	Person(s) Responsible for CA	DQI	MPC
Method Blank	One per batch of up to 20 samples	Analyte concentration must be $< \frac{1}{2}$ LOQ.	Correct problem, re-prepare and reanalyze along with associated samples.	Analyst, Supervisor	Contamination / Bias	Same as QC Acceptance Limits.
LCS	One per batch of up to 20 samples	%R must be within 90-110%.	Correct problem, re-prepare, and reanalyze along with associated samples.	Analyst, Supervisor	Accuracy / Bias	Same as QC Acceptance Limits.
MS/MSD	One set is performed for each batch of up to 10 samples of the same matrix.	%R must be between 80-120%, MS/MSD %RPD must be $< 20\%$ .	Failure to meet the control limits shall be discussed in the case narrative. If both the LCS and MS are unacceptable, all associated samples must be re-analyzed.	Analyst, Supervisor	Precision / Accuracy	Same as Method/SOP QC Acceptance Limits.

**Matrix:** Soil, Sediment, Surface water, Groundwater, and Aqueous QC Blanks

**Analytical Group:** Metals

**Analytical Method/SOP Reference:** SW-846 6020A/ ANA6020

QC Sample	Frequency / Number	Method / SOP QC Acceptance Limits	Corrective Action	Person(s) Responsible for CA	DQI	MPC
Method Blank	One per preparatory batch of 20 or fewer samples of similar matrix	All target analytes must be $\leq \frac{1}{2}$ LOQ.	Re-analyze to confirm the positive value. Notify the PM for further action. Re-prepare the samples associated with the Blank. Noncompliance report will be required for data reported.	Analyst, Supervisor	Bias / Contamination	Same as QC Acceptance Limits
IS (applies to SW-846 6020A only)	Every sample.	For each sample, IS intensity must be within 30-120% of that of initial calibration standard.	Reanalyze affected samples.	Analyst, Supervisor	Precision	Same as QC Acceptance Limits.
LCS	One per preparatory batch of 20 or fewer samples of similar matrix	%R must be within 80-120%.	Evaluate and reanalyze, if possible. If the LCS recoveries are high, but the sample results are < LOQ, then narrate. Otherwise, re-digest and reanalyze all associated samples for failed target analyte(s).	Analyst, Supervisor	Accuracy / Bias	Same as QC Acceptance Limits
MS	One per preparatory batch of 20 or fewer samples of similar matrix	%R should be within 80-120% (if sample is < 4x spike added).	Flag results for affected analytes for all associated samples with "N".	Analyst, Supervisor	Accuracy / Bias	Same as QC Acceptance Limits
Sample Duplicate	One per preparatory batch of 20 or fewer samples of similar matrix	The RPD should be $\leq 20\%$ for duplicate samples for both water and soils.	Narrate any results that are outside control limits.	Analyst, Supervisor	Precision	Same as QC Acceptance Limits
Serial Dilution	One per preparatory batch with sample concentration(s) >50x LOD	The 5-fold dilution result must agree within $\pm 10\%$ D of the original sample result if result is >50x LOD.	Perform post-spike addition.	Analyst, Supervisor	Accuracy / Bias	Same as QC Acceptance Limits
Post Digestion Spike (does not apply to mercury)	One is performed when serial dilution fails or target analyte concentration(s) in all samples are < 50x LOD	The %R must be within 75-125% of expected value to verify the absence of an interference. Spike addition should produce a concentration of 10-100x LOQ.	Flag results for affected analytes for all associated samples with "J".	Analyst, Supervisor	Accuracy / Bias	Same as QC Acceptance Limits
Results between DL and LOQ	Not known at this time	Apply "J" qualifier to results between DL and LOQ.	None	Analyst, Supervisor	Accuracy	Same as QC Acceptance Limits

**Matrix:** Groundwater, and Aqueous QC Blanks

**Analytical Group:** Anions

**Analytical Method/SOP Reference:** EPA 300.0 / ANA300.0

QC Sample	Frequency / Number	Method / SOP QC Acceptance Limits	Corrective Action	Person(s) Responsible for CA	DQI	MPC
Method Blank	One per batch of up to 20 samples	Analyte concentration must be $< \frac{1}{2}$ LOQ.	Correct problem, re-prepare and reanalyze along with associated samples.	Analyst, Supervisor	Contamination /Bias	Same as QC Acceptance Limits.
LCS	One per batch of up to 20 samples	%R must be within 90-110%.	Correct problem, re-prepare, and reanalyze along with associated samples.	Analyst, Supervisor	Accuracy/Bias	Same as QC Acceptance Limits.
MS/MSD	One set is performed for each batch of up to 10 samples of the same matrix.	%R must be between 80-120%, MS/MSD %RPD must be $< 20\%$ .	Failure to meet the control limits shall be discussed in the case narrative. If both the LCS and MS are unacceptable, all associated samples must be re-analyzed.	Analyst, Supervisor	Precision / Accuracy	Same as Method/SOP QC Acceptance Limits.

**Matrix:** Soil, Groundwater, and Aqueous QC Blanks

**Analytical Group:** TOC

**Analytical Method/SOP Reference:** Walkley Black and SW846 Method 9060 / ANA9060A & ANAWALKLEY

QC Sample	Frequency / Number	Method / SOP QC Acceptance Limits	Corrective Action	Person(s) Responsible for CA	DQI	MPC
Method Blank	One per preparatory batch of 20 or fewer samples	The target analyte must be $\leq \frac{1}{2}$ LOQ.	Correct problem, re-prepare and reanalyze along with associated samples.	Analyst, Supervisor	Bias/ Contamination	Same as QC Acceptance Limits
LCS	One per preparatory batch of 20 or fewer samples	%R must be within 80-120% of true value.	Correct problem, re-prepare, and reanalyze along with associated samples.	Analyst, Supervisor	Accuracy/ Bias	Same as QC Acceptance Limits
MS/MSD	One per preparatory batch of 20 or fewer samples per matrix	%R should be within 80-120% of true value. RPD should be $\leq 20\%$ .	Contact client for guidance.	Analyst, Supervisor	Accuracy/ Bias/ Precision	Same as QC Acceptance Limits

**Matrix:** Groundwater, and Aqueous QC Blanks**Analytical Group:** Dissolved Methane**Analytical Method/SOP Reference:** RSK SOP 175 / ANARSK-175

QC Sample	Frequency / Number	Method / SOP QC Acceptance Limits	Corrective Action	Person(s) Responsible for CA	DQI	MPC
Method Blank	One per batch of up to 20 samples	Analyte concentration must be $< \frac{1}{2}$ LOQ.	Correct problem, re-prepare and reanalyze along with associated samples.	Analyst, Supervisor	Contamination /Bias	Same as QC Acceptance Limits.
LCS	One per batch of up to 20 samples	%R must be within 80-120% of the expected value.	Correct problem, re-prepare, and reanalyze along with associated samples.	Analyst, Supervisor	Accuracy/Bias	Same as QC Acceptance Limits.
MS/MSD	One per batch of up to 20 samples	%R should be within 75-125% of the expected value.  RPD $\leq$ 20%	Contact client for guidance.	Analyst, Supervisor	Accuracy/Bias/Precision	Same as QC Acceptance Limits.

## 12 DATA VERIFICATION AND VALIDATION (STEPS I AND IIa/IIb) PROCESS TABLE

(UFP-QAPP Manual Section 5.2.1, Section 5.2.2, Table 9, and Figure 37; and UFP-QAPP Workbook WS #34, #35, and #36)

Data Review Input	Description	Responsible for Verification	Internal/ External
Chain of Custody (CoC) Forms	The Tt FOL or designee will review and sign the CoC form to verify that all samples listed are included in the shipment to the laboratory and the sample information is accurate. The forms will be signed by the sampler and a copy will be retained for the project file, the Tt PM, and the Tt Data Validators. The Tt FOL or designee will review the chain-of-custody form to verify that all samples listed in the SAP have been collected. All deviations should be documented in the report.	Sampler and FOL, Tt	Internal
CoC Forms	1. The Laboratory Sample Custodian will review the sample shipment for completeness and integrity, and sign accepting the shipment. 2. The Tt Data Validators will check that the chain-of-custody form was signed and dated by the Tt FOL or designee relinquishing the samples and also by the Laboratory Sample Custodian receiving the samples for analyses.	1 - Laboratory Sample Custodian, APPL 2 - Data Validators, Tt	External
CoC Forms and SAP	Ensure that the custody and integrity of the samples was maintained from collection to analysis and the custody records are complete and any deviations are recorded. Review that the samples were shipped and stored at the required temperature and preservation conditions for chemically-preserved samples meet the requirements listed in the SAP. Ensure that the analyses were performed within the holding times listed in the SAP.	Data Validators, Tt	External
Sample Log Sheets, CoC Forms, SAP, and Laboratory sample login documentation	Verify that information recorded in the log sheets is accurate and complete. Verify that samples were correctly identified, that sampling location coordinates are accurate, and that documentation establishes an unbroken trail of documented chain-of-custody from sample collection to report generation. Verify that the correct sampling and analytical methods/SOPs were applied. Verify that the sampling plan was implemented and carried out as written and that any deviations are documented. Document any discrepancies in the final report.	PM, FOL, or designee, Tt	Internal
SAP, Analytical SOPs, and Analytical Data Packages	Ensure that all laboratory SOPs were followed. Verify that the correct analytical methods/SOPs were applied. Establish that all method QC samples were analyzed and in control as listed in the analytical SOPs. If method QA is not in control, the Laboratory QAM will contact the Tt PM verbally or via e-mail for guidance prior to report preparation.	Laboratory QAM, APPL	Internal
SAP/ CoC Forms	Check that all field QC samples determined necessary were collected as required.	FOL or designee, Tt	Internal
Analytical Data Package	Verify all analytical data packages for completeness. The Laboratory QAM will sign the case narrative for each data package.	Laboratory QAM, APPL	Internal
Electronic Data Deliverables (EDDs)/ Analytical Data Packages	Check each EDD against the chain-of-custody and hard copy data package for accuracy and completeness. Compare laboratory analytical results to the electronic analytical results to verify accuracy. Evaluate sample results for laboratory contamination and qualify false detections using the laboratory method/preparation blank summaries. Qualify analyte concentrations between the DL and the LOQ as estimated. Remove extraneous laboratory qualifiers from the validation qualifier.	Data Validators, Tt	External
Analytical Data Package	Verify each data package for completeness. Request missing information from the Laboratory PM.	Data Validators, Tt	External
SAP/ Laboratory Data Packages/ EDDs	Ensure that the laboratory QC samples were analyzed and that the MPCs listed in were met for all field samples and QC analyses. Check that specified field QC samples were collected and analyzed and that the analytical QC criteria set up for this project were met.	Data Validators, Tt	External
SAP/ Laboratory Data Packages/ EDDs	Check the field sampling precision by calculating RPDs for field duplicate samples. Check laboratory precision by reviewing the RPD or percent difference values from laboratory duplicate analyses; MS/MSDs; and LCS/LCSD, if available. Ensure compliance with the methods and project MPCs accuracy goals listed in the SAP.	Data Validators, Tt	External
SAP/ Laboratory Data Packages/ EDDs	Check that the laboratory recorded the temperature at sample receipt and the pH of samples preserved with acid or base to ensure sample integrity from sample collection to analysis.	Data Validators, Tt	External

12. DATA VERIFICATION AND VALIDATION PROCESS TABLE

Data Review Input	Description	Responsible for Verification	Internal/ External
SAP/ Laboratory Data Packages/ EDDs	Review the chain-of-custody forms generated in the field to ensure that the required analytical samples have been collected, appropriate sample identifications have been used, and correct analytical methods have been applied. The Tt Data Validator will verify that elements of the data package required for validation are present, and if not, the laboratory will be contacted and the missing information will be requested. Check that all data have been transferred correctly and completely to the Tt SQL database.	Data Validators, Tt	External
SAP/ Laboratory Data Packages/ EDDs	Ensure that the project LOQs listed in SAP were achieved.	Data Validators, Tt	External
SAP/ Laboratory Data Packages/ EDDs	Discuss the impact on DLs that are elevated because of matrix interferences. Be especially cognizant of and evaluate the impact of sample dilutions on low-concentration analytes when the dilution was performed because of the high concentration of one or more other contaminants. Document this usability issue and inform the Tt PM. Review and add PALs to the laboratory EDDs. Flag samples and notify the Tt PM of samples that exceed PALs listed in SAP.	Data Validators, Tt	External
SAP/ Laboratory Data Packages/ EDDs	Ensure that all QC samples specified in the SAP were collected and analyzed and that the associated results were within prescribed SAP acceptance limits. Ensure that QC samples and standards prescribed in analytical SOPs were analyzed and within the prescribed control limits. If any significant QC deviations occur, the Laboratory QAM shall have contacted the Tt PM.	Data Validators, Tt	External
SAP/ Laboratory Data Packages/ EDDs	Summarize deviations from methods, procedures, or contracts in the Data Validation Report. Determine the impact of any deviation from sampling or analytical methods and SOPs requirements and matrix interferences effect on the analytical results. Qualify data results based on method or QC deviation and explain all the data qualifications. Print a copy of qualified data stored the project database to depict data qualifiers and data qualifier codes that summarize the reason for data qualifications. Determine if the data met the MPCs and determine the impact of any deviations on the technical usability of the data.	Data Validators, Tt	External
Surface and Subsurface Soil, Groundwater and Surface Water- SVOCs, PAHs, Energetics	Validation will be performed using criteria for SW-846 Methods 8270D, 8270D SIM, 6850 and 8330B listed in this SAP and the current DoD QSM. The logic outlined in USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review USEPA-540/R-99-008, (USEPA, October 1999) will be used to apply qualifiers to data to the extent possible.	Data Validators, Tt	External
Surface and Subsurface Soil, Groundwater and Surface Water – Metals	Validation will be performed using criteria for SW-846 Method 6020A listed in this SAP and the current DoD QSM. The logic outlined in USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review (USEPA, October 2004) will be used to apply qualifiers to data to the extent possible.	Data Validators, Tt	External

## 12.1 Validation Summary

Analytical Group	Validation Criteria	Data Validator (title and organizational affiliation)
PAHs, Phthalates, Energetics and Perchlorate	Full validation will be performed using criteria for SW-846 Methods 8270D SIM, 8330B and 6850 listed in this SAP and the current DoD QSM. The logic outlined in the Region 3 Modifications to the National Functional Guidelines for Organic Data Review (USEPA, 1994) should be used to apply qualifiers to data.	Data Validation Specialist, Tt
Metals	Full validation will be performed using criteria for SW-846 Method 6020A/7470A/7471B listed in this SAP and the current DoD QSM. The logic outlined in the Region 3 Modifications to the Laboratory Data Validation Functional Guidelines for Evaluating Inorganic Analyses (USEPA, 1993) should be used to apply qualifiers to data.	Data Validation Specialist, Tt
TOC, Anions, Dissolved Methane, Nitrate/Nitrite	Validation will be performed using the method specific criteria listed in this SAP and the current DOD QSM to the extent possible will be used.	Data Validation Specialist, Tt

Full data validation is defined as in-depth examination of data to check for adherence to method requirements, technical quality, analyte identification, and result quantitation. It is conducted to support risk assessments and to propose No Further Action scenarios. A formal report is prepared which details technical findings, presents qualified analytical data and results as reported by the laboratory prior to validation, and includes laboratory quality control summaries and calculation verifications as supporting documentation. IDW and Microbial analyses will not be validated.



## REFERENCES

Bender, K.S., S.M. O'Connor, R. Chakraborty, J.D. Coates and L.A. Achenbach, 2002. *Sequencing and Transcriptional Analysis of the Chlorite Dismutase Gene of Dechloromonas agitata and Its Use as a Metabolic Probe*. *Applied Environmental Microbiology*. 68(10): 4820-4826.

Chaudhuri, S.K, S.M. O'Connor, R.L. Gustavson, L.A. Achenbach, and J.D. Coates, 2002. *Environmental Factors that Control Microbial Perchlorate Reduction*. *Applied Environmental Microbiology*. 68(9): 4425-4430.

Coates, J.D., U. Michaelidou, R.A. Bruce, S.M. O'Connor, J.N. Crespi, and L.A. Achenbach, 1999. *Ubiquity and Diversity of Dissimilatory (Per)chlorate-Reducing Bacteria*. *Applied Environmental Microbiology*. 65(12): 5234-5241.

Cooley, A., M. Ferrey, M. Harkness, R.R. Dupont, H. Stroo, and J. Spain, 2005. *Monitored Natural Attenuation Forum: A Panel Discussion*. *Remediation*: Spring 2005; p 83-95.

DoD (Department of Defense), 2007. *DoD Perchlorate Handbook*. Revision 1, Change 1. Department of Defense Environmental Data Quality Workgroup. August.

EPA, 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*. EPA/540/G-89/004. OSWER Directive 9355.3-01. October.

EPA, 1998. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water*. EPA/600/R-98/128. September.

EPA, 1999. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*. OSWER Directive 9200.4-17P. EPA-540-R-99-009. April 21.

EPA, 2005. *Perchlorate Treatment Technology Update: Federal Facilities Forum Issue Paper*. EPA-542-R05-015.

ESTCP (Environmental Security Technology Certification Program), 2006a. *Evaluation of Potential for Monitored Natural Attenuation of Perchlorate in Groundwater: Technology Demonstration Plan for Building 1419 Site, Naval Surface Warfare Center, Indian Head, MD*. ESTCP Project No. ER-0428. Prepared by Solutions-IES. February.

ESTCP, 2006b. *Edible Oil Barriers for Treatment of Perchlorate Contaminated Groundwater*. Prepared by Solutions-IES. February.

ESTCP, 2006c. *Protocol for Enhanced In Situ Bioremediation Using Emulsified Edible Oil*. Prepared by Solutions-IES. May.

ESTCP, 2008. *Natural Attenuation of Perchlorate In Groundwater: Processes, Tools, and Monitoring Techniques*. ESTCP Project No. ER-0428. Prepared by Solutions-IES, Inc. August.

ESTCP, 2010a. *Final Report: Evaluation of Potential for Monitored Natural Attenuation of Perchlorate in Groundwater (Indian Head)*. ESTCP Project No. ER-200428. Prepared by Solutions-IES, Inc. July.

ESTCP, 2010b. *Cost and Performance Report: Monitored Natural Attenuation of Perchlorate in Groundwater*. ESTCP Project No. ER-200428. Prepared by Solutions-IES, Inc. September.

ITRC (Interstate Technology and Regulatory Council), 2002. *Technical/Regulatory Guidelines: A Systematic Approach to In Situ Bioremediation in Groundwater Including Decision Trees for In Situ Bioremediation of Nitrates, Carbon Tetrachloride, and Perchlorate*. August. <http://www.itrcweb.org>.

ITRC, 2005. *Perchlorate: Overview of Issues, Status, and Remedial Options*. September. <http://www.itrcweb.org>.

MDE (Maryland Department of Environment), 2010. Communication from Mr. John Fairbank (Chief of Federal Facilities Division, Hazardous Waste Program, Maryland Department of Environment) at the Indian Head Installation Restoration Tier I Partnering Meeting held on April 1, 2010.

MDE, 2008. *Cleanup Standards for Soil and Groundwater*. State of Maryland. Department of the Environment. Update No. 2.1. June.

Motzer, W.E., 2001. *Perchlorate Problems, Detection, and Solutions*. *Environmental Forensics* 2(4): 301-311.

Navy, 2006a. *Navy Perchlorate Sampling and Management Policy*. May 16.

Navy, 2006b. *Navy Environmental Restoration Program Manual*. August.

Navy, 2010. *Navy Perchlorate Release Management Policy*. March 3.

NOSSA (Naval Ordnance Safety and Security Activity), 2004. *Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419*. Naval Sea Systems Command. By Randall J. Cramer and Carey Yates, Naval Surface Warfare Center – Indian Head Division, and Paul Hatzinger and Jay Diebold, Shaw Environmental and Infrastructure, Inc. (Shaw). NOSSA-TR-2004-001. January 22.

NSF-IH (Naval Support Facility Indian Head), 2006. Email communication from Shawn Jorgensen of NSF-IH Environmental to Jeff Morris and Joseph Rail of NAVFAC Washington. February 24.

Nzengung, V.A., M.T. Lieberman, and H.F. Stroo, 2008 (submitted for publication). *Emerging Technologies for Perchlorate Bioremediation in In Situ Bioremediation of Perchlorate in Groundwater*. Stroo, H.F., C. Vogel and C.H. Ward (Eds). Springer.

SERDP (Strategic Environmental Research and Development Program), 2002. *In Situ Bioremediation of Perchlorate*. SERDP Project No. CU-1163. Prepared by Envirogen. May 21.

Tt (Tetra Tech), 2002. *Background Soil Investigation Report for Indian Head and Stump Neck Annex, Naval Surface Warfare Center, Indian Head, Maryland*. October.

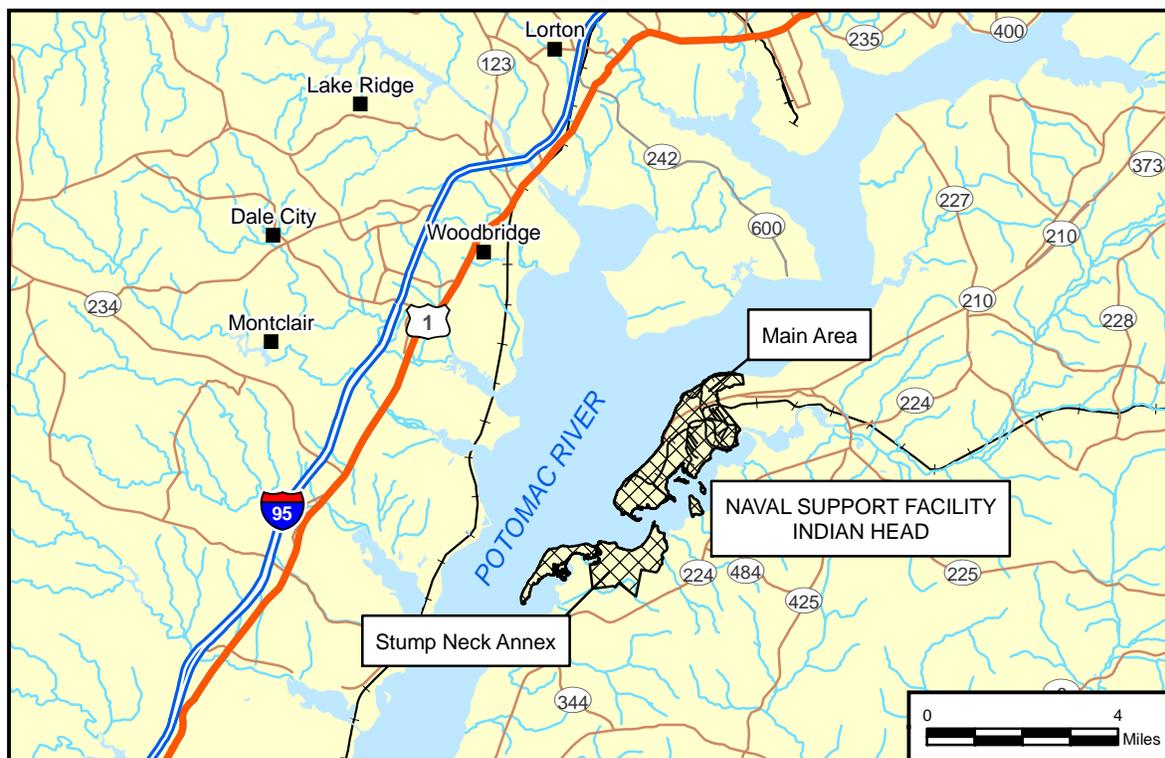
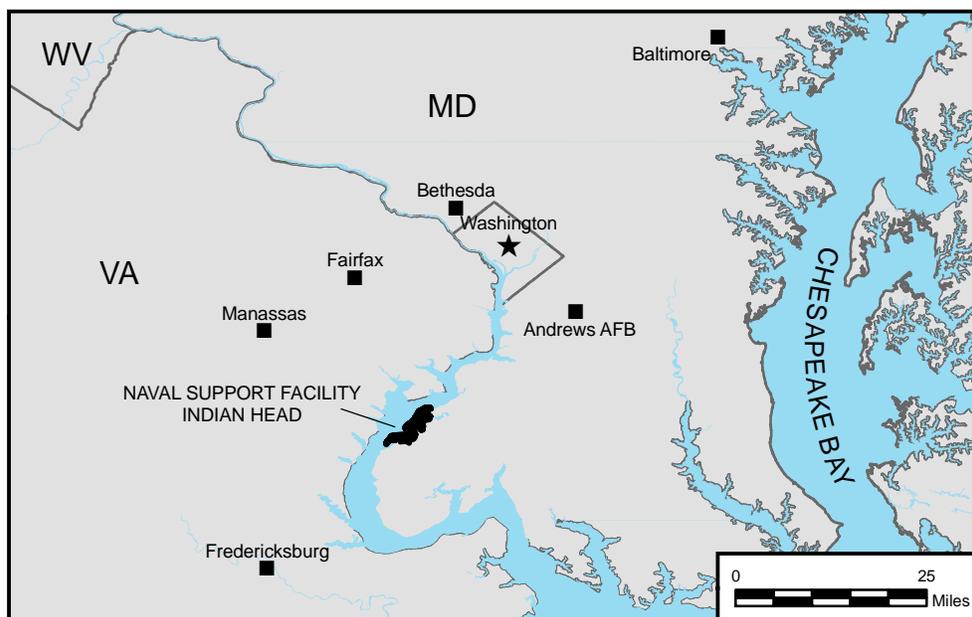
Tt, 2009. *Master Sampling and Analysis Plan (Field Sampling Plan and Quality Assurance Project Plan) for Installation Restoration Program and Munitions Response Program Environmental Investigations, NSF-IH, Indian Head, Maryland*. May.

Tt, 2011. *Final Desktop Audit: Summary of Perchlorate at Site 67 – Hog-Out Facility, Naval Support Facility Indian Head, Indian Head, Maryland. Technical Memorandum*. March 25.

Tt, 2012. *Site Management Plan for Installation Restoration Program, Naval Support Facility Indian Head, Indian Head, Maryland, Fiscal Years 2012 to 2013*. October.

## Figures





DRAWN BY K. MOORE DATE 03/20/09	 <b>TETRA TECH</b>	CONTRACT NUMBER CTO JU11	
CHECKED BY E. CORACK DATE 06/20/11		APPROVED BY E. CORACK DATE 06/20/11	
DRAWN BY J. ENGLISH DATE 06/21/11	FACILITY LOCATION MAP NAVAL SUPPORT FACILITY INDIAN HEAD INDIAN HEAD, MARYLAND	APPROVED BY — DATE —	DATE —
SCALE AS NOTED		FIGURE NO. FIGURE 1	REV 0

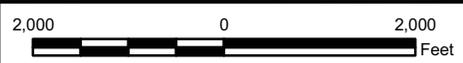


Aerial photograph taken in 2009.



**Legend**

- Site Boundary
- Facility Boundary



DRAWN BY	DATE
J. ENGLISH	06/22/11
CHECKED BY	DATE
E. CORACK	06/23/11
REVISED BY	DATE



**SITE LOCATION**  
**SITE 67 REMEDIAL**  
**INVESTIGATION WORK PLAN**  
**NAVAL SUPPORT FACILITY INDIAN HEAD**  
**INDIAN HEAD, MARYLAND**

CONTRACT NUMBER	CTO NUMBER
02622	JU11
APPROVED BY	DATE
_____	_____
APPROVED BY	DATE
_____	_____
FIGURE NO.	REV
FIGURE 2	0

SCALE  
AS NOTED



Aerial photograph taken in 2009.



**Legend**

Approximate IR Site Boundary

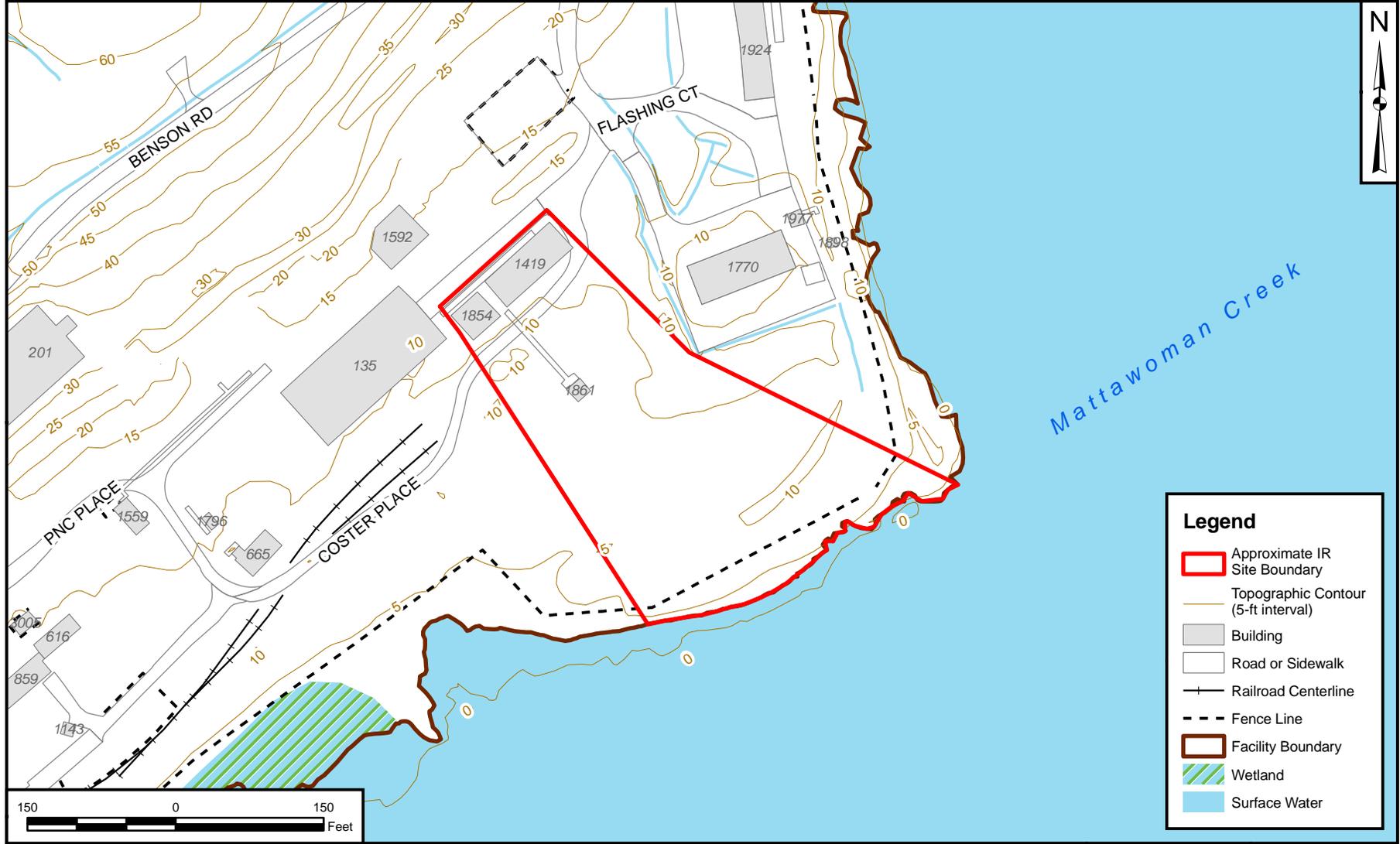
DRAWN BY	DATE
J. ENGLISH	06/21/11
CHECKED BY	DATE
E. CORACK	06/23/11
REVISD BY	DATE
SCALE AS NOTED	



**SITE PLAN - AERIAL**  
**SITE 67 REMEDIAL INVESTIGATION WORK PLAN**  
**NAVAL SUPPORT FACILITY INDIAN HEAD**  
**INDIAN HEAD, MARYLAND**

CONTRACT NUMBER	CTO NUMBER
02622	JU11
APPROVED BY	DATE
—	—
APPROVED BY	DATE
—	—
FIGURE NO.	REV
FIGURE 3	0





**Legend**

- Approximate IR Site Boundary
- Topographic Contour (5-ft interval)
- Building
- Road or Sidewalk
- Railroad Centerline
- Fence Line
- Facility Boundary
- Wetland
- Surface Water

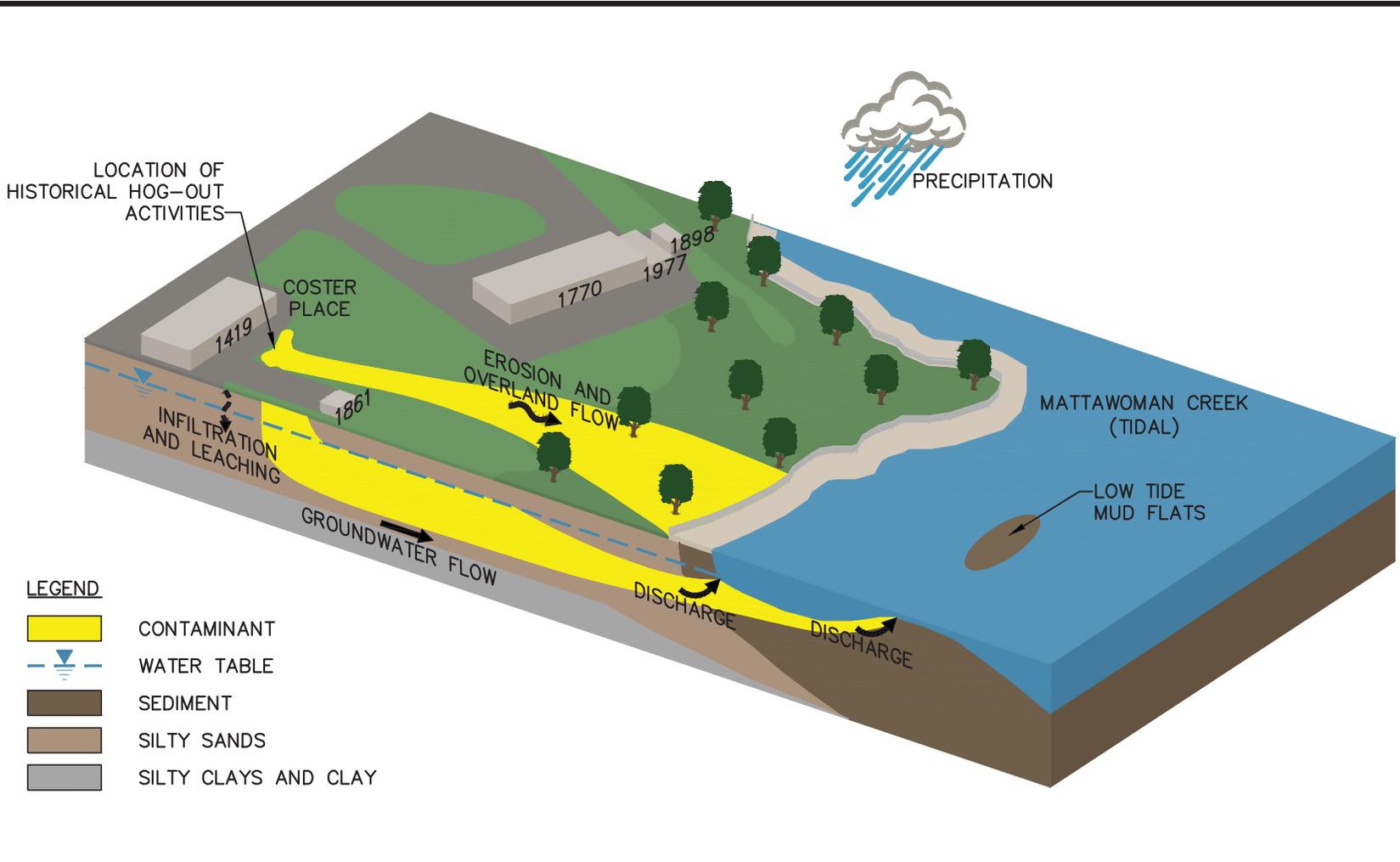
DRAWN BY	DATE
J. ENGLISH	06/21/11
CHECKED BY	DATE
E. CORACK	06/23/11
REVISED BY	DATE
SCALE AS NOTED	



**SITE PLAN - TOPOGRAPHY**  
**SITE 67 REMEDIAL INVESTIGATION WORK PLAN**  
**NAVAL SUPPORT FACILITY INDIAN HEAD**  
**INDIAN HEAD, MARYLAND**

CONTRACT NUMBER	CTO NUMBER
02622	JU11
APPROVED BY	DATE
APPROVED BY	DATE
FIGURE NO.	REV
FIGURE 4	0





- LEGEND**
- CONTAMINANT
  - WATER TABLE
  - SEDIMENT
  - SILTY SANDS
  - SILTY CLAYS AND CLAY

DRAWN BY	DATE
CK	7/27/11
CHECKED BY	DATE
REVISIED BY	DATE
SCALE	
NOT TO SCALE	



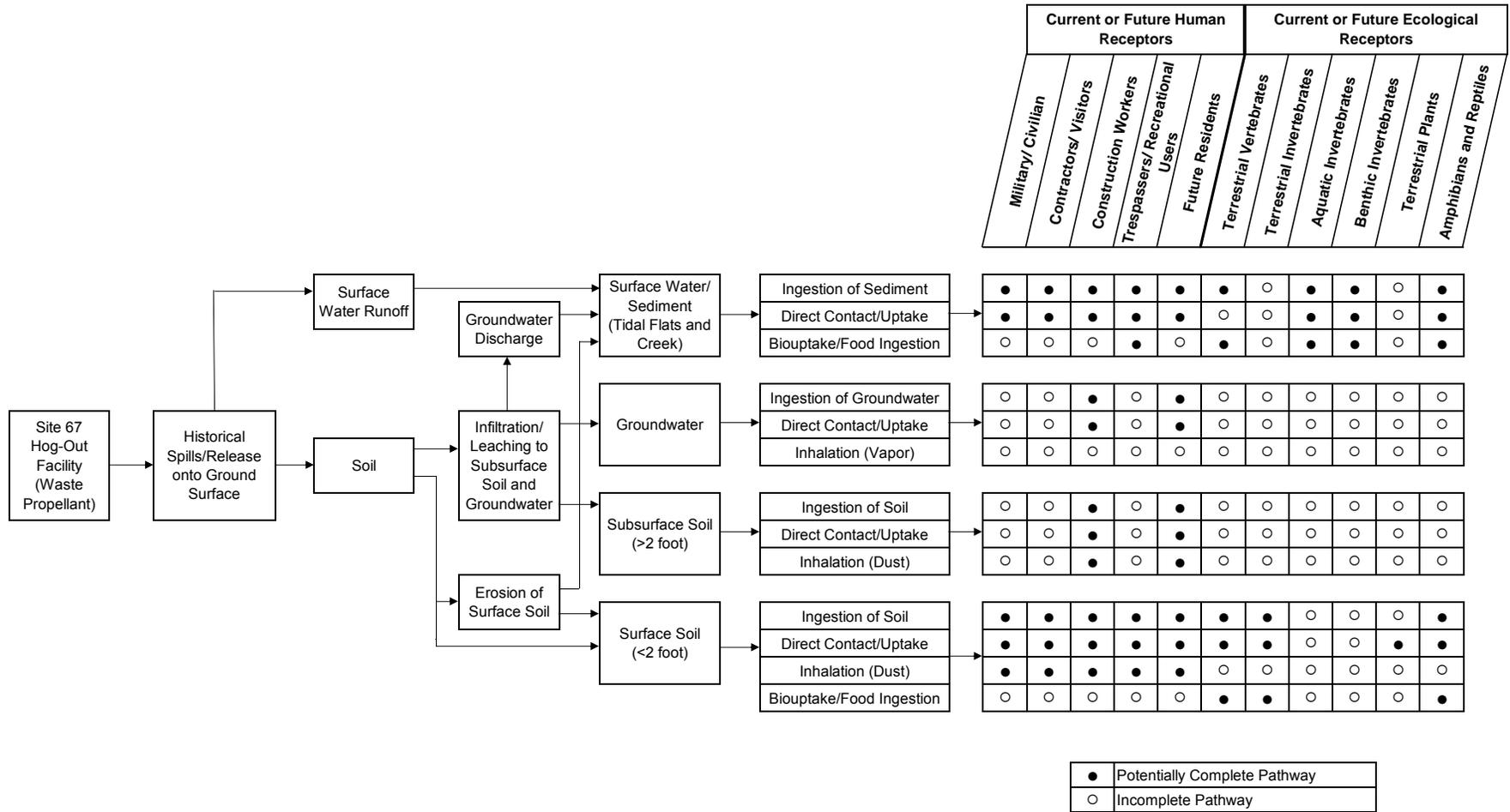
**INTERPRETIVE CONCEPTUAL SITE MODEL**  
**SITE 67**  
**REMEDIAL INVESTIGATION**  
**NAVAL SUPPORT FACILITY INDIAN HEAD**  
**INDIAN HEAD, MARYLAND**

CONTRACT NO. 2622	
OWNER NO.	
APPROVED BY	DATE
DRAWING NO. FIGURE 5	REV. 0

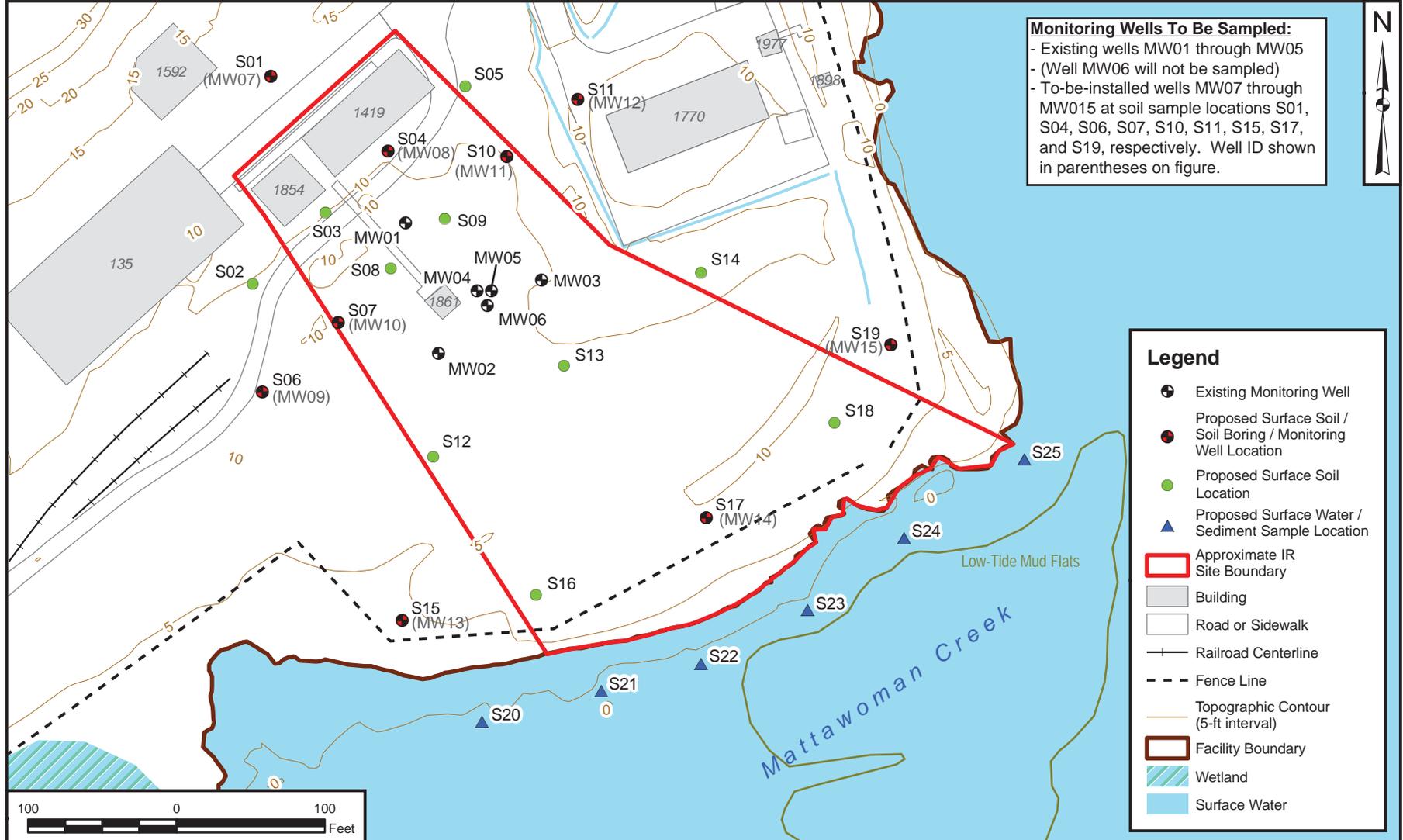


**FIGURE 6  
EXPOSURE PATHWAY ANALYSIS  
SITE 67 - HOG-OUT FACILITY  
NSF INDIAN HEAD  
INDIAN HEAD, MARYLAND**

Primary Contaminant Source	Primary Source Release Mechanism	Secondary Source Medium	Secondary Release Mechanisms	Exposure Medium	Exposure Mechanism	Receptors
----------------------------	----------------------------------	-------------------------	------------------------------	-----------------	--------------------	-----------







DRAWN BY	DATE
J. ENGLISH	07/20/11
CHECKED BY	DATE
E. CORACK	07/27/11
REVISED BY	DATE



SCALE  
AS NOTED

**PROPOSED SAMPLE LOCATIONS**  
**SITE 67 REMEDIAL INVESTIGATION WORK PLAN**  
**NAVAL SUPPORT FACILITY INDIAN HEAD**  
**INDIAN HEAD, MARYLAND**

CONTRACT NUMBER 02622	CTO NUMBER JU11
APPROVED BY —	DATE —
APPROVED BY —	DATE —
FIGURE NO. FIGURE 7	REV 0



## **Appendix A**

### **Supporting Information / Historical Documents**



## TECHNICAL MEMORANDUM

DATE: March 25, 2011

TO: Indian Head Installation Restoration Team

FROM: Tetra Tech NUS, Inc.

SUBJECT: **Final Desktop Audit**  
**Summary of Perchlorate at Site 67 – Hog-Out Facility**  
Naval Support Facility Indian Head (NSF-IH), Indian Head, MD  
CLEAN Contract No. N62470-08-D-1001, Contract Task Order JU11

### INTRODUCTION

This technical memorandum (tech memo) summarizes the following activities and documents for Site 67 – Hot-Out Facility at NSF-IH in Indian Head, MD. The tech memo also serves to provide general information and discussion on perchlorate contamination and the site, and suggest a path forward.

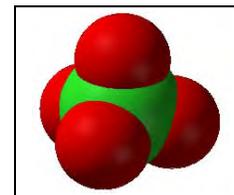
- **Activity: 2002 Pilot Test.**  
**Document:** Naval Ordnance Safety and Security Activity (NOSSA) (2004) *Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419.*
- **Activity: 2006 Technology Demonstration Plan.**  
**Document:** Environmental Security Technology Certification Program (ESTCP) (2006a) *Evaluation of Potential for Monitored Natural Attenuation of Perchlorate in Groundwater: Technology Demonstration Plan for Building 1419 Site, Naval Surface Warfare Center, Indian Head, MD.*
- **Activity: 2008 Perchlorate Attenuation Guidance.**  
**Document:** ESTCP (2008) *Natural Attenuation of Perchlorate in Groundwater: Processes, Tools, and Monitoring Techniques.*

### SITE 67 – HOG-OUT FACILITY

Site 67 – Hog-Out Facility is located on the southeast side of NSF-IH bordering Mattawoman Creek ([Figure 1](#)). The site is described as perchlorate-contaminated groundwater resulting from historical site practices at Building 1419 ([Figure 2](#)), which consisted of cleaning out (hogging out) solid propellant from various devices, including rockets and ejection seat motors (Tetra Tech, 2009). The 2-acre grassy site contains a small drum storage building. Direct dumping of the hog-out wastewater occurred from the 1960s to the mid-1990s (Tetra Tech, 2009). Wastewaters at the site now are drummed and disposed appropriately (NSF-IH, 2006).

## **PERCHLORATE**

Perchlorate ( $\text{ClO}_4^-$ ) is composed of a chloride atom bonded to four oxygen atoms. Perchlorate is usually found as the anion component of a salt and is released when the solid salts of ammonium ( $\text{NH}_4\text{ClO}_4$ ), sodium ( $\text{NaClO}_4$ ), or potassium perchlorate ( $\text{KClO}_4$ ) and perchloric acid ( $\text{HClO}_4$ ) dissolve in water (ESTCP, 2008; Motzer, 2001). Perchlorate has been manufactured since the 1890s and is most commonly found as a manufactured compound (ITRC [Interstate Technology and Regulatory Council], 2005). Ammonium perchlorate is used as an oxidizing agent for solid propellant rockets and missiles. Other common uses for perchlorate are shown below (ITRC, 2005). Considering these uses, other contaminants typically are found with perchlorate such as volatile organic compounds (VOCs), halogenated solvents, explosive compounds (e.g., trinitrotoluene [TNT]; hexahydro-1,3,5-trinitro-1,3,5-triazine [RDX]; and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine [HMX]), nitrate, and sulfate (ESTCP, 2008; ITRC, 2002). Other contaminants may originate from specific types of rocket motors (e.g., polycyclic aromatic hydrocarbons [PAHs] from jet-assisted takeoff [JATO] motors) (Maryland Department of Environment [MDE], 2010).

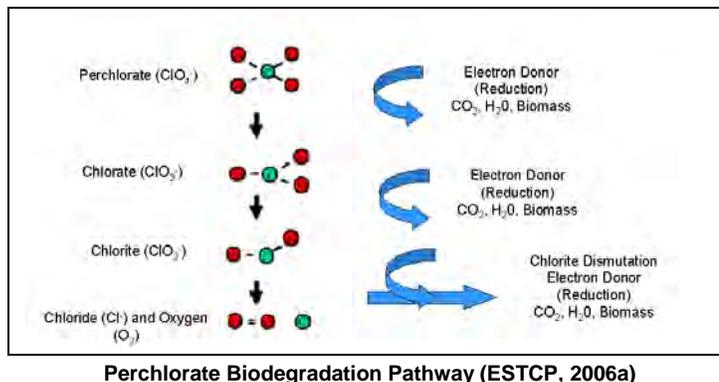


**Perchlorate Anion  
(ITRC, 2005)**

Chemical and Electrical Uses	Explosive and Propellant Uses	Miscellaneous Uses
cathodic protection systems	military devices	steel plate bonding
brine separation	geoseismic devices	Li-ion batteries
chlorate/chlorite	chemical cutter	enamel paints
manufacturing	ordnance	fertilizer
cloud seeding	tracer bullets	laundry bleach
dielectric for transformers	solid rocket motor	pharmaceutical
electroplating	rocket motor	diagnosis/treatment
	airbags	pool sanitizer
	ejection seats	
	fireworks	

Perchlorate contamination in soil and groundwater primarily results from the production of the compound for aerospace and military applications, the testing of rockets and munitions, and the periodic removal and replacement of solid fuels in rockets (Strategic Environmental Research and Development Program [SERDP], 2002). The removal and replacement procedure, referred to as hog-out, is required periodically because solid perchlorate fuels have a limited usable life. Solid propellant is initially washed from the casing using high-pressure water, then the solid fuel is replaced or the casing is discarded. The improper disposal of this wastewater, which contains high concentrations of perchlorate and other salts, as well as the disposal techniques traditionally used during manufacturing and testing results in substantial perchlorate contamination (SERDP, 2002). Perchlorate salts are highly soluble in water, dissociating completely to perchlorate anions that are nonvolatile, highly mobile, and chemically stable in aqueous systems (groundwater and surface water) under normal conditions. However, “solid perchlorate salts like ammonium perchlorate and highly concentrated solutions of perchlorate, known as brine, can behave similarly to dense non-aqueous phase liquid (DNAPL) when released into an aquifer system. As such, the perchlorate tends to sink through the water column until the mass reaches a low permeability confining layer (Motzer, 2001) where it persists causing secondary or recurring perchlorate contamination (ITRC, 2002) (ESTCP, 2008).”

Perchlorate biodegradation occurs in a somewhat similar manner as reductive dechlorination,<sup>1</sup> but through a different metabolic mechanism. Indigenous chlorate-reducing bacteria and associated enzymes in the aquifer utilize a substrate (electron donor) under favorable anaerobic conditions to convert perchlorate to chlorate, chlorite, and finally chloride (SERDP, 2002; ESTCP, 2006b and 2006c).<sup>2</sup> From ESTCP (2006a):



Work by Coates et al. (1999), Chaudhuri et al. (2002), and Bender et al. (2002) indicates that the *Dechloromonas sp.* and *Dechlorosoma sp.* represent the primary chlorate- and perchlorate-reducing bacteria in the environment, but more than 30 different strains of perchlorate-reducing microbes have been identified (EPA, 2005). The rate-limiting step in the three-step degradation process is the conversion of perchlorate to chlorate by a perchlorate reductase enzyme. Subsequent conversion of chlorate to chlorite is also catalyzed by a perchlorate reductase enzyme. Chlorite removal by the chlorite dismutase enzyme is the final step in perchlorate reduction.

Perchlorate respiration also is similar to denitrification, where bacteria utilize a substrate and reduce nitrate as the terminal electron acceptor to nitrogen gas (SERDP, 2002). The other natural attenuation mechanisms (advection, dispersion, diffusion, and sorption) also affect (i.e., decrease) perchlorate concentrations.

## 2002 PILOT TEST

The perchlorate biodegradation field demonstration (pilot test) methodology and results are presented in the NOSSA (2004) document. A brief summary of the previous SERDP-funded field and lab work in 2000 is introduced prior to the pilot study presentation.

### 2000 SERDP Study

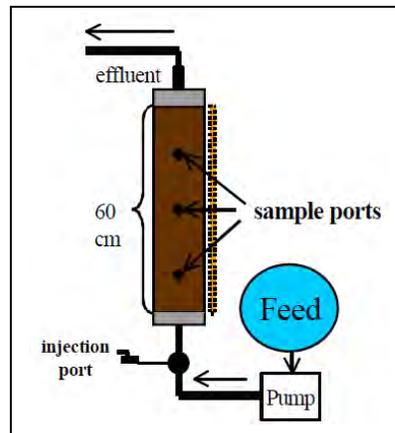
The “2000 SERDP Study” included collecting sediments and groundwater from perchlorate-contaminated aquifers at multiple facilities, including NSF-IH (samples were collected from Building 1190 and Building 1419 [Site 67]) (SERDP, 2002; NOSSA, 2004). The objective of the study was to “develop a biological treatment technology for in situ remediation of perchlorate in subsurface environments.” Four key factors were hypothesized to contribute to the persistence of perchlorate at various sites:

<sup>1</sup> The primary pathway for biodegradation of chlorinated volatile organic compounds (VOCs) occurs under anaerobic conditions via reductive dechlorination. During this biotic process, the chlorinated VOCs are used as an electron acceptor by dechlorinating / dehalogenating bacteria in the presence of a carbon source (electron donor), and a chlorine atom is removed and replaced with a hydrogen atom (EPA, September 1998). If the bacteria are able to obtain metabolically useful energy from reductive dechlorination, the process is also referred to as halo-respiration (ESTCP, 2006c).

<sup>2</sup> Perchlorate biodegradation can occur under strict anaerobic conditions as well as facultative anaerobic conditions (ESTCP, 2006a and 2006b). Facultative anaerobic microorganisms are capable of both aerobic respiration under low oxygen tension and fermentation when anaerobic conditions prevail. This metabolic versatility suggests a variety of indigenous perchlorate-reducing microbial populations exist.

- Absence of an appropriate substrate (electron donor) for growth of indigenous perchlorate-degrading bacteria.
- Presence of alternative electron acceptors for bacterial respiration, including oxygen, nitrate, and nitrite in groundwater.
- Lack of an indigenous population of bacteria capable of perchlorate reduction.
- Unfavorable environmental conditions for activity of indigenous perchlorate degraders.

The mixed sediment and groundwater aquifer samples were subjected to microcosm studies. No perchlorate was detected in the Building 1190 samples (so perchlorate was added to these samples for the studies), whereas perchlorate was detected at 45 milligrams per liter (mg/L) (or 45,000 micrograms per liter [ $\mu\text{g/L}$ ]) in the homogenized samples from Building 1419. Various electron donors were tested for efficacy: methanol, ethanol, acetate, benzoate, lactate, sucrose, molasses, ethanol with yeast extract, hydrogen gas, and propane. A specific enrichment culture (bacteria), *Dechlorospirillum sp.*,<sup>3</sup> was also inoculated into one sample. All samples were incubated at 15 degrees Celsius ( $^{\circ}\text{C}$ ) and analyzed at 11, 20, 36, and 71 days for perchlorate via U.S. Environmental Protection Agency (EPA) Method 314.0. The tests showed perchlorate degradation in the Building 1090 samples, but not in the Building 1419 samples, despite confirming the presence of active indigenous cultures (and one sample was inoculated with *Dechlorospirillum sp.*). It was observed that the pH of the samples from Building 1190 was at 7, while the pH of the samples from Building 1419 was at 4.3.



Aquifer Microcosm (SERDP, 2002)

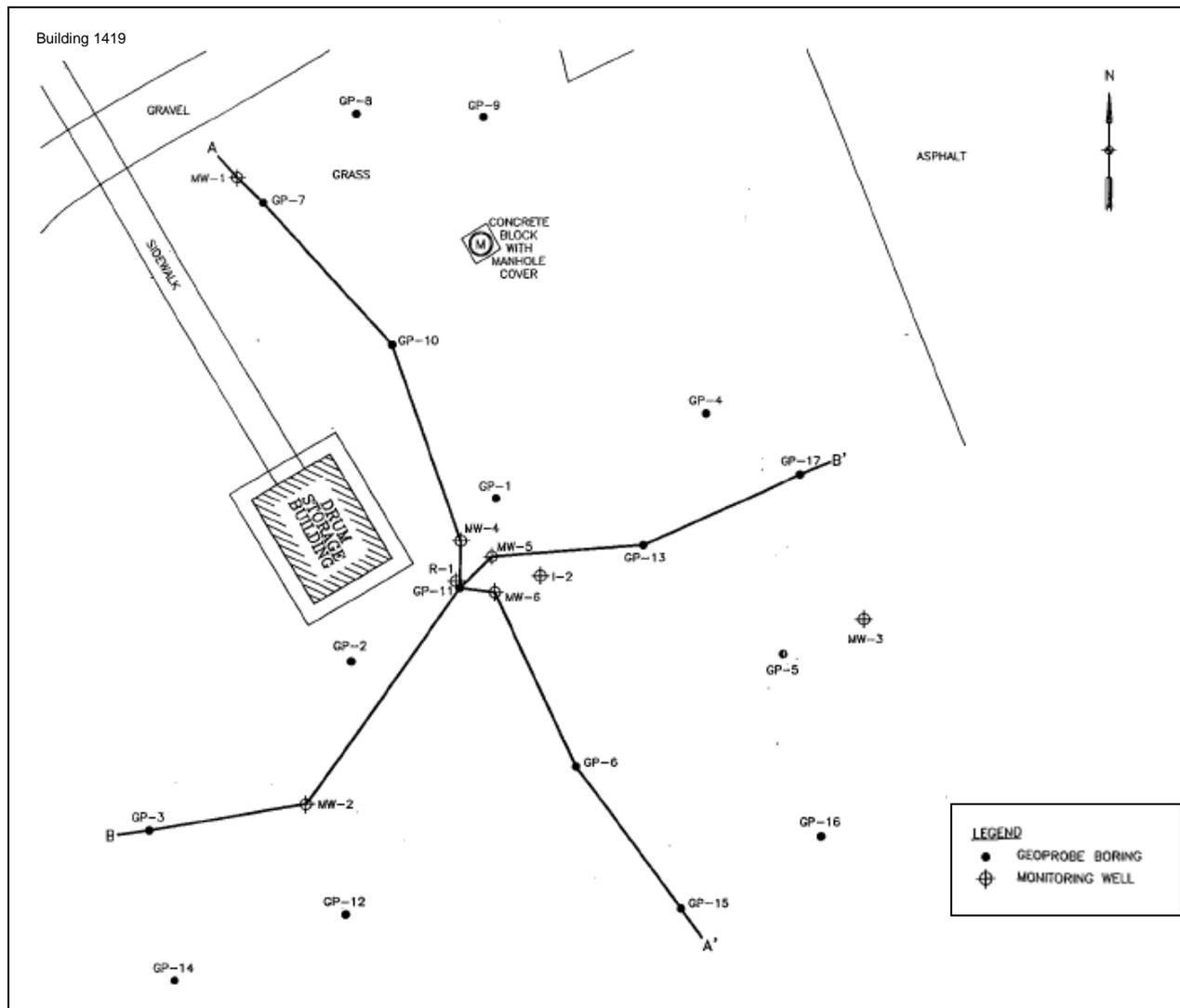
The study concluded that there may be a pH below which perchlorate biodegradation is physiologically inhibited, or that some other geochemical factor (e.g., heavy metal toxicity or trace metal unavailability) prevents perchlorate biodegradation at low pH. Once the Building 1419 samples were buffered in follow up tests (pH was increased to 7), perchlorate degradation was observed. The overall results from the 2000 SERDP Study revealed the following:

1. Perchlorate-degrading bacteria are widely distributed in groundwater aquifers.
2. These organisms can be stimulated to biodegrade perchlorate under anoxic conditions using a variety of different electron donors, although the most effective donors vary on a site-specific basis.
3. Perchlorate biodegradation is inhibited in aquifers where the pH is naturally below approximately 5.5. However, the indigenous bacteria exist / can survive at the lower pH (prior to stimulation and pH adjustment).

<sup>3</sup> This culture was isolated from a perchlorate fluidized bed treatment system in use in California at the time.

## 2002 NOSSA PILOT TEST

Based on the success of the 2000 SERDP Study, the NOSSA field-pilot demonstration proceeded at Site 67 to evaluate the potential for in situ treatment of perchlorate in the shallow aquifer. Seventeen Geoprobe® (i.e., direct push technology [DPT]) borings were installed in January 2002 to collect soil lithology and groundwater samples approximately 300 feet (ft) upgradient of Mattawoman Creek. After logging the soil, temporary wells were installed to collect groundwater samples. Six larger soil borings also were installed in January through February 2002 to accommodate six new permanent groundwater monitoring wells (locations were based on the perchlorate results from the DPT samples).



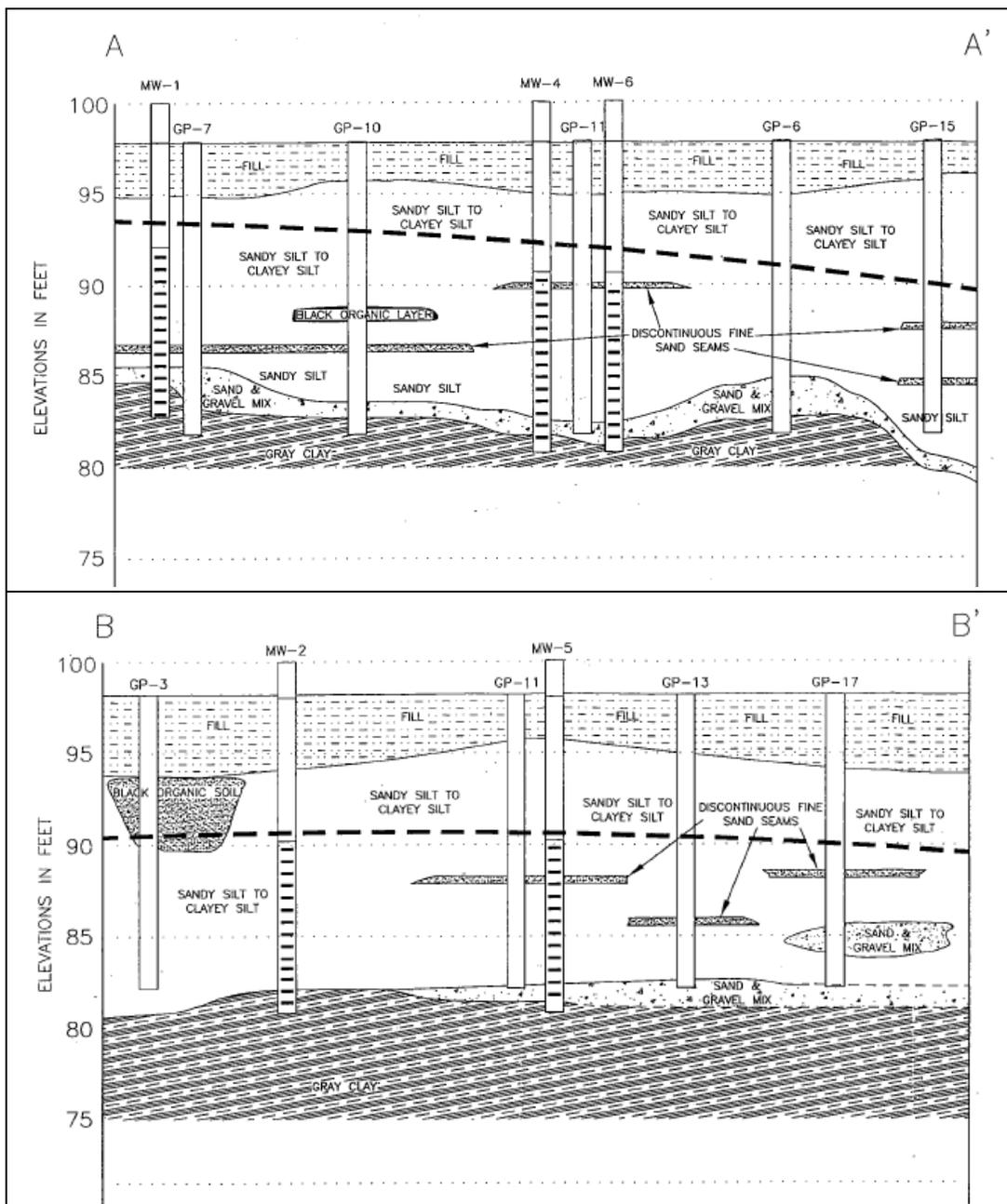
January through February 2002 – DPT Locations, Monitoring Wells, and Cross-Section Transects

The site geology was described as follows in NOSSA (2004):

The top 2 to 4 ft of soil consisted of fill material including organic material, gravel, and silty sand. The underlying 11 to 13 ft consisted of mottled light to olive brown clay to sandy silts. The clay and sand fraction of the silts varied horizontally and vertically. Fine grained sand seams 1 to 2 inches in thickness were seen in many of the boring locations, but these seams were not continuous from boring to boring. At a depth of approximately

15 ft below ground surface (bgs), a 1- to 1.5-ft-thick layer of sand and gravel was encountered. This layer was found to be continuous throughout the area near the test plot. The sand and gravel layer is underlain by a gray clay layer, which extends to a depth of at least 20 ft bgs, the deepest extent of the [DPT and monitoring well] borings.

Interpretive cross-sections A-A' and B-B' are provided below from NOSSA (2004).



Water level gauging was performed to determine water table conditions and surficial aquifer groundwater flow at the site. Groundwater flow generally followed topography southeast toward Mattawoman Creek, with an average hydraulic gradient of 0.023. Depth to the water table ranged from 6.5 to 10.3 ft bgs. Slug tests were performed on three monitoring wells nearest the planned test plot area. Using the Bower-

Rice unconfined aquifer method, the average hydraulic conductivity (K) was determined to be 0.012 ft per minute.

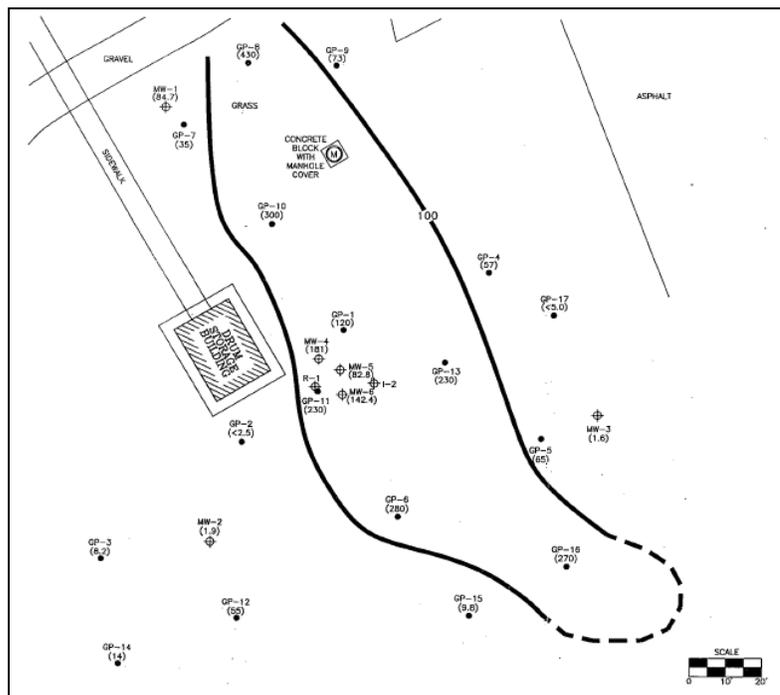
A varying step pump test was performed for 12 hours with sustained pumping rates of 0.15 to 0.2 gallons per minute (gpm). Based on the data, K estimates ranged from 0.011 to 0.044 ft per minute. Using a hydraulic conductivity of 0.02 ft per minute and an assumed effective porosity of 25 percent, the estimated groundwater velocity at the site is calculated at 970 feet per year. The pump test was followed with an injection test, which showed the aquifer could receive 1.2 gpm at less than 3.5 pounds per square inch (psi) pressure.

The groundwater samples from each of the 17 DPT temporary wells were analyzed for perchlorate, nitrate, sulfate, pH, and dissolved oxygen (DO). Perchlorate concentrations ranged from less than (<) 2.5 (nondetect [ND]) to 430 mg/L, nitrate (as nitrogen) ranged from < 0.2 (ND) to 14 mg/L, sulfate ranged from 56 to 280 mg/L, pH ranged from 4.2 to 8.1, and DO ranged from < 0.2 (ND) to 1.5 mg/L. The highest perchlorate and nitrate concentrations occurred at GP-8, where no DO was detected and the pH was 4.6.

The groundwater samples from each of the six permanent monitoring wells were analyzed for perchlorate, pH, and DO. In the monitoring well groundwater samples, perchlorate ranged from 1.6 to 142 mg/L, pH ranged from 4.1 to 6.8, and DO ranged from 1.1 to 6.6. The highest perchlorate concentration occurred at monitoring well MW-6, where DO was 1.33 mg/L and pH was 5. The combined perchlorate results showed a shallow, narrow plume of perchlorate.

The results were used to design the field demonstration. The objectives of the demonstration were as follows:

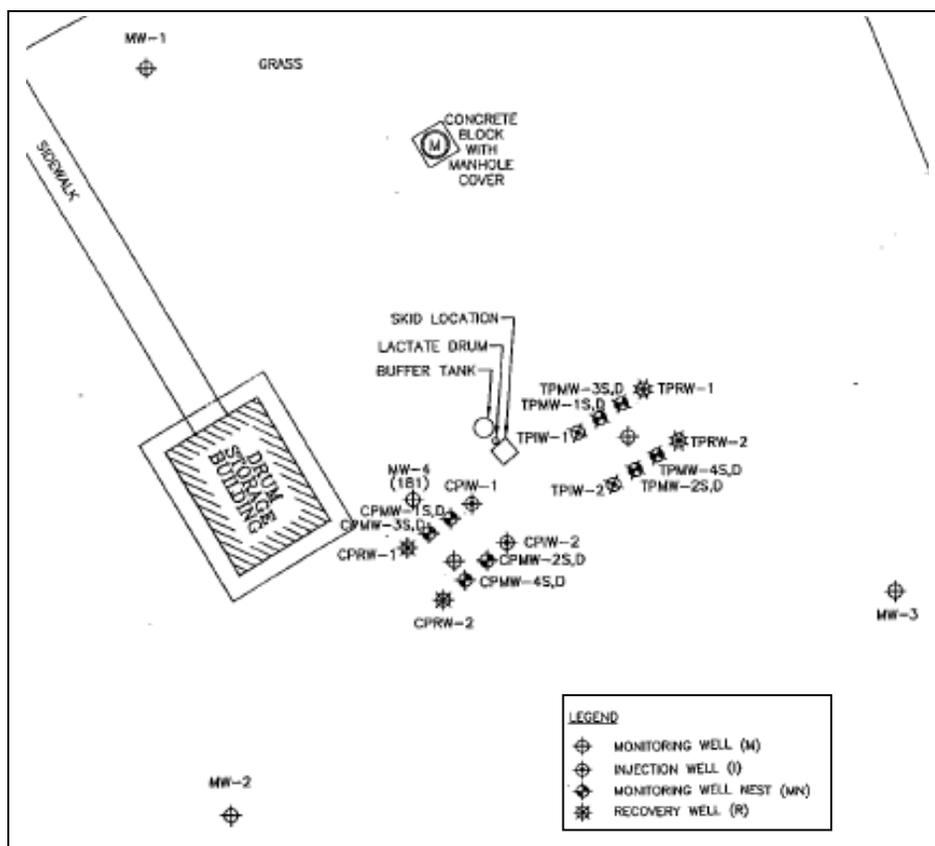
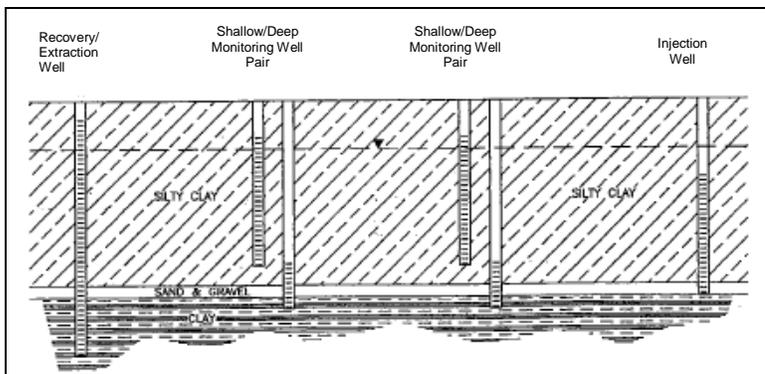
1. Demonstrate that the aquifer can be effectively buffered using a mixture of carbonate and bicarbonate.
2. Show that electron donor (lactate) can be effectively distributed throughout the contaminated aquifer using a groundwater extraction-injection design.
3. Demonstrate that perchlorate and nitrate can be biodegraded in the buffered aquifer using lactate as an electron donor, with minimal reduction of sulfate.
4. Quantify the time required for perchlorate biodegradation and the levels of degradation achievable.



January through February 2002 Groundwater Perchlorate Distribution

5. Identify key design and operational factors that influence full-scale application of in situ perchlorate bioremediation at this and other sites.

The test plot and control plot layouts of injection, extraction (for recirculation), and monitoring wells were initially determined using “a simple single-layer numeric model,” which was calibrated with the pump test data. The final layout of each plot consisted of two injection wells and two extraction wells installed 12 ft apart in each of the plots, with two sets of shallow/deep monitoring wells installed between the injection and extraction wells. The plots were set up 20 ft away from each other. The injection wells were installed at the clay layer interface while the extraction wells were keyed 4 ft into the clay layer.



Test Plot (TP) and Control Plot (CP) Recirculation Cell Layouts

Prior to the full-scale demonstration, a tracer test using sodium bromide was used to confirm the hydraulic connectivity between the injection, extraction, and monitoring wells. The results confirmed connectivity between all wells in the test plot where the buffer and electron donor were added to the aquifer.

During the full-scale demonstration, test plot water was amended with electron donor and buffer periodically (approximately once per week) during the recirculation/reinjection process. Sixty percent (by

weight) of food-grade sodium lactate syrup (neutral pH) was added along with 6.7 percent food-grade sodium carbonate and/or sodium bicarbonate. The ratio of carbonate to bicarbonate varied throughout the test. The pH and alkalinity of the test plot water were monitored throughout the study. By the end of the test, a total of 58 kilograms (kg) of lactate (24 gallons of 60 percent lactate) was added to the aquifer in the test plot.

Over 20,000 gallons of groundwater were recirculated through each plot during the demonstration (140 to 180 gallons per day through each cell). Excessive rainfall during the test caused elevated water table conditions, which required an early system shut down at day 111 because the aquifer could not accept the injected/recirculated material. Despite the early shut down, samples were still collected at day 140 to complete the originally planned test duration.

Baseline groundwater samples were collected from the test plot and control plot monitoring wells at 10 weeks and 1 week prior to system startup. During system operation, samples were collected in the test plot at 2, 3, 7, 10, 15, and 20 weeks, and from the control plot at 2, 7, 15, and 20 weeks. Each sample was analyzed for pH and alkalinity, lactate, perchlorate, nitrate, and sulfate. Nitrate and sulfate levels were monitored because nitrate reduction occurs prior to perchlorate reduction and sulfate reduction occurs after perchlorate reduction. Thus, these parameters served as aquifer condition and reduction indicators.

The pH and alkalinity increased throughout the test duration in the test plot due to the buffer addition. There was no appreciable increase in these parameters in the control plot. Lactate samples in the test plot demonstrated effective distribution of the electron donor: The sample data showed initial increases in lactate concentrations followed by decreases as the aquifer biota consumed the lactate at increasing rates.

Perchlorate concentrations within the test plot showed a steady decline throughout the demonstration, decreasing by 95 percent to 99 percent in all but one well. The one well in question was thought to be affected by groundwater flow patterns from outside the test plot area. There was “no consistent reduction in perchlorate levels in any of the wells in the control plot during the demonstration period.” Further:

The data from the demonstration clearly show that the addition of buffer and electron donor to the test plot stimulated the microbial reduction of perchlorate in the aquifer. Losses of perchlorate to dilution or any other abiotic process would have been observed in both plots.

It was stated that this particular study was one of the first successful field demonstrations of in situ perchlorate bioremediation in a groundwater aquifer, the first conducted on the East Coast of the U.S., the first performed in an acidic aquifer, and the first to show perchlorate levels above 200 mg/L can be treated in situ. NOSSA (2004) concluded that the acidic aquifer was effectively buffered using both carbonate and bicarbonate, and that the recirculation cell design provided effective distribution of both buffer and electron donor. The data from the demonstration suggested that in situ bioremediation is “a viable option for perchlorate treatment in aquifers containing localized, high concentrations of the oxidant... [including] source areas from hog-out operations, demolition and open burn areas, and other regions where perchlorate or perchlorate-laden fuels are discharged.

## **2006 TECHNOLOGY DEMONSTRATION PLAN**

The work plan and design for additional field studies and guidance development at Site 67 is presented in the ESTCP (2006) *Technology Demonstration Plan* prepared by Solutions-IES. Site 67 was selected

from among several candidate sites for the demonstration after three levels of site evaluation were conducted. The overall goals of the project were as follows:

1. Provide managers with the tools needed to evaluate whether monitored natural attenuation (MNA) may be appropriate for management of perchlorate releases on their site(s).
2. Demonstrate to regulatory agencies that perchlorate MNA is effective for controlling adverse impacts to the environment.

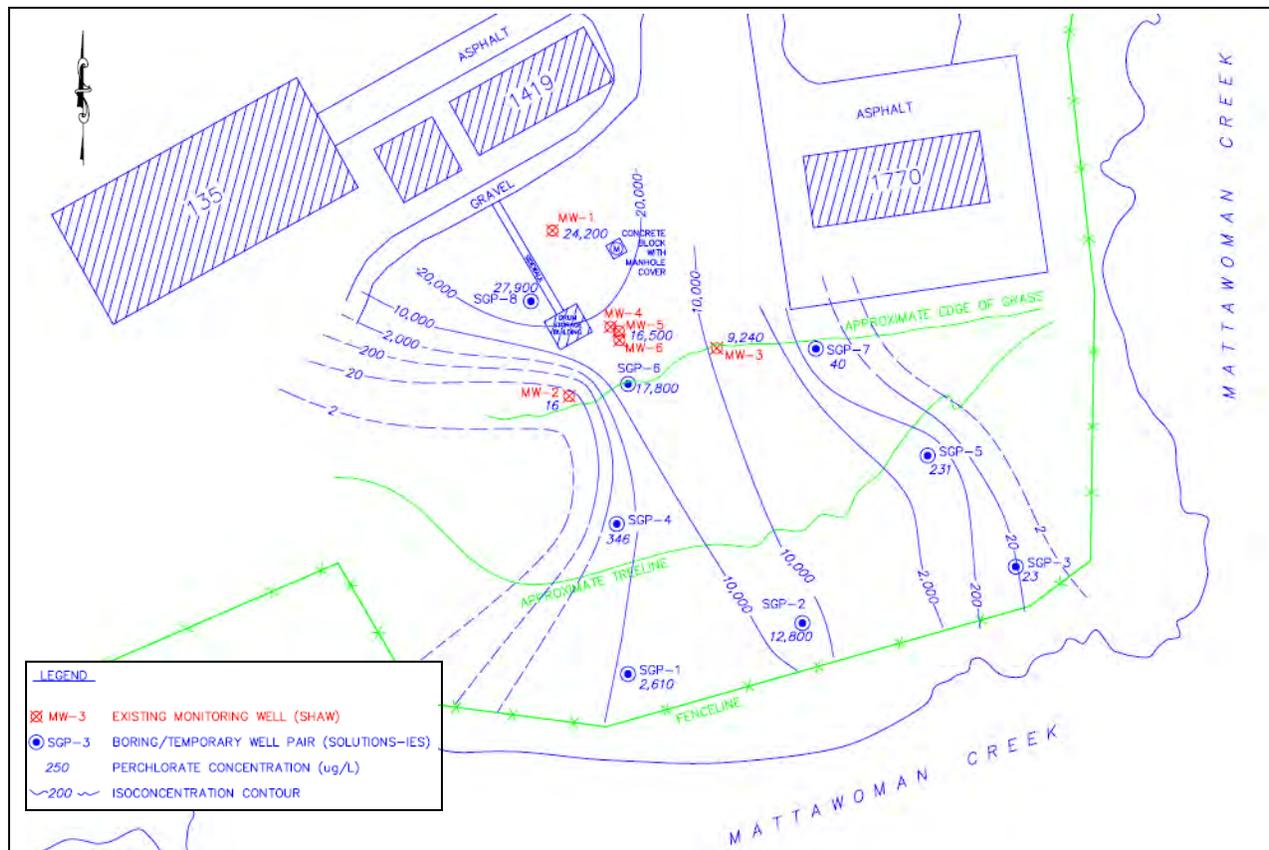
The project objectives were to evaluate MNA's efficacy at remediating perchlorate in groundwater, and to evaluate innovative tools to determine if biodegradation is occurring and at what rates. That is, to develop lines of evidence for MNA of perchlorate and to test these in the field to verify if they will be adequate for use in a protocol. The following lines of evidence were defined for evaluation:

- Using existing and new monitoring wells, determine the horizontal and vertical distribution of perchlorate and mass flux with distance.
- Observe changes in groundwater bio-geochemistry as supporting evidence for attenuation.
- Confirm and obtain additional microbiological evidence for the in situ activity of perchlorate-degrading organisms using an analysis for chlorite dismutase<sup>4</sup> and in situ biodegradation study results.
- Identify changes in isotopic composition of perchlorate as an indicator of biodegradation.

To support development of the Technology Demonstration Plan, ESTCP collected groundwater samples from existing monitoring wells at Site 67 in 2005, followed by the installation of seven new soil borings for lithology collection and groundwater sampling from temporary monitoring wells. Site lithology and groundwater flow was determined to be consistent with previous findings documented in NOSSA (2004). In addition, specific capacity tests were performed on two existing monitoring wells. Groundwater sample data did not clearly indicate a source area for the perchlorate release, but suggested that perchlorate was discharging to the mudflat adjoining Mattawoman Creek in excess of 10 mg/L (10,000 µg/L). The mudflat area, extending over 400 ft from the shoreline, submerged under 2 ft of water during high tide, and exposed during low tide, would be the focus of the biodegradation study.

---

<sup>4</sup> The specificity of chlorite dismutase could be useful as an indicator of perchlorate biodegradation and, therefore, provide supporting evidence for MNA of perchlorate.



**2005 Perchlorate Isoconcentration Contour Map – Shallow Groundwater**

The study would consist of installation of approximately eight new shallow/deep monitoring well pairs onsite, six new monitoring wells within the mudflat area, and a set of biocolumns (i.e., in situ columns to estimate the biodegradation rate as perchlorate migrates upward through the surficial mudflat sediments containing organic carbon) within the mudflat area. Specific capacity tests would be performed on all new wells to obtain additional hydraulic conductivity data.

Soil samples would be collected from all borings advanced in the mudflats to be tested for total organic carbon (TOC). Baseline and performance monitoring groundwater samples would be collected. All groundwater samples would be tested for perchlorate, TOC, chloride, nitrate, sulfate, and methane. A subset of the samples also would be tested for iron, manganese, ammonia, alkalinity, chlorite dismutase, and a specific chloride isotope ( $\delta^{37}\text{Cl}$ ).

## 2008 PERCHLORATE ATTENUATION GUIDANCE

Site 67 is presented as a case study in the ESTCP (2008) perchlorate attenuation guidance document prepared by Solutions-IES.

### GUIDANCE/PROTOCOL

The document discusses background information on MNA, perchlorate, and tools and techniques for evaluating perchlorate attenuation (e.g., field and laboratory methods, geochemical and microbial indicators, etc.). The document points out that as of 2008 (Nzungu et al., 2008):

The biodegradation pathways are well understood and the microorganisms involved in perchlorate biodegradation are known, they can use a variety of different organic substrates as electron donors, are relatively ubiquitous in soil and groundwater environments, and function as strict or facultative anaerobes. This suggests that natural attenuation of perchlorate should occur at many sites (Cooley et al., 2005), and that MNA can be effective in managing the risks posed by perchlorate contamination of groundwater under favorable conditions.

A three-tier approach for the assessment of natural attenuation of perchlorate is defined as follows (similar to EPA [1999]):

- **Tier 1 – Spatial and temporal distribution of perchlorate** (plume stability and geometry, shrinking plume, and reduction in concentrations).
- **Tier 2 – Bio-geochemical conditions for perchlorate biodegradation** (indicator parameters to demonstrate favorable conditions—similar to evaluating favorable conditions for biodegradation of chlorinated VOCs—pH near neutrality; no or low DO; negative oxidation-reduction potential [ORP]; presence of available organic carbon [electron donor]; methane [reducing, methanogenic conditions]; nitrate [denitrification conditions]; iron [reducing environment], and increasing chloride).
- **Tier 3 – Microbiological indicators of perchlorate biodegradation** (similar to evaluating biodegradation of chlorinated VOCs, but different daughter products [chlorate, chlorite, and chloride], bacteria, and specific enzymes [perchlorate reductase and chlorite dismutase]).

### **SITE 67 CASE STUDY PRESENTATION**

The case study for Site 67 is appended to the ESTCP (2008) guidance document. The case study reviews the 2005 pre-demonstration results and presents the subsequent sampling results and findings. The study confirmed general groundwater flow southeast through the site, and that groundwater flow direction offsite varies daily and seasonally according to tide levels in Mattawoman Creek. At high tide, water flows downward through the mudflat sediments into the aquifer, whereas at low tide, the groundwater flows up through the “organic rich sediments before discharging to the surface as a series of small springs and seeps.”

Perchlorate concentrations were measured as high as 93 mg/L near Building 1419 and over 10 mg/L at the bank of the creek. However, concentrations decrease over 99 percent as groundwater migrates upward through the mudflat sediments. Bio-geochemical conditions showed conducive conditions for perchlorate biodegradation. Specifically, TOC and methane concentrations increase and ORP values decrease as groundwater migrates upward through the mudflat sediments.

Both macrocosm (in situ) and microcosm (laboratory) studies were performed. The macrocosm results showed 40 percent reduction in perchlorate in 2 weeks. The microcosm results showed perchlorate reduction to below detection limits in less than 2 months. First-order biodegradation rates were estimated at 24 to 61 per year. Enzyme analysis showed that chlorite dismutase gene was present in the mudflat sediments, indicating the capability of perchlorate biodegradation by indigenous microbial communities. Molecular analysis showed that perchlorate reductase genes were also present, which are involved in the degradation of perchlorate to chlorate and chlorite. “In general, higher numbers of gene copies were reported in locations with lower perchlorate concentrations, suggesting that perchlorate is biodegrading as a result of perchlorate reductase activity.”

In summary, the results of the three-tier assessment for perchlorate attenuation at Site 67 were as follows:

- **Tier 1** – Perchlorate concentrations decrease with time and distance due to biodegradation, dilution, and dispersion.
- **Tier 2** – Most ideal geochemical conditions coincide with greatest perchlorate reduction.
- **Tier 3** – Greatest perchlorate reduction occurs where highest population of perchlorate-reducing bacteria indicators are measured.

Therefore, MNA likely is an acceptable final remedy for the site. However, additional sampling should be performed to create a more robust temporal dataset for Tiers 1 and 2. Further, additional sampling locations are necessary to fully delineate the perchlorate plume and define the source area.

## **PATH FORWARD FOR SITE 67**

Based on the research, lab results, field results, conclusions, and guidance presented in NOSSA (2004) and ESTCP (2006a and 2008), it is expected that perchlorate concentrations at Site 67 will continue to decline via multiple natural attenuation mechanisms (e.g., biodegradation and dilution). However, groundwater concentrations of perchlorate may not reach an appropriate cleanup level<sup>5</sup> in a reasonable timeframe (not considering land use) via natural attenuation only.

While perchlorate contamination in the surficial aquifer is evident at the site, the soil medium and other potential contaminants in all media require investigation. Therefore, a Remedial Investigation (RI) is recommended by the Navy to completely characterize the site. A Feasibility Study (FS) likely will be required to evaluate remedial alternatives for site cleanup.

## **REFERENCES**

- Bender, K.S., S.M. O'Connor, R. Chakraborty, J.D. Coates and L.A. Achenbach, 2002. *Sequencing and Transcriptional Analysis of the Chlorite Dismutase Gene of Dechloromonas agitata and Its Use as a Metabolic Probe*. Applied Environmental Microbiology. 68(10): 4820-4826.
- Chaudhuri, S.K, S.M. O'Connor, R.L. Gustavson, L.A. Achenbach, and J.D. Coates, 2002. *Environmental Factors that Control Microbial Perchlorate Reduction*. Applied Environmental Microbiology. 68(9): 4425-4430.
- Coates, J.D., U. Michaelidou, R.A. Bruce, S.M. O'Connor, J.N. Crespi, and L.A. Achenbach, 1999. *Ubiquity and Diversity of Dissimilatory (Per)chlorate-Reducing Bacteria*. Applied Environmental Microbiology. 65(12): 5234-5241.
- Cooley, A., M. Ferrey, M. Harkness, R.R. Dupont, H. Stroo, and J. Spain, 2005. *Monitored Natural Attenuation Forum: A Panel Discussion*. Remediation: Spring 2005; p 83-95.

---

<sup>5</sup> The cleanup level for perchlorate (and any other contaminants) will be developed in the Feasibility Study (FS). Note that the U.S. Environmental Protection Agency (EPA) issued an Interim Drinking Water Health Advisory of 15 µg/L for perchlorate in January 2009.

NOSSA, 2004. *Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419*. Naval Sea Systems Command. By Randall J. Cramer and Carey Yates, Naval Surface Warfare Center – Indian Head Division, and Paul Hatzinger and Jay Diebold, Shaw Environmental and Infrastructure, Inc. (Shaw). NOSSA-TR-2004-001. January 22.

EPA, 1998. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water*. EPA/600/R-98/128. September.

EPA, 1999. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*. OSWER Directive 9200.4-17P. EPA-540-R-99-009. April 21.

EPA, 2005. *Perchlorate Treatment Technology Update: Federal Facilities Forum Issue Paper*. EPA-542-R05-015.

ESTCP, 2006a. *Evaluation of Potential for Monitored Natural Attenuation of Perchlorate in Groundwater: Technology Demonstration Plan for Building 1419 Site, Naval Surface Warfare Center, Indian Head, MD*. ESTCP Project No. ER-0428. Prepared by Solutions-IES. February.

ESTCP, 2006b. *Edible Oil Barriers for Treatment of Perchlorate Contaminated Groundwater*. Prepared by Solutions-IES. February.

ESTCP, 2006c. *Protocol for Enhanced In Situ Bioremediation Using Emulsified Edible Oil*. Prepared by Solutions-IES. May.

ESTCP, 2008. *Natural Attenuation of Perchlorate in Groundwater: Processes, Tools, and Monitoring Techniques*. ESTCP Project No. ER-0428. Prepared by Solutions-IES. August.

ITRC, 2002. *Technical/Regulatory Guidelines: A Systematic Approach to In Situ Bioremediation in Groundwater Including Decision Trees for In Situ Bioremediation of Nitrates, Carbon Tetrachloride, and Perchlorate*. August. <http://www.itrcweb.org>.

ITRC, 2005. *Perchlorate: Overview of Issues, Status, and Remedial Options*. September. <http://www.itrcweb.org>.

MDE, 2010. Communication from Mr. John Fairbank (Chief of Federal Facilities Division, Hazardous Waste Program, Maryland Department of Environment) at the Indian Head Installation Restoration Tier I Partnering Meeting held on April 1, 2010.

NSF-IH, 2006. Email communication from Shawn Jorgensen of NSF-IH Environmental to Jeff Morris and Joseph Rail of NAVFAC Washington. February 24.

Nzungung, V.A., M.T. Lieberman, and H.F. Stroo, 2008 (submitted for publication). *Emerging Technologies for Perchlorate Bioremediation in In Situ Bioremediation of Perchlorate in Groundwater*. Stroo, H.F., C. Vogel and C.H. Ward (Eds). Springer.

SERDP, 2002. *In Situ Bioremediation of Perchlorate*. SERDP Project No. CU-1163. Prepared by Envirogen. May 21.

Tetra Tech, 2009. *Site Management Plan for Installation Restoration Program, Naval Support Facility Indian Head, Indian Head, Maryland, Fiscal Years 2009 to 2010*. October.



**IR SITE KEY**

- 1 Thorium Spill
- 2 Waste Crank Case Oil Applied to Torrence Road
- 3 Nitroglycerin Explosion, Nitration Building Area
- 4 Lloyd Road Oil Spill Sites
- 5 X-Ray Building 731
- 6 Hypo Spill, Radiographic Facility Accelerator
- 7 HMX Spill, Slurry Mix Building 682
- 8 Mercury Contamination From Building 766
- 9 Patterson Avenue Oil Spill
- 10 Single-base Propellant Grains Spill (Also UXO 9)
- 11 Caffee Road Landfill
- 12 Town Gut Landfill
- 13 Paint Solvents Disposal Ground
- 14 Waste Acid Disposal Pit
- 15 Mercury Deposits in Manhole, Fluorine Lab
- 16 Laboratory Chemical Disposal
- 17 Disposed Metal Parts Along Shoreline
- 18 Hog Island
- 19 Catch Basin at Chip Collection House (1051)
- 20 Single-base Powder Facility
- 21 Bronson Road Landfill
- 22 NG Slums Burning Site (Also UXO 6)
- 23 Hydraulic Oil Discharges from Extrusion Plant
- 24 Abandoned Drain Lines
- 25 Hypo Discharge X-Ray Building No. 2
- 26 Thermal Destructor 2
- 27 Thermal Destructor 1
- 28 Original Burning Ground (Also UXO 8)
- 29 The Valley (Also UXO 11)
- 39 Silver Release to Sediment
- 40 Palladium Catalyst in Sediment
- 41 Scrap Yard (Also UXO 32)
- 42 Olsen Road Landfill
- 43 Toluene Disposal Site
- 44 Soak Out Area
- 45 Abandoned Drums
- 46 Cadmium Sandblast Grit Area
- 47 Mercuric Nitrate Disposal Area
- 48 Nitroglycerine Plant Disposal Area
- 49 Chemical Disposal Pit
- 50 Building 103, Crawl Space
- 51/54 Building 101, Dry Well/Building 101
- 52/55 Building 102, Dry Well/Building 102
- 53 Mercury Contamination of the Sewage System
- 56 Lead Contamination at IW Outfall 87
- 57 Building 292 TCE Contamination
- 66 Turkey Run Disposal Area
- 67 Hog Out Facility

**MRP UXO KEY**

- 6 NG Slums Burning Site (Also IR Site 22)
- 8 Original Burning Ground (Also IR Site 28)
- 9 Single-base Propellant Grains Spill (Also IR Site 10)
- 11 The Valley (Also IR Site 29)
- 13 FDR Skeet Range
- 20 Safety Thermal Treatment Point
- 29 Southwestern Pistol Range
- 30 Gate 3 Burning Ground
- 32 Scrap Yard (Also IR Site 41)

**LEGEND**

- Approximate Site Boundary
- IR Site Number
- MRP UXO Number



DRAWN BY K. PEILA	DATE 7/26/02
CHECKED BY K. TURNBULL	DATE 6/09/08
COST/SCHEDULE-AREA	
SCALE AS NOTED	



Site Location Map  
Naval Support Facility Indian Head - Main Area  
Indian Head, Maryland

CONTRACT NUMBER 2193		OWNER NUMBER ---	
APPROVED BY GJL		DATE 12/29/06	
APPROVED BY ---		DATE ---	
DRAWING NO. Figure 1			REV 0



LEGEND	
	Approximate Site Boundary
	Asphalt Road
	Dirt Road
	Gravel Road
	Buildings
	Railroad
	Water



DRAWN BY K. PEILA CHECKED BY G.JL COST/SCHEDULE-AREA SCALE AS NOTED	DATE 6/22/05 DATE 12/29/06	Tetra Tech NUS, Inc. Site 67 - Hog-Out Facility Naval Support Facility Indian Head Indian Head, Maryland	CONTRACT NUMBER 2193 APPROVED BY G.JL APPROVED BY — DRAWING NO. Figure 2	OWNER NUMBER — DATE 12/29/06 DATE — REV 0
---	-------------------------------------	---	--	--

CU1163-2

24 MAY 2002

## ***In Situ* Bioremediation of Perchlorate**

### **SERDP Project CU-1163 Final Report**

Prepared by

**Envirogen Inc.  
4100 Quakerbridge Road  
Lawrenceville, NJ 08648**

**DISTRIBUTION STATEMENT A**  
Approved for Public Release  
Distribution Unlimited

Prepared for

**Strategic Environmental Research and Development Program  
901 North Stuart Street, Suite 303  
Arlington, VA 22203**

**May 21, 2002**

**20030103 234**

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 074-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

<b>1. AGENCY USE ONLY (Leave blank)</b>		<b>2. REPORT DATE</b> May 21, 2002	<b>3. REPORT TYPE AND DATES COVERED</b> Final Report	
<b>4. TITLE AND SUBTITLE</b> <i>In Situ</i> Bioremediation of Perchlorate			<b>5. FUNDING NUMBERS</b> N/A	
<b>6. AUTHOR(S)</b> Envirogen Inc.				
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> Envirogen Inc. 4100 Quakerbridge Rd. Lawrenceville, NJ 08648			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b> N/A	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> SERDP 901 North Stuart St. Suite 303 Arlington, VA 22203			<b>10. SPONSORING / MONITORING AGENCY REPORT NUMBER</b> N/A	
<b>11. SUPPLEMENTARY NOTES</b> No copyright is asserted in the United States under Title 17, U.S. code. The U.S. Government has a royalty-free license to exercise all rights under the copyright claimed herein for Government purposes. All other rights are reserved by the copyright owner.				
<b>12a. DISTRIBUTION / AVAILABILITY STATEMENT</b> Approved for public release: distribution is unlimited.			<b>12b. DISTRIBUTION CODE</b> A	
<b>13. ABSTRACT (Maximum 200 Words)</b> The objective of this project is to develop a biological treatment technology for <i>in situ</i> remediation of perchlorate in subsurface environments. The development of an effective technology for perchlorate remediation requires a fundamental understanding of the conditions that limit biological perchlorate reduction in groundwater and the most effective means to overcome such limitations. This research effort is designed to provide this fundamental understanding. We hypothesize that four key factors may be contributing to the persistence of perchlorate at various subsurface sites. These key factors and our approach to their evaluation in the research paper are as follows: (1) Absence of an appropriate substrate (electron donor) for growth of indigenous perchlorate degrading bacteria; (2) Presence of alternative electron acceptors for bacterial respiration, including O <sub>2</sub> , NO <sub>3</sub> <sup>-</sup> , and NO <sub>2</sub> <sup>-</sup> in groundwater; (3) Lack of an indigenous population of bacteria capable of perchlorate reduction; and (4) Unfavorable environmental conditions for activity of indigenous perchlorate degraders. The research performed during this project was designed to provide extensive information on (1) the potential for successful perchlorate remediation at subsurface sites by addition of electron donors (i.e., biostimulation); the most effective electron donors to use in biostimulation efforts, and the expected concentrations and remediation kinetics achievable with these donors; (3) the possibility for successful bioaugmentation (i.e., injection of bacterial isolates) for subsurface perchlorate remediation; and (4) the probable influence of alternate electron acceptors and environmental variables on perchlorate reduction during				
<b>14. SUBJECT TERMS</b> SERDP, SERDP Collection, perchlorate, electron donors, electron acceptors, subsurface remediation			<b>15. NUMBER OF PAGES</b> 172	
			<b>16. PRICE CODE</b> N/A	
<b>17. SECURITY CLASSIFICATION OF REPORT</b> unclass	<b>18. SECURITY CLASSIFICATION OF THIS PAGE</b> unclass	<b>19. SECURITY CLASSIFICATION OF ABSTRACT</b> unclass	<b>20. LIMITATION OF ABSTRACT</b> UL	

## TABLE OF CONTENTS

1.0 PROJECT BACKGROUND .....	3
2.0 PROJECT OBJECTIVES .....	7
3.0 TECHNICAL APPROACH.....	9
4.0 PROJECT ACCOMPLISHMENTS .....	13
4.1 SAMPLE COLLECTION.....	13
4.2 ISOLATION AND IDENTIFICATION OF PERCHLORATE DEGRADING BACTERIA FROM FBRS AND FIELD SITES.....	13
4.3 LABORATORY MICROCOSM STUDIES.....	16
4.3.1 JET PROPULSION LABORATORY (JPL) .....	16
4.3.1.1 Sample Collection.....	17
4.3.1.2 Electron Donor Addition and Bioaugmentation.....	17
4.3.1.3 Influence of Alternate Electron Acceptors.....	20
4.3.1.4 Influence of pH and Salinity on Perchlorate Degradation.....	24
4.3.2 INDIAN HEAD DIVISION, NAVAL SURFACE WARFARE CENTER (IHDIV), INDIAN HEAD, MARYLAND .....	27
4.3.2.1 Sample Collection .....	27
4.3.2.2 IHDIV Building 1190 Site – Evaluation of Electron Donors and Electron Donor Concentration on Perchlorate Biodegradation.....	27
4.3.2.3 IHDIV Hog Out Facility – Evaluation of Electron Donors and pH on Perchlorate Reduction.....	31
4.3.3 ROCKY MOUNTAIN COMMERCIAL FACILITY (RM), UTAH .....	36
4.3.3.1 Evaluation of Electron Donors and Influence of Chlorinated Solvents and BTEX on Perchlorate Reduction.....	36
4.3.4 LONGHORN ARMY AMMUNITION PLANT, KARNACK, TEXAS. ....	41
4.3.4.1 Sample Collection.....	41
4.3.4.2 LHAAP Site 16 – Landfill Leachate.....	42
4.3.4.3 LHAAP Site 25 – Propellant Mixing Facility.....	45
4.3.4.4 LHAAP Site 25C – Biodegradation of Perchlorate in Surface Soils .....	48
4.3.5 BOEING CORPORATION, SACRAMENTO, CALIFORNIA.....	50
4.3.5.1 Sample Collection .....	51
4.3.5.2 Microcosm Studies to Evaluate Biodegradation of Low Perchlorate Concentrations and the Influence of Different Substrates on Sulfate Reduction.....	51
4.4 EVALUATE PERCHLORATE TRANSPORT AND BIODEGRADATION IN PILOT-SCALE MODEL AQUIFERS.....	53
4.4.1 MODEL AQUIFER CONSTRUCTION .....	53
4.4.2 EVALUATION OF INFLUENT WATER MIXING.....	54
4.4.3 TRANSPORT OF PERCHLORATE THROUGH SILICA SAND AND AQUIFER SEDIMENT .....	57
4.4.4 EVALUATION OF PERCHLORATE AND NITRATE BIODEGRADATION.....	59
4.4.5 INFLUENCE OF pH ON PERCHLORATE REDUCTION .....	68
4.4.6 INFLUENCE OF CHLORATE ON PERCHLORATE REDUCTION .....	70
4.4.7 SUSTAINED BIODEGRADATION OF PERCHLORATE AT LOW CONCENTRATIONS.....	72
4.4.8 INFLUENCE OF RDX ON PERCHLORATE BIODEGRADATION AND POTENTIAL FOR COMBINED TREATMENT .....	75
4.5 PERCHLORATE BIODEGRADATION MODEL .....	81
4.5.1 MODEL DESCRIPTION .....	81
4.5.2 ELECTRON DONOR CONSUMPTION.....	81
4.5.3 MICROBIAL POPULATIONS .....	81
4.5.4 ELECTRON ACCEPTORS.....	82
4.5.5 MODEL ASSUMPTIONS.....	82
4.5.6 EXPERIMENTAL DETERMINATION OF MODEL PARAMETERS.....	82
4.5.6.1 Experimental Quantification of Model Parameters.....	84
4.5.6.2 Experimental Quantification of Cell Yield and Decay .....	90
4.5.6.3 Utilization of Competing Electron Acceptors.....	94
4.5.6.4 Influence of Nitrate and Oxygen on Perchlorate Biodegradation .....	96
4.5.6.4.1 Influence of Nitrate on Perchlorate Reduction .....	96

4.5.6.4.2	Estimation of a Nitrate Inhibition Factor for Perchlorate Reduction.....	98
4.5.6.4.3	Influence of Oxygen on Perchlorate Reduction.....	99
4.5.6.5	Model Simulation of Perchlorate and Nitrate Biodegradation by <i>D. suillum</i> JPLRND.....	100
4.6	PERCHLORATE TRANSPORT MODEL.....	106
4.6.1	MODEL SIMULATION OF PERCHLORATE AND BROMIDE TRANSPORT IN THE MODEL AQUIFER.....	106
4.7	COUPLED TRANSPORT AND BIODEGRADATION MODEL FOR PERCHLORATE.....	108
4.7.1	EXPERIMENTAL APPROACH.....	108
4.7.2	MODEL PARAMETERS.....	108
4.7.3	MODEL RESULTS.....	109
4.8	ADDITIONAL MODEL DEVELOPMENT.....	114
4.9	ANALYTICAL METHOD DEVELOPMENT.....	114
4.9.1	BACKGROUND.....	114
4.9.2	OBJECTIVES OF ANALYTICAL METHOD DEVELOPMENT.....	117
4.9.3	TECHNICAL APPROACH.....	117
4.9.4	RESULTS OF ANALYTICAL METHOD.....	119
4.9.4.1	Construction of Analytical System.....	119
4.9.4.2	Results and Conclusions from Sample Analysis.....	120
5.0	TRANSITION PLAN - FIELD DEMONSTRATIONS.....	122
5.1	EVALUATION OF ELECTRON DONOR ADDITION FOR PERCHLORATE TREATMENT AT IHDIV.....	122
5.2	EVALUATION OF ELECTRON DONOR ADDITION FOR PERCHLORATE TREATMENT USING HORIZONTAL FLOW TREATMENT WELLS.....	124
5.2.1	TECHNICAL DESCRIPTION, SCHEDULE, AND TECHNOLOGY TRANSFER FOR ESTCP DEMONSTRATION.....	124
5.3	OTHER MEANS OF TECHNOLOGY TRANSFER.....	126
6.0	REFERENCES CITED.....	128
7.0	APPENDICES.....	131
7.1.	APPENDIX A: TECHNICAL PRESENTATIONS, PUBLICATIONS, AND ABSTRACTS	
7.2	APPENDIX B: KINETIC MODEL TO DESCRIBE PERCHLORATE BIODEGRADATION	

## 1.0 PROJECT BACKGROUND

Ammonium perchlorate ( $\text{NH}_4\text{ClO}_4$ ) has been used for several decades in the United States as an oxidant in solid propellants and explosives. It is the primary oxidant used in many rocket motors and boosters, such as those powering the space shuttle and intercontinental ballistic missiles (ICBMs). For example, a single rocket booster for the space shuttle contains approximately 350,000 kg of ammonium perchlorate. Various perchlorate salts (e.g., ammonium, potassium, and magnesium perchlorate) are also used in flares, fireworks, matches, and air bags as well as in leather tanning, electroplating, and for ionic strength adjustment in analytical chemistry (Gulick et al., 2001; USEPA, 2001a). Perchlorate is also present in a naturally-occurring nitrate formation that is mined in Chile (Chilean caliche) for use in some agricultural fertilizers (USEPA, 2001b). However, a majority of fertilizers used in the United States are not produced with this material and do not appear to contain environmentally significant levels of perchlorate (Renner, 2001). Rather, the primary sources of soil and groundwater contamination with perchlorate are related to the production of the compound for aerospace and military applications, the testing of rockets and munitions, and the periodic removal and replacement of solid fuels in rockets. The latter procedure, which is referred to as hog out, is required because solid perchlorate fuels have a limited shelf life and must be periodically removed and replaced. During the hog out procedure, solid propellant is initially washed from the missile or rocket casing using high-pressure water, then the solid fuel is replaced or the casing is discarded. The wastewater resulting from this operation contains high concentrations of perchlorate and other salts. The improper disposal of this wastewater as well as the disposal techniques traditionally used during manufacturing and testing has resulted in substantial perchlorate contamination in several states including Texas, California, Utah, New Mexico, and Nevada.

A sensitive detection method for perchlorate was developed by the California Department of Health Services (CDHS) in 1997 (CDHS, 1997). Because this technique has only been available for a few years, the total scope of perchlorate contamination in the United States is not yet known. However, perchlorate has now been detected in 14 states, and current estimates suggest that the drinking water of as many as 15 million people may be impacted by this compound (USEPA, 1999; Logan, 2001). For example, as of April 2002, CDHS had sampled 629 public water systems in California and found 69 (11 %) with detectable perchlorate ( $> 4 \mu\text{g/L}$ ) (CDHS, 2002a). Of the 3,864 non-public drinking water sources tested by the agency, 246 (6.4%) tested positive for the oxidant. Perchlorate has been manufactured or used in at least 44 states nationwide, so groundwater pollution may extend beyond recent reports (USEPA, 2001a; USEPA, 2002b). There is currently no federal action level for perchlorate in groundwater. However, several states, including Arizona, California, Nevada, and Texas have set provisional action levels ranging from 4 to 31  $\mu\text{g/L}$  (ppb), and site-specific clean-up levels of 1.5  $\mu\text{g/L}$  and below have been set by regulators. Based on results from a draft toxicological document prepared by

the USEPA, CDHS recently lowered the action level for perchlorate in groundwater from 18 µg/L to 4 µg/L (CDHS, 2002b; USEPA, 2002a). Perchlorate has also been placed on the USEPA Unregulated Contaminant Monitoring Regulation list (UCMR) and Contaminant Candidate List (CCL) for regulatory consideration (USEPA, 2000).

The potential human health risks of ammonium perchlorate are based largely on the ability of the perchlorate anion to inhibit the transport of iodide into the thyroid gland (Wolff, 1998). Because iodide regulates the synthesis of thyroid hormone (T<sub>2</sub>), exposure to perchlorate can disrupt T<sub>2</sub> regulation, and subsequently influence levels of thyroxine (T<sub>4</sub>) and thyroid-stimulating hormone (TSH) (OEHHA, 2002). The levels these two hormones are regulated in a feedback loop with T<sub>2</sub>. Because perchlorate salts disrupt iodide uptake, they have been used therapeutically in large doses to treat hyperthyroid conditions, such as that resulting from Graves' disease. Although a variety of different studies have been conducted during the past several years to evaluate the influence of perchlorate on human health (e.g., Lawrence et al., 2000; 2001, Lamm and Doemland, 1999), many questions remain concerning the risks of low levels of perchlorate exposure to humans through drinking water. The EPA has recently reevaluated the human health risks associated with perchlorate contamination (USEPA, 2002a). At the writing of this report, the EPA risk assessment document is still undergoing review. However, a draft reference dose (RfD) of 0.03 µg/kg/d was proposed in this document to ensure public protection from adverse effects of perchlorate in water over a lifetime. This value, which corresponds to a drinking water concentration of only 1 µg/L, is approximately 30-fold lower than the RfD proposed by EPA in a previous toxicological document in 1998 (0.9 µg/kg/d) (USEPA, 1998; CDHS, 2002b). The revised reference dose reflects new data concerning perchlorate toxicity, the need to protect the most sensitive populations, including pregnant women and their unborn children, and a level of uncertainty spanning about one order of magnitude based on current data gaps (USEPA, 2002b).

In addition to human health issues, perchlorate is anticipated to have toxicological effects on various terrestrial and aquatic species, including rodents, fish, and amphibians (York et al., 2001; Smith et al., 2001; Manzon and Youson, 1997). Perchlorate is known to influence metamorphosis, so amphibians, may be particularly sensitive to this compound. For example, Goleman et al. (2002) recently reported that perchlorate concentrations in the part-per-billion range caused significant impacts on forelimb emergence, tail resorption, and hindlimb growth in frogs (*Xenopus laevis*) undergoing metamorphosis. The compound, however, exhibited low toxicity to eggs and larvae of this species (LC<sub>50</sub> = 223 to 510 mg/kg). Although research is ongoing, the current database concerning the ecological impacts of environmentally-relevant concentrations of perchlorate is sparse. Thus, the environmental and human health effects resulting from long-term exposure to low levels of perchlorate remain somewhat unclear at the current time.

Perchlorate salts are highly soluble in water (e.g., ammonium perchlorate is soluble to ~ 200 g/L) and dissociate completely. The resulting perchlorate anion is nonvolatile, highly mobile, and chemically stable in aqueous systems under normal conditions present in ground and surface water. As a result, in areas where substantial quantities of perchlorate salts have been discarded, expansive groundwater plumes of perchlorate are often observed. Because of its physical characteristics (i.e., low reactivity, low volatility, high solubility), water treatment technologies including ultrafiltration, air-stripping, carbon adsorption, and advanced oxidation are not effective options for perchlorate removal from groundwater (Damian and Pontius, 1999; Logan, 1998; USEPA, 2001a). Ion exchange using one or more selective resins is a viable approach for removing low concentrations of perchlorate from water (e.g., Gu et al., 2000; 2002). However, the perchlorate anion is not destroyed during the ion exchange process, but rather is reversibly bound to the resin. The exchange resins eventually become saturated with the perchlorate (and other anions which also bind to the resin) and must then be replaced or regenerated using a high strength salt solution (Urbansky, 1998; Logan, 2001). If the latter procedure is used, the waste brine from the regeneration procedure contains concentrated perchlorate, which then must undergo additional treatment or disposal.

Unlike abiotic approaches, biological treatment represents a promising technology for the effective and economical removal of perchlorate from water (Logan, 2001; Urbansky, 1998). A number of bacteria have been isolated which are able to degrade perchlorate to the harmless products chloride and water (Rikken et al., 1996; Wallace et al., 1996; Coates et al., 1999; Achenbach et al., 2001). These bacteria grow through anaerobic respiration. During this process, the bacteria require an organic or inorganic electron donor (e.g., ethanol, acetate, hydrogen gas) for growth and utilize the perchlorate molecule as a terminal electron acceptor. A perchlorate reductase enzyme appears to catalyze an initial two-step reduction of perchlorate ( $\text{ClO}_4^-$ ) to chlorate ( $\text{ClO}_3^-$ ) and then chlorite ( $\text{ClO}_2^-$ ) (Kengen et al., 1999). The chlorite is then further reduced by the enzyme chlorite dismutase to chloride ( $\text{Cl}^-$ ) and oxygen ( $\text{O}_2$ ) (van Ginkel et al., 1996). Thus, microbial degradation of perchlorate yields two innocuous products, chloride and oxygen. Perchlorate respiration is similar to denitrification, where bacteria utilize a substrate and reduce nitrate as the terminal electron acceptor to nitrogen gas.

*Ex situ* biological treatment systems have been successfully developed at full-scale to treat perchlorate-contaminated water. Electron donors, such as ethanol and acetate, are supplied to perchlorate reducing bacteria in these reactors to promote biological reduction of the propellant. An initial bioreactor design was developed and tested in the early 1990s by researchers at Tyndall Air Force Base to treat heavily contaminated wastewater from hog out and other operations. This stirred-tank reactor utilizes the bacterium *Wolinella succinogenes* HAP-1 for perchlorate reduction (Attaway and Smith, 1994; Hurley et al., 1996). This design works well for low-flow, high-concentration perchlorate wastes, and has been

applied at full-scale for this application. However, the reactor is not well-suited for high-flow groundwater applications, where perchlorate concentrations are likely to be in the  $\mu\text{g/L}$  (ppb) to low  $\text{mg/L}$  (ppm) range, and flow rates of thousands of gallons per minute may be required. Other bioreactor designs, including packed bed reactors (Miller and Logan, 2000; Wallace et al., 1998; Logan, 2001) and fluidized bed reactors (Green and Pitre, 1999; Hatzinger et al., 2000; 2002) have subsequently been developed specifically for treatment of low levels of perchlorate in high-flow groundwater applications. Three commercial-scale fluidized bed reactors are currently treating perchlorate in groundwater at flow rates ranging from 50 to 4,000 gallons per minute (Hatzinger et al., 2002).

The success of *ex situ* biological treatment of perchlorate suggests that *in situ* treatment through electron donor addition may also be possible. For this technology to be successful, however, perchlorate reducing bacteria must be present in contaminated aquifers, and these bacteria must be stimulated to degrade perchlorate from existing levels to below state regulatory levels (e.g.,  $< 4 \mu\text{g/L}$  in California). A few recent papers suggest that perchlorate reducing bacteria are naturally-occurring in various environments, including soils, sludges, raw wastewater, and farm animal waste (Coates et al., 1999; Wu et al., 2001). However, few data exist concerning the presence and distribution of perchlorate reducing bacteria in groundwater aquifers. In addition, the most effective substrates to stimulate perchlorate reduction by these organisms have not been determined nor have geochemical factors that may influence this process. The key to utilizing perchlorate reducing bacteria for *in situ* remediation is understanding the conditions that limit their activity in subsurface environments and then devising effective technologies to overcome these limitations and subsequently stimulate perchlorate degradation. To date, little research has been conducted to develop an *in situ* technology for perchlorate bioremediation. The assessment and development of such a technology is the goal of this SERDP project.

This project was a collaborative effort between scientists at Envirogen Inc. (Envirogen) in Lawrenceville, NJ and the Indian Head Division, Naval Surface Warfare Center, Naval Sea Systems Command in Indian Head, Maryland. Envirogen is a leader in developing *in situ* and *ex situ* treatment technologies for hazardous wastes, and has constructed three full-scale *ex situ* reactor systems for perchlorate treatment. Scientists at Envirogen conducted microcosm, column, and pure culture studies to provide a better understanding of perchlorate biodegradation in subsurface aquifers and developed a mathematical model to describe the kinetics of perchlorate biodegradation in the presence of competing electron acceptors. The scientists and engineers at IHDIV have a comprehensive understanding of the chemistry, analysis, and military applications of ammonium perchlorate, as this compound has been used at IHDIV for more than 50 years to prepare solid rocket propellants. The researchers at IHDIV developed an improved method for perchlorate analysis in saline environments, provided field samples for use in laboratory studies, and are currently funding a field demonstration of *in situ* perchlorate treatment as part

of the technology transfer scope of this SERDP project. The collaboration between researchers at Envirogen and IHDIV has rapidly lead to an improved understanding of perchlorate biodegradation in subsurface environments. This research is now being used to develop and test effective bioremediation strategies for perchlorate-contaminated groundwater.

## 2.0 PROJECT OBJECTIVES

**The objective of this project is to develop a biological treatment technology for *in situ* remediation of perchlorate in subsurface environments.** The development of an effective technology for *in situ* perchlorate remediation requires a fundamental understanding of the conditions that limit biological perchlorate reduction in groundwater and the most effective means to overcome such limitations. This research effort is designed to provide this fundamental understanding. We hypothesize that four key factors may be contributing to the persistence of perchlorate at various subsurface sites. These key factors and our approach to their evaluation in this research effort are as follows:

- (1) **Absence of an appropriate substrate (electron donor) for growth of indigenous perchlorate degrading bacteria.** Based on preliminary studies, we believe that the absence of an oxidizable substrate is the key factor limiting biological perchlorate degradation at many subsurface sites. Therefore, experiments were conducted using aquifer samples from contaminated field sites to evaluate the potential of numerous organic and inorganic electron donors to stimulate perchlorate reduction *in situ*. The most promising electron donors were tested in a flow-through aquifer system to provide relevant kinetic data for modeling and field trials.
  
- (2) **Presence of alternative electron acceptors for bacterial respiration, including O<sub>2</sub>, NO<sub>3</sub><sup>-</sup>, and NO<sub>2</sub><sup>-</sup> in groundwater.** Perchlorate serves as an electron acceptor for bacteria during anaerobic respiration. The microbial reduction of one electron acceptor is frequently influenced by the presence of others (e.g., oxygen inhibits dissimilatory nitrate reduction). The general relationship between perchlorate and other common electron acceptors is unclear. However, nitrate, nitrite, and oxygen have been observed to inhibit perchlorate reduction by a few bacterial cultures (Attaway and Smith, 1993; Logan, 1998). Because each of these molecules as well as other electron acceptors such as sulfate and iron are frequently present in groundwater, understanding their influence on microbial perchlorate reduction is critical to successful remediation efforts. Experiments conducted during this project were

designed to assess the influence of common electron acceptors, such as oxygen and nitrate, on perchlorate degradation by naturally occurring bacteria in field samples and by microbial isolates.

**(3) Lack of an indigenous population of bacteria capable of perchlorate reduction.** In some environments, bacteria with the metabolic enzymes to reduce perchlorate to chloride may be absent. In such cases, augmentation with exogenous microorganisms will be required for *in situ* remediation. As part of this research effort, bacterial strains and consortia were isolated from Envirogen's FBR systems that are currently treating perchlorate and from aquifer samples collected from perchlorate-contaminated sites. The potential for these strains to degrade perchlorate *in situ* under relevant environmental conditions was then evaluated in microcosm studies. These cultures were also used to provide necessary parameters for a biodegradation model developed during this research project.

**(4) Unfavorable environmental conditions for activity of indigenous perchlorate degraders.** The role of environmental variables on *in situ* perchlorate degradation has not been extensively studied. In addition to evaluating the effect of electron acceptors such as nitrate on perchlorate reduction, experiments were undertaken to look at the effect of salinity (ionic strength), pH, and co-contaminants on microbial perchlorate degradation. These factors may be extremely important at specific sites (e.g., salinity in groundwater at coastal sites) but, as yet, they have not been investigated.

The research performed during this project was designed to provide extensive information on (1) the potential for successful perchlorate remediation at subsurface sites by addition of electron donors (i.e., biostimulation); (2) the most effective electron donors to use in biostimulation efforts, and the expected concentrations and remediation kinetics achievable with these donors; (3) the possibility for successful bioaugmentation (i.e., injection of bacterial isolates) for subsurface perchlorate remediation; and (4) the probable influence of alternate electron acceptors and environmental variables on perchlorate reduction during biostimulation and/or bioaugmentation efforts. These data will provide the fundamental knowledge required for the design and implementation of pilot-scale and full-scale remediation efforts at perchlorate contaminated sites.

### 3.0 TECHNICAL APPROACH

The research tasks conducted during this project are summarized in the following section.

**Task 1. Collect Aquifer Solids and Groundwater from Field Sites.** Aquifer samples from perchlorate-contaminated sites with widely differing geochemical characteristics and contaminant concentrations were obtained for use in enrichment, microcosm, and column studies. These samples were collected from five perchlorate-contaminated locations in California (2 sites), Texas, Maryland, and Utah, respectively. Samples of a perchlorate-contaminated surface soil were also obtained from one location for studies. A total of eight different environmental samples were obtained and tested during the project. These samples were used in microcosm studies to represent a range of different environments that have experienced perchlorate contamination. Column studies were also conducted with one set of these samples to evaluate perchlorate degradation kinetics in a flow-through system.

**Task 2. Obtain Microbial Consortia and Individual Bacterial Isolates Capable of Perchlorate Degradation.** Envirogen has constructed three full-scale fluidized bed reactor (FBR) biotreatment systems for degrading perchlorate in groundwater. The first of these facilities is located at the Aerojet facility in Rancho Cordova, CA. This reactor system, which uses granular activated carbon as a matrix and ethanol as an electron donor, has been reducing perchlorate levels in feed water from approximately 4 mg/L to non-detectable levels ( $< 4 \mu\text{g/L}$ ) at flow rates of greater than 4,000 gallons per minute for more than 2 years. Food processing waste was used as the original inoculum for the FBR system. The objective of this task was to isolate individual perchlorate degrading bacteria or a mixed bacterial culture from the FBR system as well as from some of the field sites. One perchlorate degrading culture was isolated and identified from the FBR during this project. This culture, designated *Dechlorospirillum* species FBR2, was subsequently used in several different microcosm studies during the course of this project. In addition, bacterial isolates were obtained from groundwater at Jet Propulsion Labs and from the Rocky Mountain site. The kinetics of perchlorate reduction and the influence of other terminal electron acceptors on this process were extensively studied using one of the isolates from JPL, designated *Dechlorosoma suillum* JPLRND. These data were then used as parameters in a kinetic model of perchlorate reduction (see Task 5).

**Task 3. Identify Conditions Required for In situ Biostimulation of Perchlorate Degradation.** The objective of this task was to develop an understanding of the factors promoting perchlorate degradation in subsurface environments as well as the conditions that inhibit the process. Small-scale laboratory microcosms were used to evaluate both biostimulation of indigenous perchlorate degrading bacteria and the addition of exogenous perchlorate degraders (strain FBR2 isolated during *Task 2*) for aquifer remediation. The factors that were evaluated in these studies include: (A) choice of electron donor (substrate) for growth of perchlorate degrading bacteria, (B) the influence of dissolved oxygen, nitrite, and nitrate on perchlorate removal, and (C) the role of environmental factors including salinity (ionic strength), groundwater pH, and presence of organic co-contaminants on perchlorate degradation. Several of these factors were further examined during column studies. Results from these studies revealed that a variety of different organic substrates, as well as hydrogen gas, can be used to stimulate perchlorate reduction at many sites. The most effective electron donor appeared to vary by site, although acetate, lactate, and molasses were generally effective. High salinity and low pH both appear to inhibit perchlorate reduction. Perchlorate reduction could not be stimulated in low pH aquifer materials and soils (three separate sample locations) by any organic or inorganic substrate. However, when the aquifer or soil samples were amended with carbonate to increase alkalinity and pH, perchlorate biodegradation occurred in all samples by naturally-occurring microorganisms.

**Task 4. Evaluate Perchlorate Transport and Biodegradation in Pilot-Scale Model Aquifers.** The most effective treatments for perchlorate degradation in the microcosm studies were further tested using pilot-scale flow through model aquifers. A flow-through model system better approximates *in situ* aquifer conditions than either an aqueous system or a static microcosm, and being continuous flow, inputs of perchlorate, substrates, and various groundwater constituents, including terminal electron acceptors such as oxygen and nitrate, can be controlled and varied. The model aquifers, which were designed at Envirogen to simulate subsurface conditions, were constructed from steel tubing. Columns of 50-cm and 30-cm total length were used in various studies. The columns were built with sampling ports at various distances from the bottom (upward flow) where aqueous subsamples could be withdrawn by syringe. The columns were packed with subsurface sediments from the Longhorn Army Ammunition Plant (LHAAP), and an artificial groundwater was prepared based on the geochemical characteristics of the LHAAP groundwater. A peristaltic pump supplied a continuous flow of groundwater from a reservoir to a port at the bottom of the columns. Separate syringe pumps were used to supply electron donor. The entire system was airtight so that anoxic conditions could be generated within the column.

The initial 50-cm column was run for more than 200 days. The flow characteristics in the column (including mixing at the influent port and groundwater transport) were initially quantified using bromide

as a conservative tracer. The column was then fed acetate as an electron donor, and the degradation of perchlorate, acetate, oxygen, and nitrate was quantified with time and with distance in the column. The concentrations of acetate, perchlorate and nitrate were varied during the column study, and the influence of these changes on the kinetics of perchlorate biodegradation was determined. The impacts of pH and chlorate addition were also examined. The data from this column were subsequently used to test a coupled biodegradation-transport model for perchlorate in the subsurface. An additional 30-cm column was constructed and used to determine the potential use of lactate as an electron donor, to evaluate the degradation of perchlorate in the absence of nitrate, to assess the potential for sustained biodegradation of very low perchlorate concentrations (50 – 250 µg/L), and to determine if perchlorate and a second explosive compound, hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), can be biodegraded simultaneously with lactate as an electron donor.

**Task 5. Modeling.** Biodegradation and reactive transport modeling were performed as part of this SERDP project. A biodegradation model was initially developed (Task 5a), parameters required for the model were determined experimentally in the laboratory using the bacterium *Dechlorosoma suillum* JPLRND (Task 5b), and a fully-coupled biodegradation and transport model for perchlorate was then developed using the software HydroBioGeoChem123D (HBGC123). This model was tested using data from the model aquifers described in Task 4.

Task 5a. Development of a Biodegradation Model for Perchlorate. A mathematical model was developed to describe the kinetics of perchlorate biodegradation. This concept of this model is based on the program RT3D developed by Battelle Pacific Northwest National Laboratory. The biodegradation of an electron donor and consumption of multiple electron acceptors are described using modified Monod equations. The rate of perchlorate degradation is described as a function of the electron donor utilization rate, the presence of alternate electron acceptors, and rates of biomass growth and decay. Inhibition factors are included in the model to describe the effect of alternate electron acceptors (nitrate and oxygen) on perchlorate degradation. The model links the dynamics of the microbial population to the consumption of electron donor and acceptors and describes bacterial growth and decay.

Task 5b. Quantification of Model Parameters. Microcosm experiments were conducted to determine the input parameters for the biodegradation model. The studies utilized a perchlorate degrading strain (*Dechlorosoma suillum* JPLRND) isolated from groundwater underlying the Jet Propulsion Laboratory in Pasadena, CA during previous work for this project. A series of batch experiments

were conducted with the strain using a range of starting donor (acetate) concentrations where oxygen, nitrate, or perchlorate were present in excess as electron acceptors. The maximum specific growth rate and half saturation constant for growth of the organism on acetate with each electron acceptor were determined. Similar experiments were performed to determine the growth rate parameters for each acceptor when starting donor concentrations were constant and not limiting (i.e., detectable donor remained at the end of the experiment), while acceptor concentrations were varied. Due to the low solubility of oxygen, these experiments were performed only for perchlorate and nitrate. Experiments were also conducted to evaluate potential inhibition effects of nitrate and oxygen on perchlorate biodegradation. Varying concentrations of each electron acceptor were added to flasks containing a culture that was actively-degrading perchlorate, and the subsequent rate of perchlorate degradation was quantified. Inhibition factors for each terminal electron acceptor were determined for the model using the results from these studies.

Task 5c. Development of a Reactive Transport Model. Groundwater flow and reactive transport modeling was conducted to verify degradation rates derived from laboratory studies and to aid design of field-scale applications. Groundwater flow modeling was initially performed to simulate perchlorate transport in aquifer columns. The software HydroBioGeoChem123D (HBGC123D) was used to describe the one-dimensional transport of bromide and perchlorate in the laboratory columns. This software was chosen because of its capability to describe the transport and consumption of multiple electron acceptors. Once non-reactive perchlorate transport was adequately simulated, the biodegradation model developed in Task 5a was incorporated into the program. The fully-coupled model was then used to simulate perchlorate biodegradation under flowing conditions. Data from the column studies were used for simulations. The model did not adequately describe biodegradation data from the column studies. Model simulations predicted no significant losses of acetate (electron donor), perchlorate, nitrate, or oxygen within the column. Inspection of the model data revealed that the simulated biomass within the column decayed much faster than it grew, resulting in the lack of electron donor or acceptor biodegradation.

This difference between the laboratory data (which showed degradation of acetate and all three electron acceptors along the column profile) and the model prediction suggests that one or more of the assumptions of the biodegradation model were critically violated. Factors that may contribute to the discrepancy between the model and experimental data include: 1) a lower biomass decay rate in the column than the value determined from the batch experiments; 2) enzyme induction rather than biomass growth during the lag period preceding biodegradation; 3) higher biomass concentrations in the column at the onset of biodegradation as compared to the value measured at the beginning of the

laboratory experiments; and 4) the decay of microbial populations to a minimum value (capable of sustaining acetate degradation and perchlorate utilization) rather than zero, as assumed by the model. Based upon results from this task, further research and investigation are needed to improve the coupling process between the perchlorate biodegradation model developed from microcosm experiments and the transport and utilization of perchlorate in column and groundwater flow experiments.

Detailed methods and results for each research task are provided in the following section.

## **4.0 PROJECT ACCOMPLISHMENTS**

### **4.1 SAMPLE COLLECTION**

Aquifer samples were collected from five perchlorate-contaminated locations: (1) the Jet Propulsion Laboratory (JPL) in Pasadena, CA; (2) the Indian Head Division Naval Surface Warfare Center (IHDIV) in Indian Head, MD (2 field sites), (3) the Longhorn Army Ammunition Plant (LHAAP) in Karnack, TX (2 field sites, one surface soil); (4) the Boeing Company, Sacramento, CA (2 field sites), and (5) a commercial facility in the Rocky Mountains, UT. Aquifer solids and groundwater were obtained from the first three locations, and groundwater only was obtained from the Rocky Mountain and the Boeing sites. Samples of a perchlorate-contaminated surface soil were also obtained from LHAAP. Samples were collected from multiple locations at many of the sites based on geochemistry and perchlorate concentrations; a total of nine different environmental samples were collected for this project. These samples were used in microcosm studies to represent a range of different environments that have experienced perchlorate contamination. In addition, one set of samples from LHAAP was used to prepare a series of flow-through aquifer columns. The details of sample collection as well as the geochemical characteristics of each sample are provided below.

### **4.2 ISOLATION AND IDENTIFICATION OF PERCHLORATE DEGRADING BACTERIA FROM FBRs AND FIELD SITES**

#### **Methods**

One objective of this task was to enrich and isolate consortia and pure cultures of perchlorate degrading bacteria for use in microcosm studies (i.e., evaluation of bioaugmentation for perchlorate degradation) as well as to better understand variables influencing perchlorate degradation at the cellular level. The cultures were also used to develop appropriate parameters for a model of perchlorate biodegradation (see section 4.5). Enrichment cultures were prepared from Envirogen bioreactors and from subsurface

samples collected at JPL, IHDIIV, and the RM site. Samples were added to a phosphate-buffered enrichment medium containing ammonium chloride, numerous trace elements (Co, Mn, Cu, Al, etc), casamino acids (0.5 g/L) and yeast extract (0.5 g/L) as sources of vitamins and other growth factors potentially required by the organisms. This medium is a modified from that described by Hareland et al. (1975). The isolation medium was amended with ammonium perchlorate to 1000 mg/L ( $\text{ClO}_4^-$ ) and ethanol or acetate (JPL enrichment) to 500 mg/L. The samples were incubated on a rotary shaker operating at 100 rpm and 30°C in the dark.

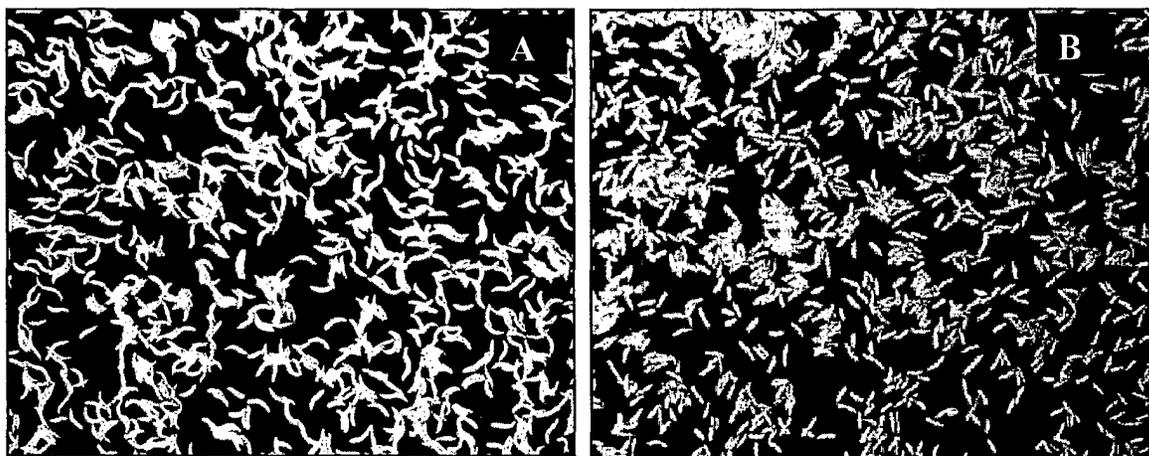
The bottles were periodically checked for signs of microbial growth (turbidity). Any samples showing turbidity were transferred to fresh, sterile media under anoxic conditions. To conduct a transfer, serum bottles were opened using aseptic conditions in the anaerobic chamber, and a small volume of the media (0.025 – 0.050 mL) was pipetted to a serum bottle with fresh media. After several transfers, perchlorate levels were checked in bottles showing microbial growth, and subsamples from each bottle showing perchlorate degradation were plated on two types of agar media. Liquid samples were plated on R2A agar, (a simple medium designed for culturing groundwater bacteria), and incubated aerobically, as most perchlorate degrading cultures are facultative anaerobes. Samples were also plated on a solid agar medium containing the same constituents as the enrichment media plus 15 g of agar per liter. Individual colonies were selected from solid agar plates and streaked on fresh plates several times in succession until each appeared to be a pure culture. The cultures were then inoculated from plates into liquid media with perchlorate, and perchlorate degradation was tested. Cultures that reduced perchlorate were rechecked for purity, then identified using 16S rRNA analysis (Acculab Inc., Newark, DE).

## Results

Some of the samples collected from IHDIIV showed microbial growth after several days of incubation and were transferred. A few of these samples again became turbid after transfer, and were passed one or two additional times. However, when levels of perchlorate were tested in the enrichments, none showed appreciable perchlorate degradation. Thus, although some microbial growth was observed in these samples, the bacteria did not appear to be perchlorate degrading strains.

One pure culture was isolated from bioreactor samples initially collected from a fluidized bed bioreactor treating perchlorate in California (Figure 1A). The culture, which was identified by 16S rRNA analysis as a *Dechlorospirillum* sp., was used in several microcosm studies. The *Dechlorospirillum* sp. (FBR2) is very similar to a bacterium (strain WD) isolated from swine waste by Dr. John Coates at Southern Illinois University (SIU). The two strains have a 0.4 % nucleotide difference. This appears to be the only other organism in the available 16S rDNA databases that has reasonable similarity to strain FBR2. In addition to strain FBR2, two pure cultures were isolated from aquifer samples collected from

JPL. These cultures were each identified at the species level as *Dechlorosoma suillum*. This perchlorate degrading genus, which was recently named and described by Achenbach et al., (2001), appears to be widely dispersed in the environment. A photomicrograph of *D. suillum* JPLRND is given in Figure 1B. This bacterium was subsequently used in a series of studies to develop kinetic data for the biodegradation model. These studies evaluated the growth rate of JPLRND on acetate, with perchlorate, nitrate, and oxygen as terminal electron acceptors. Studies were also conducted with this strain to determine possible inhibition of perchlorate reduction by both nitrate and oxygen. A positive enrichment culture was also obtained from the RM groundwater sample using lactate as a carbon source, and two perchlorate degrading strains were purified from the enrichment culture. However, because *Dechlorospirillum* sp. FBR2 and *D. suillum* JPLRND were used extensively for laboratory studies and were adequate to fulfill the objectives of this project, the two bacteria isolated from the RM water were not identified or studied further. However, all of the strains isolated during this project were sent to Dr. Coates at SIU for further study and inclusion in his collection of perchlorate degrading bacteria. In addition, the two pure cultures isolated from JPL were supplied to Dr. Mark Losi from Foster Wheeler Corporation as a seed material to inoculate fixed film bioreactors for testing performed at the JPL facility.



**Figure 1. Photomicrograph of *Dechlorospirillum* sp. FBR2 (A) and *Dechlorosoma suillum* JPLRND (B). Cells are Stained with Acridine Orange.**

### **Conclusions**

The preliminary results of this project suggest that perchlorate degrading bacteria are widely-occurring in the environment. Pure cultures were isolated from groundwater at the Jet Propulsion Laboratory, from Envirogen reactors (initially seeded with food processing waste), and from the Rocky Mountain site. Although pure cultures were not isolated from the IHDIV samples, laboratory results showed that perchlorate degrading bacteria are present at this site. The enrichment media used for culture isolation

may not have been appropriate based on the physiology of the strains in this environment. In addition, although enrichment studies were not performed with samples from the other sites, perchlorate biodegradation was stimulated in all 9 environmental samples (8 aquifer samples and 1 soil sample) when appropriate electron donors were added, although pH adjustment was also required in acidic samples (see next section). Thus, naturally-occurring perchlorate reducing strains were present in all locations. Few studies exist regarding the occurrence and phylogeny of perchlorate degrading bacteria in natural environments. However, the strains identified during this project (*Dechlorospirillum* sp., *Dechlorosoma* sp.) are similar to bacteria recently discovered by John Coates and colleagues (Coates et al., 1999; Achenbach et al., 2001) in various environmental samples. Additional studies are necessary to better understand the natural distribution and role of this newly identified group of bacteria in the environment, and to determine why the perchlorate reductase and chlorite dismutase enzymes that are characteristic of these strains are so widely conserved.

#### **4.3 LABORATORY MICROCOSM STUDIES**

The objective of this task was to develop an understanding of the factors promoting perchlorate degradation in subsurface environments as well as the conditions that inhibit the process. Small-scale laboratory microcosms were used to evaluate both biostimulation of indigenous perchlorate degrading microbes and the addition of exogenous perchlorate degraders for aquifer remediation. The factors that were evaluated in these studies include: (A) choice of electron donor (substrate) for growth of perchlorate degrading bacteria, (B) the influence of dissolved oxygen, nitrite, and nitrate on perchlorate removal, and (C) the role of environmental factors including salinity (ionic strength), groundwater pH, and presence of organic co-contaminants on perchlorate degradation. The results from microcosm studies are reported in this section on a site-specific basis.

##### **4.3.1. JET PROPULSION LABORATORY (JPL)**

Groundwater samples and well-bottom sediments were collected from the Jet Propulsion Laboratory (JPL) on April 27, 2000. These samples were used in a series of microcosm studies to evaluate (1) the most effective electron donors for the stimulation of perchlorate reducing bacteria at the site (adding substrate but not bacteria); (2) the possibility for successful bioaugmentation (i.e., injection of bacterial isolates) for subsurface perchlorate remediation; (3) the influence of alternate electron acceptors (nitrate, nitrite, and oxygen) on perchlorate degradation; and (4) the roles of two environmental variables, pH and salinity, on perchlorate degradation.

#### 4.3.1.1 Sample Collection

*Groundwater:* Groundwater was collected from monitoring well 7 (MW-7) at the JPL site. Aseptic sampling techniques and sterile sample containers were used to prevent contamination of groundwater with non-native bacteria.

*Aquifer Solids:* Aquifer core samples were not collected for these studies. The extreme depth to contaminated groundwater at JPL (> 200 ft) makes collection of subsurface solids problematic and expensive. However, a bailing device was used to collect sediments from the bottom of MW-7. The well sediments provided sediment material (and associated microflora) for microcosms. Microcosms were set up using groundwater only and groundwater mixed with solids from the bottom of the well.

#### 4.3.1.2 Electron Donor Addition and Bioaugmentation

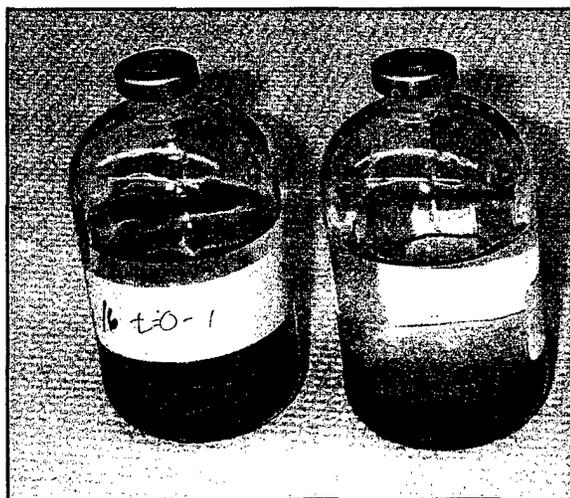
##### Methods

Small-scale laboratory microcosms were used to evaluate both biostimulation of indigenous perchlorate degrading microorganisms and the addition of exogenous perchlorate degraders for aquifer remediation at JPL (Figure 2). Microorganisms capable of degrading perchlorate utilize the molecule as an electron acceptor during growth on either an organic or inorganic substrate. The absence of an appropriate electron donor in subsurface aquifers contaminated with perchlorate is probably one of the key factors leading to its persistence *in situ*. The factors influencing the choice of substrate to promote perchlorate biodegradation are likely to include the physiology of the perchlorate degrading strains, the character of the natural microflora competing with those strains for growth, and the geochemistry at the site. The objective of this phase of work was to test a variety of substrates in groundwater samples collected from JPL and determine which substrates, if any, are most efficient at stimulating perchlorate reduction.

Microcosms to evaluate perchlorate degradation were prepared in sterile, 160-mL serum bottles. All experimental work was performed in a Coy Environmental Chamber with a nitrogen headspace. In one study, groundwater and well solids (silty material) were mixed together in a ratio of approximately 6:1 in a large sterile bottle. The slurry material was amended with a sterile stock of diammonium phosphate to provide nitrogen (5 mg/L as NH<sub>4</sub>) and phosphorus (4.5 mg/L as P) as nutrients for bacterial growth, then 120-mL volumes were added to serum bottles. Triplicate serum bottles were amended with one of the following substrates to 200 mg/L: methanol, ethanol, acetate, benzoate, lactate, sucrose, molasses or a mixture of ethanol/yeast extract (100 mg/L each). Triplicate bottles also received hydrogen gas or propane in the headspace as gaseous substrates. Several microcosms were inoculated with *Dechlorospirillum* sp. FBR2. Acetate and ethanol/yeast extract were tested as electron donors in these

samples. Triplicate samples were prepared without any substrate, and triplicate bottles received formaldehyde (1 %) to inhibit all biological activity. All bottles were crimp-sealed with sterilized Teflon-lined septa and incubated at 15°C to approximate *in situ* temperatures. After 10 and 21 days of incubation, a 20-mL subsample was removed from each bottle. The samples were analyzed for perchlorate by ion chromatography (IC) using EPA Method 314.0.

A second microcosm study was conducted using only groundwater collected from MW-7 (i.e., no sediment). Sterile serum bottles received 120-mL of groundwater and acetate, yeast extract, methanol, or molasses at a concentration of 200 mg/L. Microcosms without added substrate were also prepared as were killed controls (1 % formaldehyde). Sampling and analysis were conducted as described for the previous study.



**Figure 2. Photograph of Aquifer Microcosms.**

## Results

The water collected from well MW-7 contained perchlorate at 307  $\mu\text{g/L}$  (ppb). The water also contained nitrate at a starting concentration of 18.6 mg/L (as  $\text{NO}_3$ ), sulfate at 44 mg/L, 140 mg/L of alkalinity (as  $\text{CaCO}_3$ ) and dissolved oxygen at 2.6 mg/L.

*Sediment/Groundwater Microcosms:* The starting perchlorate concentration in microcosms prepared with groundwater and sediments was 310  $\mu\text{g/L}$ . The initial pH was 7.6. The microcosms also contained high levels of ferric iron ( $> 600$  mg/L), which was present in the sediment sample. The iron was probably well casing that had oxidized and settled to the well bottom. After 10 days of incubation at 15°C, perchlorate levels were below detection (PQL; 5  $\mu\text{g/L}$ ) in microcosms amended with acetate, ethanol, ethanol/yeast

extract, lactate and molasses (Table 1). The perchlorate concentration in all samples augmented with exogenous perchlorate degrading bacteria (*D. suillum* FBR2) was also below detection after 10 days. After 21 days of incubation, perchlorate was below detection in all live samples except those amended with benzoate as an electron donor. Interestingly, perchlorate was also degraded in samples without added electron donor. An organic or inorganic electron donor associated with the well sediments (e.g., reduced iron, natural organic matter) probably supported biological perchlorate reduction in these samples. This hypothesis is supported by the observation that perchlorate was not degraded in groundwater samples without electron donor added (see next section). No perchlorate loss was evident in samples that were treated with formaldehyde to inhibit biological activity. Nitrate was also degraded to below detection in the live aquifer microcosms, but not in killed controls (data not shown).

**Table 1. Perchlorate Degradation in JPL Sediment/Groundwater Microcosms Amended with Various Electron Donors or Perchlorate Degrading Bacteria.**

Treatment	Perchlorate Concentration ( $\mu\text{g/L}$ ) <sup>1</sup>		
	Day 0	Day 10	Day 21
<b>Electron Donors</b>			
Killed Control	310 $\pm$ 0	293 $\pm$ 6	320 $\pm$ 0
Benzoate	310 $\pm$ 0	297 $\pm$ 6	150 $\pm$ 135
Methanol	310 $\pm$ 0	77 $\pm$ 57	< 5
Hydrogen	310 $\pm$ 0	177 $\pm$ 61	< 5
Propane	310 $\pm$ 0	283 $\pm$ 6	< 5
No Addition	310 $\pm$ 0	14 $\pm$ 19	< 5
Sucrose	310 $\pm$ 0	92 $\pm$ 67	< 5
Ethanol	310 $\pm$ 0	< 5	NS <sup>2</sup>
Lactate	310 $\pm$ 0	< 5	NS
Molasses	310 $\pm$ 0	< 5	NS
Yeast Extract/Ethanol	310 $\pm$ 0	< 5	NS
Acetate	310 $\pm$ 0	< 5	NS
<b>Bioaugmentation</b>			
Killed + <i>Dechlorospirillum</i> FBR2 <sup>3</sup>	310 $\pm$ 0	385 $\pm$ 7	415 $\pm$ 7
<i>Dechlorospirillum</i> FBR2+ YE/Etoh	310 $\pm$ 0	< 5	NS
<i>Dechlorospirillum</i> FBR2+ Acetate	310 $\pm$ 0	< 5	NS

<sup>1</sup> Values are the mean  $\pm$  standard deviation from triplicate microcosms.

<sup>2</sup> NS: Not sampled because previous sample point was below detection.

<sup>3</sup> *Dechlorospirillum* sp. FBR2 is a perchlorate degrading culture isolated from a fluidized bed bioreactor.

**Groundwater Microcosms:** Perchlorate degradation was somewhat slower in microcosms containing groundwater compared to those with sediments (Figure 3). However, after 21 days of incubation, perchlorate was below detection (PQL; 5  $\mu\text{g/L}$ ) in triplicate samples amended with acetate. Appreciable degradation of perchlorate was also observed in samples amended with yeast extract or molasses.

Perchlorate was not degraded in samples treated with methanol as an electron donor or in those without added electron donor. The killed samples (1 % formaldehyde) also showed no loss of perchlorate.

### Conclusions

The results from the microcosm study using aquifer samples from JPL suggest the following: (1) indigenous bacteria capable of degrading perchlorate are present in the aquifer underlying JPL; (2) these bacteria can be stimulated to degrade perchlorate by the addition of electron donors; and (3) perchlorate levels can be reduced to below 5  $\mu\text{g/L}$  through biostimulation. The fact that perchlorate degradation was observed in groundwater microcosms, without sediment, is very promising, since microbial biomass in aquifers is usually associated primarily with solids.

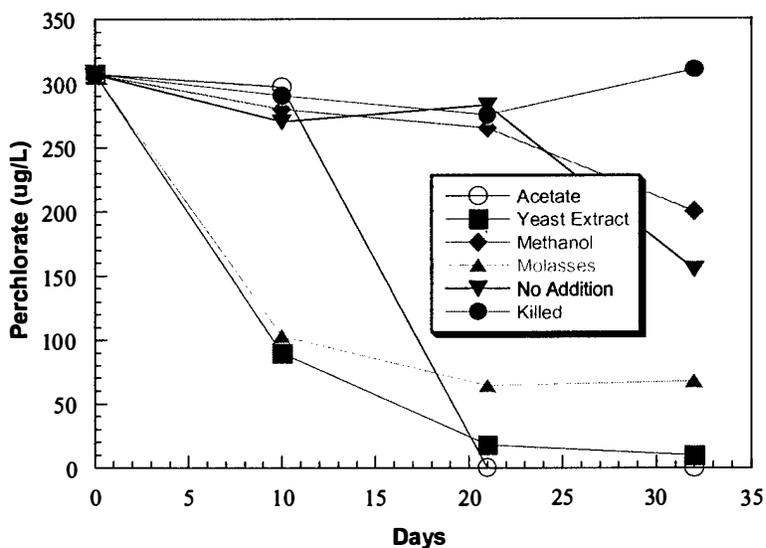


Figure 3. Influence of Different Electron Donors on Perchlorate Biodegradation in Groundwater Microcosms from JPL.

#### 4.3.1.3. Influence of Alternate Electron Acceptors on Perchlorate Biodegradation

##### Methods

The objective of this study was to determine the influence of oxygen, nitrate, and nitrite on perchlorate degradation by natural microflora in aquifer samples from JPL. Aquifer microcosms were used to assess the role of these molecules on perchlorate reduction by natural microflora in the subsurface samples. Based on results from the previous study of electron donors, ethanol was chosen as the electron donor for these experiments.

The microcosms were set up as described in the previous section (160-mL serum bottles, 120-mL aquifer slurry of sediments and groundwater). Eight microcosms were initially amended with perchlorate

to provide a starting concentration of 100 mg/L. Duplicate microcosms at an initial concentration of 100 mg/L perchlorate received the following treatments: (1) ethanol only (100 mg/L); (2) ethanol (100 mg/L) and  $\text{NO}_3$  (100 mg/L); (3) nitrate only (100 mg/L) (i.e., no ethanol); or (4) ethanol (100 mg/L),  $\text{NO}_3$  (100 mg/L), and formaldehyde (*killed control*). To evaluate the role of nitrite ( $\text{NO}_2^-$ ) on perchlorate degradation, duplicate bottles were amended with the following (1) ethanol (100 mg/L) and 1 mg/L nitrite; (2) ethanol (100 mg/L) and 10 mg/L nitrite; or (3) ethanol only. A killed control was also prepared for this study by adding 1 % formaldehyde to one set of duplicate samples. In a third experiment, the effect of oxygen on perchlorate degradation was determined by oxygenating the headspace of two bottles containing 300  $\mu\text{g/L}$  perchlorate and ethanol (100 mg/L). The samples were incubated at 15°C. Aqueous subsamples were periodically removed from each microcosm for perchlorate analysis by EPA Method 314.0 and analysis of nitrate and nitrite by EPA 300.0 series methods.

## Results

There was no loss of perchlorate, nitrate, or nitrite in any of the samples that were treated with formaldehyde to inhibit microbial activity. Thus, all reductions in the concentrations of these anions in aquifer samples are assumed to be biological. Nitrate was degraded before perchlorate in samples that received both anions at initial concentrations of 100 mg/L (Figure 4). Nitrate was reduced to below detection after only 4 days of incubation, with no apparent lag period. Nitrite, which is the initial product in biological denitrification and nitrate reduction, was detected in samples at day 4, but this anion was also degraded to below detection by day 7. A lag period of approximately 16 days occurred before perchlorate degradation commenced in these microcosms. However, perchlorate was reduced from 100 mg/L to below detection ( $< 5 \mu\text{g/L}$ ) between day 16 and day 28. Interestingly, the degradation of perchlorate was slightly more rapid in samples that were initially amended with nitrate to 100 mg/L compared to those that did not receive the anion (Figure 5). This may reflect the growth of a population of denitrifying bacteria (stimulated by nitrate addition) that subsequently degraded perchlorate.

Samples that were not amended with ethanol as an electron donor showed no perchlorate degradation during a 22-day incubation period (Figure 6). In these same samples, however, nitrate levels declined from 100 to approximately 40 mg/L during the initial 7 days of incubation. During this same time, levels of nitrite in the samples increased from below detection to nearly 40 mg/L. On a molar basis, this represents a nearly stoichiometric reduction of nitrate to nitrite. Thus, the data show that nitrate was biologically reduced to nitrite, but not further (i.e., to nitrogen gas or ammonia) in the absence of an added electron donor. The substrate supporting this reaction is unclear, but may be organic matter associated with the well-bottom sediments.

Like nitrate, nitrite added to aquifer microcosms at either 1 or 10 mg/L was degraded before perchlorate (data not shown). The addition of nitrite at these levels did not appear to influence the rate of perchlorate degradation (i.e. after the initial lag period, the rate of perchlorate reduction was the same in samples with and without added nitrite). The degradation of perchlorate was completely inhibited by the presence of oxygen in aquifer samples (Figure 7). This result confirms previous findings that perchlorate degradation occurs only under anoxic conditions.

### Conclusions

The data from this set of experiments suggest that nitrate and nitrite are degraded preferentially to perchlorate in this subsurface environment. It is unclear from these results whether the presence of nitrate or nitrite actually inhibits biological perchlorate degradation, however, in no instance was perchlorate degradation observed until both of these competing electron acceptors were degraded in the samples. In subsequent studies with a pure culture isolated from this site (*D. suillum* JPLRND), nitrate was observed to inhibit active perchlorate degradation, suggesting that it may be a biochemical inhibitor of biological perchlorate reduction (see section 4.5.6.4.1. *Influence of Nitrate on Perchlorate Reduction*). An understanding of the relationship between perchlorate and competing electron acceptors (e.g., oxygen, nitrate, nitrite, ferric iron) is important because these molecules frequently occur with perchlorate in groundwater. For example, the groundwater collected from JPL contained 18.6 mg/L of nitrate but only 300  $\mu\text{g/L}$  or perchlorate. Therefore, an understanding of whether nitrate impedes perchlorate degradation (i.e., due to enzyme inhibition or other factors) may be important in evaluating treatment options at contaminated sites.

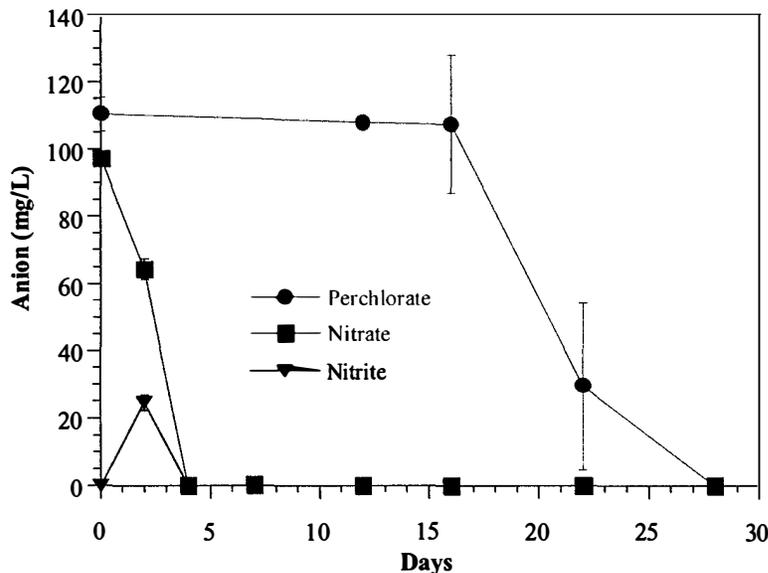
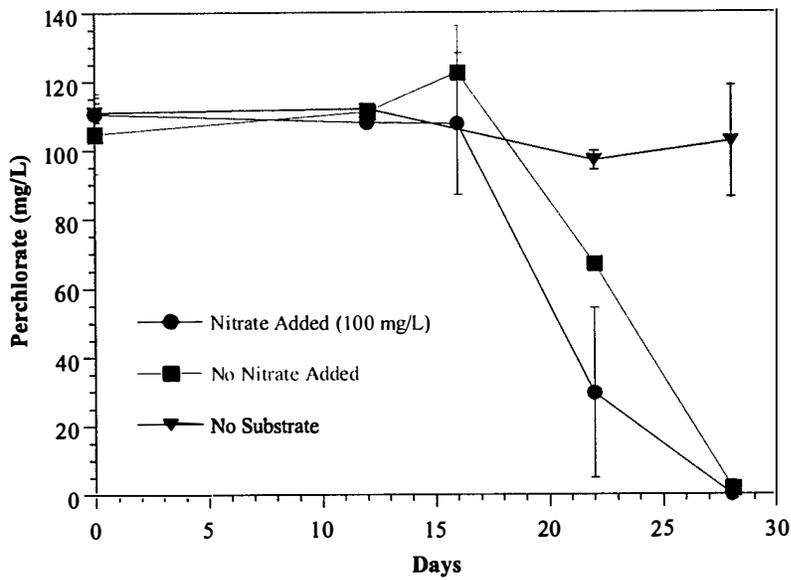
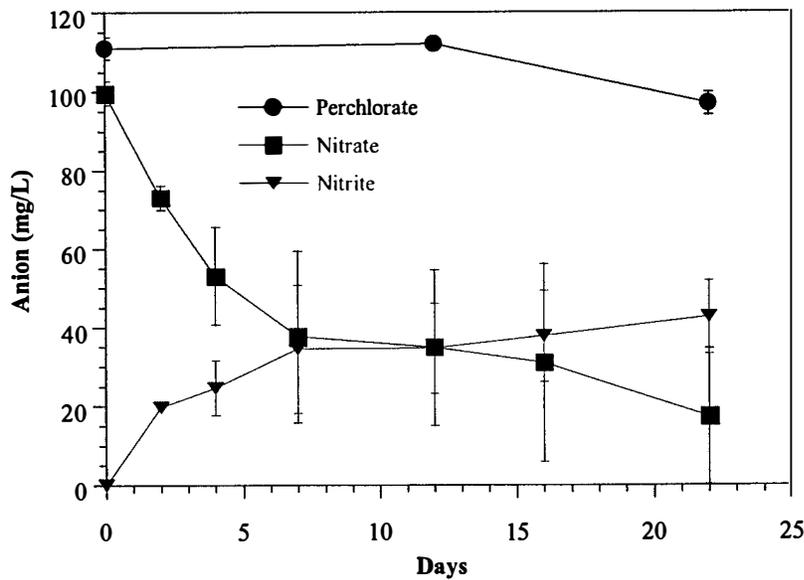


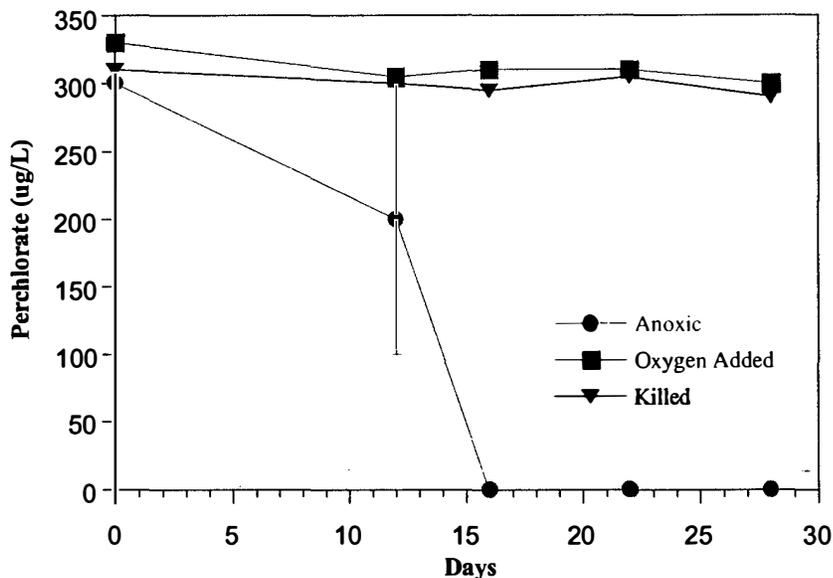
Figure 4. Sequential Biodegradation of Nitrate and Perchlorate in Aquifer Microcosms from JPL.



**Figure 5. Influence of Nitrate on Perchlorate Biodegradation in Aquifer Microcosms from JPL.**



**Figure 6. Biodegradation of Perchlorate (100 mg/L) and Nitrate (100 mg/L) in Aquifer Microcosms with No Substrate Added.**



**Figure 7. Influence of Oxygen on Perchlorate Biodegradation in Aquifer Microcosms from JPL.**

#### 4.3.1.4 Influence of pH and Salinity on Perchlorate Degradation

##### Methods

Little information exists on the influence of environmental variables such as temperature, pH, salinity, redox potential, alkalinity, and the presence of additional contaminants on biological degradation of perchlorate in groundwater. The influence of two environmental variables, pH and salinity, on perchlorate degradation was tested using aquifer samples from JPL. To assess the influence of salinity on perchlorate removal in field samples, a synthetic seawater medium (Atlas, 1995) was prepared at 0.5X, 1X, and 2X concentrations. The stocks were then mixed 1:1 with groundwater from the field site yielding salinities ranging from 0.25 X to 1 X that of seawater. The samples were then amended with perchlorate back to the initial concentration (~ 300 µg/L). Ethanol was used as the electron donor in these studies. Killed controls were prepared at each level of salinity by adding formaldehyde to samples to a final concentration of 1%. All microcosms were prepared and incubated under anoxic conditions. Aqueous subsamples were removed periodically and analyzed for perchlorate as described previously.

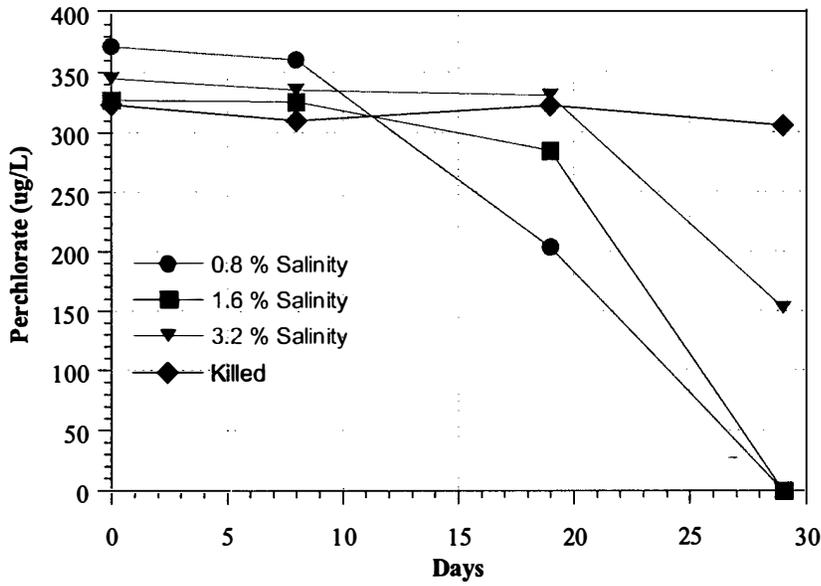
The role of pH on perchlorate biodegradation was evaluated essentially as described for salinity. In this case, however, the pH rather than the ionic strength of the aquifer material was manipulated. Because the buffering capacity of groundwater is limited, MES (2-[N-morpholino]ethanesulfonic acid; pKa = 6.1) buffer was added to samples at a concentration of 2 mM to maintain pH at desired levels. The

slurry material was then divided into 5 sterile beakers in the anaerobic chamber and the pH of each sample was adjusted using sterilized HCl or NaOH. The final pH levels of the slurries were 4.0, 5.0, 6.0, 7.0, or 8.0. The pH-adjusted slurry material was then added to sterile 160-mL serum bottles in triplicate. One bottle at each pH was amended with formaldehyde to a final concentration of 1% to inhibit microbial activity. Aqueous subsamples were removed from each sample at various times during incubation at 15°C and analyzed for perchlorate by EPA Method 314.0.

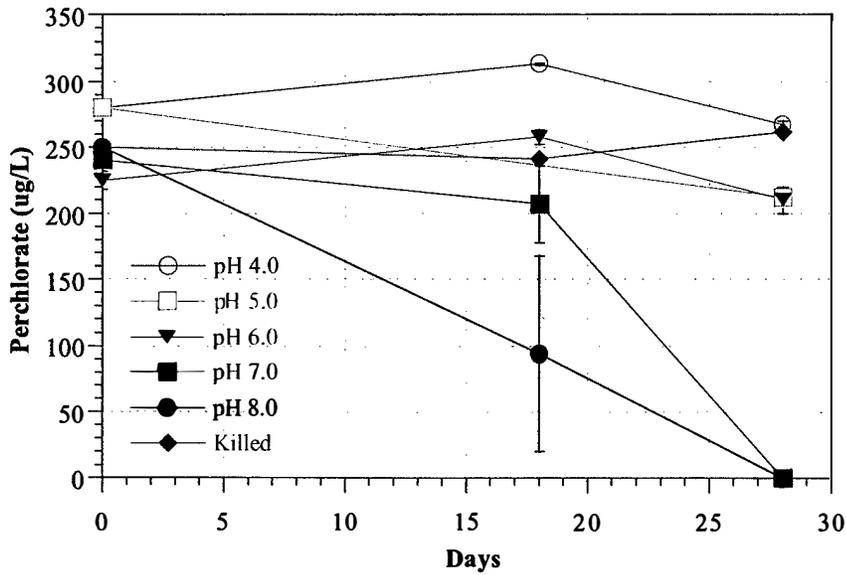
## Results and Conclusions

*Salinity:* The rate of perchlorate degradation in microcosms prepared from the JPL aquifer samples declined moderately with increasing salinity (Figure 8). During a 29-day incubation period, the perchlorate concentration in samples containing salinity at 25 or 50% that of seawater (0.8% and 1.6%, respectively) declined from a starting concentration of approximately 350 µg/L to below detection (PQL; 4 µg/L). The perchlorate concentration in samples brought to the salinity of seawater (~3.2% total salinity) also declined during 29 days, but approximately 150 µg/L remained at the end of the incubation period. There was no degradation in the killed controls. The results from this experiment show that perchlorate degradation is possible at salt levels at least as high as in sea water, although rates may be appreciably reduced compared to less saline environments. This observation confirms recent work by Logan et al. (2001) in which the authors successfully developed three perchlorate degrading enrichment cultures at a salinities ranging from 3 - 7%. Pure cultures were not obtained during this study. In addition, the rates of cell growth appeared to be extremely slow (with maximum cell doubling times of greater than 10 days) compared to non-salt-tolerant cultures. The 5 isolates obtained during this SERDP project were subsequently tested for salt tolerance by adding 1 – 5% NaCl to BSM medium. None of the cultures degraded perchlorate at salt levels of 1% or higher. Thus, while salt tolerant perchlorate degrading strains appear to exist based on our data from JPL and data from other laboratories, this trait appears not to be common among this group of organisms.

*pH:* The biodegradation of perchlorate was most rapid in JPL aquifer samples brought to a pH of 8.0 (Figure 9). Levels of perchlorate declined from approximately 250 µg/L to less than 4 µg/L in 28 days. Perchlorate was also completely degraded in samples at a pH of 7.0 during the 28-day incubation. However, at pH values of 4.0, 5.0, and 6.0, little or no perchlorate losses were observed in the aquifer microcosms. These results are supported by data from two additional sites (IHDIIV and LHAAP) that suggest that low pH is inhibitory to perchlorate reduction in environmental samples (see next two sections).



**Figure 8. Influence of Salinity on Perchlorate Biodegradation in Groundwater Microcosms from JPL.**



**Figure 9. Influence of pH on Perchlorate Biodegradation in Aquifer Microcosms from JPL.**

### **4.3.2 INDIAN HEAD DIVISION, NAVAL SURFACE WARFARE CENTER (IHDIV), INDIAN HEAD, MARYLAND**

#### **4.3.2.1 Sample Collection**

Aquifer solids and groundwater were collected from two separate locations at IHDIV on August 1, 2000 using a Geoprobe (Figure 10). The extent of perchlorate contamination in the shallow aquifer at this site was unknown, so sampling locations were chosen based on historical use and disposal of perchlorate at the site. The initial sample site was the drainage area behind a propellant mixing facility at IHDIV (Building 1190 site). The level of the water table at this site is approximately 4 ft below grade. Sediments were collected from 4 to 12 ft and groundwater from 6 to 12 ft below grade. The second sample location was an open meadow behind building 1419, the rocket "Hog Out" facility at IHDIV (Hog Out site). Solid fuel is removed from rockets and missiles in this building using a high-pressure washout procedure (i.e., Hog Out procedure). Before 1996, the washout water was discharged through the region where the field samples were collected. Sediment samples from 2 to 13 ft below grade were collected and homogenized. Groundwater was taken from 6 to 12 feet below grade at the site.

#### **4.3.2.2 IHDIV Building 1190 Site – Evaluation of Electron Donors and Electron Donor Concentration on Perchlorate Biodegradation**

##### **Methods**

*General Preparation and Sampling:* All experimental work was performed in a Coy Environmental Chamber with a nitrogen headspace. Sampling for analysis of perchlorate and other parameters was performed outside of the chamber. Prior to sample collection, a volume of nitrogen gas was added via syringe to the headspace of each microcosm bottle. The addition of nitrogen created backpressure in the bottle to facilitate sample withdrawal. More importantly, this method ensured that no oxygen was introduced into the bottles during sampling. All samples were analyzed for perchlorate by ion chromatography (IC) using EPA Method 314.0.

*Evaluation of Electron Donors:* Microcosms to evaluate the influence of different electron donors on perchlorate degradation were prepared in sterile, 160-mL serum bottles. Groundwater from the Building 1190 site was amended with a sterile stock of diammonium phosphate to provide nitrogen (5 mg/L as  $\text{NH}_4$ ) and phosphorus (4.5 mg/L as P) as nutrients for bacterial growth. Groundwater and sediment from the site were added to each 160-mL bottle at a ratio of approximately 3:1 (100-mL groundwater and 30-g sediment). Each bottle was spiked with a filter-sterilized sodium perchlorate stock solution to a final

perchlorate concentration of 125 mg/L. Triplicate serum bottles were amended with acetate, ethanol, or molasses to 200 mg/L. Triplicate bottles also received hydrogen in the headspace as a gaseous substrate. Triplicate bottles were inoculated with a perchlorate degrading culture (FBR2) isolated at Envirogen; ethanol was tested as electron donor in these bottles. Killed controls were prepared with acetate as a substrate and 1 % formaldehyde to inhibit all biological activity. The bottles were crimp-sealed with sterilized Teflon-lined septa and incubated at 15°C to approximate *in situ* temperatures. At 11, 19, and 34 days of incubation, a 15-mL subsample was removed from each bottle. Preservation of the samples was accomplished by passing the water through sterile nylon filters and storing at 4°C until analysis.



**Figure 10. Collection of Field Samples from the IHDIV Hog Out Site.**

*Electron Donor Concentration:* The objective of this study was to determine the amount of electron donor needed to support perchlorate reduction, and to compare the actual electron donor requirement to the theoretical requirement. Acetate was used as an electron donor (based on results from the previous study), and the quantity required to degrade a given quantity of perchlorate in aquifer microcosms was determined. Microcosms were prepared in sterile, 60-mL serum bottles. Nutrient-amended groundwater and sediment were combined in each bottle at a ratio of about 4.5:1 (45-mL groundwater and 10-g sediment). Each bottle was spiked with a filter-sterilized sodium perchlorate stock solution to a final perchlorate concentration of 100 mg/L (109 mg/L actual measured). Sodium acetate was added to triplicate bottles at concentrations of 0, 10, 25, 50, 75, and 100 mg/L as acetate. One killed control was prepared by adding 1% formaldehyde to a microcosm containing 100 mg/L acetate. All bottles were

crimp-sealed with sterilized Teflon-lined septa and incubated at 15°C to approximate *in situ* temperatures. At 4, 6, 8, 10, and 13 days of incubation, a 7-mL subsample was removed from each bottle. The samples were filtered and exposed to air, then frozen to inhibit any additional perchlorate or acetate degradation. Perchlorate concentrations were measured in each sample using EPA Method 314.0.

## Results

*Groundwater Analysis:* The groundwater collected from the Building 1190 site did not contain perchlorate (<4 µg/L), nitrate (< 0.2 mg/L) or nitrite (< 0.2 mg/L) above detection limits. Sulfate was present at 12 mg/L, chloride at 43 mg/L, and alkalinity was 40 mg/L (as CaCO<sub>3</sub>). The pH of the water was 5.9. A slurry containing 30 g of sediment and 100 mL of water had a pH of 6.1.

*Evaluation of Electron Donors:* Perchlorate was not detected in samples collected from the Building 1190 site, so the aquifer microcosms were amended with the anion to a starting concentration of ~125 mg/L. After 11 days of incubation at 15°C, perchlorate levels were below detection in microcosms amended with hydrogen gas (Figure 11). Samples that received acetate declined to 3 mg/L total perchlorate during this time. After 34 days of incubation, perchlorate was below detection in samples treated with molasses or acetate, as well as those receiving hydrogen as an electron donor. Samples receiving ethanol as an electron donor showed no appreciable decline in perchlorate levels. Likewise, no perchlorate loss was evident in acetate-amended microcosms that received formaldehyde to inhibit biological activity. The perchlorate concentration in live samples that did not receive any exogenous substrate declined from 126 to 76 mg/L during 34 days of incubation. A similar decline was previously observed with JPL microcosms containing groundwater and sediments (but not groundwater only). This decline suggests that an electron donor present at the site, such as natural organic matter or an organic co-contaminant, may support degradation of perchlorate at this location. The absence of detectable perchlorate in this region, which served as a deposition area for wash-down water from the Building 1190 facility, further supports this hypothesis.

*Electron Donor Concentration:* Based on stoichiometric calculations, the quantity of acetate required for a bacterium to degrade perchlorate is 0.61 mg per mg perchlorate. This ratio was tested in samples from the Building 1190 location by varying the acetate dose added to microcosms and evaluating perchlorate degradation. Microcosm samples initially received 100 mg/L of perchlorate and either 0, 10, 25, 50, 75, or 100 mg/L of acetate. After 10 days of incubation, samples amended with 100 or 75 mg/L of acetate no longer had perchlorate at detectable levels (Figure 12). After 13 days, concentrations of perchlorate in samples amended with 50 mg/L of acetate were also below detection and samples treated with 0, 10, and

25 mg/L acetate had mean perchlorate levels of 81, 52, and 41 mg/L, respectively. The quantity of acetate required for complete removal of perchlorate from the microcosm samples was less than determined from reaction stoichiometry. However, as observed in previous samples from this site, perchlorate degradation occurred in unamended samples, presumably supported by natural organic materials at the site. When this loss is taken into account, the perchlorate degradation observed with different levels of acetate become much closer to that expected based on theoretical calculations. These ratios are presented for 10, 25, and 50 mg/L acetate in Figure 12. Additional studies concerning the ratio of electron donor required for perchlorate degradation in natural samples will be conducted in flow-through column studies in Year 2.

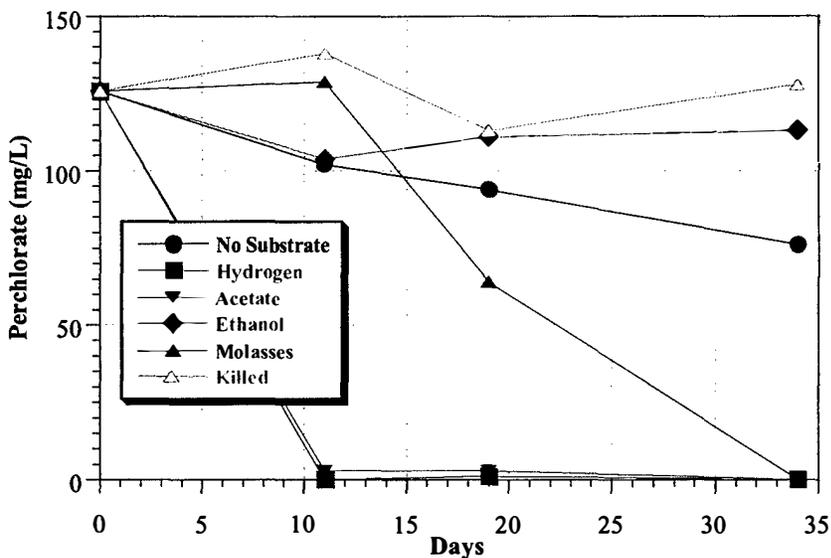
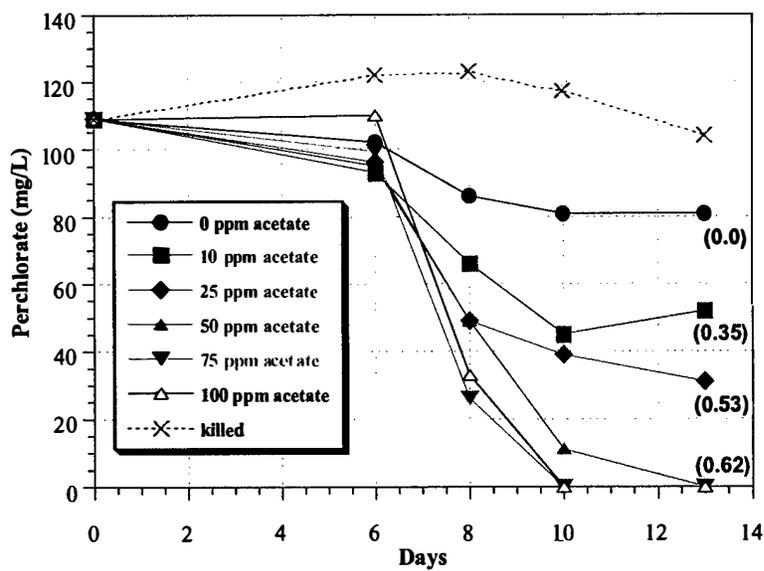


Figure 11. Influence of Different Electron Donors on Perchlorate Biodegradation in Aquifer Microcosms from the IHDIV Building 1190 Site.



**Figure 12. Biodegradation of Perchlorate in Aquifer Microcosms Amended with Different Concentrations of Acetate as Electron Donor. Values in Parentheses represent the ratio of Acetate/Perchlorate (mg/L).**

### Conclusions

The results from the microcosm study using aquifer samples from the Building 1190 site suggest the following: (1) indigenous bacteria capable of degrading perchlorate are present in the shallow aquifer in the vicinity of Building 1190, and (2) these bacteria can be rapidly stimulated to degrade perchlorate to below 4  $\mu\text{g/L}$  by the addition of several electron donors. The data also suggest that natural attenuation of perchlorate is possible at this location. This area was used for the disposal of perchlorate-containing wastewater from the mixing facility until 1998, yet the anion was not detected in subsurface samples, which suggests attenuation by either transport or biodegradation. In addition, samples amended with perchlorate but no electron donor showed significant losses of the anion in microcosm studies. A natural electron donor (e.g., humic material) or an organic co-contaminant most likely served as an electron donor for biological perchlorate reduction in these samples.

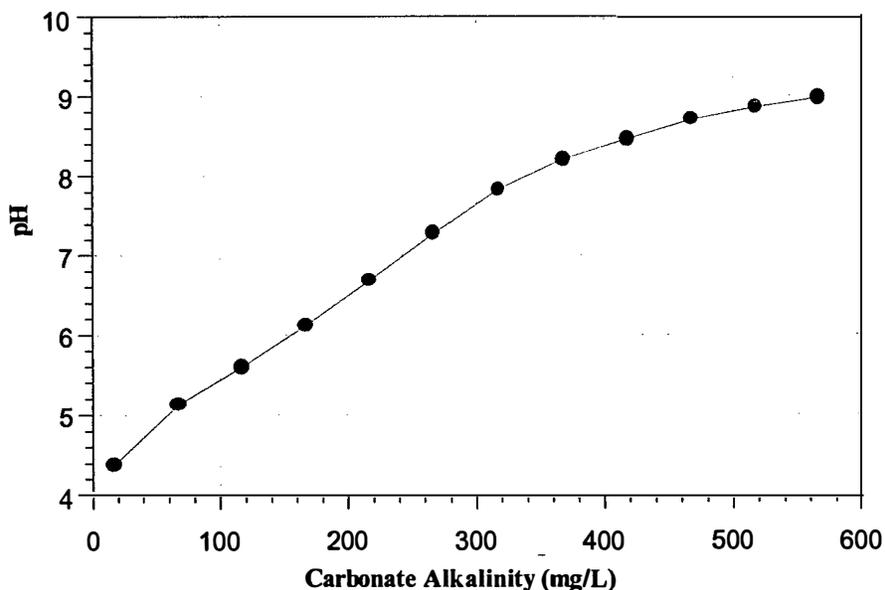
#### 4.3.2.3 IHDIV Hog Out Facility – Evaluation of Electron Donors and pH on Perchlorate Reduction

##### Methods

*Electron Donor Addition:* A second microcosm study was conducted using groundwater and sediment collected from the Hog Out site at IHDIV (Building 1419). The experiment was prepared in the same manner as described for the previous study, except that no perchlorate addition was required. The starting perchlorate concentration in the mixed groundwater and sediment was approximately 45 mg/L. Triplicate serum bottles were amended with nutrients (N and P from diammonium phosphate) and one of the

following substrates at 200 mg/L: methanol, ethanol, acetate, benzoate, lactate, sucrose, molasses, or a mixture of ethanol and yeast extract (100 mg/L each). Triplicate bottles also received hydrogen gas or propane in the headspace as gaseous substrates. Triplicate bottles were inoculated with the perchlorate degrading enrichment FBR2; ethanol was used as an electron donor in these bottles. In addition, triplicate microcosms were prepared with nutrients (N and P) but no substrate, substrate (acetate) but no nutrients, and without addition of substrate or nutrients. Killed control samples were prepared with acetate and received formaldehyde (1 %) to inhibit all biological activity. All bottles were crimp-sealed with sterilized Teflon-lined septa and incubated at 15°C to approximate *in situ* temperatures. At 11, 20, 36, and 71 days of incubation, a 15-mL subsample was removed from each bottle. The samples were preserved and analyzed as described for the previous experiment.

*Influence of pH on Perchlorate Biodegradation:* An experiment was conducted to determine whether the low pH (4.3) of the Hog Out site samples was inhibiting perchlorate degradation at the site. Prior to adjusting the pH, the influence of increasing carbonate concentration on slurry pH was tested. The resulting titration curve showed that approximately 240 mg/L of additional carbonate was required to increase the pH of the slurry to 7.0 (Figure 13). Microcosms were prepared in sterile, 160-mL serum bottles. The groundwater was amended with a sterile stock of diammonium phosphate to provide nitrogen (1 mg/L NH<sub>4</sub> as N) and phosphorus (1 mg/L PO<sub>4</sub> as P) as nutrients for bacterial growth. Groundwater and sediment were added to each 160-mL bottle at a ratio of approximately 3:1 (100-mL groundwater and 30-g sediment). Acetate was added as the electron donor at 75 mg/L. Perchlorate was not added, as the perchlorate concentration in the mixed groundwater and sediment was approximately 45 mg/L. In eight of the fourteen bottles prepared, the pH was increased from 4.3 to approximately 7.0 by adding sodium carbonate. The pH of the remaining six microcosms was not adjusted (i.e., pH 4.3). Three of the bottles at pH 4.3 and three at pH 7.0 were inoculated with the perchlorate degrading culture FBR2, and three bottles at each pH remained uninoculated. Two of the bottles at pH 7.0 received formaldehyde (1 %) to inhibit all biological activity. The bottles were incubated on a rotary shaker at 15°C. After 7, 16, and 28 days of incubation, a 7-mL subsample was removed from each bottle. Each sample was initially centrifuged for approximately 30 minutes at 3,500 rpm to remove sediment fines. The supernatant was then passed through a nylon filter and placed at 4°C until analysis. A freshly grown inoculum of the FBR2 culture was re-added to three bottles at each pH on Day 10. This procedure was conducted to ensure that all bottles amended with the bacterium received active perchlorate degrading bacteria.



**Figure 13. Carbonate Titration Curve for Sediment Slurries from the IHDIV Hog Out Site.**

## Results

*Groundwater Analysis:* The groundwater collected from the Hog Out site contained perchlorate at 25 mg/L. In a slurry containing 30-g sediment and 100-mL groundwater, perchlorate was detected at 45 mg/L suggesting that the anion was present at a higher concentration in the sediments collected from the site than in the groundwater. This difference may represent perchlorate present in the unsaturated zone of the shallow aquifer. Nitrate and nitrite were not detected in samples. Sulfate was present at 88 mg/L, chloride at 26 mg/L, and alkalinity was 19 mg/L (as  $\text{CO}_3$ ). The pH of the water was 4.8, and a slurry of water (100 mL) and sediment (30 g) had a pH of 4.3.

*Electron Donor Addition:* There was no appreciable loss of perchlorate during the 71-day incubation period in any of the microcosms prepared from the Hog Out site samples (Table 2). Ten different electron donors did not stimulate perchlorate biodegradation in the samples. Bioaugmentation with an exogenous perchlorate degrading culture (FBR2) also did not reduce perchlorate levels. These results differ from those with the Building 1190 samples, where several electron donors quickly stimulated perchlorate degradation. Rapid reduction in perchlorate levels was also observed in aquifer microcosms from the Jet Propulsion Lab and a commercial site in the Rocky Mountains (see following section). The most apparent difference between the Hog Out samples and those from other sites is the comparatively low pH of the microcosms compared to other samples. The pH of the Hog Out site microcosms was

measured at 4.3. Other samples tested prior to this had pH values no lower than 6.1. An experiment was subsequently conducted to assess the influence of pH on perchlorate degradation in the Hog Out samples.

**Table 2. Perchlorate Degradation in Aquifer Microcosms from the IHDIV Hog Out Site.**

Treatment	Perchlorate Concentration (mg/L) <sup>1</sup>				
	Day 0	Day 11	Day 20	Day 36	Day 71
<b><i>Electron Donors</i></b>					
Killed Control	42 ± 4	41 ± 1	44 ± 2	36 ± 4	37 ± 2
No Substrate	42 ± 4	37 ± 1	36 ± 4	38 ± 1	39 ± 5
Nutrients Only	42 ± 4	38 ± 2	41 ± 4	42 ± 1	34 ± 1
Hydrogen	42 ± 4	38 ± 2	40 ± 4	32 ± 5	35 ± 2
Propane	42 ± 4	38 ± 1	39 ± 2	34 ± 2	37 ± 2
Ethanol	42 ± 4	39 ± 2	41 ± 2	36 ± 4	36 ± 3
Methanol	42 ± 4	41 ± 2	41 ± 1	32 ± 2	34 ± 2
Acetate	42 ± 4	39 ± 1	42 ± 2	33 ± 1	37 ± 1
Benzoate	42 ± 4	40 ± 1	43 ± 0	32 ± 1	38 ± 1
Lactate	42 ± 4	38 ± 3	43 ± 3	33 ± 2	37 ± 2
Molasses	42 ± 4	43 ± 2	43 ± 2	28 ± 1	36 ± 2
Sucrose	42 ± 4	44 ± 1	45 ± 0	31 ± 0	35 ± 0
Yeast Extract/Ethanol	42 ± 4	43 ± 2	44 ± 2	35 ± 3	37 ± 2
<b><i>Bioaugmentation</i></b>					
Inoculum FBR2+ Ethanol	42 ± 4	41 ± 1	44 ± 3	36 ± 2	36 ± 2

<sup>1</sup> Values are the mean ± standard deviation from triplicate microcosms.

*Influence of pH on Perchlorate Degradation:* The perchlorate levels in the samples at pH 4.3 did not decline appreciably during the study, regardless of whether the samples were bioaugmented (Figure 14). Conversely, the samples in which the pH was increased to 7.0 all showed perchlorate biodegradation. Perchlorate levels in samples receiving *Dechlorospirillum* sp. FBR2 declined from 43 to 9 mg/L from day 7 to day 16, and then to 0.16 mg/L by day 28. The perchlorate concentration in samples that were brought to pH 7.0 but not augmented with the culture declined more slowly, but perchlorate was below detection by day 28 of the experiment. Thus, the data suggest that low pH is inhibiting perchlorate degradation in the Hog Out site samples. It is interesting that indigenous perchlorate degrading microorganisms could be stimulated to degrade the anion at a pH of 7.0 but not at a pH of 4.3. These bacteria are obviously able to survive at the low pH, which occurs naturally at this site, yet appear not to degrade perchlorate at this pH. The results suggest that there may be a pH below which perchlorate biodegradation is physiologically inhibited.

## Conclusions

Data from experiments conducted with samples from the Hog Out site at IHDIV suggest that low pH is inhibitory to biological perchlorate reduction. Neither biostimulation nor bioaugmentation promoted perchlorate degradation at the site pH of 4.3. However, when the pH of the samples was increased to neutrality, perchlorate biodegradation was observed in samples receiving only acetate as well as those augmented with *Dechlorospirillum* sp. FBR2. The inhibition of perchlorate degradation at low pH in these field samples is consistent with previous observations at Envirogen during experiments with *ex situ* reactor systems. During a laboratory pilot study, perchlorate treatment in a fluidized bed reactor was observed to decline appreciably when the pH of the system declined below approximately 5.5. The performance was regained when the pH was increased to neutrality. Perchlorate inhibition at low pH was also observed in soil and groundwater samples from the Longhorn Army Ammunition Plant (LHAAP). These data are reported in section 4.3.4.

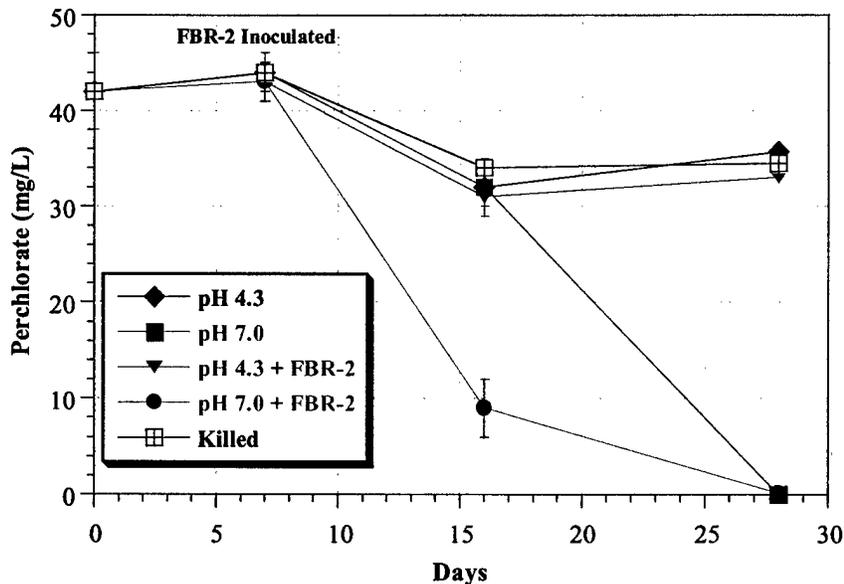


Figure 14. Influence of pH on Perchlorate Degradation in Aquifer Microcosms from the IHDIV Hog Out Site.

### **4.3.3 ROCKY MOUNTAIN COMMERCIAL FACILITY (RM), UTAH**

#### **4.3.3.1. Evaluation of Electron Donors and Influence of Chlorinated Solvents and BTEX on Perchlorate Reduction**

##### **Methods**

*Sample Collection:* Groundwater samples were collected by site personnel at an industrial manufacturing facility in the Rocky Mountains. Sediment samples were not available.

*Groundwater Microcosms:* Microcosms were used to evaluate the potential for perchlorate biodegradation in a subsurface aquifer in the Rocky Mountains. Subsurface sediments were not available for this study, so groundwater only was used in the experiments. The Rocky Mountain groundwater was amended with a sterile stock of diammonium phosphate to provide nitrogen (5 mg/L as NH<sub>4</sub>) and phosphorus (4.5 mg/L as P) as nutrients for bacterial growth. Each 160-mL bottle received 100 mL of site groundwater. The perchlorate concentration in the groundwater was approximately 57 mg/L. Duplicate serum bottles were amended with one of the following substrates to 100 mg/L: acetate, ethanol, methanol, benzoate, lactate, sucrose, molasses or a mixture of ethanol and yeast extract (100 mg/L each). Duplicate bottles also received hydrogen or propane in the headspace as gaseous substrates. Duplicate bottles were inoculated with *Dechlorospirillum* sp. FBR2 and ethanol as electron donor. Duplicate samples were also prepared with nutrients (N and P) but no substrate, no nutrients or substrate, or substrate (acetate) without nutrients. Killed controls received acetate as substrate and formaldehyde (1%) to inhibit all biological activity. All bottles were crimp-sealed with sterilized Teflon-lined septa and incubated at 15°C to approximate *in situ* temperatures. At 6, 14, 22, and 35 days of incubation, a 15-mL subsample was removed from each bottle. Preservation of the samples was accomplished by filtration and refrigeration, as described previously.

*Influence of Co-Contaminants:* Because chlorinated solvents such as trichloroethylene (TCE) and perchloroethylene (PCE) often occur in conjunction with perchlorate in contaminated groundwater, two experiments were conducted to determine the influence of these compounds on perchlorate degradation. The influence of high concentrations of PCE and TCE was initially examined, then, in a second study, the influence of several lower concentrations of these co-contaminants was evaluated. In the initial study, the role of BTEX contamination on perchlorate reduction was also examined.

In the first study, serum bottles were amended with lactate (100 mg/L), nutrients, and one of the following co-contaminants at a starting concentration of 100 mg/L: PCE, TCE, or the mixed gasoline

constituents benzene, toluene, ethylbenzene, and xylenes (BTEX). The bottles were sealed and placed on a rotary shaker operating at 15°C. Subsamples were periodically collected and analyzed for perchlorate. In the second study, the groundwater samples were amended with lactate (100 mg/L), nutrients, and either PCE or TCE at starting concentrations of 0, 5, 10, or 25 mg/L. The initial stocks of the chlorinated solvents were prepared in site groundwater. The bottles were sealed with Teflon septa and placed on a rotary shaker operating at 15°C. Subsamples were periodically collected and analyzed for perchlorate. Initial samples were also analyzed for TCE and PCE using a gas chromatograph equipped with a flame ionization detector (GC/FID).

## Results

*Groundwater Analysis:* Groundwater from the Rocky Mountain site was collected from an existing monitoring well screened to a depth of 89 – 99 ft below grade. The water contained perchlorate at 57 mg/L, which is consistent with historical levels in the well. Other anion levels included nitrate at 5.2 mg/L (as N), sulfate at 364 mg/L, chloride at 2,500 mg/L, and 285 mg/L of alkalinity (as CaCO<sub>3</sub>). The total dissolved solids (TDS) in the groundwater was 5,000 mg/L, and the pH was 7.7. Historical data provided to Envirogen by the commercial facility showed trichloroethene in the well water between 1 and 2 mg/L, and lesser chlorinated ethenes and ethanes at trace (ppb) levels. However, no volatile organic compounds were detected in the groundwater upon analysis by Envirogen's Analytical Lab. These compounds most likely volatilized during collection and shipment of the groundwater samples. The sampling techniques were designed to ensure aseptic collection of groundwater but not quantitative preservation of *in situ* VOC levels (since perchlorate is non-volatile).

*Groundwater Microcosms:* The starting perchlorate concentration in microcosms prepared with groundwater was 57 mg/L. After 6 days of incubation at 15°C, the perchlorate concentrations in samples augmented with exogenous perchlorate degrading bacteria (*Dechlorospirillum* sp. FBR2) had decreased to 15 mg/L. Perchlorate levels did not decline in any of the other treatments. After 14 days of incubation, perchlorate levels were below detection (PQL; 0.5 mg/L) in the FBR2-inoculated microcosms and in microcosms amended with sucrose, lactate, and molasses (Table 3). In microcosms amended with both ethanol and yeast extract, perchlorate levels had decreased to 1 mg/L after 14 days, and were non-detect (PQL; 0.5 mg/L) after 22 days. In microcosms receiving acetate, perchlorate levels declined to 31 mg/L after 14 days. After 35 days, perchlorate levels in the acetate bottles were less than 0.5 mg/L. However, no perchlorate loss was observed in microcosms prepared with acetate as electron donor but without nutrients (supplemental nitrogen and phosphorus), indicating that phosphorus may be a limiting nutrient for microbial growth in the groundwater. Nitrogen is probably not limiting because high levels of nitrate

are present in the water. No perchlorate loss was observed in those microcosms amended with hydrogen, benzoate, ethanol, methanol, or propane as electron donors. No perchlorate loss was evident in samples that were treated with formaldehyde to inhibit biological activity, nor in samples that were prepared with nutrients only (no substrate) or those receiving no nutrient or substrate addition.

*Influence of Co-Contaminants.* In the first study, perchlorate levels in samples that did not receive co-contaminants declined from 52.7 mg/L to 1.7 mg/L during the initial 15 days of incubation and were below detection by day 29 (Figure 15). In samples that received TCE at 100 mg/L, perchlorate degradation was slightly retarded compared to the samples without the co-contaminant, but perchlorate was also below detection by day 29. Conversely, during the 29-day study, samples receiving either BTEX or PCE showed no degradation of perchlorate.

In the second study, perchlorate levels in samples that did not receive co-contaminants declined from 52 mg/L to 19 mg/L during the initial 15 days of incubation and then to 0.9 mg/L by day 22. Interestingly, perchlorate levels in samples receiving TCE at 10 or 25 mg/L were all below detection (< 0.025 mg/L) after 15 days of incubation (Figure 16). Samples treated with TCE at 5 mg/L showed perchlorate levels of 10 mg/L after 15 days and were below detection for perchlorate after 22 days. Thus, in this study, TCE appeared to stimulate the rate of perchlorate degradation in groundwater samples. Analysis of TCE after 15 days of incubation showed no significant losses of the solvent in sample bottles. The mean levels of TCE in bottles initially receiving 5, 10, and 25 mg/L were 6, 12, and 26 mg/L after 15 days. Conversely, perchlorate degradation was somewhat inhibited in groundwater samples with PCE (Figure 17). After 15 days of incubation, perchlorate was detected at 36 mg/L in samples which were initially treated with 10 mg/L PCE and at 46 mg/L in samples receiving 25 mg/L PCE, compared to 10 mg/L in samples with no PCE. By 22 days, samples with 25 mg/L PCE still had more than 30 mg/L perchlorate, while all others were less than 1 mg/L. PCE levels in the sample bottles after 15 days were appreciably reduced compared to initial levels. Bottles initially receiving 5, 10, and 25 mg/L PCE showed 3, 3, and 9 mg/L, respectively, after 15 days. The method of analysis (GC/FID) did not allow accurate detection of PCE biodegradation daughter products (e.g., *cis*-DCE) and killed controls at each PCE level were not prepared, so it is unclear whether PCE was biologically degraded or lost due to volatilization or by another abiotic process from the samples.

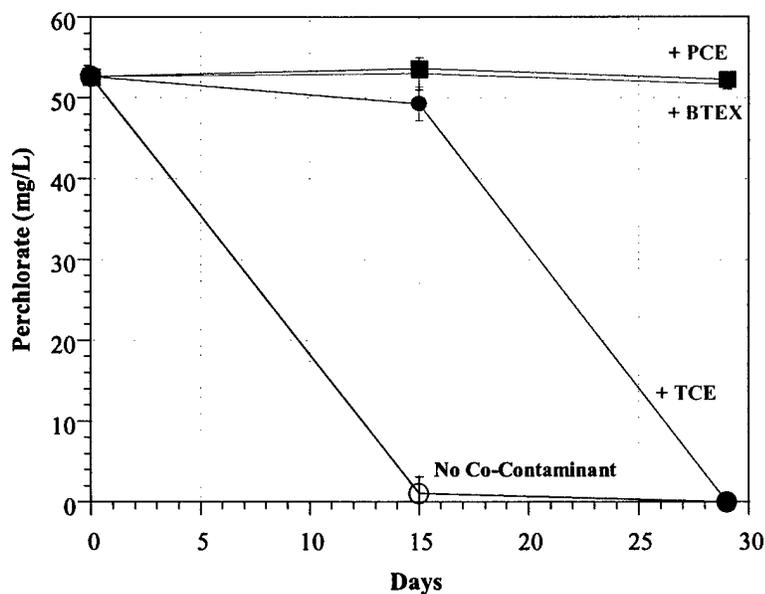
**Table 3. Perchlorate Degradation in Groundwater Microcosms from the Rocky Mountain Site.**

Treatment	Perchlorate Concentration (mg/L) <sup>1</sup>				
	Day 0	Day 6	Day 14	Day 22	Day 35
<i>Electron Donors</i>					
Killed	57 ± 2	60 ± 2	53 ± 2	60 <sup>3</sup>	55 <sup>3</sup>
No Addition	57 ± 2	60 ± 1	53 ± 1	53 ± 2	54 ± 1
Nitrogen/Phosphorus only	57 ± 2	62 ± 5	55 ± 1	59 ± 1	55 ± 2
Hydrogen	57 ± 2	61 ± 1	63 ± 10	52 ± 1	54 ± 1
Propane	57 ± 2	62 ± 0	66 ± 1	49 ± 0	53 ± 0
Benzoate	57 ± 2	62 ± 2	62 ± 1	49 ± 3	48 ± 2
Ethanol	57 ± 2	59 ± 3	63 ± 2	51 ± 0	43 ± 1
Methanol	57 ± 2	62 ± 2	63 ± 1	46 ± 4	47 ± 6
Acetate (no N or P)	57 ± 2	60 ± 5	54 ± 0	59 ± 1	49 ± 1
Acetate	57 ± 2	62 ± 1	31 ± 6	2 ± 2	< 0.5
Yeast Extract/Ethanol	57 ± 2	60 ± 0	1 ± 1	< 0.5	NS <sup>2</sup>
Lactate	57 ± 2	60 ± 1	< 0.5	< 0.5	NS
Molasses	57 ± 2	59 ± 1	< 0.5	< 0.5	NS
Sucrose	57 ± 2	61 ± 1	< 0.5	< 0.5	NS
<i>Bioaugmentation</i>					
Culture FBR2 + Ethanol	57 ± 2	15 ± 1	< 0.5	< 0.5	NS

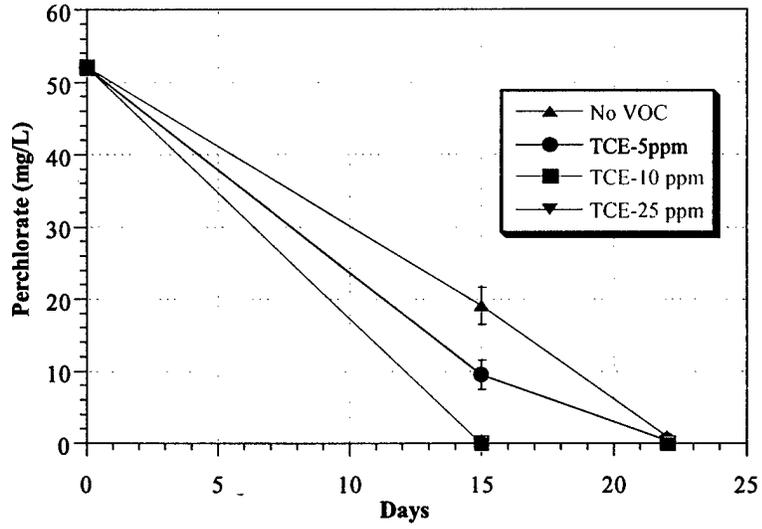
<sup>1</sup> Values are the means and standard deviations from duplicate microcosms.

<sup>2</sup> NS: Not sampled because perchlorate was previously below detection.

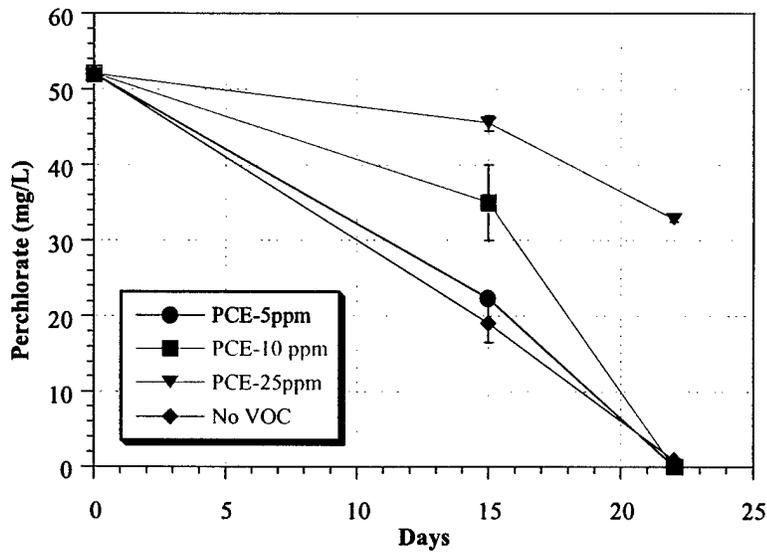
<sup>3</sup> Single analysis due to broken sample bottle.



**Figure 15. Influence of Co-Contaminants on the Biodegradation of Perchlorate in Groundwater from the RM Site.**



**Figure 16. Influence of Varying Concentrations of Trichloroethene (TCE) on Perchlorate Biodegradation in Groundwater Microcosms from the RM Site.**



**Figure 17. Influence of Varying Concentrations of Perchloroethene (PCE) on Perchlorate Biodegradation in Groundwater Microcosms from the RM Site.**

## **Conclusions**

Bioaugmentation with *Dechlorospirillum* sp. FBR2 caused the most rapid reduction in perchlorate levels in the Rocky Mountain samples. However, addition of some substrates (lactate, molasses, sucrose, yeast extract/ethanol) also promoted perchlorate biodegradation by indigenous bacteria. Other substrates that yielded rapid perchlorate biodegradation at the JPL site or the IHDIV Building 1190 Site, such as ethanol (JPL) and hydrogen gas (IHDIV), did not stimulate biodegradation of the anion at this site. Differences in the indigenous populations of perchlorate degrading bacteria at each site may account for the observed differences among sites in substrate effectiveness for perchlorate bioremediation.

The observed inhibition of perchlorate degradation by high concentrations of PCE and BTEX most likely reflects toxicity of these compounds on the perchlorate degrading strains in the RM groundwater. It is however, interesting that TCE appeared to be less toxic at 100 mg/L than PCE, since the former is more soluble and solvent toxicity often increases with solubility. An initial screening suggested that neither TCE or PCE were appreciably degraded during the course of the experiment. In the second study with lower solvent concentrations, PCE again inhibited perchlorate reduction, with the extent of inhibition varying directly with concentration. This likely reflects toxicity of the chlorinated solvent to perchlorate degrading bacteria.. It is also possible, although unlikely, that some perchlorate degrading strains also use PCE as an electron acceptor and that the observed inhibition reflects competition between the two electron acceptors. More detailed experiments are required to evaluate this possibility. Unlike PCE, TCE appeared to stimulate perchlorate degradation in the second study in a dose-dependent manner, even though the solvent was not apparently degraded. The reason for this effect is unclear, and requires additional experimentation. These studies are important because chlorinated solvents, including PCE and TCE, are often found with perchlorate at contaminated field sites.

### **4.3.4 LONGHORN ARMY AMMUNITION PLANT, KARNACK, TEXAS**

#### **4.3.4.1 Sample Collection**

Aquifer sediments and groundwater containing perchlorate were collected from two locations (Site 16, Site 25G) at the Longhorn Army Ammunition Plant (LHAAP) in Karnack, Texas. A Geoprobe rig was used for collection of sediments, and groundwater was taken from existing monitoring wells at the site. The samples were used for the final set of microcosm studies to be conducted during this project using natural sediments. Sediments from one of these locations are also being used for initial flow-through column studies. In addition, samples of a contaminated surface soil (Site 25C) at LHAAP were taken for testing. A total of seven different aquifer samples were collected from five sites across the country during the microcosm testing for this project.

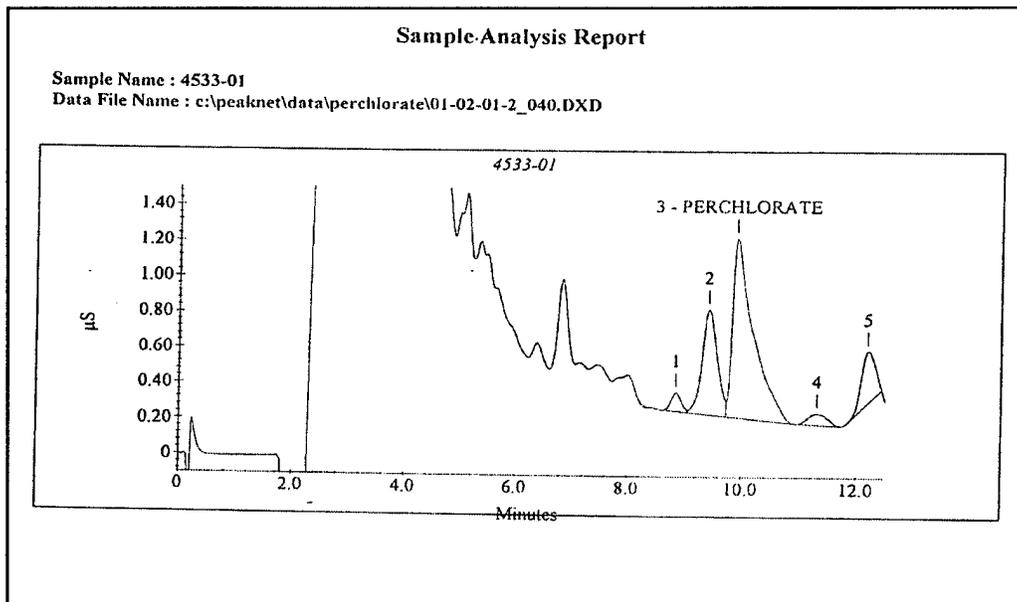
#### 4.3.4.2 LHAAP Site 16 –Landfill Leachate

##### Methods

Groundwater and sediment samples were collected from Site 16, which is a contaminated groundwater plume that is downgradient from a capped landfill at LHAAP. Sediments were taken from 22 – 26' below land surface using a Geoprobe rig and groundwater was collected from an existing monitoring well (EW-1). The groundwater at the site is bright yellow due to the presence of a tricarbonyl iron compound [(tetrahydrocyclopentadienone)tricarbonyliron(oxide)] leaching from the landfill. The initial concentration of perchlorate in the site water was approximately 0.7 mg/L and nitrate was present at 1.0 mg/L. Sulfate was present at 1600 mg/L, chloride at 810 mg/L, the alkalinity was 350 mg/L, and the pH was 6.7. To evaluate the influence of different electron donors on perchlorate degradation, microcosms were prepared in an anaerobic chamber using 30 g of sediment and 100 mL of site groundwater in 160-mL serum bottles. Duplicate bottles received acetate, ethanol, benzoate, molasses, lactate or soybean oil at 20 mg/L. The bottles also received diammonium phosphate to provide approximately 4 mg/L  $\text{NH}_3$  as N and 5 mg/L  $\text{PO}_4$  as P. Duplicate bottles were amended with acetate and 1% formaldehyde to inhibit all microbial activity, and duplicate bottles received no substrate or nutrients. The bottles were incubated at 15°C on a rotary shaker, and subsamples were periodically collected for perchlorate analysis by ion chromatography.

##### Results

Perchlorate analysis in the Site 16 samples proved to be difficult, particularly in samples showing appreciable biodegradation, due to the presence of one or two interfering ions (Figure 18). One of these compounds may be the tricarbonyl iron molecule causing the yellow color of the water. In some instances, the perchlorate ion and a second ion did not separate sufficiently during ion chromatography to allow accurate detection of perchlorate. The water was passed through several filters, including barium, silver, and humic acid filters, but these did not remove the competing ions or improve detection (the humic acid filter actually removed perchlorate at low concentrations). During some sample runs, depending on column pressure and other factors, the perchlorate could be sufficiently separated from the second peak to allow accurate detection. In instances where perchlorate could not be confirmed, samples were reanalyzed until accurate analytical results were obtained.



**Figure 18. Ion Chromatograph of Perchlorate and Interfering Anions in LHAAP Site 16 Groundwater.**

The average concentration of perchlorate in the samples at time 0 was 0.74 mg/L and nitrate was 0.96 mg/L. Nitrate was degraded in samples receiving all substrates except benzoate to near or below detection (0.1 mg/L) during the initial 8 days of the study. No loss of perchlorate was observed during this time. After 21 days of incubation, however, samples receiving molasses, lactate, and acetate showed appreciable perchlorate degradation (Figure 19). Microcosms amended with ethanol also showed perchlorate losses by day 33. Soybean oil and benzoate did not enhance perchlorate biodegradation at this site. On day 36, sample bottles with acetate, molasses, lactate, and no substrate were spiked with additional perchlorate to a concentration of approximately 5 mg/L to confirm that perchlorate degradation was occurring. Perchlorate in the bottles without substrate remained near 5 mg/L. However, those with the three substrates added declined to below detection by day 50 (14 days after perchlorate addition) (Figure 20). Thus, perchlorate biodegradation by indigenous bacteria was stimulated in the Site 16 samples using several substrates.

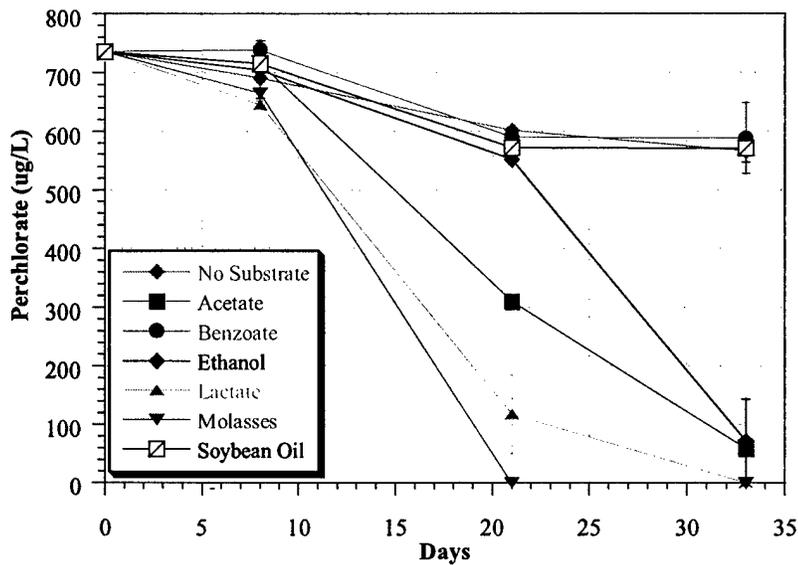


Figure 19. Influence of Different Electron Donors on Perchlorate Levels in LHAAP Aquifer Microcosms.

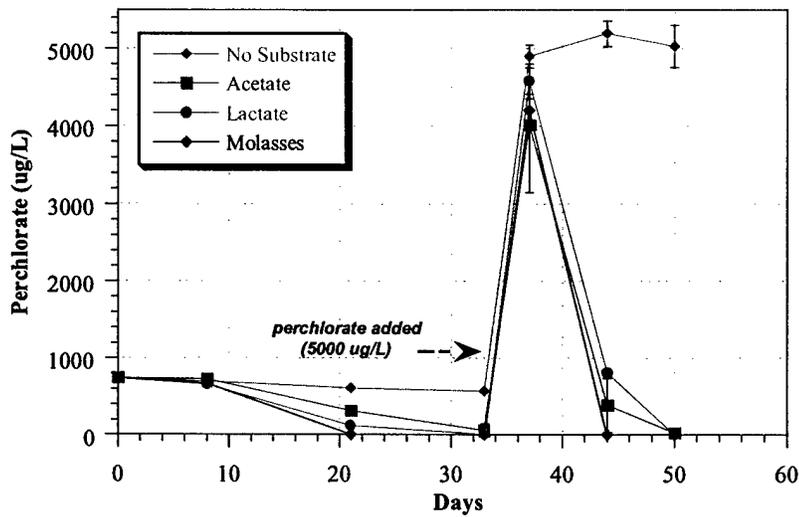


Figure 20. Biodegradation of Perchlorate in LHAAP Microcosms after Respiking with Perchlorate.

#### 4.3.4.3 LHAAP Site 25 – Propellant Mixing Facility

##### Methods

Site 25G at LHAAP is near a former perchlorate mixing facility. Soils and groundwater in the vicinity are heavily contaminated with the propellant. Sediment samples were collected by Geoprobe from a depth of 12 – 16 feet bls. Groundwater was from a nearby monitoring well (LHS-MW6C). The initial concentration of perchlorate in a slurry of the sediment and groundwater was 77 mg/L, nitrate was 1.0 mg/L, sulfate was 280 mg/L, chloride was 140 mg/L, the alkalinity was 51 mg/L, and the pH was 5.73. Microcosms were set up and incubated as described previously for Site 16 using ethanol, acetate, lactate, and molasses as substrates. The starting concentration of each was 200 mg/L. No interfering anions were observed in the Site 25G samples. Unlike Site 16, perchlorate was not degraded in any of the Site 25G microcosm bottles during the 33-day incubation period of the study (Table 4). Nitrate, however was degraded from 1 mg/L to less than 0.2 mg/L in all microcosms receiving ethanol, lactate, and molasses (but not acetate) after only 8 days of incubation. There are numerous differences in geochemistry between the two locations at LHAAP that could cause the difference in perchlorate degradation between the sites. However, one factor previously observed to be inhibitory to perchlorate degradation in samples from the Indian Head Division Naval Surface Warfare Center (IHDIW) was low pH. Although the pH in the Site 25G samples is not particularly low, and is appreciably higher than at IHDIW (5.7 vs 4.3, respectively), an experiment was conducted to determine whether pH adjustment could be used to enhance perchlorate degradation in the samples.

##### Results

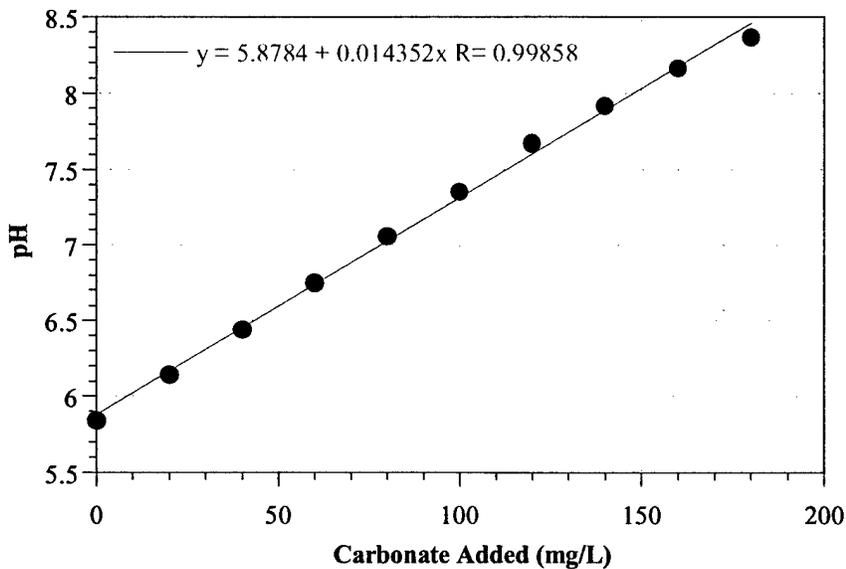
Initially, a titration with carbonate was performed using slurries of groundwater and sediment from site 25G to determine the amount of alkalinity required to increase the pH of the samples to 7. These data are shown in Figure 21. On day 36 of the microcosm study, individual microcosm bottles with ethanol and lactate were amended with carbonate to provide a final pH of 7.2. The duplicate sample microcosm remained at pH 5.7. After 24 days of additional incubation at 15°C (day 60 of the study), the perchlorate in the bottle with ethanol at pH 7.2 declined to 1 mg/L and then to 0.024 mg/L by day 33 (day 69 of the study) (Figure 22). The microcosm with lactate that was brought to a pH of 7.2 also showed appreciably decline in perchlorate by day 33 (< 5 mg/L). Unlike the pH-adjusted samples, no significant losses of perchlorate were observed in the microcosms with ethanol or lactate that remained at a pH of 5.7. Thus, the data clearly show that even a slightly acidic pH (i.e. 5.7), can completely inhibit perchlorate biodegradation in subsurface environments.

An additional study was conducted with Site 25G samples in which the pH was adjusted to 7.2 or left at 5.7, and the samples received one of two pure cultures of perchlorate degrading bacteria isolated during this project (*Dechlorosoma suillum* JPLRND or *Dechlorospirillum* sp. FBR2). Duplicate sample bottles received 15 g of sediment, 30 mL of site water, and one of the perchlorate degrading strains. Carbonate (4 mg) was added to adjust the pH to 7.2 in some samples, and all bottles were incubated at 15°C. In bottles brought to pH 7.2, perchlorate was completely degraded by the augmented strains after 5 days for JPLRND and 15 days for FBR2 (Figure 23). Conversely, no perchlorate degradation was observed at pH 5.7 in any of the samples.

**Table 4. Perchlorate Degradation in Sediment/Groundwater Microcosms from LHAAP Site 25G.**

<i>Electron Donors</i>	Perchlorate Concentration (mg/L) <sup>1</sup>			
	<i>Day 0</i>	<i>Day 8</i>	<i>Day 21</i>	<i>Day 33</i>
Killed Control (Acetate)	77 ± 0	72 ± 0	80 ± 0	79 ± 1
No Addition	77 ± 0	74 ± 2	81 ± 1	82 ± 4
Nutrients Only	77 ± 0	75 ± 1	80 ± 1	80 ± 3
Acetate	77 ± 0	73 ± 1	81 ± 1	78
Ethanol	77 ± 0	74 ± 0	82 ± 0	85 ± 8
Lactate	77 ± 0	74 ± 1	80 ± 1	85 ± 9
Molasses	77 ± 0	72 ± 0	80 ± 1	77 ± 3

<sup>1</sup> Values are the mean ± standard deviation from duplicate microcosms.



**Figure 21. Carbonate Titration Curve for Sediment Slurries from LHAAP Site 25G.**

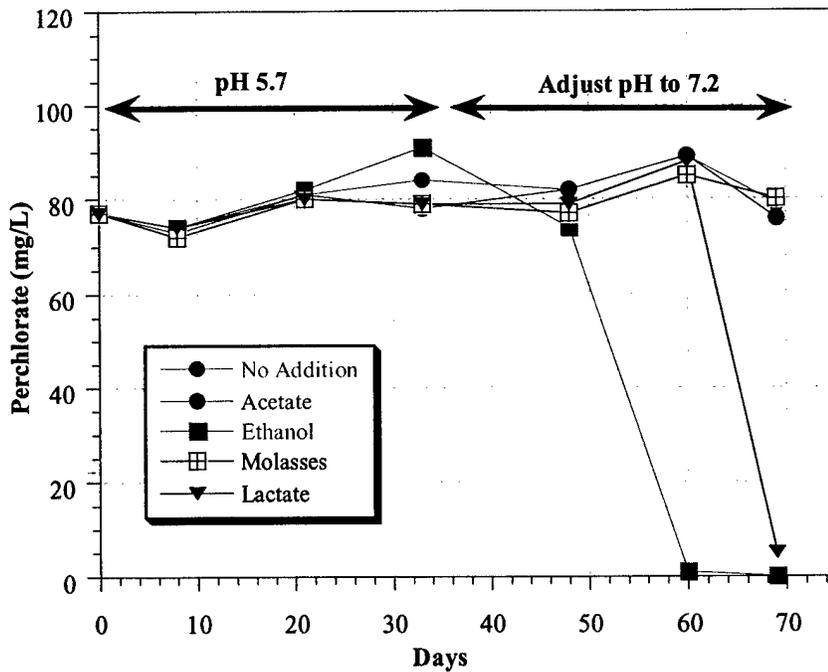


Figure 22. Influence of pH Adjustment on Perchlorate Biodegradation in LHAAP Site 25G Aquifer Microcosms.

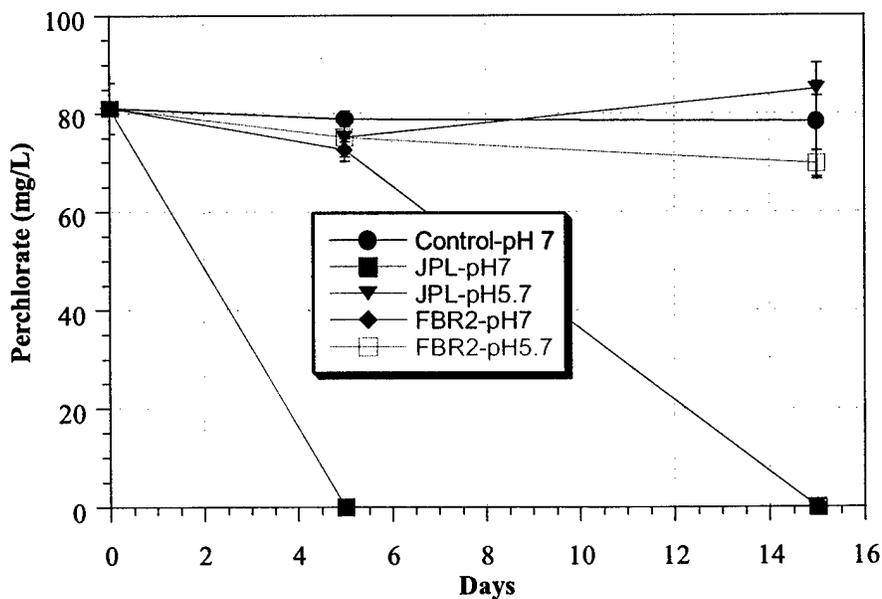


Figure 23. Influence of pH and Bioaugmentation (*Dechlorospirillum* sp. FBR2 or *D. suillum* JPLRND) on Perchlorate Biodegradation in LHAAP Site 25G Microcosms.

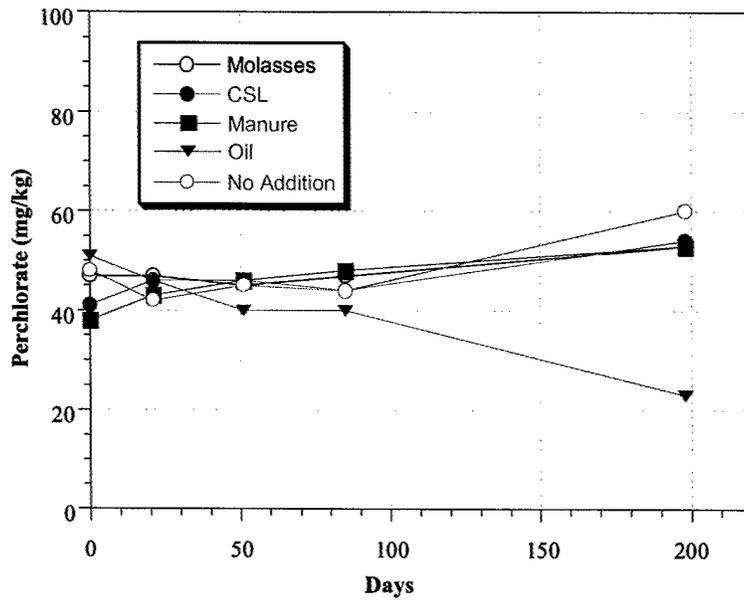
#### 4.3.4.4. LHAAP Site 25C – Biodegradation of Perchlorate in Surface Soils

##### Methods

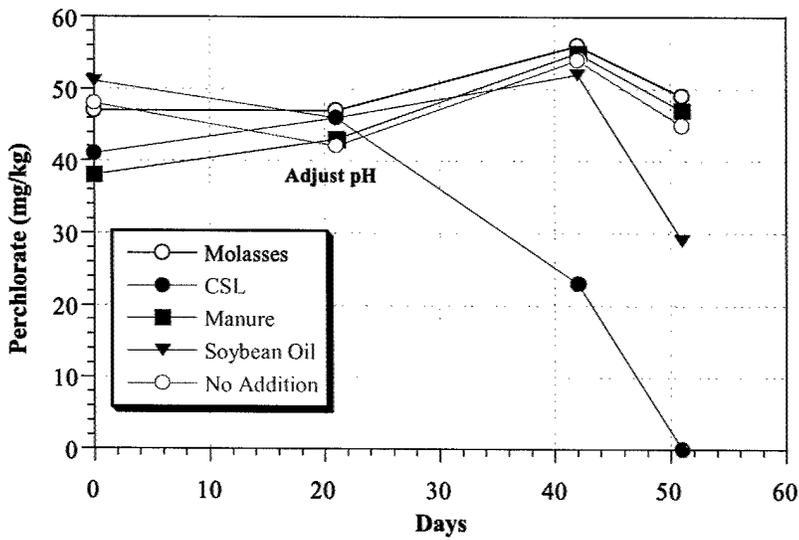
A surface soil was collected from Site 25C at LHAAP from an area with known perchlorate contamination in the high mg/kg range. The surface soils taken only had approximately 1 mg/kg perchlorate upon laboratory testing, so they were spiked with additional perchlorate to an initial level of about 50 mg/kg. The soil was homogenized and 500-g portions were placed in mason jars (1 qt) and amended with bulk substrates including corn-steep liquor, molasses, horse manure, and soybean oil at 1000 mg/kg. A control was prepared by adding mercuric chloride and sodium azide to inhibit microbial activity. The bottles were sealed and incubated at 15°C without shaking. Five-gram subsamples were removed from the bottles periodically in an anaerobic chamber. The samples were extracted by shaking for 1 hour with water, centrifuged to remove solids, and analyzed for perchlorate by IC.

##### Results

Perchlorate degradation was not observed in any of the surface soil samples from Site 25C during more than 80 days of incubation (Figure 24). An additional set of samples were collected after 198 days, and some perchlorate biodegradation was evident (levels reduced to 23 mg/kg) in samples amended with vegetable oil, but not in those with the other electron donors or samples with no electron donor added. The pH of the surface soil was measured at 4.8. Thus, as was observed previously with two sets of aquifer samples, it appears that acidic pH is inhibitory to perchlorate reduction in this surface soil. To test this hypothesis, 200-g subsamples of soil were removed from each sample jar after 21 days of incubation, and the pH in these samples was adjusted to neutrality using lime (calcium carbonate). As with site 25G, a titration was conducted to determine the lime required for appropriate pH adjustment. The increase in pH stimulated perchlorate biodegradation in the samples receiving corn-steep liquor after 20 days and perchlorate was below detection in the soil by 31 days (Figure 25). Soybean oil also stimulated perchlorate degradation in the pH-adjusted soil much more rapidly than in the acidic soil.



**Figure 24. Perchlorate Levels in Surface Soil from LHAAP Site 25C After Amendment with Different Electron Donors.**



**Figure 25. Influence of pH Adjustment on Perchlorate Biodegradation in LHAAP Site 25C Soil Samples Amended with Different Electron Donors.**

## **Conclusions**

The most important finding of the LHAAP microcosm studies is that even a slightly acidic pH (i.e. 5.7) can significantly or completely inhibit perchlorate degradation in site samples, regardless of electron donor addition or bioaugmentation. These results confirm initial findings at the IHDIV site in Maryland and clearly show the importance of evaluating the potential for perchlorate biodegradation using a variety of samples with differing geochemistries. If all samples tested during this project were from the western States where groundwater is usually neutral, this pH effect would not have been observed. The reason that an acidic pH inhibits perchlorate reduction is unclear. It is obvious from all data gathered at this time that perchlorate reducing strains are indigenous in acidic aquifers and soils. It is possible that the perchlorate reductase enzyme or another enzyme in the reduction pathway is inhibited at acidic pH values. Such inhibition could lead to a complete absence of perchlorate degradation (if perchlorate reductase is inhibited) or to the release of a toxic partial degradation product (e.g., chlorite) if a later enzyme is inhibited. This finding may also reflect a less obvious effect of low pH, such as increased solubility and toxicity of metals. Additional pure culture studies are required to better understand the influence of pH on perchlorate degradation.

### ***4.3.5 BOEING CORPORATION, SACRAMENTO, CA***

In the first year of this project, microcosm studies were conducted with samples from several different sites, including the Indian Head Naval Surface Warfare Center (MD), the Longhorn Army Ammunition Plant (TX), Rocky Mountain site (UT), and Jet Propulsion Laboratories (CA) (see previous sections). In the second year, studies focused primarily on flow-through model aquifers, pure cultures, and modeling. However, one additional set of site samples were collected for evaluation of perchlorate biodegradation. These samples were from the Boeing site near Sacramento, CA. The objective of these studies was to determine if perchlorate biodegradation could be stimulated in samples containing extremely low concentrations of perchlorate and without appreciable nitrate. In some instances, bacteria are known to have thresholds below which they will not biodegrade organic substrates (Alexander, 1994). It is unclear whether this threshold may also occur for electron acceptors such as perchlorate. Because there are many perchlorate plumes with concentration levels less than 100 µg/L that may have to be reduced further to less than 4 µg/L, a study was undertaken to evaluate the feasibility of biostimulation for perchlorate treatment at low initial concentrations.

#### 4.3.5.1 Sample Collection

Groundwater samples were collected from the Boeing site into sterile 1L jars from two different contaminated wells and sent to Envirogen on ice. The starting concentration of perchlorate in these samples was 49.8 µg/L (Well 58) and 102 µg/L (Well 44A). Nitrate levels were less than 1 mg/L for each well. During sample collection, the pH of groundwater from well 44A was 7.0, and the redox was -125 mV. The pH of groundwater from well 58 was 6.7, and the redox was -150 mV. Dissolved oxygen was below detection in each well.

#### 4.3.5.2 Microcosm Studies to Evaluate Biodegradation of Low Perchlorate Concentrations and the Influence of Different Substrates on Sulfate Reduction

##### Methods

Groundwater from each well was added in 120-mL volumes to sterile 160-mL serum bottles in a Coy Environmental Chamber (nitrogen headspace). Duplicate samples were then amended with acetate, molasses, or lactate at 20 mg/L each or hydrogen gas (5 mL in headspace). Microcosms were also prepared without added substrate or with 1% formaldehyde (killed controls). Bottles were incubated at 15°C with shaking, and 20-mL subsamples were collected after 9 and 21 days. Samples were filtered, then analyzed for perchlorate (EPA 314.0) and sulfate (EPA 300.0).

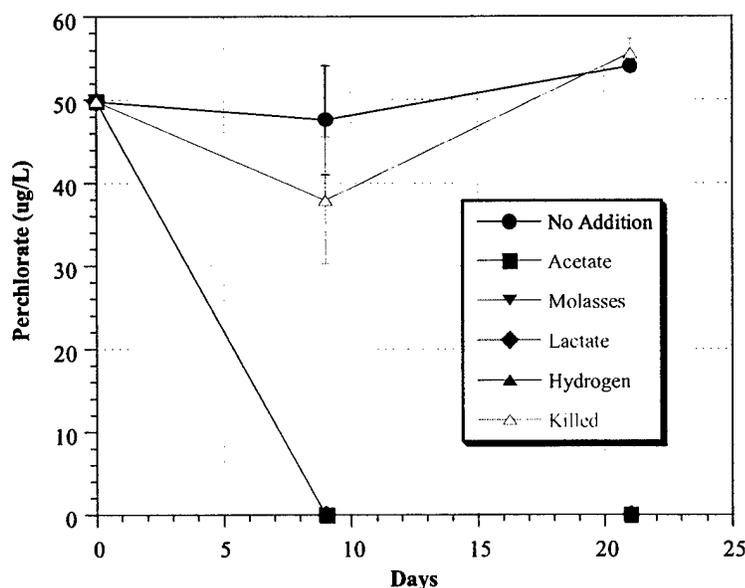
##### Results

The perchlorate levels in groundwater samples from Well 44A were below 8 µg/L in all bottles that received a substrate (acetate, hydrogen, lactate or molasses) after 9 days of incubation. (Figure 26). The concentration in samples without added substrate was 48 µg/L, and that in the killed controls was 38 µg/L after this time. The level of sulfate in all bottles was near the starting concentration of 9 mg/L. By 21 days, all samples with substrate added had perchlorate below 4 µg/L. The sulfate levels were below detection (< 0.4 mg/L) in bottles with molasses and lactate, and had dropped to 5.7 mg/L in samples with hydrogen. The formation of iron sulfide (black precipitate) was also apparent in these samples. Thus, perchlorate biodegradation preceded sulfate reduction in all samples. Interestingly, however, samples amended with acetate showed no sulfate reduction; levels remained near 9 mg/L, and were similar to levels in microcosms without added substrate and in killed controls.

Perchlorate reduction in samples from Well 58 was somewhat variable among replicate microcosms at day 9. For example, in duplicate microcosms with molasses, perchlorate in one bottle was below detection, while that in the second was nearly 100 µg/L. However, by day 21, perchlorate was below 4 µg/L in all sample bottles with organic substrate added. Perchlorate levels in the bottles with

hydrogen averaged 6.2  $\mu\text{g/L}$ . The starting sulfate concentration in samples from this well was approximately 2.5 mg/L. After 21 days of incubation, sulfate in all samples with molasses, lactate, and hydrogen was below detection ( $< 0.4$  mg/L), while that in samples with acetate remained at 2.5 mg/L. There was also no sulfate reduction in samples without added substrate or in killed controls.

After incubation for 75 days, aqueous samples were taken from each bottle and sulfate levels were determined. In well 44A, average sulfate levels were 8.7 mg/L and 9.0 mg/L in samples without electron donor and in killed controls, respectively. These levels were near the initial level of 8.5 mg/L. In samples amended with molasses, lactate, and hydrogen, sulfate levels were less than 0.4 mg/L and samples were black, showing that appreciable sulfate reduction had occurred. Conversely, sulfate levels in bottles amended with acetate averaged 7.4 mg/L. Thus, some sulfate was probably reduced in these samples (about 1 mg/L) based on control values, but the extent of this process was much less than observed with other substrates. In samples from well 58, the starting sulfate concentration was 2.7 mg/L. There was no appreciable loss of sulfate in killed controls (2.7 mg/L sulfate) or those without electron donor added (3.0 mg/L sulfate) after 75 days. The average sulfate was below detection ( $< 0.2$  mg/L) in samples receiving hydrogen, lactate, and molasses. The final sulfate concentration in acetate-amended samples was 0.65 mg/L. Thus, about 2 mg/L sulfate was reduced in these samples. Although there was some sulfate reduction in acetate-amended samples over 75 days of incubation, the data suggest that acetate is a much poorer substrate for sulfate-reducing bacteria than the others tested. Sulfate reduction is not a desired side effect in drinking water aquifers. These data suggest that acetate may be one substrate that effectively stimulates perchlorate reduction but does not yield reduction of sulfate.



**Figure 26. Biodegradation of Low Concentrations of Perchlorate in Groundwater Microcosms from Boeing Corp.**

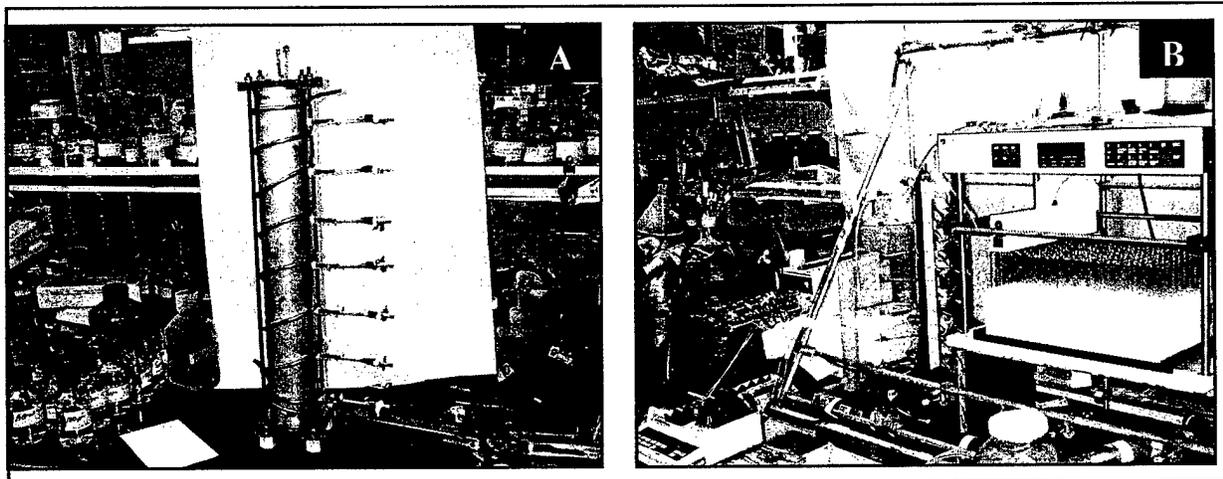
## Conclusions

Although there is now appreciable data from this and the two companion SERDP projects showing that perchlorate reduction can be stimulated in the subsurface by addition of various electron donors, the results of this study using groundwater samples from Boeing Corp. are significant for two reasons. First, these are the first data showing that perchlorate treatment to less than 4  $\mu\text{g/L}$  is possible from starting concentrations as low as 50  $\mu\text{g/L}$  using biostimulation. Second, the data reveal that lactate, molasses, and hydrogen support rapid and appreciable sulfate reduction after perchlorate is biodegraded, but that sulfate reduction is much less prevalent with acetate as a substrate. The formation of hydrogen sulfide from sulfate reduction may not be an acceptable endpoint from *in situ* perchlorate treatment, particularly in drinking water aquifers. These data suggest that acetate may be a better choice than several other substrates for perchlorate bioremediation.

## 4.4 EVALUATE PERCHLORATE BIODEGRADATION AND TRANSPORT IN PILOT-SCALE MODEL AQUIFERS

### 4.4.1 MODEL AQUIFER CONSTRUCTION

A flow-through model system better approximates *in situ* aquifer conditions than either an aqueous system or a static microcosm, and being continuous flow, inputs of perchlorate, substrates, and other groundwater constituents can be controlled and varied. A model aquifer was constructed and flow characteristics with sand and a natural subsurface sediment were tested. Two photos of the aquifer column are provided in Figure 27. The aquifer column was constructed from a stainless steel tube 50-cm long by 7.6-cm diameter (*see* Figure 28 for details). The bottom and top of the column are set in acrylic plates with ports for influent and effluent water flow. The two acrylic plates are held together with threaded rods on each corner. An aluminum diffuser plate is placed just above the influent flow port to provide mixing of water at the bottom of the column. Several experiments were conducted to determine the optimal design for the diffuser plate. The columns have sampling ports every 3.5 cm from the bottom (upward flow) which consist of an 18-gauge steel needle inserted to the center of the column through a barbed plastic fitting. Each needle is sealed with Norprene tubing to prevent leaks. Every other sample port is offset by 90 degrees. The entire column is wrapped in copper tubing over which is a layer of foam insulation. Water at 15°C is run through the copper tubing to maintain the entire column at groundwater temperature. A peristaltic pump supplies a continuous flow of groundwater from a reservoir (also temperature controlled) to the influent port at the bottom of the column. An additional syringe pump is attached in series to allow a slug of aqueous solution (containing substrate, electron acceptors, bacteria, etc.) to be independently applied to the column. The entire system is airtight so that anaerobic conditions can be generated within the column.



**Figure 27. Photographs of the 50-cm Model Aquifer Column During Construction (A) and Receiving Groundwater Flow During Tracer Studies (B).**

#### **4.4.2 EVALUATION OF INFLUENT WATER MIXING**

The column was initially packed with 3000 g of a silica quartz sand (99.4 % SiO<sub>2</sub>) of 0.45 – 0.50 mm diameter. The total pore volume of the sand column was measured at 946 mL, giving a porosity of 315 mL/kg sand. Initial bromide tracer tests were conducted to evaluate mixing of water at the bottom of the column. To conduct these studies influent water was amended with a pulse of bromide (~ 40 mg/L for 60 min) and passed through the column at a flow rate of approximately 50 mL/hr. Aqueous samples were removed with time from the sampling port 7 cm from the bottom of the column. The water was sampled from the center of the column, ½ the radius of the column, and at column outer edge, to determine the distribution of bromide (and thus water mixing) through the bottom section of the sand column. In the initial studies, the aluminum diffuser plate had 16 holes drilled at ½ the radius of the column. Thus, water entering the column was forced to distribute through these holes rather than moving in a slug up the center of the column from a single port. The initial mixing study showed that the water was traveling preferentially up the side of the column (Figure 29). The data suggested that, although the diffuser plate was fit tightly into the column, water was moving around as well as through the plate. The diffuser was sealed into the column with silicone caulk to prevent this flow path. The experiment was repeated and the results showed a much more equal distribution of bromide across the column, suggesting reasonable mixing (Figure 30). There was some lag in water flow at the edge of the column with the diffuser design, so a second diffuser with two rows of holes at 1/3 and 2/3 of the radius of the plate was tested to determine if mixing at the bottom of the column could be improved further. The results of the second diffuser were not appreciably different than the first. The mixing at the bottom of the column was deemed to be adequate for modeling work with either diffuser design.

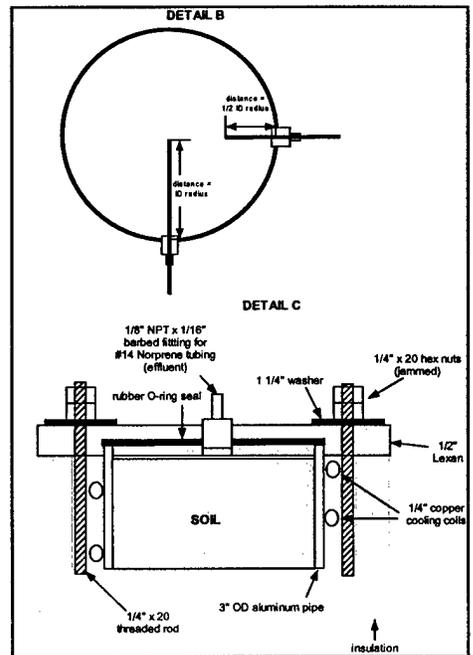
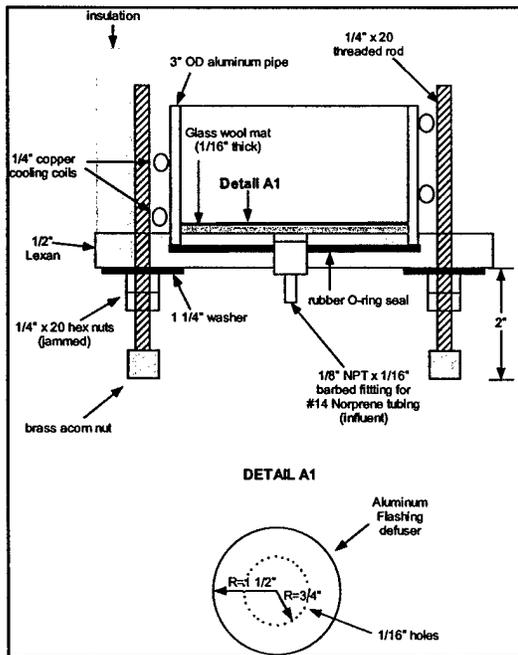
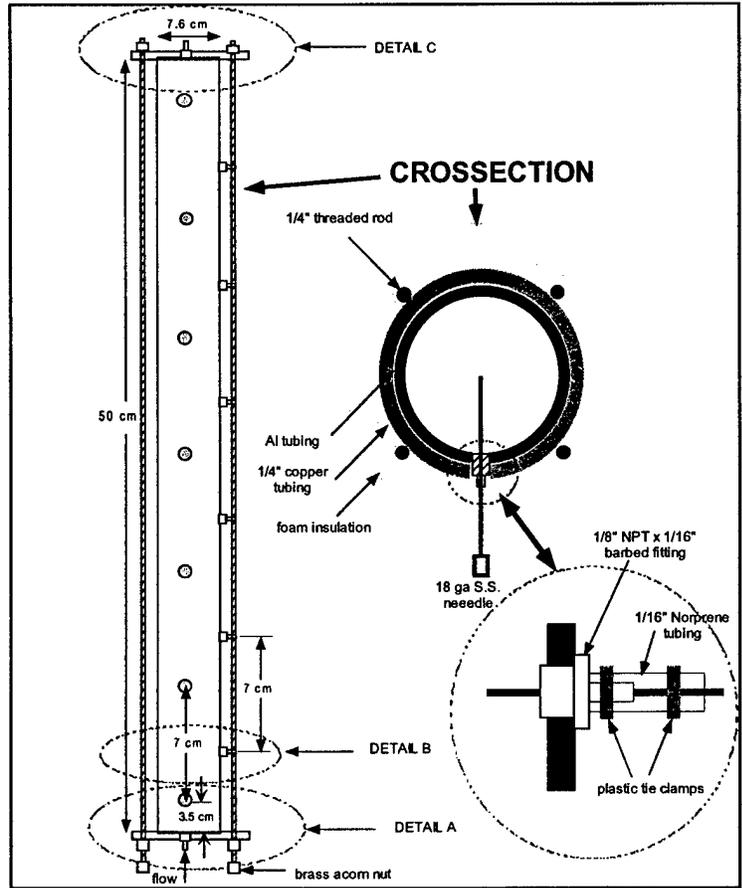
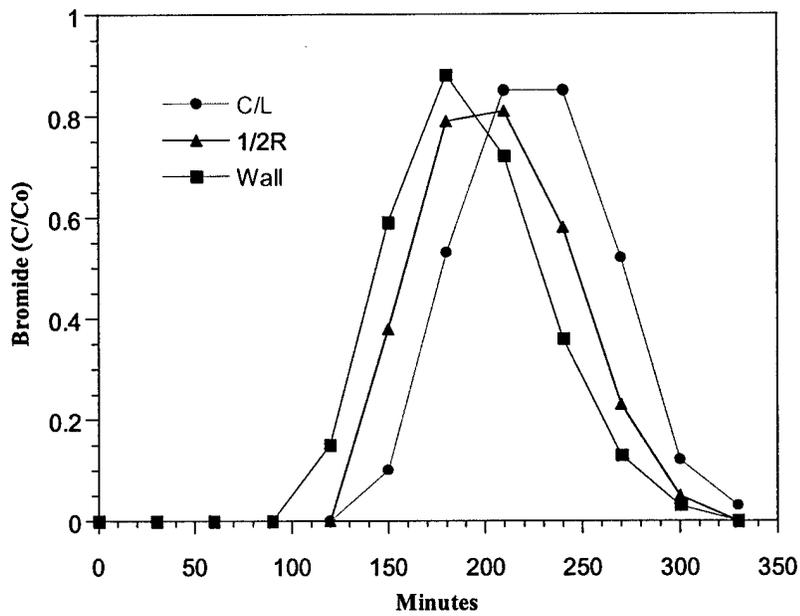
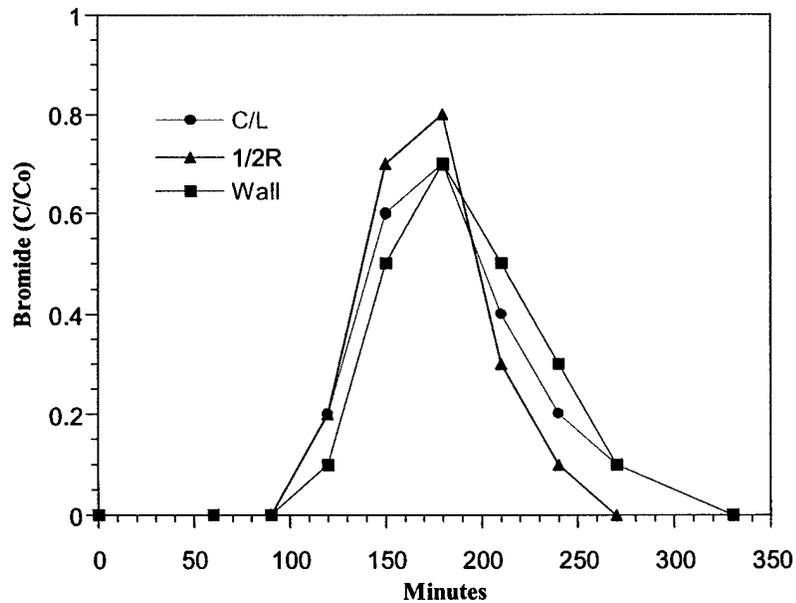


Figure 28. Design Specifications of Model Aquifer Column.



**Figure 29. Flow of Bromide Through the Model Aquifer with Unsealed Diffuser Plate. Notations are as Follows: C/L = Column Center; 1/2R = 1/2 Column Radius; Wall = Column Wall.**

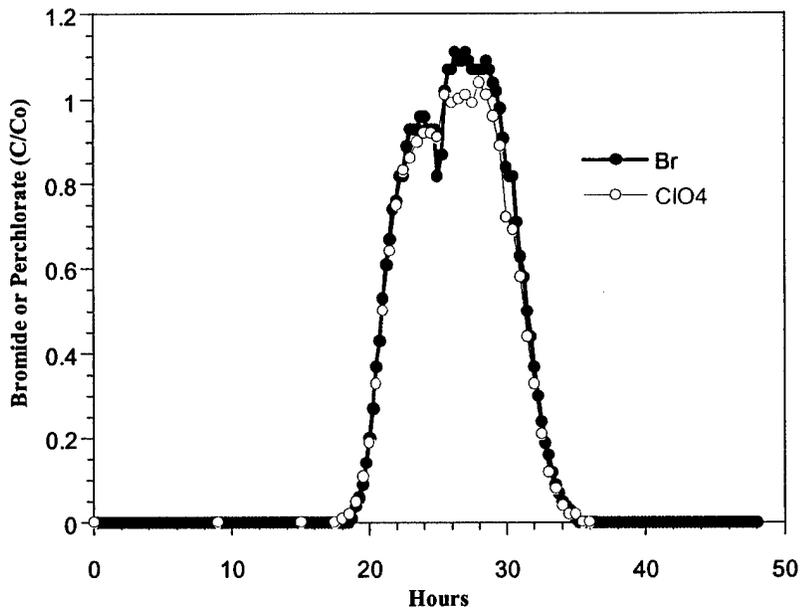


**Figure 30. Flow of Bromide Through the Model Aquifer with Sealed Diffuser Plate. Notations are as Follows: C/L = Column Center; 1/2R = 1/2 Column Radius; Wall = Column Wall.**

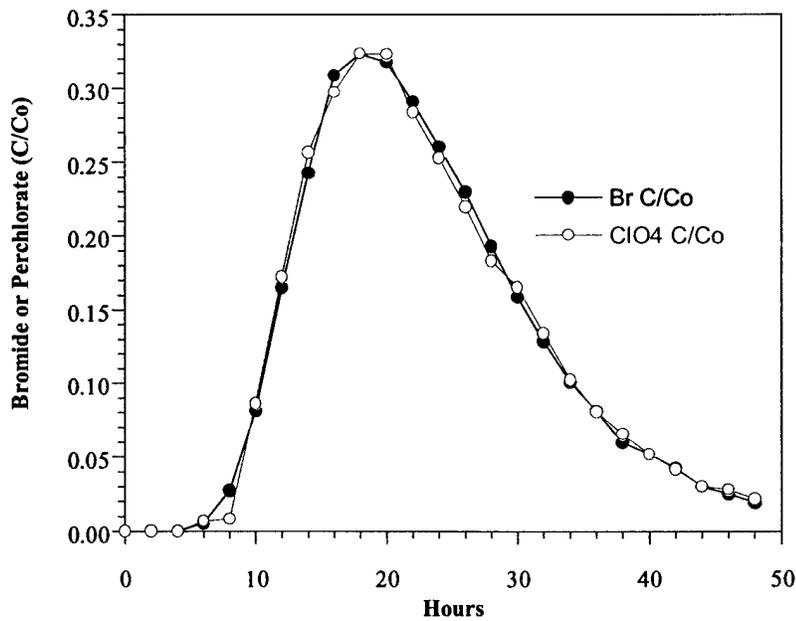
#### **4.4.3. TRANSPORT OF PERCHLORATE THROUGH SILICA SAND AND AQUIFER SEDIMENT**

The transport of perchlorate through the sand column was tested using bromide as a conservative tracer. To conduct this study, approximately ½ pore volume (480 mL measured) of tracer containing bromide and perchlorate at 50 mg/L each was applied to the column in an artificial groundwater (AGW). The AGW recipe was designed to mimic site groundwater from a location in Virginia. The water was oxygenated to ensure that perchlorate was not biodegraded during the study. The initial pulse of perchlorate and bromide was followed by AGW only. Fractions were collected at the effluent port of the column at 15-min intervals and analyzed for both bromide and perchlorate using ion selective probes. The effluent data revealed that perchlorate and bromide moved very similarly through the sand column (Figure 31). Perchlorate breakthrough was slightly more rapid than for bromide, which may reflect exclusion of perchlorate in some small pores, as bromide is a smaller molecule. There was also a slightly higher fraction ( $C/C_0$ ) of bromide compared to perchlorate at the peak of the breakthrough curve. However, studies conducted after this tracer test revealed that the bromide probe was inaccurate (reading high) at higher bromide concentrations, even after appropriate standardization. Additional tracer experiments were analyzed by ion chromatography to verify probe results.

After the studies with silica sand were finished, the aquifer column was cleaned and packed with sediment from LHAAP Site 16. The sediments, which were collected from 16 – 26 ft bls, were removed from core liners, passed through a 4-mm sieve to remove rocks and debris, and thoroughly homogenized. The column was packed with 3258 g of field moist sediment (2891 g dry wt). The total pore volume in the column was 988 mL and the porosity was calculated as 303 mL/kg soil. An artificial groundwater was prepared based on the characteristics of water collected from EW-1 at Site 16 for use in column studies. A bromide tracer test was initially conducted to evaluate the flow characteristics of water through the LHAAP sediment core (Figure 32). This test was followed by two tracer studies to characterize the conservative transport of perchlorate through the column. In the initial test, the transport of perchlorate was measured at a flow rate of approximately 42 mL/hr. The second test was conducted at approximately half of this flow rate. As with the sand core, the tracer studies revealed that perchlorate and bromide moved in a similar fashion through the site sediments.



**Figure 31. Transport of Bromide and Perchlorate Through the Model Aquifer Column Packed with Silica Sand.**



**Figure 32. Transport of Bromide and Perchlorate Through a Model Aquifer Column Packed with LHAAP Site 16 Sediment.**

#### **4.4.4 EVALUATION OF PERCHLORATE AND NITRATE BIODEGRADATION**

After initial experiments to evaluate transport through the column, nitrate and perchlorate were added to influent groundwater and flow was initiated. For initial conditions in the column, perchlorate was added at 25 mg/L, nitrate was added at 16 mg/L, and oxygen was present at approximately 8 mg/L. These additions represent approximately equimolar quantities (0.25 mM) of each of these three electron acceptors. These values are not the same as those found naturally at LHAAP Site 16, but were used for laboratory experimentation. The other ions in the groundwater include sulfate at 1700 mg/L, chloride at 933 mg/L, calcium at 241 mg/L, magnesium at 176 mg/L, sodium at 989 mg/L. The alkalinity was 350 mg/L (as calcium carbonate), and the pH was 6.9.

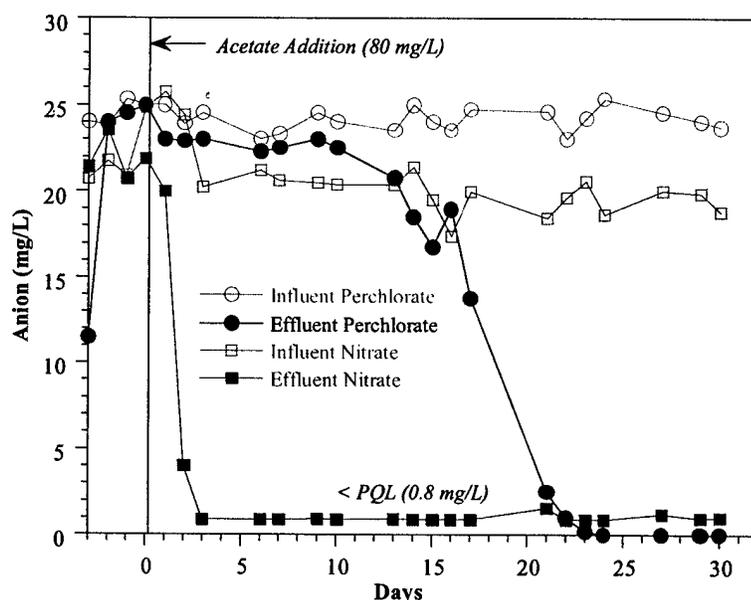
The initial groundwater flow rate to the column was set at 40 mL/hr which equals a residence time of approximately 24 hrs and a flow of 50 cm/day. Groundwater was passed through the column for 3 days without addition of acetate. The perchlorate and nitrate concentrations in the influent were the same as in the effluent water when the acetate flow was started (i.e., neither electron acceptor was degrading in the column). A separate syringe pump was used to add acetate to the influent flow line to the column. The pump was set initially to supply the electron donor at a concentration of 80 mg/L. This quantity of acetate is two times that stoichiometrically required to reduce oxygen, nitrate, and perchlorate in the feed water. The influent feed was also amended with diammonium phosphate to supply approximately 4 mg/L ammonia and 8 mg/L phosphate as inorganic nutrients.

The influent and effluent lines were sampled for perchlorate, nitrate, dissolved oxygen, and acetate 4 to 5 times per week. At least once per week, a profile was collected along the length of the column to determine the concentrations of each of the electron acceptors and acetate with distance up the column. The profile was taken by sampling points at 0, 3.5, 7, 14, 21, 28, 35, 42, and 50 cm from the bottom of the column. Because of the limited sample volume available, dissolved oxygen was analyzed using a colorimetric test kit (Chemets; Chemetrics, Inc., Calverton, VA). Nitrate was analyzed using ion chromatography (EPA 300.0) and perchlorate was analyzed using an ion-specific electrode and by ion chromatography (EPA 314.0) depending on concentration. Acetate was analyzed using gas chromatography with flame ionization detection (GC-FID). The lower detection limit for acetate was approximately 5 mg/L using this method. All water samples were passed through a 0.22-micron filter after collection. A subsample for acetate was collected from the original sample and further preserved using mercuric chloride.

The column was operated under the conditions described for a period of 48 days after acetate addition began. Levels of perchlorate and nitrate in the influent and effluent water are provided in Figure 33. The concentration of nitrate in the effluent declined from approximately 20 mg/L when the acetate

addition began to less than 1 mg/L (PQL) by day 3 after electron donor addition commenced. The nitrate remained below detection in the effluent throughout the duration of the 48-day period. The level of DO in the column influent varied between 7 and 9 mg/L. The effluent concentration prior to acetate addition was approximately 4 – 4.5 mg/L. This level declined to 2 mg/L by day 3, then to <1 mg/L by day 13. The oxygen remained at or below 1 mg/L according to the colorimetric assay. Perchlorate biodegradation began after approximately 2 weeks of operation. The level of perchlorate declined to 14 mg/L by day 17 (from an influent concentration of 25 mg/L), and was below detection by day 24 (PQL: 40 µg/L). Perchlorate remained below detection in the column effluent for the remainder of the 48-day duration of this experimental phase.

The target level of acetate in the influent water of the column was 80 mg/L. This level was expected to provide approximately 40 mg/L excess acetate based on stoichiometric calculations. Acetate measurements during the initial few weeks of column operation were not reliable because biodegradation was occurring in some of the samples during storage. Although the samples were filtered and stored at 4°C awaiting analysis, some were apparently contaminated during subsampling for perchlorate and nitrate. This problem was resolved by taking subsamples for acetate analysis at the time of collection and preserving them with mercuric chloride. When reliable data were obtained, the influent acetate levels varied from approximately 66 to 99 mg/L. When the column was in an apparent steady state on days 42 – 44, influent acetate values were 97, 99, and 95 mg/L and effluent concentrations were 23, 28, and 21 mg/L, on days 42, 43, and 44, respectively. Thus, the average acetate consumption during this period was 73 mg/L. This is approximately 30 mg/L greater than predicted from reaction stoichiometry, even taking biomass growth into account. Although there is a high concentration of sulfate in the groundwater (1700 mg/L), sulfate reduction was not occurring in the column based on periodic sulfate measurements and based on odor (no hydrogen sulfide was detected during sampling). Greater than expected acetate consumption has also been noted in previous serum bottle studies as well as in studies with fluidized bed reactors when nitrate and perchlorate were present. The reason for the extra consumption of acetate is not yet clear.



**Figure 33. Initial Biodegradation of Perchlorate and Nitrate in Model Aquifer with LHAAP Site 16 Sediment.**

The column profiles were taken beginning on day 14 after acetate addition. Most of the added nitrate was found to be degrading within the first 3.5 cm of the column in profiles taken from day 14 to day 48. Occasionally a small amount of nitrate was detected further in the column, but generally all was degraded by the first sample point. Conversely, perchlorate degradation was observed to begin well after the nitrate was biodegraded. A representative column profile from day 44 is provided in Figure 34. The profile of perchlorate degradation slowly moved down the column with time (i.e., the anion was degraded over a shorter column distance with time in the study). However, perchlorate degradation always occurred after nitrate, and thus appears to be appreciably slower than nitrate reduction. A series of perchlorate profiles in the model aquifer column with time (day 16 – day 44) are given in Figure 35.

After 48 days of groundwater flow and acetate addition, the acetate and nutrient feed pump was turned off. Without addition of electron donor, perchlorate in the effluent from the column increased from below detection at day 49 to 7 mg/L at day 50 and then to greater than 17 mg/L by day 52. Influent and effluent concentrations of the anion were the same from day 52 to day 59 (when the acetate feed was started again). Nitrate was also observed in the effluent water in the absence of added electron donor. Effluent concentrations of 4 and 13.5 mg/L were recorded on day 49 and day 52, respectively. The effluent concentration did not increase all the way back to the influent concentration by day 59, but remained in the vicinity of 14 mg/L, while the feed concentration was about 20 mg/L. Thus, some residual denitrification, but not perchlorate reduction, occurred during the period when electron donor

was not supplied. A graph showing perchlorate concentrations in feed and effluent water through greater than 100 days of operation is given in Figure 36.

The acetate feed pump was restarted at the previous rate on day 59 and the flow and anion concentrations were the same as before the electron donor was shut off. Perchlorate and nitrate levels in the column effluent again decreased to below detection within a few days. Between days 76 and 80, the nitrate concentration was increased from approximately 20 mg/L to 80 mg/L and then greater than 100 mg/L. When nitrate levels reached 100 mg/L, perchlorate biodegradation was no longer occurring in the column (i.e., influent and effluent concentrations were the same). Nitrate levels in the effluent water were approximately 25 mg/L during this time. No perchlorate degradation was observed during this time, rather all of the acetate supplied to the column (~ 80 mg/L) was consumed during reduction of oxygen and nitrate. In addition, the amounts of oxygen and nitrate consumed during acetate consumption was very close to that expected based on stoichiometry. Thus, the initial extra use of electron donor during the first phase of testing appears to reflect increased acetate consumption for perchlorate reduction. A column profile showing concentrations of acetate, nitrate, and perchlorate after nitrate levels were increased is provided in Figure 37 (day 84).

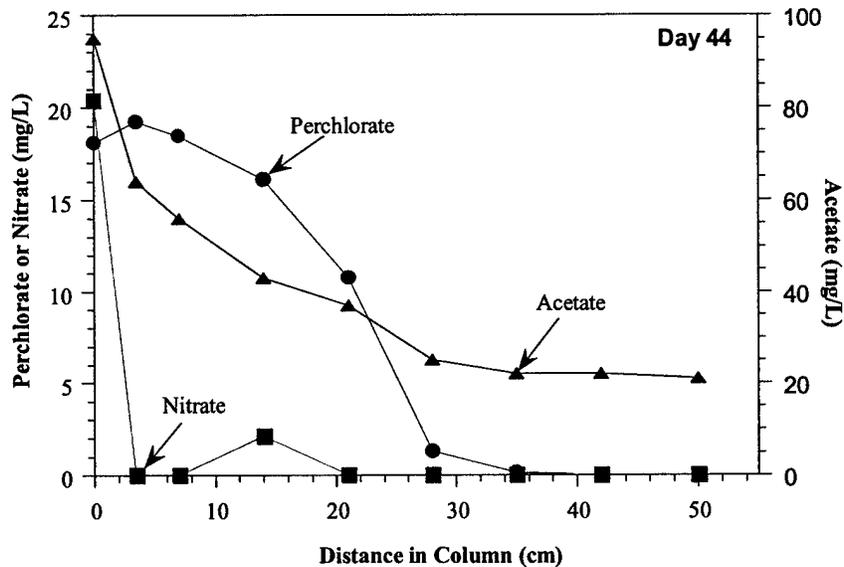


Figure 34. Representative Profile of Perchlorate, Nitrate, and Acetate Biodegradation in Model Aquifer Column.

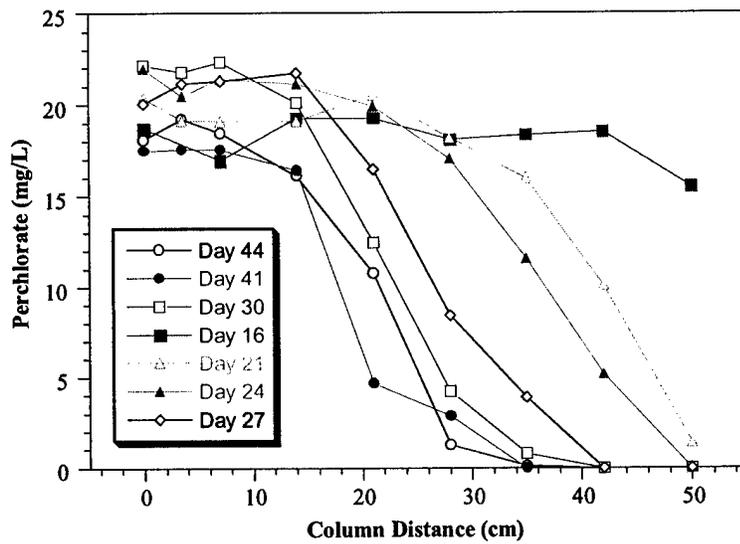


Figure 35. Perchlorate Profiles in Model Aquifer Column as a Function of Time.

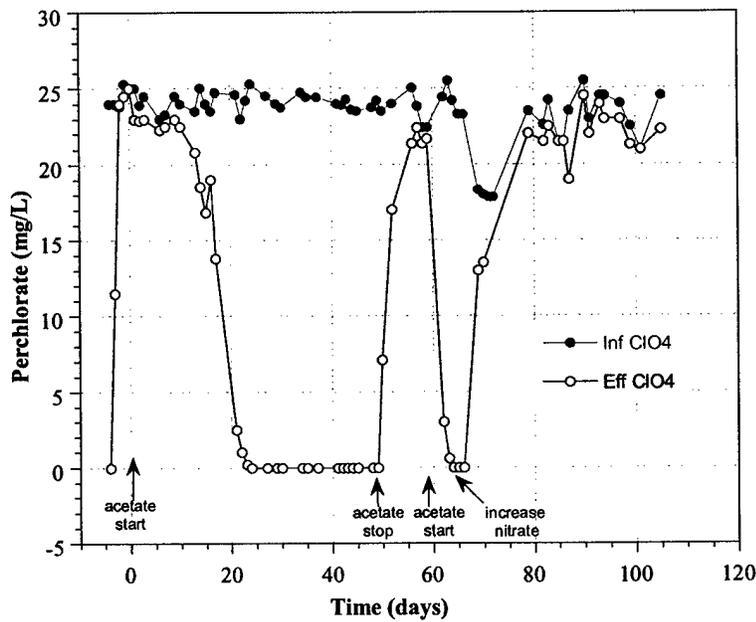
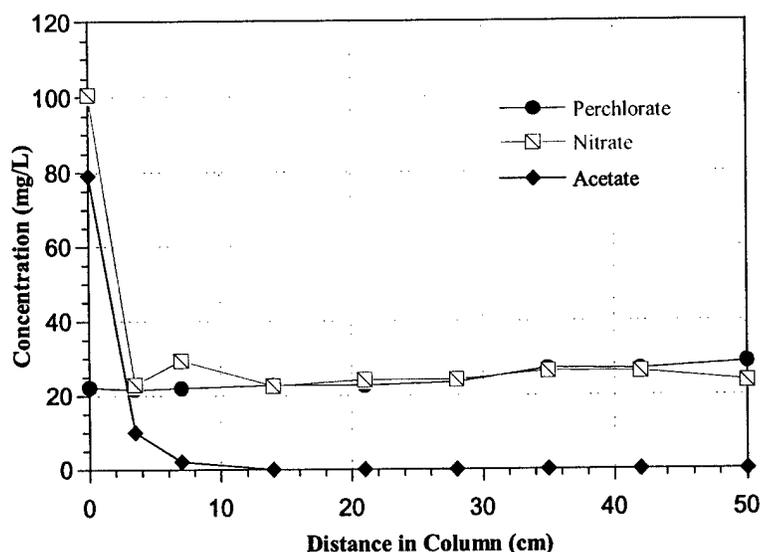


Figure 36. Influent and Effluent Concentrations of Perchlorate in Model Aquifer Column Packed with LHAAP Site 16 Sediment.



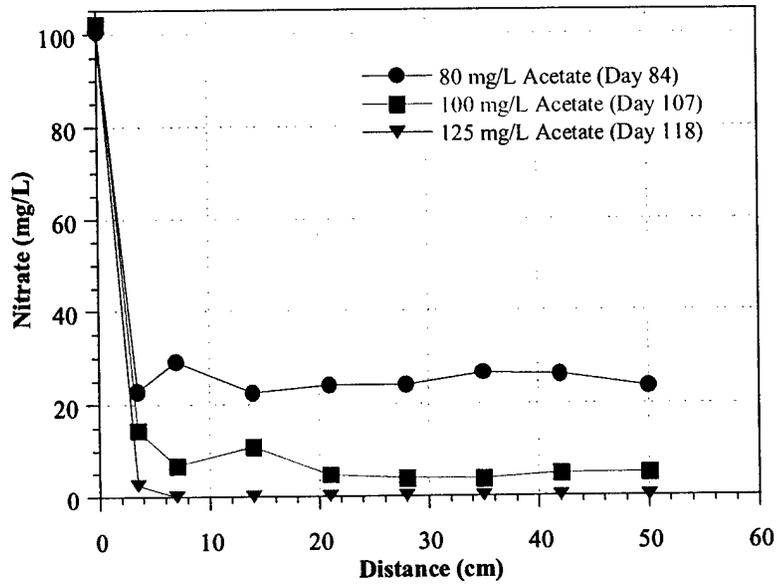
**Figure 37. Profile of Perchlorate, Nitrate, and Acetate Biodegradation in Model Aquifer Column After Nitrate Levels were Increased.**

The feed of electron donor (acetate) was increased from approximately 80 to 100 and then to 125 mg/L to determine if perchlorate reduction could be stimulated when nitrate was depleted, or if some perchlorate would degrade in the presence of low levels of nitrate. The increase in acetate supply was achieved by increasing the flow of the syringe pump supplying the electron donor, rather than changing concentration. The increase in electron donor from 80 to 100 mg/L caused residual nitrate levels to decline from 25 to approximately 5 mg/L (Figure 38). No reduction of perchlorate was observed after this increase in acetate (Figure 39), and all of the acetate was consumed within the first 7 cm of the column (Figure 40). Increasing the acetate feed to 125 mg/L resulted in perchlorate biodegradation. After this increase, all of the nitrate entering the column was degraded within the first 3.5 cm of the column and perchlorate biodegradation was then observed from approximately 14 to 28 cm in the 50-cm column. Thus, at 125 mg/L addition, the quantity of acetate entering the aquifer column was sufficient to support degradation of all nitrate (100 mg/L) and oxygen (8 mg/L), then approximately 80% of the perchlorate. Perchlorate reduction was not observed until each of these competing electron donors was consumed, and enough residual acetate was present to support perchlorate biodegradation.

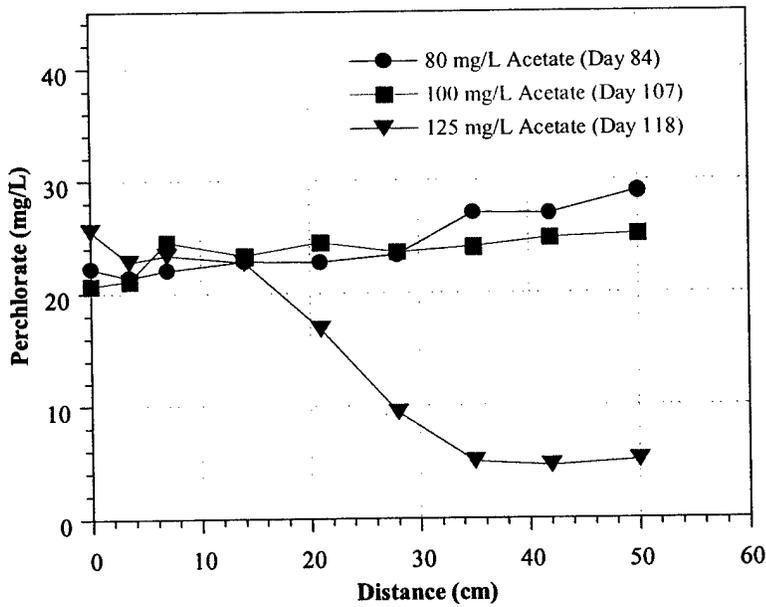
After this phase of testing, nitrate was removed from the artificial groundwater (prepared in the laboratory to simulate groundwater at LHAAP), the perchlorate concentration was increased to 50 mg/L, and the acetate feed was again reduced to 80 mg/L. Perchlorate was present in the effluent water at a concentration of 11.5 mg/L after 3 days without nitrate (day 125). The concentration then declined to 3.4 mg/L on day 4, and to below detection by day 5. After 12 days, nitrate was again added to the

groundwater at a concentration of approximately 100 mg/L. A column profile taken 18.5 hrs (1 day) after addition of nitrate revealed that both electron acceptors (nitrate and perchlorate) were degrading simultaneously within the column (Figure 41). However, denitrification rapidly replaced perchlorate reduction as the dominant microbial process within the 50-cm column. Perchlorate, which was below detection in the column effluent for several days prior to nitrate addition, was present in the effluent water at 3.7 mg/L 18.5 hrs after addition of nitrate (~ 0.8 pore volumes). The perchlorate concentration in the effluent increased to 26.4 mg/L two days after addition of nitrate, then to greater than 40 mg/L by day 5 after nitrate addition. The decline in perchlorate reduction after nitrate addition is apparent in column profiles taken during this period (Figure 42). One of the interesting findings of this phase of column testing is that biological nitrate reduction occurs preferentially to perchlorate reduction, even though the thermodynamics of the two processes are similar. The kinetics of nitrate reduction with acetate as electron donor appear to be favorable to the kinetics of perchlorate reduction. Thus, in general, when electron donor is limiting, all electron donor is consumed during denitrification, and perchlorate reduction does not occur. Another possible explanation for this finding is that nitrate actually inhibits perchlorate reduction through a biochemical mechanism (i.e., competitive or noncompetitive enzyme inhibition).

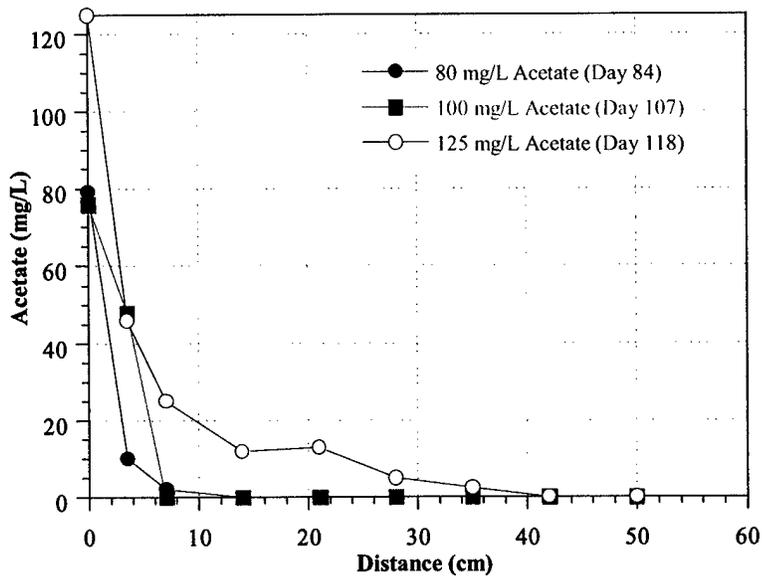
As described in section 4.5.6, a pure culture study was conducted to evaluate whether the prevalence of denitrification over perchlorate reduction reflects the relative kinetics of the two processes or a biochemical inhibition. In this experiment, *Dechlorosoma suillum* JPLRND (pure culture isolated from groundwater at the Jet Propulsion Laboratory) was incubated with perchlorate (and acetate as electron donor) until active degradation of perchlorate was observed. At this time, the culture was quickly split into several flasks, and these flasks were amended with different concentrations of nitrate. The data from this study showed that the rate of perchlorate reduction was reduced dramatically by the addition of nitrate, and that this reduction was directly proportional to nitrate concentration. The results suggest that nitrate is a biochemical inhibitor of perchlorate reduction, (probably an inhibitor of the perchlorate reductase enzyme). The data also provide one explanation for the preferential degradation of nitrate compared to perchlorate in the flow-through columns.



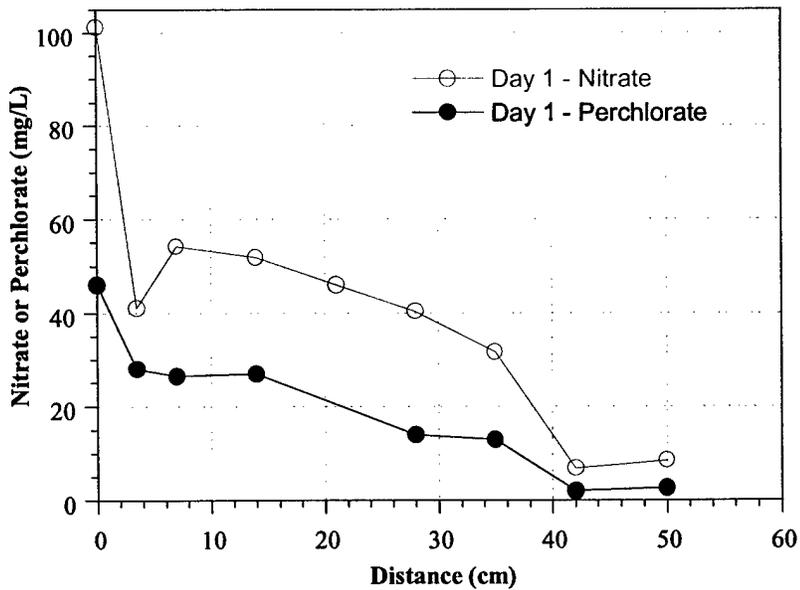
**Figure 38. Profiles of Nitrate in Aquifer Column with Increasing Levels of Electron Donor (Acetate).**



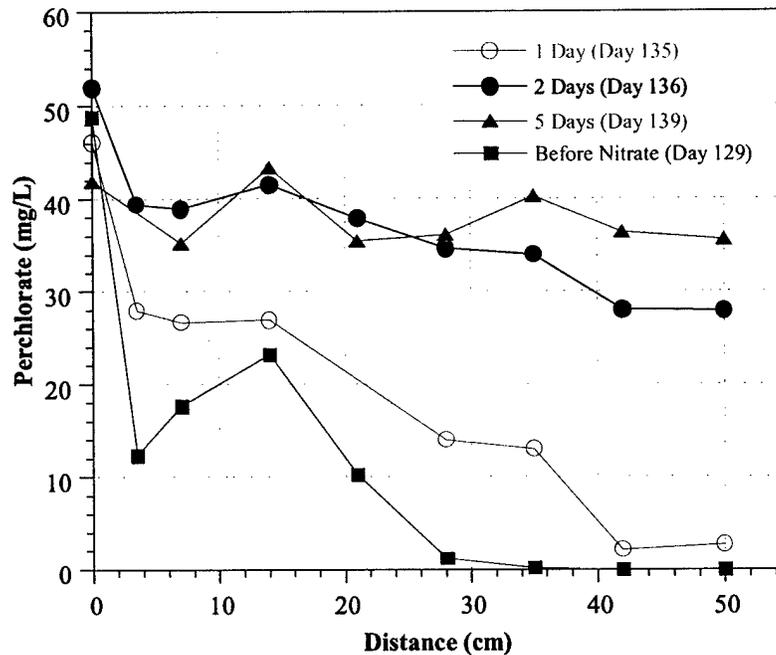
**Figure 39. Profiles of Perchlorate in Aquifer Column with Increasing Levels of Electron Donor (Acetate).**



**Figure 40. Profile of Acetate in Aquifer Column with Increasing Levels of Electron Donor (Acetate).**



**Figure 41. Profile of Nitrate and Perchlorate in the Aquifer Column 1 Day (18.5 hrs) after Nitrate was Added to Groundwater.**



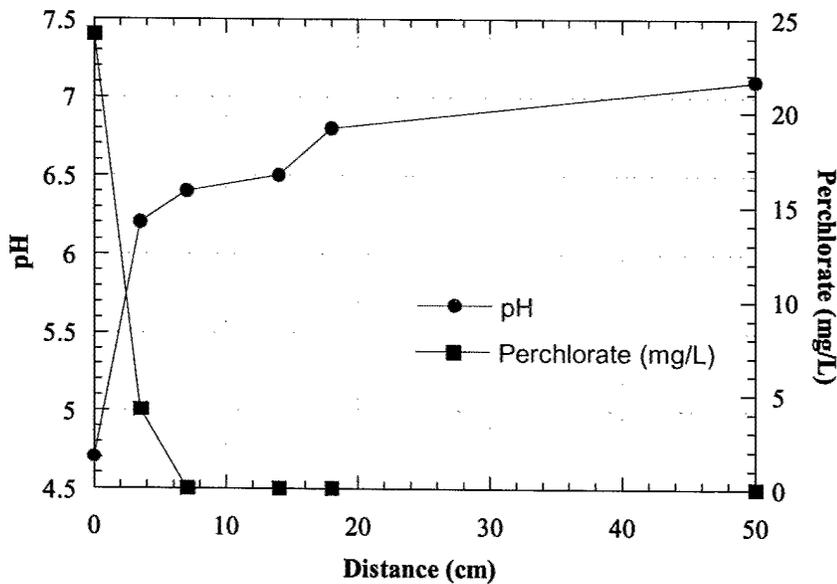
**Figure 42. Profiles of Perchlorate in the Aquifer Column with Time after Nitrate (100 mg/L) was Added to Groundwater.**

#### **4.4.5. INFLUENCE OF pH ON PERCHLORATE REDUCTION**

At the conclusion of studies with nitrate, the influence of groundwater pH on perchlorate reduction was evaluated in the 50-cm aquifer column. Previous microcosm studies with site samples from LHAAP and IHDIV revealed that perchlorate degradation is inhibited below a pH of approximately 5.7, but that degradation can be quickly stimulated with buffering to pH 7. An attempt was made to explore this effect further using the model aquifer. To do this, sodium bicarbonate was initially removed from the artificial groundwater used in the column studies. This reduced the pH from 7 to approximately 5. Prior to this modification, the starting perchlorate level was adjusted down to approximately 25 mg/L and the nitrate was adjusted to 16 mg/L (approximately 0.25 mM each). The initial acetate concentration was 80 mg/L. Prior to pH adjustment, both perchlorate and nitrate were degrading from initial levels to below detection within the first 7 cm of the 50-cm column. The adjustment in pH did not influence the kinetics of perchlorate reduction. However, the buffering capacity of the soil in the column was quickly bringing the pH of the groundwater back up to 7.0. In an attempt to overcome this effect, the buffer MES (2-[N-morpholino]ethanesulfonic acid; pKa = 6.1) was added to the water at a concentration of 2 mM, and the

groundwater pH was adjusted to between 4.5 and 5.0. The buffered groundwater was run through the column for approximately 33 days.

The acidification of the groundwater did not influence denitrification. Nitrate was degraded from a starting concentration of 16 mg/L to below detection within the first 3.5 cm of the column throughout the study period. For the first week that the buffered groundwater was added to the column, perchlorate was also degraded to below detection within the first few centimeters of the aquifer column. However, profiles collected after 8 and 14 days showed a moderate reduction in the rate of perchlorate degradation. The column profiles also showed that the groundwater pH was still quickly buffered in the column, increasing from approximately 4.5 in the influent to 6.2 within 3.5 cm (Figure 43). Because we were unable to dramatically alter the pH across the profile of the column with buffered water, and did not want to attempt more rigorous methods (e.g., acid addition), the study was discontinued after 33 days. The data show some reduction in the rate of perchlorate degradation (but not denitrification) upon moderate acidification in the first few cm of the column, but because of the high buffering capacity of the sediments, the results of this phase of the study were inconclusive.



**Figure 43. Groundwater pH and Perchlorate Levels in Column Profile.**

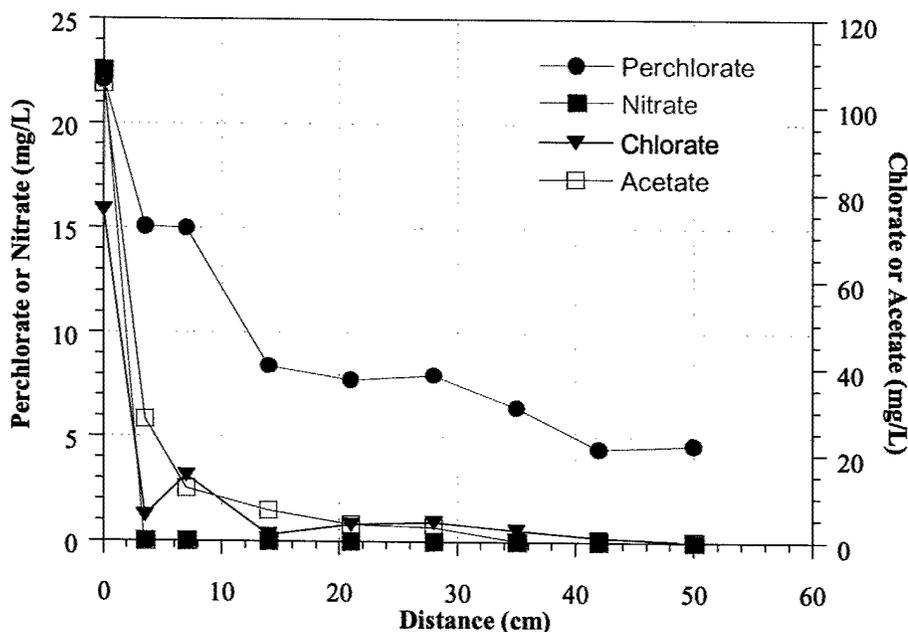
#### **4.4.6 INFLUENCE OF CHLORATE ON PERCHLORATE REDUCTION**

An additional experiment was conducted with the aquifer column to evaluate the influence of chlorate addition on perchlorate reduction. Chlorate and perchlorate appear to be degraded by the same enzyme pathway in perchlorate reducing bacteria, therefore the degradation of both of these anions together in a natural system is interesting. In addition, chlorate has been found experimentally to inhibit nitrate reduction in some instances. Thus, the presence of chlorate in groundwater could reduce nitrate reduction, and based on our previous findings, the residual nitrate could then impact perchlorate degradation. To evaluate the influence of chlorate, the anion was added to the influent groundwater in the column at a concentration of approximately 80 mg/L (1 mM). The influent perchlorate concentration was approximately 25 mg/L (0.25 mM), the nitrate concentration was approximately 16 mg/L (0.25 mM), and the acetate feed was supplying approximately 100 mg/L to the column influent.

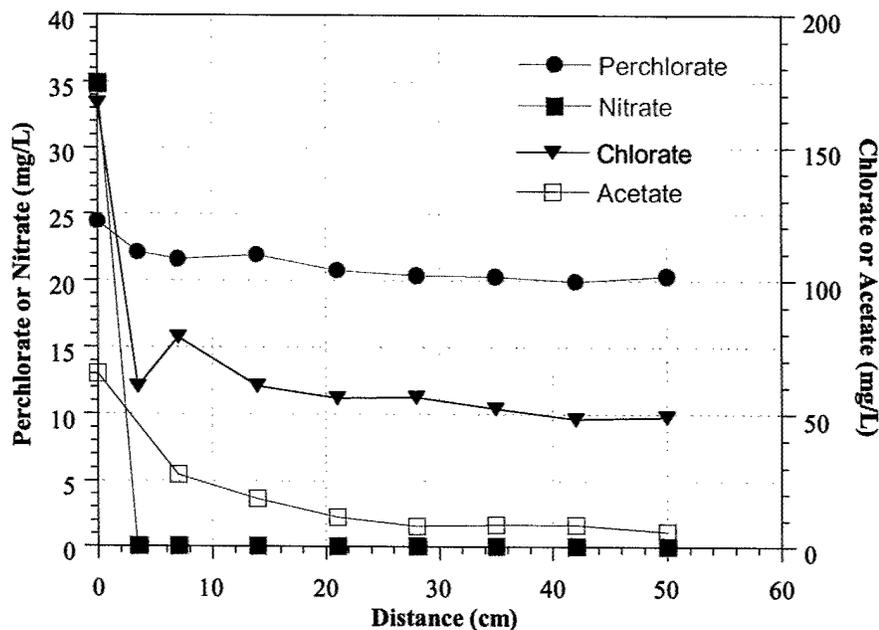
Prior to chlorate addition, both perchlorate and nitrate were degrading to below detection within the first 3.5 cm of the aquifer column. There was approximately 40 mg/L of residual acetate. Within one day after chlorate addition, perchlorate was detected in the column effluent (50 cm sample). Nitrate, however, was still biodegrading within the first 3.5 cm of the column. Seven days after chlorate was added to the influent groundwater, nitrate was still degraded in the first 3.5 cm of the column (Figure 44). A majority of the chlorate was also biodegraded within this initial zone of the column. The concentration dropped from 76 mg/L in the influent to 5.8 mg/L after 3.5 cm of transport in the column, a loss of 94 %. Perchlorate biodegradation occurred throughout the length of the column. The perchlorate concentration declined from 22 to 15 mg/L in the first 3.5 cm, then to 7.7 mg/L by the middle of the column (21 cm), and 4.6 mg/L remained in the effluent. Acetate was below detection after 35 cm in the column. The profile for the three electron acceptors remained approximately the same in additional profiles taken during the following several days.

The chlorate concentration was increased to 160 mg/L (2 mM) approximately 3 weeks after chlorate was initially added. This increase did not appear to influence nitrate degradation. Nitrate was still completely degraded in the initial 3.5 cm of the column sediment (Figure 45). The rate and extent of perchlorate biodegradation, however, were each further reduced by the increased chlorate concentration. After 5 days, perchlorate levels were only declining marginally through the column. Most of the chlorate degradation continued within the initial few cm of the column, but a residual level of approximately 50 mg/L remained after this initial degradation. Although the acetate profile showed low residual concentrations of the electron donor in the latter half of the column, it is likely that it was actually all consumed within the first half of the column. The detection limit for acetate by the GC method employed is approximately 5 mg/L, but the method has proven not to be reliable below 10 mg/L.

The data from this study showed that chlorate did not influence the biodegradation of nitrate in the aquifer column. Nitrate was degraded within the first few cm of the column in the absence of chlorate as well as in the presence of 160 mg/L (2 mM) of the anion. The rate and extent of perchlorate reduction, however, were dramatically affected by chlorate addition. Perchlorate reduction was not completely inhibited by chlorate, as was observed for nitrate, but it was decreased substantially. Before chlorate addition, all of the added perchlorate (~ 25 mg/L) was degraded in the first 3.5 cm of the column. After addition of 80 mg/L chlorate, perchlorate was observed to be present in the effluent of the 50-cm column at approximately 5 mg/L. This residual increased to about 20 mg/L after the addition of 160 mg/L chlorate. Pure culture studies with JPLRND to evaluate the influence of chlorate on perchlorate reduction were not conducted. However, based on previous findings with other strains, it is likely that both of these anions are substrates for the (per)chlorate reductase enzyme. Thus, the influence of chlorate on perchlorate reduction probably results from competitive effects of the two anions at the active site of the enzyme.



**Figure 44. Biodegradation of Perchlorate, Chlorate, and Nitrate in Model Aquifer with Acetate as Electron Donor.**



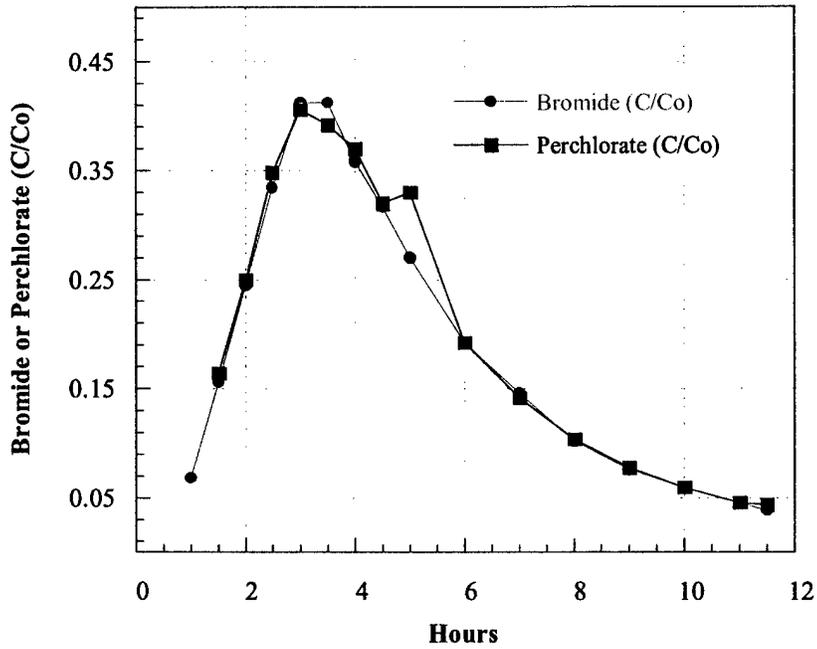
**Figure 45. Biodegradation of Perchlorate, Chlorate, and Nitrate in Model Aquifer After Chlorate Levels were Increased to 160 mg/L.**

#### **4.4.7 SUSTAINED BIODEGRADATION OF PERCHLORATE AT LOW CONCENTRATIONS**

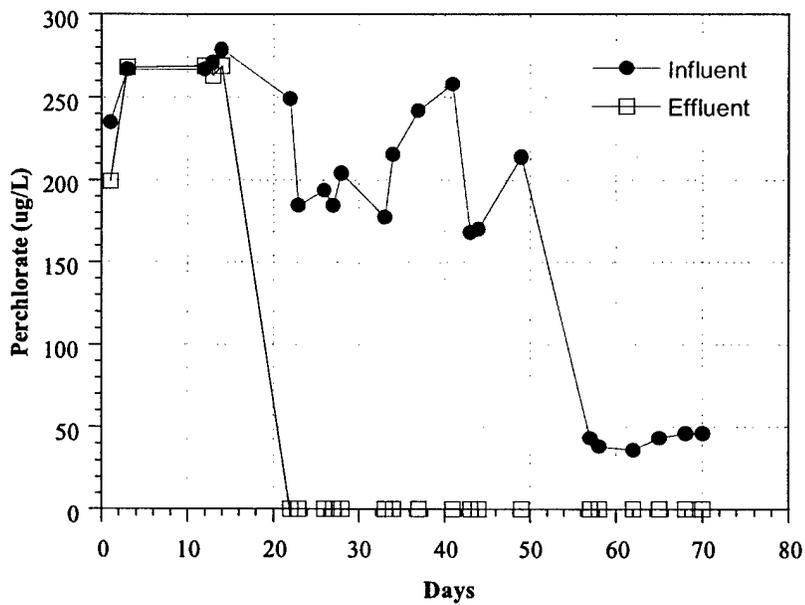
An additional flow-through model aquifer was constructed to evaluate perchlorate biodegradation at low concentrations (in the absence of nitrate), and to test the influence of co-contaminants on perchlorate biodegradation. The second column was constructed as described originally except that the length of the column was reduced from 50 cm to 30 cm, and the sampling points were placed at 2.5, 5.0, 10.0, 15.0, 20.0, 25.0, and 30-cm from the bottom of the column. After construction, the column was packed with sediments from the Longhorn Army Ammunition Plant (LHAAP) and a bromide tracer experiment was conducted to quantify flow characteristics. Artificial groundwater was prepared with similar chemistry as described for the initial column experiments. The sustained biodegradation of low concentrations of perchlorate in the absence of nitrate was tested. Initially, perchlorate was added to the influent groundwater at a concentration of 250  $\mu\text{g/L}$ , and oxygen was present at approximately 8 mg/L. These conditions are similar to those at the location from which the sediments were originally collected (LHAAP Site 16 Landfill). The geochemistry of the artificial groundwater is also based on this location. Unlike the previous column, in which acetate was used as an electron donor, this column received lactic acid as an electron donor. The target concentration in the influent groundwater was 20 mg/L.

The column was initially packed with 2280 g of sieved, moist sediments from LHAAP Site 16 (1750 g dry wt). These sediments contained much more clay than the sample used to pack the 50-cm column. The pore volume of the column was estimated at 540 mL. During the initial tracer test, bromide and perchlorate were added to the column at 50 mg/L each in a 180 mL (~1/3 pore volume) pulse. The flow rate was approximately 45 mL/hr. The breakthrough curves for bromide and perchlorate are provided in Figure 46. The two anions moved through the column together, as observed previously for the 50-cm column. The breakthrough curves displayed a more significant tail than was observed for the 50-cm column, suggesting that there may be some preferential flow in the column.

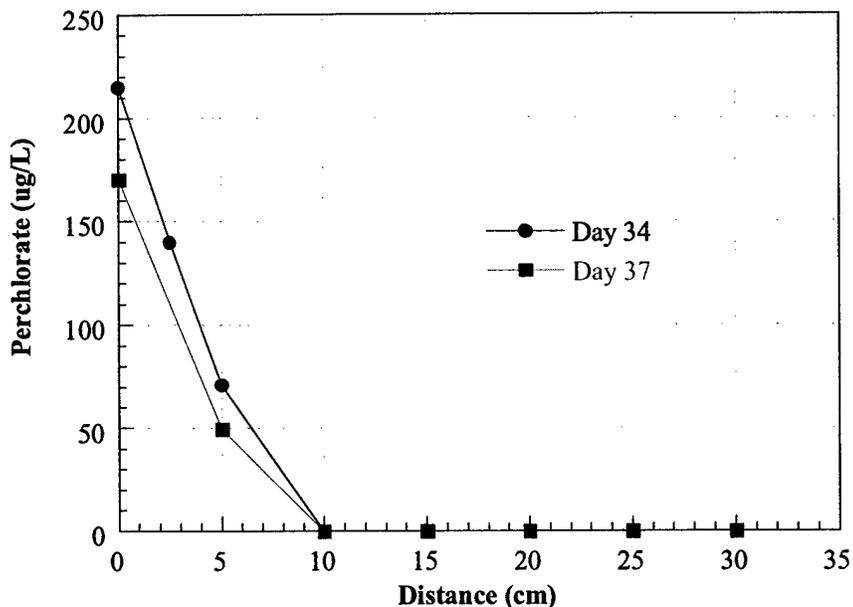
There was no appreciable reduction in perchlorate through the column for the first 14 days after the lactate addition was initiated. By day 22, however, perchlorate was below detection in the column effluent (Figure 47). The minimum detection limit for perchlorate for this phase of testing was 8 µg/L. The column effluent remained below detection throughout the remainder of the study period. Column profiles taken on days 36 and 37 showed that most of the perchlorate was degrading within the first 10 cm of the column (Figure 48). At day 56, the influent perchlorate concentration was reduced to 50 µg/L. The effluent perchlorate concentration remained below detection after the influent perchlorate was reduced to this level. The minimum detection limit was 4 µg/L during this phase of testing. The data show that lactic acid will support biological perchlorate reduction at this site. The data also show that perchlorate biodegradation can be stimulated and sustained (to < 4 µg/L) even when initial concentrations of the anion in groundwater are very low (i.e., 50 – 250 µg/L) and nitrate, an alternate electron acceptor for most perchlorate-respiring bacteria, is not initially present. There are a number of large perchlorate plumes in which the initial levels of the anion in groundwater are several to several hundred µg/L, and in which nitrate is not present. The data from this experiment suggest that sustained *in situ* perchlorate bioremediation may be possible for these sites. If a lower threshold for perchlorate biodegradation exists, as has been found for many organic contaminants acting as electron donors, it appears that this level is below the low µg/L levels which are relevant for current regulatory requirements.



**Figure 46. Transport of Bromide and Perchlorate Through the 30-cm Model Aquifer Column Packed with LHAAP Site 16 Sediment.**



**Figure 47. Sustained Biodegradation of Perchlorate at Low Influent Concentrations with Lactate as Electron Donor.**



**Figure 48. Profiles of Perchlorate Biodegradation in the 30-cm Aquifer Column with Lactate as Electron Donor.**

#### **4.4.8 INFLUENCE OF RDX ON PERCHLORATE BIODEGRADATION AND POTENTIAL FOR COMBINED TREATMENT**

Previous microcosm experiments performed during this project evaluated the influence of chlorinated solvents (PCE and TCE) on perchlorate degradation. In addition, in one of the companion projects, Geosyntec researchers have been examining the joint bioremediation of chlorinated solvents and perchlorate in laboratory and field studies. Therefore, rather than looking at chlorinated solvents in a column experiment, we decided to examine the influence of a second co-contaminant, the nitramine explosive hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), on perchlorate degradation. RDX, and a similar explosive, octahydro-1,3,5,7-tetranitro-1,3,5,7-tetraazocine (HMX) are widespread environmental contaminants at many current and former military facilities. For example, a recent report suggests that at least 28 U.S. Army installations and more than 200 facilities in Germany are contaminated with these compounds (Stahl et al., 2001). The majority of this contamination is the result of historical manufacturing, handling, and disposal procedures for munitions. However, past and current activities on military training ranges may also be resulting in releases of these energetics into the environment. For example, groundwater underlying impact ranges at the Massachusetts Military Reservation (MMR) on Cape Cod has recently been found to be contaminated with various explosives, including both RDX and

HMX (Burt, 1999). This groundwater is also contaminated with low levels of perchlorate from training activities or from another source (e.g., burn pits). It is likely that other sites also have co-contamination with perchlorate and RDX.

Based on this information as well as the current interest in RDX treatment methods, we conducted a column study to examine (1) whether RDX impacts perchlorate treatment, and (2) whether both RDX and perchlorate can be biodegraded using electron donor addition. There is a growing body of literature on the biodegradation of nitramine explosives, and although the mechanism by which bacteria utilize these compounds (i.e., as growth substrates, cometabolites, or terminal electron acceptors) remains unclear, the preponderance of scientific evidence suggests that the most rapid degradation of RDX and HMX occurs under anoxic or anaerobic conditions. In addition, the application of a suitable organic growth substrate is often required to achieve rapid and complete degradation of the nitramine explosives (Boopathy and Manning, 1998; Boopathy et al., 1993). Therefore, treatment methods to stimulate perchlorate biodegradation in groundwater may also stimulate RDX biodegradation.

To examine this possibility, RDX was added at ~ 5 mg/L in the influent water of the 30-cm aquifer column. The explosive was added in crystalline form from a military stock containing 93% RDX and 7 % HMX. The column used was the same column described previously to evaluate degradation of low concentrations of perchlorate (previous section). The influent feed of perchlorate remained at approximately 50 µg/L and lactate addition was continued at 20 mg/L. Subsamples were taken periodically from the influent and effluent of the column, and from the sampling points along the profile. The samples were analyzed for perchlorate by IC (EPA 314.0) and RDX by HPLC (EPA 8330).

There was no apparent decline in the rate or extent of perchlorate biodegradation upon adding RDX to the influent water to the column (Day 70 after column flow was started). The anion continued to degrade from 50 µg/L to near or below detection within the first 10 cm of the 30-cm column. Interestingly, RDX levels also declined appreciably during transport through the aquifer column. The influent concentrations varied from about 2.5 to 5 mg/L, but losses of approximately 70% to 90% were observed across the column. A profile of perchlorate and RDX in the aquifer column 22 days after RDX was initially added is given in Figure 49. Perchlorate was reduced from 45 to less than 4 µg/L in the first 2.5 cm of the column, and RDX levels declined from 5.17 mg/L to 1.27 mg/L across the 30-cm column length.

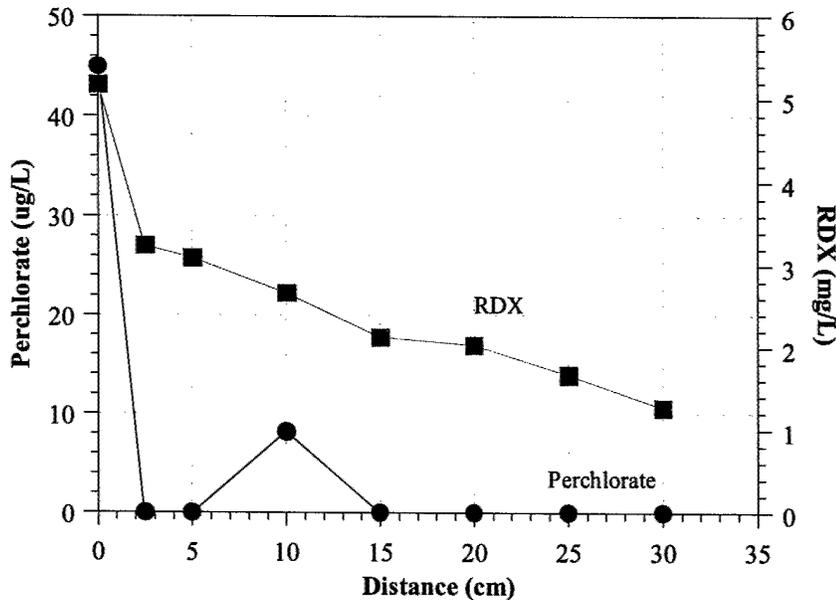
Because electron donor was being supplied to the column at the time that RDX was added, it is unclear whether the initial losses of the explosive in the column represented biodegradation or merely adsorption to aquifer sediments. RDX has a low octanol-water partition coefficient ( $\text{Log } K_{ow} = 0.86$ ) and does not sorb appreciably to most constituents of soils or sediments (Schumacher et al., 1992; Sheremata et al., 2001). However, sorption of nitramines to some clays has been observed. Therefore, to examine

whether the decline in RDX levels in the column was due to biodegradation (supported by lactate addition) or to sorption only, the electron donor feed to the column was discontinued on day 27 after RDX addition. Three days after the lactate feed was shut off (approximately 6 pore volumes), perchlorate was observed in the column effluent. The RDX levels across the column also increased, although far more gradually than for perchlorate. A profile for both RDX and perchlorate before and after the lactate feed was shut off (Day 27 and Day 30, respectively) is given in Figure 50. The lactate feed remained off for 33 days. After several days, influent and effluent perchlorate levels were similar (i.e., biodegradation no longer occurred). However, levels of RDX in the effluent continued to decline by 60 – 70% across the column during the period that the lactate feed was off. A column profile for day 44 (17 days after lactate feed was shut off) is provided in Figure 51. The data suggest that RDX was biodegraded in the absence of added electron donor, although the extent of degradation was less than in the presence of lactate.

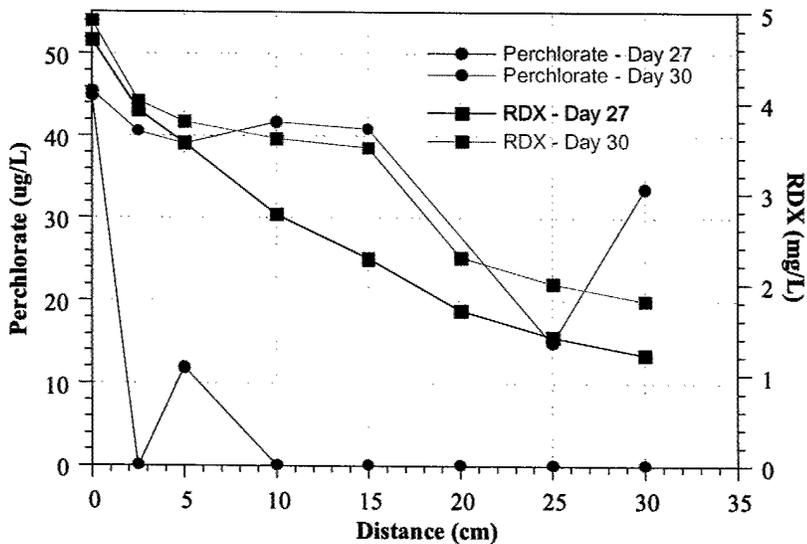
To evaluate whether the extent of biodegradation of RDX could be enhanced by electron donor addition, the lactate feed was restarted on day 50 at a concentration of 40 mg/L (compared to 20 mg/L in the previous phase). The addition of lactate did not appear to appreciably influence the loss of RDX across the column. After 13 days, the flow rate to the column was cut approximately in half from 45 mL/hr to 24 mL/hr in order to increase the hydraulic retention time (HRT) of groundwater within the column from approximately 12 to 23 hrs. When the retention time was increased, effluent levels of RDX declined appreciably (Figure 52). The effluent levels of RDX from the column declined to approximately 200 -300  $\mu\text{g/L}$  after the HRT was increased. The degradation across the column was greater than 92% of the influent RDX after the HRT was increased to 23 hrs, compared to approximately 70% when the HRT was 12 hrs.

The biodegradation pathway for RDX under anoxic conditions is postulated to proceed by sequential reduction of the nitro ( $\text{NO}_2$ ) groups to nitroso ( $-\text{NO}$ ) groups, resulting in the formation of hexahydro-1,3,5-trinitroso-1,3,5-triazine (TNX) (e.g., Hawari et al., 2000). In addition to monitoring RDX, the initial nitroso- breakdown products of RDX [hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine (MNX), hexahydro-1,3-dinitroso-5-nitro-1,3,5-triazine (DNX), and TNX] were quantified by HPLC for some of the column profiles (beginning on Day 58 after initial RDX addition) using appropriate standards for each metabolite. TNX and MNX were routinely detected throughout the column during analyses. Conversely, DNX was either below detection or was observed only in a few samples in the column profiles that were collected. A column profile showing RDX degradation and levels of each of the three metabolites at an influent flow rate of 45 mL/hr (12 hr HRT) is provided in Figure 53 and a similar profile at a flow rate of 24 mL/hr (23 hr HRT) is provided in Figure 54. The column was being supplied with lactate at 40 mg/L when each profile was taken. At the more rapid flow rate, the maximum levels of TNX and MNX in the column were 0.3 mg/L. DNX was not detected. The flow to the column was reduced on

Day 63. On day 84 when the second profile was collected, levels of MNX exceeded 1.5 mg/L through the first 10 cm of the column. Levels of TNX increased gradually through the first several centimeters of the column, reaching a maximum concentration at the 10 cm point, and decreasing thereafter. A small amount of DNX was detected at the 10-cm sample point, but nowhere else in the column. The metabolite data clearly show that RDX biodegradation is occurring within the column in conjunction with perchlorate degradation.



**Figure 49. Profiles of Perchlorate and RDX in Aquifer Column 22 Days after Initial Addition of RDX.**



**Figure 50. Profile of Perchlorate and RDX in Aquifer Column on Day 27 (+ Lactate Feed) and Day 30 (- Lactate Feed) after Initial Addition of RDX to Groundwater.**

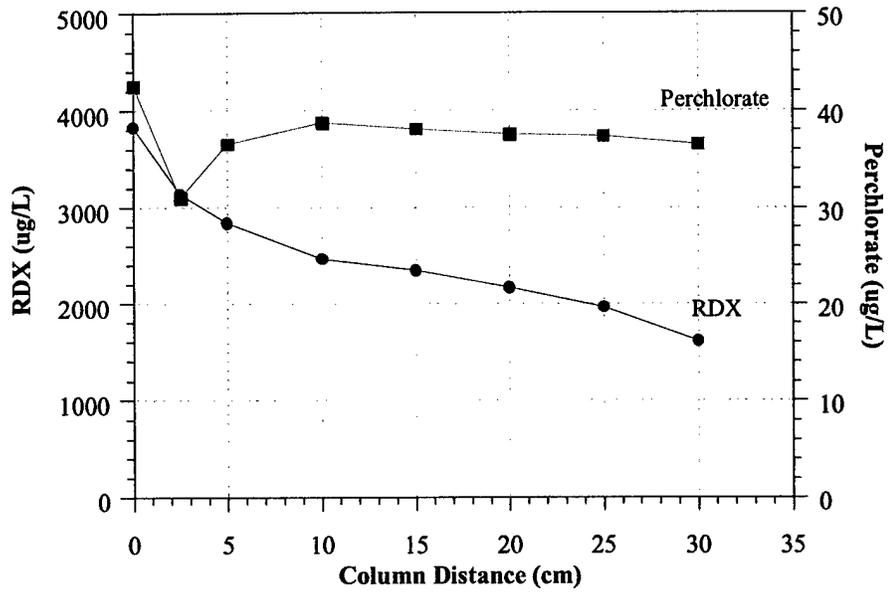


Figure 51. Profile of Perchlorate and RDX in Aquifer Column with Electron Donor Feed Off (Day 44).

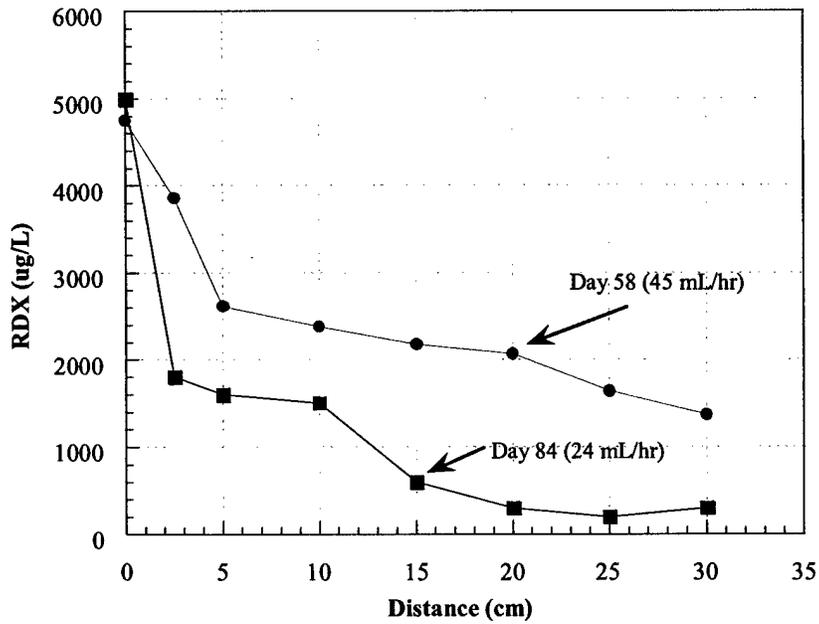
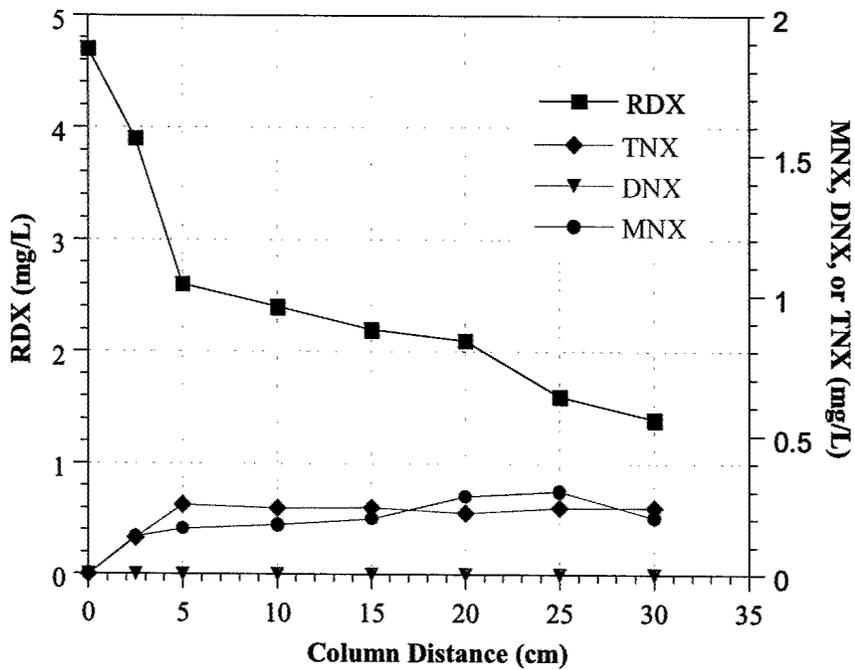
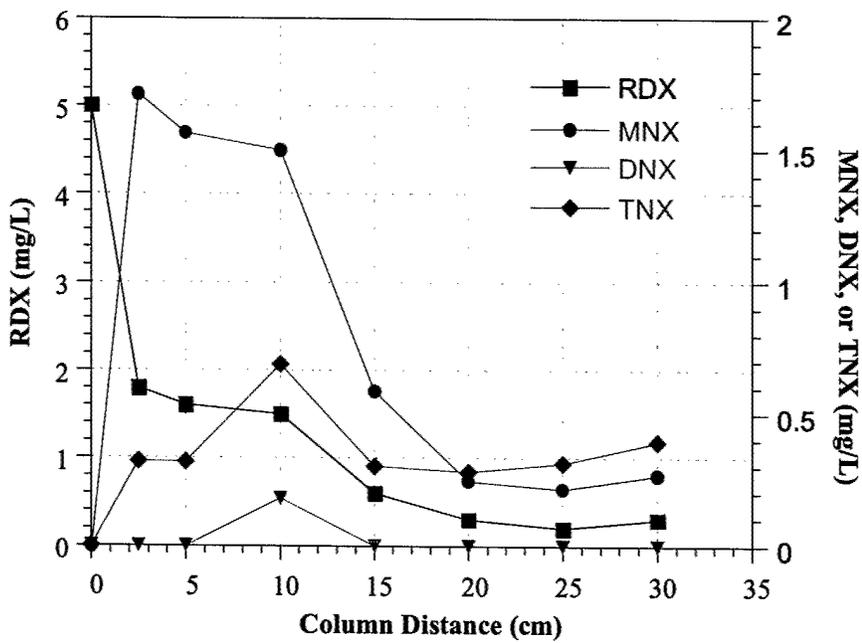


Figure 52. Biodegradation of RDX in Aquifer Column at Flow Rates of 45 mL/hr (12 hr HRT) and 24 mL/hr (23 hr HRT).



**Figure 53. Biodegradation of RDX and Formation of RDX Metabolites in Aquifer Column at Flow Rate of 45 mL/hr (12 hr HRT; Day 58).**



**Figure 54. Biodegradation of RDX and Formation of RDX Metabolites in Aquifer Column at Flow Rate of 24 mL/hr (23 hr HRT; Day 84).**

## **4.5 PERCHLORATE BIODEGRADATION MODEL**

### **4.5.1 MODEL DESCRIPTION**

A mathematical model has been developed to describe the biodegradation kinetics of perchlorate (an electron acceptor) in the presence of an electron donor and other alternate electron acceptors. The model is based on the modeling program RT3D, developed by Battelle Pacific Northwest National Laboratory. The rate of perchlorate degradation is described as a function of the electron donor (acetate) utilization rate, presence and utilization of alternate electron acceptors (oxygen and nitrate), and rates of biomass growth and decay. The kinetics of biomass growth are described using a modified Monod model. To describe the effect of alternate electron acceptors on perchlorate degradation an inhibition factor is included as a modification to the Monod model. Specific details of the model are given in the sections below.

### **4.5.2 ELECTRON DONOR CONSUMPTION**

The model describes sequential degradation of acetate (the electron donor) in the presence of oxygen, nitrate, and perchlorate (the electron acceptors). Also, the influence of biomass populations on the utilization of acetate is included in the model (see Section 4.5.3 below). In the model, it is assumed that the total amount of acetate consumed is equal to the sum of three terms: 1) the amount of acetate consumed using oxygen as an electron acceptor; 2) the amount of acetate consumed using nitrate as an electron acceptor; and 3) the amount of acetate consumed using perchlorate as an electron acceptor. The rate of acetate consumption using each electron acceptor is written as a function of acetate concentration, electron acceptor concentration, bacterial population, the maximum specific rate of degradation, and the half-saturation constant for that reaction. For the reaction where nitrate is utilized as an electron acceptor, oxygen is modeled as a competitive inhibitor to the reaction. Similarly, for the reaction where perchlorate is utilized as the electron acceptor, nitrate and oxygen are modeled as competitive inhibitors of the reaction. The complete model equations are provided in Appendix B (section 7.2).

### **4.5.3 MICROBIAL POPULATIONS**

In the model, two primary processes are used to describe changes in the microbial populations: 1) growth due to electron donor consumption; and 2) indigenous cell decay. The rate of change in the biomass due to growth is dependent upon the starting biomass concentration, the biomass yield, and the rate of electron donor utilization. Biomass concentrations are included in the mathematical expression for calculating the rate of utilization of the electron donor and each electron acceptor.

#### **4.5.4 ELECTRON ACCEPTORS**

In the model, changes in the electron acceptor concentrations are directly linked to the consumption of the electron donor. The change in concentration of each acceptor is calculated as a function of the specific electron donor utilization rate for that acceptor, the mass of acceptor consumed per mass of substrate consumed (the donor/acceptor yield coefficient), the biomass concentration, and the concentration of the other electron acceptors. The donor/acceptor yield coefficients were determined theoretically based upon the stoichiometric half-reactions for each electron acceptor and compared to observations in the laboratory. Inhibition among the different electron acceptors was modeled using the assumption that the electron acceptors are used sequentially as follows: oxygen, nitrate, and perchlorate. Previous experimental work has demonstrated this sequential electron acceptor use is relatively accurate. Microcosm experiments were performed during this study to further evaluate this relationship.

#### **4.5.5 MODEL ASSUMPTIONS**

Some of the basic assumptions made to develop the model include the following:

1. Maximum specific growth rate and the half saturation constant do not significantly change with the different electron acceptors.
2. Cell yield does not change with different electron acceptors.
3. Competition among the different electron acceptors is a continuous function, i.e., not based on "threshold concentrations".
4. The electron donor and electron acceptors described do not volatilize into air or sorb onto soil.
5. Any lag periods observed during the microcosm studies are due to microbial growth only.
6. Biomass may decay to zero or grow indefinitely.

#### **4.5.6 EXPERIMENTAL DETERMINATION OF MODEL PARAMETERS**

##### **Electron Donor Parameters**

Experiments were performed to estimate the different input parameters for the model. These studies utilized a perchlorate degrading strain, *Dechlorosoma suillum* JPLRND, hereafter referred to as JPLRND, which was isolated from groundwater underlying the Jet Propulsion Laboratory in Pasadena, CA, during previous work in this project. A series of batch experiments were conducted with this strain using a range of starting electron donor (acetate) concentrations where individual electron acceptors (oxygen, nitrate, or perchlorate) were constant and not limiting (i.e., supplied in excess). The electron donor levels and the microbial population density were measured over time in each microcosm. Using the biomass versus time graph, the biomass growth rate for each microcosm was determined from the exponential growth

stage of each graph. Consequently, a "Monod growth" curve was constructed by plotting the exponential growth rate of the bacterium versus the starting electron donor concentration for that microcosm. The maximum specific growth rate ( $k_{max}$ ) and half-saturation constant ( $K_s$ ) for JPLRND using acetate as each electron donor were determined from each Monod curve. These values represent the maximum specific growth rate ( $k_{max}$ ) of the culture on the acetate (donor), whereas  $K_s$  represents the concentration where the specific growth rate is half the  $k_{max}$  value. These two parameters were determined for each electron acceptor. As stated in the Model Assumptions (Section 4.5.5), it was assumed that the maximum specific growth rate ( $k_{max}$ ) and the half saturation constant ( $K_s$ ) do not vary significantly among the different electron acceptors. This assumption was tested by fitting  $k_{max}$  and  $K_s$  values for acetate and each electron acceptor and comparing the variability in these parameters. The notation for  $k_{max}$  values for the three electron acceptors is as follows:  $k_{max}^{don/oxy}$ ,  $k_{max}^{don/nit}$ , and  $k_{max}^{don/per}$ . As discussed below, the average value of these parameters (designated as  $k_{max}$ ) was used for subsequent modeling of perchlorate biodegradation.

Similarly, three  $K_s$  values for acetate, corresponding to the three electron acceptors, were fit to the data and examined for variability. The notation for these three parameters is as follows:  $K_s^{don/oxy}$ ,  $K_s^{don/nit}$ , and  $K_s^{don/per}$ . As discussed below, the average of these three parameters, designated as  $K_s$ , was used for subsequent modeling of perchlorate biodegradation.

### Electron Acceptor Parameters

Experiments were performed to determine the growth rate parameters for the bacterium when the electron acceptor concentrations (nitrate or perchlorate only) were limiting to the biodegradation process while the electron donor (acetate) was present in excess (i.e., did not influence the biodegradation kinetics). The maximum growth rate and half saturation constant for growth under these conditions were determined. These parameters were determined for the electron acceptors nitrate and perchlorate only. Experiments where oxygen was limiting were not performed because of the difficulty of measuring oxygen concentrations in microcosm experiments. The notations for the maximum growth rate and half saturation constant for these fits are as follows:  $k_{max}^{nit/don}$ ,  $k_{max}^{per/don}$ ,  $K_s^{nit/don}$ , and  $K_s^{per/don}$ . It is expected that  $k_{max}^{nit/don}$  and  $k_{max}^{per/don}$  should equal the values  $k_{max}^{don/nit}$  and  $k_{max}^{don/per}$ . On the other hand, given that  $K_s^{nit/don}$  represents a nitrate concentration,  $K_s^{per/don}$  represents a perchlorate concentration,  $K_s^{don/nit}$ ,  $K_s^{don/per}$  represent acetate concentrations, it is expected that these half-saturation constants will be different in value.

#### 4.5.6.1 Experimental Quantification of Model Parameters

##### Electron Donor Parameters

##### Methods

Three groups of experiments were conducted to determine the different  $K_S$  and  $k_{max}$  values for JPLRND growing on acetate. In each group, one electron acceptor (oxygen, nitrate, or perchlorate) was tested using seven flasks initially prepared with basal salts medium (BSM) and supplied with varying acetate concentrations, ranging from 0 to 600 mg/L. The starting concentration of nitrate or perchlorate in each of the flasks was 1000 mg/L, while oxygen was maintained at saturation (approximately 8 mg/L). These concentrations were used to ensure that the electron acceptors did not become limiting during these experiments. For the nitrate and perchlorate groups, an additional control flask was prepared, to which no acceptor (nitrate or perchlorate) was added. This control flask was setup to confirm that the culture was not using oxygen as an electron acceptor in those experiments. All flasks were prepared in a Coy Environmental Chamber with nitrogen headspace. After preparation of the flasks for each group, two subsamples (8 mL) were extracted from each flask and added to 10-mL screw-cap spectrophotometer tubes. These tubes were then inoculated with JPLRND to an initial optical density (OD) of ~0.03. The tubes were sealed (to prevent oxygen intrusion) and incubated at 22°C. In the experiment in which growth on oxygen was tested, the culture was inoculated into 250-mL Erlenmeyer flasks rather than the 10-ml spectrophotometer tubes to minimize the potential for oxygen depletion. In addition, the flasks were placed on a rotary shaker operating at 200 rpm to ensure that oxygen transfer did not become limiting during the experiment. The OD was used as a measure of the microbial population in each experiment. For the nitrate and perchlorate experiments, the OD was measured by simply placing the 10-ml tube in the spectrophotometer. For the oxygen experiment, the OD was measured by collecting a 5-mL subsample from the experimental flasks and placing it in an OD-tube for OD measurement.

##### Results

The specific growth rate of JPLRND at each acetate (the electron donor) concentration was determined by plotting the natural log of the optical density (x 1000) versus time. The rate of change of optical density (i.e., the slope of the line in the plot) represents the growth rate of JPLRND at that acetate concentration. The growth of JPLRND on acetate at 250 mg/L with two different electron acceptors, perchlorate and oxygen, is presented in Figure 55. The slope of each curve shown in the figure was taken from the steepest portion of the OD versus time curve. Again, the slope value represents the growth rate of the culture at the donor concentration at the beginning of the experiment. A plot of the growth rate versus starting donor concentration can be constructed for each electron acceptor (Figures 56, 57, 58). This plot

represents the Monod growth curve for JPLRND using acetate. Non-linear regression analysis was used to fit the Monod curves in Figures 56, 57, and 58 using the model presented in Appendix B.

The model was fit to the Monod curve by numerically solving the equations presented in Appendix B and varying values of the maximum specific growth rate ( $k_{\max}$ ) and the half-saturation constant ( $K_S$ ) to minimize the difference between data and model. The model fits are shown in Figures 56, 57, and 58. The fitted  $k_{\max}$  and  $K_S$  values are presented in Table 5. The maximum growth rates of the culture on acetate when it was grown in the presence of perchlorate and nitrate were  $0.14 \text{ h}^{-1}$  and  $0.15 \text{ h}^{-1}$ , respectively. The growth rate of the culture in the presence of oxygen was slightly higher ( $0.21 \text{ h}^{-1}$ ). The half-saturation constants for acetate with perchlorate, nitrate, and oxygen as electron acceptors were 120 mg/L, 70 mg/L, and 90 mg/L, respectively. The relatively low variability of these parameters among the different electron acceptors suggests that our assumption that the different electron acceptors do not significantly influence the biodegradation kinetics is valid.

## **Electron Acceptor Parameters**

### **Methods and Results**

Similar experiments were performed to determine the kinetic parameters for each electron acceptor when the starting acetate concentration was constant and not limiting (i.e., excess acetate remained at the end of the experiment), while the electron acceptor was limiting. The parameters were determined from the experimental data similarly to the method used for obtaining the electron donor parameters. The growth rate of JPLRND at each electron acceptor concentration was taken as the steepest part in the optical density ( $\times 1000$ ) versus time graph. A Monod curve for each electron acceptor was made by plotting the growth rate (i.e., the slopes of the steepest part of the curve) versus the starting electron acceptor concentration. Non-linear regression was then used to fit of the model presented in Appendix B to the Monod curve. As described above, the equations in Appendix B were solved numerically and fit to the data by varying the maximum specific degradation rate and the half saturation constant for the electron acceptors. The "variable electron acceptor" experiments were performed only for perchlorate and nitrate, and not for oxygen. The Monod curves for these two experiments are presented in Figures 59 and 60 with the corresponding fitted model parameters presented in Table 6. The maximum specific growth rates for nitrate and perchlorate were  $0.21 \text{ h}^{-1}$  and  $0.071 \text{ h}^{-1}$ , respectively. These values are within a factor of two of the maximum specific growth rates determined during the electron donor studies above. As discussed above, it was assumed that the maximum specific growth rate of the culture does not significantly vary with the electron acceptor being used by the culture. Based upon the fact that the maximum specific growth rates vary only over a factor of two for all the different experiments conducted (see Tables 5 and 6), this assumptions seems to be valid. The half-saturation constants for nitrate and perchlorate during these experiments were 180 mg/L and 150 mg/L, respectively.

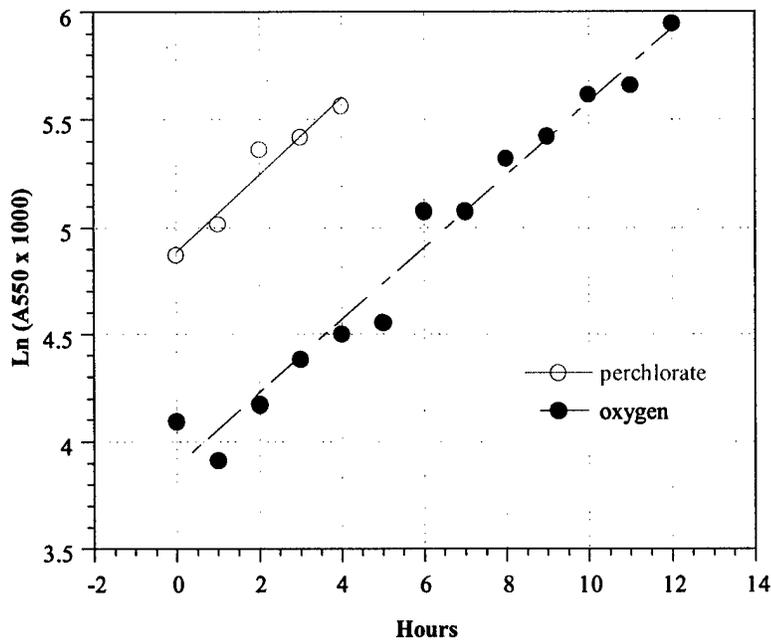


Figure 55. Growth of JPLRND on Acetate with Either Oxygen or Perchlorate as Electron Acceptor.

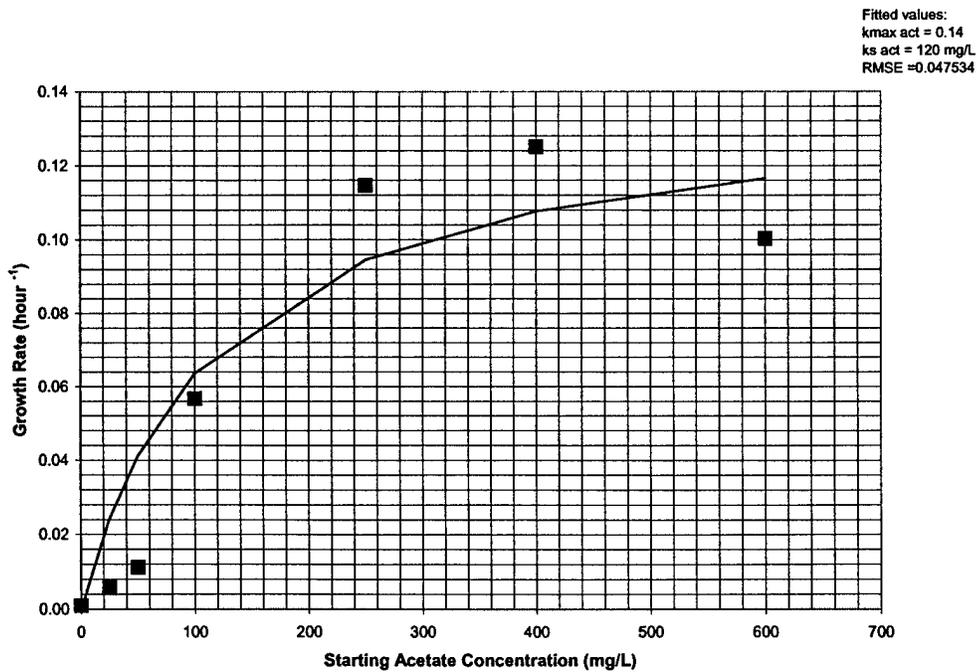


Figure 56. Growth Rate of JPLRND on Acetate with Perchlorate as Electron Acceptor: Acetate Varied; Determination of  $K_s$  and  $k_{max}$ .

Fitted values:  
 $k_{max\ act} = 0.21$   
 $k_s\ act = 90\ mg/L$   
RMSE: 0.028561

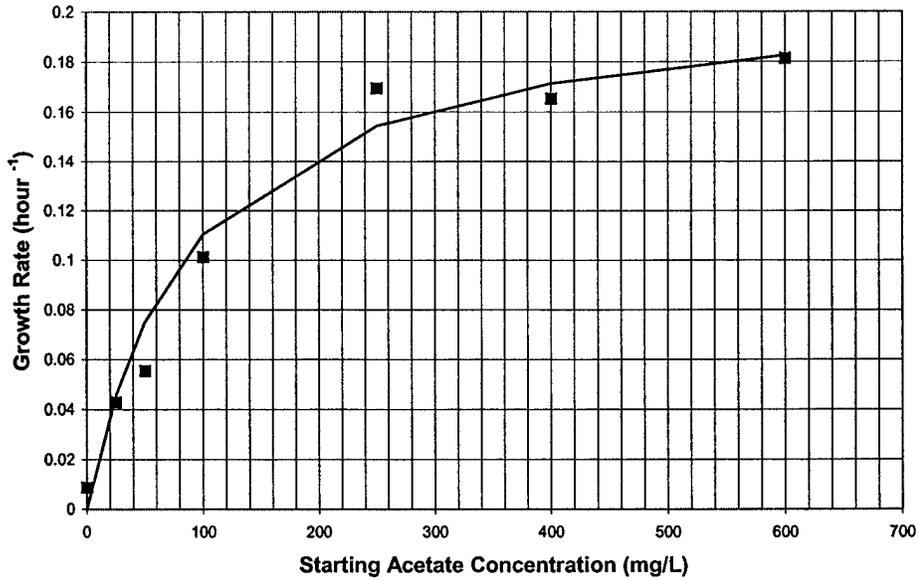


Figure 57. Growth Rate of JPLRND on Acetate with Oxygen as Electron Acceptor: Acetate Varied; Determination of  $K_s$  and  $k_{max}$ .

Fitted values:  
 $k_{max\ act} = 0.145$   
 $k_s\ act = 70$   
RMSE= 0.03066

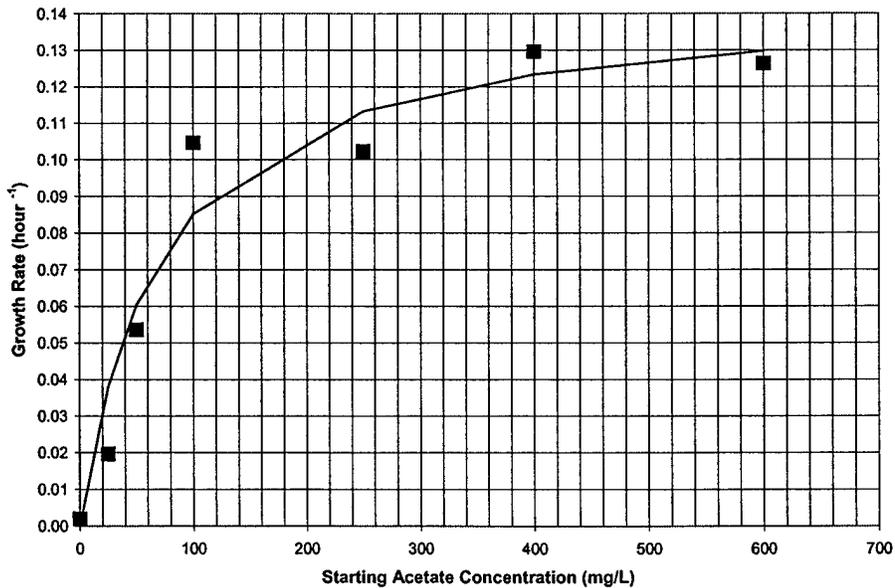


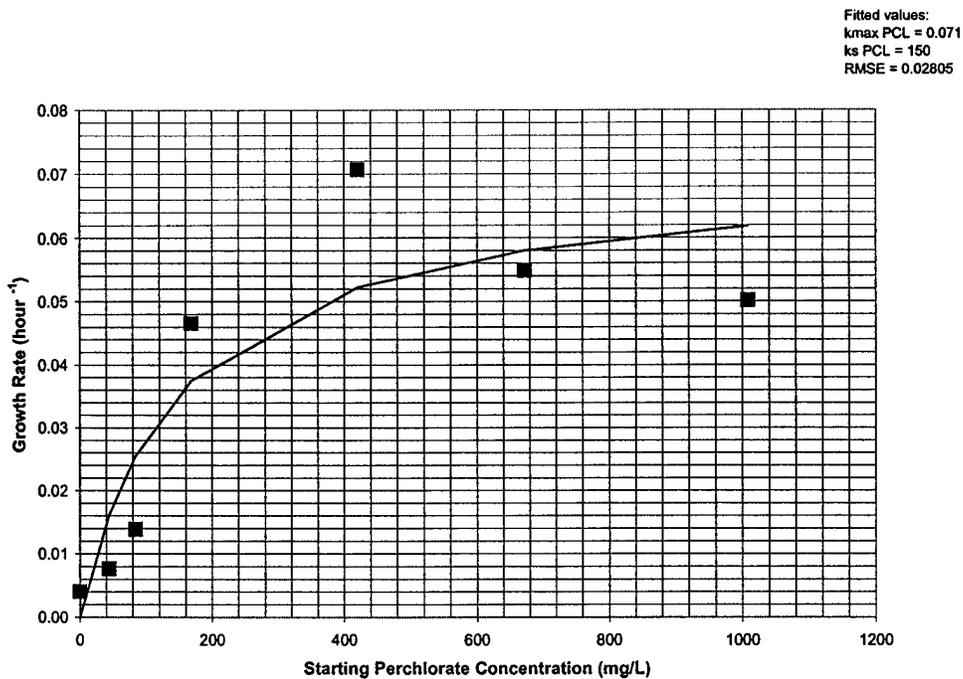
Figure 58. Growth Rate of JPLRND on Acetate with Nitrate as Electron Acceptor: Acetate Varied; Determination of  $K_s$  and  $k_{max}$ .

**Table 5. Growth Rate Parameters with the Electron Donor (Acetate) Varied.**

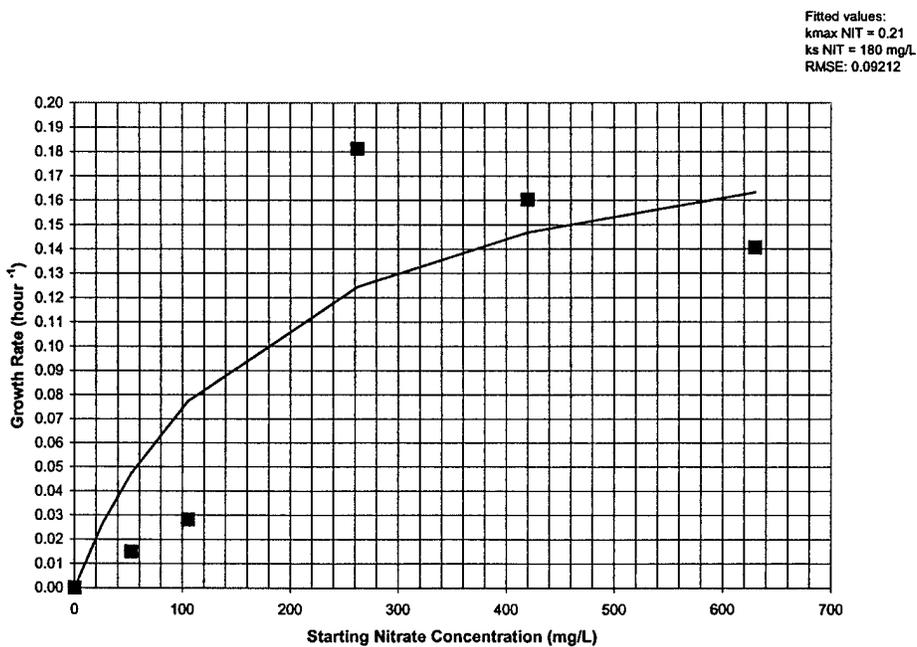
Parameter (units)	Value	Method of Determination
$k_{\max}^{\text{don/per}}$ ( $\text{h}^{-1}$ )	0.140	Determined by measuring OD550 values of the culture with acetate (substrate) varied and acceptor in excess, constructing the Monod curve for acetate, and fitting the model to this curve (Figure 56). This parameter represents the "asymptotic" rate value observed in Figure 56.
$k_{\max}^{\text{don/nit}}$ ( $\text{h}^{-1}$ )	0.145	Determined by measuring OD550 values of the culture with acetate (substrate) varied and acceptor in excess, constructing the Monod curve for acetate, and fitting the model to this curve (Figure 58). This parameter represents the "asymptotic" rate value observed in Figure 58.
$k_{\max}^{\text{don/oxy}}$ ( $\text{h}^{-1}$ )	0.21	Determined by measuring OD550 values of the culture with acetate (substrate) varied and acceptor in excess, constructing the Monod curve for acetate, and fitting the model to this curve (Figure 57). This parameter represents the "asymptotic" rate value observed in Figure 57.
$K_S^{\text{don/per}}$ (mg/L)	120	Determined as the acetate concentration where the growth rate in the Monod curve for acetate and perchlorate (Figure 56) is $\frac{1}{2} k_{\max}$ .
$K_S^{\text{don/nit}}$ (mg/L)	70	Determined as the acetate concentration where the growth rate in the Monod curve for acetate and nitrate (Figure 58) is $\frac{1}{2} k_{\max}$ .
$K_S^{\text{don/oxy}}$ (mg/L)	90	Determined as the acetate concentration where the growth rate in the Monod curve for acetate and oxygen (Figure 57) is $\frac{1}{2} k_{\max}$ .

**Table 6. Growth Rate Parameters with the Electron Acceptors (Nitrate and Perchlorate) Varied.**

Parameter (units)	Value	Method of determination
$k_{\max}^{\text{per/don}}$ ( $\text{h}^{-1}$ )	0.071	Determined by measuring OD550 values of the culture with acetate (substrate) in excess and perchlorate (electron acceptor) varied, constructing the Monod curve for perchlorate, and fitting the model to this curve (Figure 59). This parameter represents the "asymptotic" rate value observed in Figure 59.
$k_{\max}^{\text{nit/don}}$ ( $\text{h}^{-1}$ )	0.21	Determined by measuring OD550 values of the culture with acetate (substrate) in excess and nitrate (electron acceptor) varied, constructing the Monod curve for nitrate, and fitting the model to this curve (Figure 60). This parameter represents the "asymptotic" rate value observed in Figure 60.
$K_S^{\text{per/don}}$ (mg/L)	150	Determined as the perchlorate concentration where the growth rate in the Monod curve for perchlorate and acetate (Figure 59) is $\frac{1}{2} k_{\max}$ .
$K_S^{\text{nit/don}}$ (mg/L)	180	Determined as the nitrate concentration where the growth rate in the Monod curve for nitrate and acetate (Figure 60) is $\frac{1}{2} k_{\max}$ .



**Figure 59. Growth Rate of JPLRND on Acetate with Perchlorate as Electron Acceptor: Perchlorate Varied; Determination of  $K_s$  and  $k_{max}$ .**



**Figure 60. Growth Rate of JPLRND on Acetate with Nitrate as Electron Acceptor: Nitrate Varied; Determination of  $K_s$  and  $k_{max}$ .**

#### 4.5.6.2. Experimental Quantification of Cell Yield and Decay

##### Cell Yield

To determine the biomass yield on perchlorate, nitrate, and oxygen, flasks were prepared with acetate as the electron donor and one of these three compounds as electron acceptor. The electron acceptor was added in excess based on stoichiometric requirements for acetate metabolism. In the case of oxygen, the culture was incubated aerobically with vigorous shaking to ensure adequate oxygen supply. After measuring the starting acetate concentration in each flask, the flasks were inoculated with JPLRND, and growth was measured by periodically taking optical density measurements on subsamples collected from each flask. When the culture reached the late phase of its exponential growth, the concentrations of electron donor and acceptor (nitrate or perchlorate) in each flask were quantified. At that point, a 500 – 750 mL volume from each flask was centrifuged to concentrate the bacterial cells. This concentrate was resuspended in 5 – 10 mL of water and filtered under vacuum through an oven-dry cellulose filter (47 mm diameter, 0.45 micron pore-size; Gelman Sciences). The filter was oven-dried (at 105°C for 24 hours) to determine the weight of biomass in each flask. Consequently, the mass of dried biomass produced per mass of electron donor (i.e., the yield coefficient) was determined.

*Dechlorosoma suillum* JPLRND was grown on 1250 mg/L acetate and 1750 mg/L perchlorate to determine the yield of the culture while using perchlorate as an electron acceptor. During this experiment, JPLRND consumed 1246 mg of acetate and 961 mg of perchlorate, giving a ratio of 1.30 mg acetate/mg perchlorate utilized. The consumption of acetate by JPLRND was nearly twice that expected based on stoichiometric calculations (0.69 mg acetate per mg perchlorate). The cell yield on acetate was 0.173 mg dry biomass per mg acetate utilized. This corresponds to 0.225 mg dry biomass per mg perchlorate consumed.

The yield of JPLRND during growth on acetate while utilizing nitrate was slightly lower than for perchlorate. The strain metabolized 560 mg of acetate and 682 mg of nitrate to produce 73.3 mg of biomass. Based on these numbers, the yield of the strain was 0.131 mg biomass/mg acetate and 0.107 mg biomass/mg nitrate. The ratio of electron donor to electron acceptor was 0.82 mg acetate/mg nitrate consumed. This value is close to the calculated stoichiometric ratio of 0.76 mg acetate/mg nitrate consumed.

Two yield studies were performed with oxygen as the electron acceptor. In the first study, JPLRND utilized 1030 mg acetate to produce 326 mg of biomass, giving a yield of 0.317 mg dry biomass per mg acetate consumed. In the second study, the cells consumed 966 mg acetate to produce 313 mg biomass for a yield of 0.324 mg dry biomass per mg acetate consumed. Oxygen consumption was not

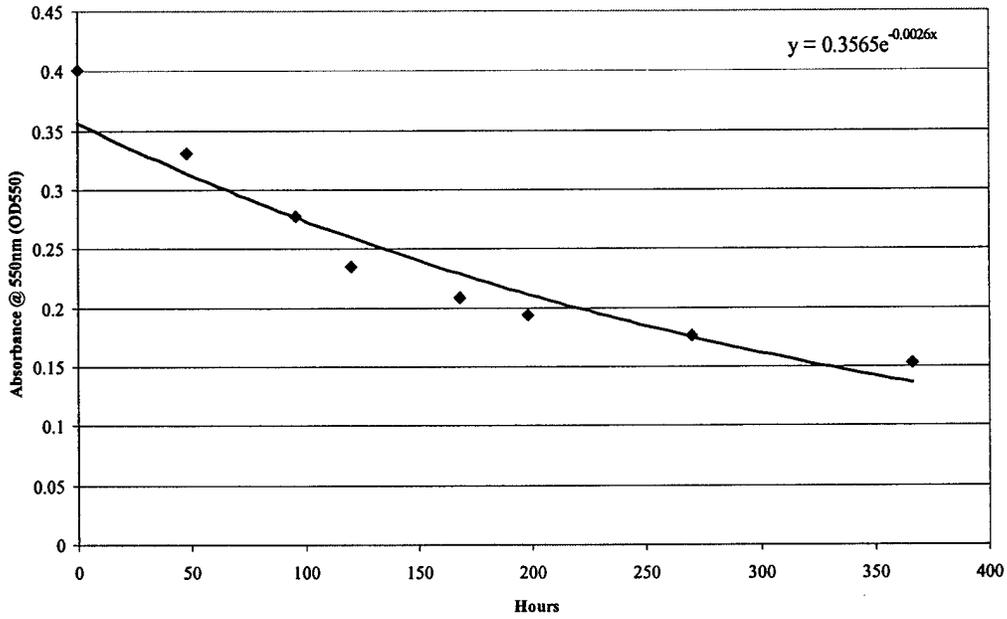
measured in these studies. Overall, the cell yield varied between 0.131 to 0.324 mg biomass/mg acetate, with an average value of 0.236 mg biomass/mg acetate.

### Cell Decay

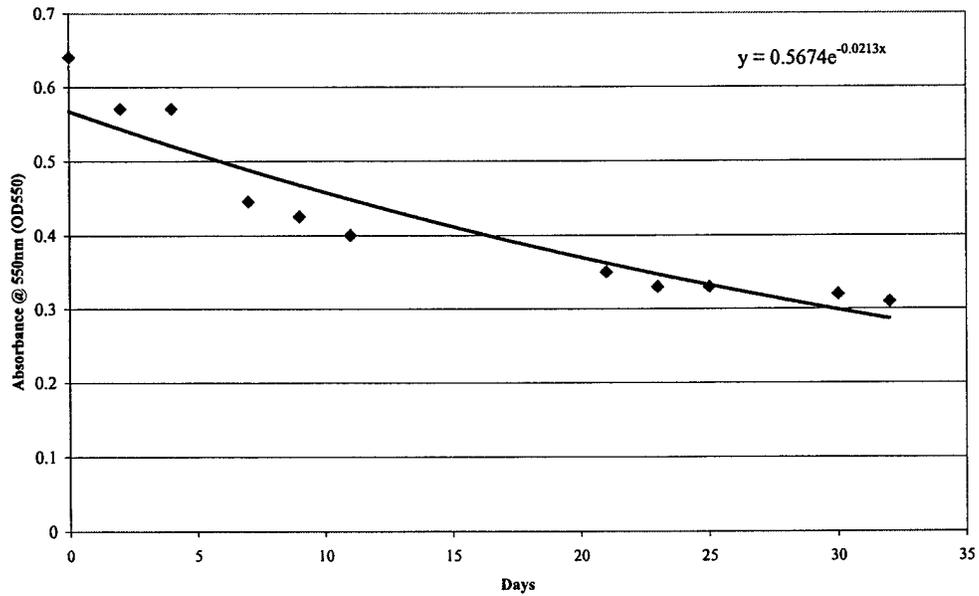
Two experiments were conducted to quantify the cell decay rate of *D. suillum* JPLRND after growth on acetate with oxygen as the electron acceptor. In the first experiment, the bacterium was inoculated into an Erlenmeyer flask containing BSM and 500 mg/L acetate. In the second experiment, the bacterium was inoculated into an Erlenmeyer flask containing BSM and 1,500 mg/L acetate. The flasks were shaken at 22°C and 200 rpm. When the culture reached the stationary phase of growth (acetate was depleted), cell numbers were measured by optical density (absorbance at 550 nm). Dilution plating was also done at that point to compare absorbance measurements with actual microbial populations. The decay curves after growth on acetate and oxygen are shown in Figures 61 and 62. The decay rate obtained from these graphs were 0.0026 h<sup>-1</sup> and 0.0213 h<sup>-1</sup>, respectively.

Two experiments were conducted to quantify the cell decay rate of *D. suillum* JPLRND after growth on acetate with nitrate as the electron acceptor. In the first experiment, the culture was grown on 750 mg/L nitrate and 500 ppm acetate. In the second experiment, the culture was grown on 750 mg/L nitrate and 1000 ppm acetate. When the culture reached stationary phase, and the acetate was depleted, cell numbers were measured by optical density (absorbance at 550 nm). Dilution plating was also done to verify absorbance measurements. The decay curves after growth on acetate and nitrate are shown in Figure 63 and 64. The decay rates obtained from these graphs were 0.0066 h<sup>-1</sup> and 0.0026 h<sup>-1</sup>, respectively.

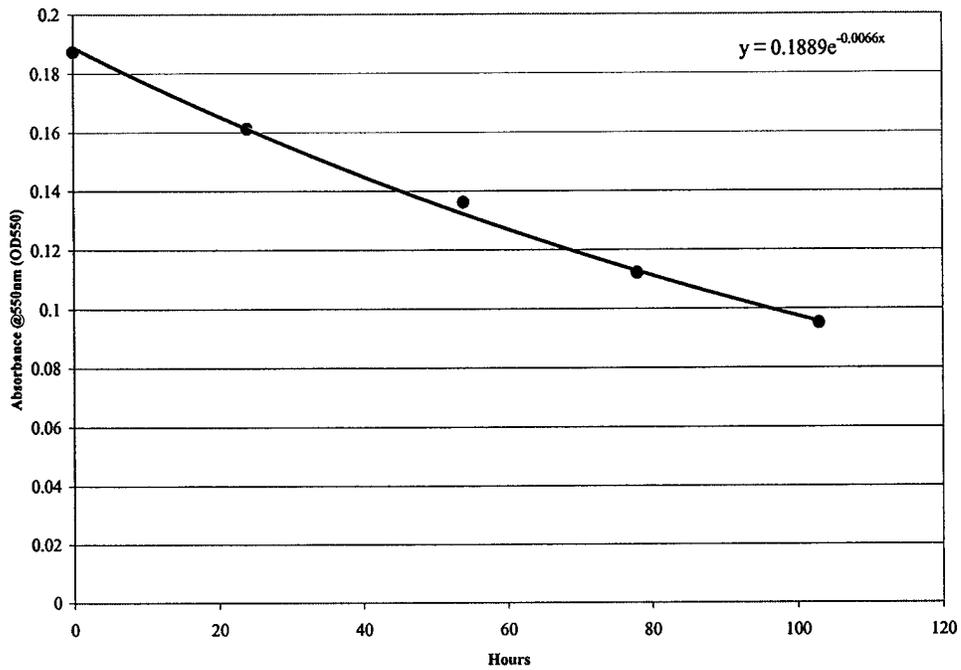
One experiment was conducted to quantify the cell decay rate of *D. suillum* JPLRND after growth on acetate with perchlorate as the electron acceptor. The culture was grown on 1000 mg/L perchlorate and 600 mg/L acetate. Measurements were taken as described for the other decay experiments. The decay curve after growth on acetate and perchlorate is shown in Figure 65. The decay rate obtained from this graph was 0.0388 h<sup>-1</sup>. The decay rates for the *D. suillum* JPLRND after growth on the three of electron acceptors ranged from 0.0026 to 0.0388 h<sup>-1</sup>, with an average of 0.014 h<sup>-1</sup>.



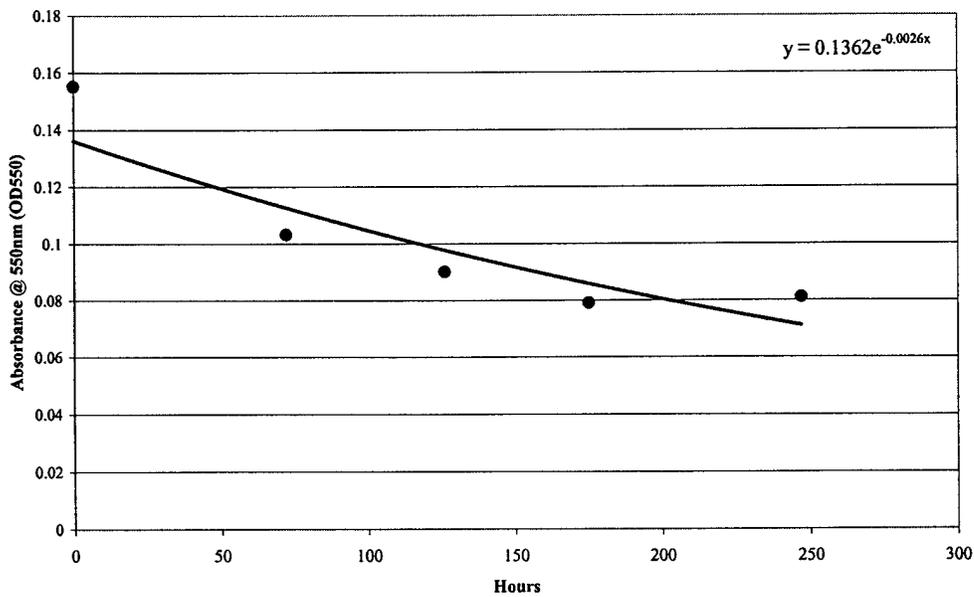
**Figure 61. Microbial Decay Curve for JPLRND after Growth on Oxygen and 500 mg/L Acetate.**



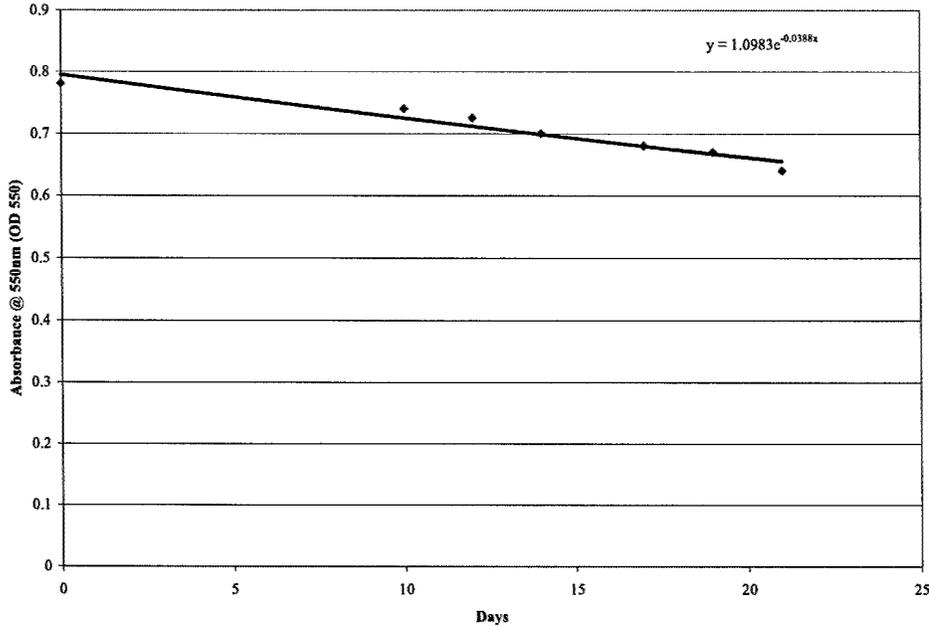
**Figure 62. Microbial Decay Curve for JPLRND after Growth on Oxygen and 1500 mg/L Acetate.**



**Figure 63. Microbial Decay Curve for JPLRND after Growth on Nitrate (750 mg/L) and Acetate (500 mg/L).**



**Figure 64. Microbial Decay Curve for JPLRND after Growth on Nitrate (750 mg/L) and Acetate (1000 mg/L).**



**Figure 65. Microbial Decay Curve for JPLRND after Growth on Perchlorate (1000 mg/L) and Acetate (600 mg/L).**

#### 4.5.6.3 Utilization of Competing Electron Acceptors

Laboratory studies were conducted to better understand the relationship among competing electron acceptors, particularly nitrate, perchlorate, and oxygen. These studies are important as a conceptual basis for the perchlorate biodegradation model and for a more thorough understanding of factors influencing perchlorate biodegradation in subsurface environments.

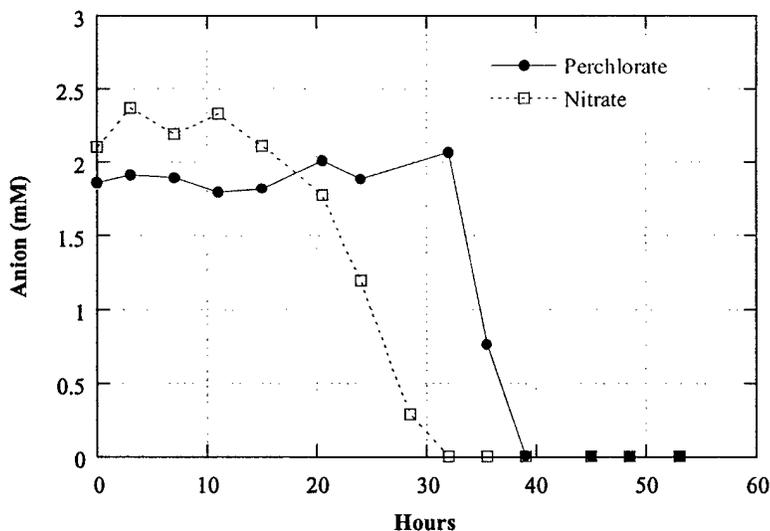
#### Methods

In one experiment, nitrate and perchlorate were added together in flasks with acetate as the electron donor. The degradation of the two electron acceptors by three JPLRND cultures grown on nitrate, perchlorate, and oxygen, respectively, was evaluated. These experiments were conducted to determine whether the initial growth conditions of the culture (i.e., which electron acceptor was used) influence the rate or order of degradation of nitrate and perchlorate by the strain. In this study, *D. suillum* JPLRND was grown to early stationary phase in media containing acetate as an electron donor and perchlorate, nitrate, or oxygen as the electron acceptor. Each culture was then centrifuged, resuspended in BSM media to the same density, then inoculated into sterile 1000-mL Erlenmeyer flasks containing 400 mL of BSM with acetate (8 mM) and a mixture of nitrate and perchlorate at 2 mM each. The flasks were incubated with shaking in a Coy Environmental Chamber with a nitrogen headspace. Subsamples were

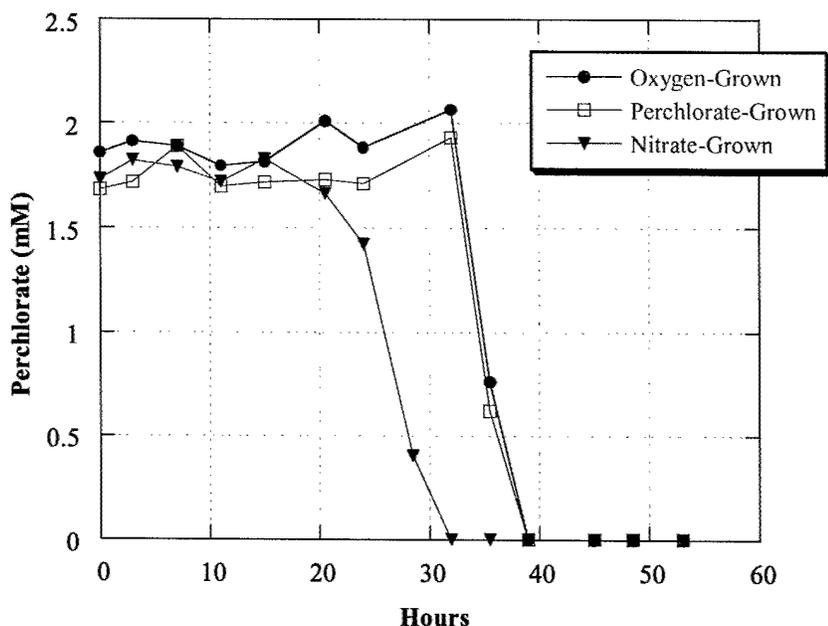
periodically removed from the flasks, filtered through a 0.22-micron syringe filter, and analyzed for nitrate, perchlorate, and acetate.

### Results

There was a lag period of 20 hrs or more before degradation of perchlorate or nitrate was observed. Then, in each treatment (oxygen-, nitrate-, or perchlorate-grown cells), the bacterium degraded nitrate prior to reducing perchlorate. A graph of perchlorate and nitrate degradation by the oxygen-grown strain is provided in Figure 66. Data for the other two electron acceptors were similar, although the lag periods for both nitrate and perchlorate reduction were appreciably shorter for the nitrate-grown strain (perchlorate data are presented in Figure 67). These data show that, regardless of the electron donor upon which JPLRND initially grows, it will degrade nitrate first, followed by perchlorate. These results are similar to those observed for a different strain isolated by John Coates at Southern Illinois University (SERDP Project CU-1162).



**Figure 66. Degradation of Nitrate and Perchlorate by an Oxygen-Grown Culture of *D. suillum* JPLRND.**



**Figure 67. Biodegradation of Perchlorate by *D. suillum* JPLRND after Growth on Nitrate, Perchlorate, or Oxygen (Electron Acceptors) with Acetate as Electron Donor.**

#### 4.5.6.4. Influence of Nitrate and Oxygen on Perchlorate Biodegradation

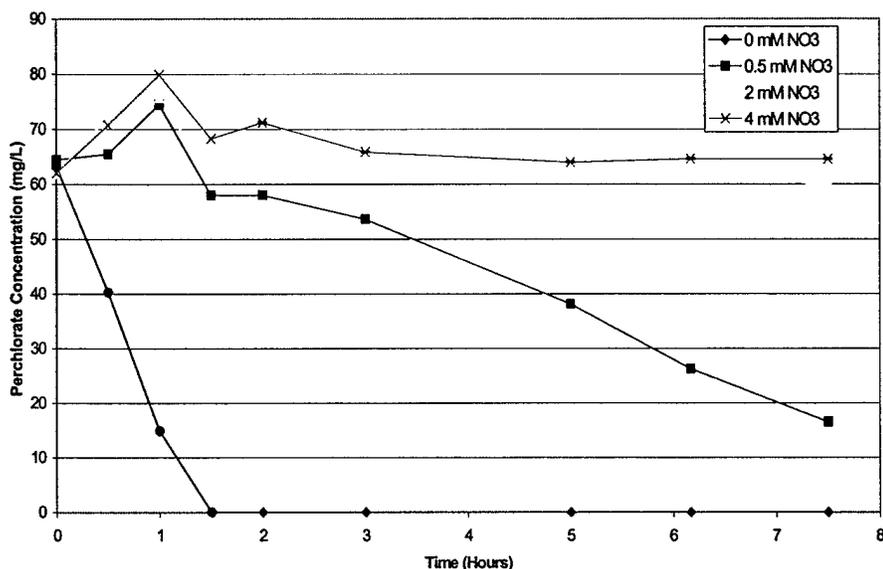
Experiments were conducted to evaluate the influence of nitrate and oxygen on perchlorate degradation by *D. suillum* JPLRND. Unlike the previous experiments, in which both nitrate and perchlorate were added to flasks simultaneously, in these studies, the culture was allowed to begin degrading perchlorate, then the second electron acceptor (oxygen or nitrate) was added.

##### 4.5.6.4.1 Influence of Nitrate on Perchlorate Reduction

###### Methods

An experiment was conducted to evaluate the influence of nitrate on perchlorate biodegradation. *Dechlorosoma suillum* JPLRND was grown in a 1-L flask using 750 mg/L acetate as electron donor and 500 mg/L perchlorate as electron acceptor. Subsamples of the culture media were collected and tested periodically using an ion specific probe to confirm that the culture was actively degrading perchlorate. When the perchlorate concentration dropped below 25 mg/L, additional perchlorate (200 mg/L; 2 mM) and acetate (460 mg/L; 8 mM) were added to the culture. After one hour, the perchlorate concentration had decreased to approximately 100 mg/L (~ 1 mM). At this point, 100 mL of the active culture was added to 4 sterile 125-mL flasks, and nitrate was added at approximately 0, 0.5, 2.0, or 4.0 mM. An

initial sample was taken from each flask, and subsequent 20-mL subsamples were taken every 0.5 hours for 2 hours, then at increasing time intervals for 22.5 hours. These subsamples were collected and filter-sterilized in the anaerobic chamber and analyzed for perchlorate and nitrate by ion chromatography. Select samples were also analyzed for acetate by gas chromatography. Data from this experiment are presented in Figure 68.



**Figure 68. Influence of Nitrate on Perchlorate Degradation by *D. suillum* JPLRND.**

## Results

After the addition of nitrate, perchlorate degradation quickly stopped in the flasks amended with 2 or 4 mM nitrate, and slowed dramatically in flasks receiving 0.5 mM nitrate. No change occurred in perchlorate concentrations in any of the flasks after 7.5 hrs, therefore, only data prior to that time are presented. Perchlorate degradation continued in the flask to which no nitrate was added, and the anion was below detection (< 5 mg/L by probe) by 1.5 hrs. Degradation of perchlorate did not resume in the flasks spiked with 2 mM or 4 mM nitrate, and nitrate was not degraded in these flasks during the experiment. In the flask to which 0.5 mM nitrate was added, perchlorate degradation ceased temporarily, but then continued at a slower rate. Perchlorate concentrations in this flask decreased from approximately 60 mg/L at 2 hrs to 16 mg/L after 7.5 hrs. Interestingly, nitrate was present in this flask at the end of the experiment at approximately 20 mg/L (the initial nitrate concentration in this flask was approximately 30

mg/L). About 300 mg/L (5 mM) acetate remained in each of the flasks at the end of the experiment (acetate data not shown). This indicates that sufficient acetate remained to support nitrate and/or perchlorate degradation.

The data indicate that, at least for this bacterial strain, nitrate is an inhibitor of perchlorate reduction at nitrate concentrations as low as 0.5 mM. The mechanism of this inhibition requires further study, which is beyond the scope of this research project. However, based upon the data collected, it is likely that nitrate is a competitive inhibitor of perchlorate reduction. Because of the short time required for nitrate to completely inhibit perchlorate degradation, it is unlikely that nitrate was inhibiting enzyme synthesis (i.e., of (per)chlorate reductase). It is more likely that nitrate was directly inhibiting enzyme activity.

#### 4.5.6.4.2 Estimation of a Nitrate Inhibition Factor for Perchlorate Reduction.

Nitrate inhibition of perchlorate utilization was described in the biodegradation model by including a nitrate inhibition factor ( $K_i^{nit}$ ) in the model equations (Appendix B, Equation 1d). This factor was estimated from experimental data from a flask study in which both nitrate and perchlorate were present and using all known or experimentally-estimated parameters in the biodegradation model. The known values included the starting nitrate and perchlorate concentrations (oxygen concentration was < 1 mg/L). Experimentally-estimated parameters included: the ratio of substrate consumed per mass of acceptor utilized,  $k_{max}$ , the half-saturation constants for each compound, the starting biomass concentration, the biomass yield coefficient and the biomass decay rate. Given all these parameters, the  $K_i^{nit}$  value was varied to obtain the best visual model fit to the data.

Initially, variation of  $K_i^{nit}$  alone did not result in good fits to the data. This indicated that one or more of the other estimated parameters did not represent conditions in the flasks. Upon investigation of experimental conditions, it was determined that the estimate for the initial biomass (30 mg/L) was the least accurate value in the model. This initial biomass value was measured at the start of the experiment, prior to enzyme induction and biomass growth (i.e., prior to the lag period). In the model, it is assumed that the biomass immediately undergoes exponential growth and decay. Thus, the initial biomass value input into the model must represent the biomass concentrations immediately before exponential growth starts. Consequently, it was determined that the measured initial biomass value (i.e., 30 mg/L) likely underestimated the actual biomass in the flasks when biodegradation commenced. Thus, the starting biomass value was increased in the model. This increase greatly improved model fits to the data. The biomass concentration was increased by an order of magnitude to 500 mg/L. This increase is believed to be reasonable because, in several experiments, including the one used to evaluate  $K_i^{nit}$ , the biomass increased by 1 to 2 orders of magnitude during the lag phase of the experiments. Given the higher initial

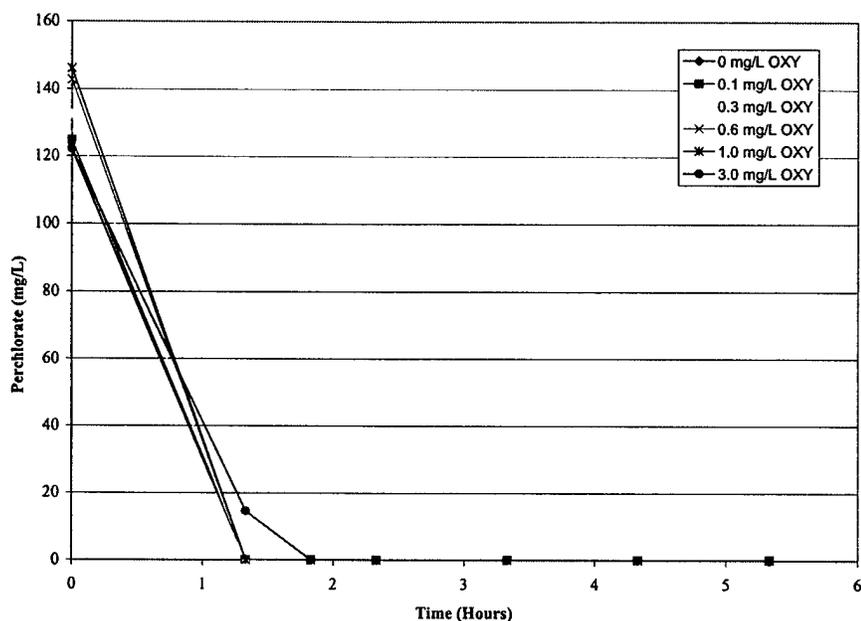
biomass value,  $K_i^{nit}$  was varied to obtain the optimal fit. The best-fit  $K_i^{nit}$  value was determined to be 7 mg/L. This is consistent with experimental data that indicate that nitrate concentrations as low as 0.5 mM (30 mg/L) inhibit perchlorate degradation. However, the effects of nitrate concentrations below 30 mg/L on perchlorate degradation were not directly examined.

#### 4.5.6.4.3 Influence of Oxygen on Perchlorate Reduction

An experiment was conducted to evaluate the effect of oxygen on perchlorate utilization. Although perchlorate degradation is known to be an anoxic process, data related to the minimum oxygen concentration at which perchlorate reduction occurs are not currently available in the literature. These values, however, have been reported for denitrification (i.e., inhibition of nitrate reductase enzyme(s) by oxygen). The experiments for evaluating the effect of oxygen on perchlorate utilization were performed in a similar fashion to the nitrate experiments described above, except that different amounts of oxygen (rather than nitrate) were added to a culture that was actively degrading perchlorate.

A culture of *Dechlorosoma suillum* JPLRND was originally grown on 1000 mg/L each of perchlorate and acetate. When the perchlorate was degraded to less than 10 mg/L, the culture was spiked with an additional 500 mg/L of perchlorate. The perchlorate was then degraded to approximately 100 mg/L, at which point an additional 2 mM perchlorate (approximately 200 mg/L) and 8 mM acetate (approximately 460 mg/L) were added. When the perchlorate concentration reached approximately 200 mg/L, 100 mL of the active culture was added to each of six sterile 160-mL serum bottles. The bottles were sealed with butyl rubber stoppers and crimp caps. A time-zero sample was taken from each bottle for perchlorate analysis, and the bottles were then removed from the anaerobic chamber. Differing volumes of air were added to each bottle based on the assumption that if the headspace of each bottle were completely filled with air and at equilibrium, the dissolved oxygen concentration in the liquid would be approximately 8.2 mg/L. Different fractions of the nitrogen headspace in each bottle were removed and replaced with an equivalent volume of air to establish the following dissolved oxygen concentrations: 0 mg/L, 0.1 mg/L, 0.3 mg/L, 0.6 mg/L, 1.0 mg/L, and 3.0 mg/L. The bottles were shaken vigorously by hand for approximately 5 minutes to speed dissolution of the headspace air into the liquid phase. The bottles were then placed on a rotary shaker in the anaerobic chamber for 1.3 h before the next sample was taken. A colorimetric test method (Chemets; Chemetrics, Calverton, VA) was used to measure the initial dissolved oxygen concentration in each bottle. However, the results from this test were determined to be inaccurate based on results from control samples. It is likely that the mineral salts solution used for the study interfered with measurement of oxygen by this technique. Therefore, the initial oxygen concentrations in solution could not be experimentally determined.

Perchlorate was degraded to below detection (< 5 mg/L by probe) by 1.3 hrs in all bottles except in the bottle to which the greatest volume of air was added. In this bottle, the rate of perchlorate biodegradation slightly decreased (Figure 69). This result suggests that oxygen inhibits perchlorate degradation at 3 mg/L, not at lower concentrations. However, because accurate measurements of dissolved oxygen concentrations could not be obtained, the results of this study may have several explanations. It is possible that the target levels of dissolved oxygen were not achieved in the 5 minutes of vigorous shaking, that the range of oxygen concentrations used was too low, or that the culture actually degraded the oxygen while continuing to degrade perchlorate.



**Figure 69. Influence of Oxygen on Perchlorate Degradation by *D. suillum* JPLRND.**

#### 4.5.6.5 Model Simulation of Perchlorate and Nitrate Biodegradation by *D. suillum* JPLRND

Experimental data from a flask study in which both nitrate and perchlorate were initially present were used for comparison with model simulations. The data were presented previously in Figure 66. Several simulations of the model were run with varying parameter values to determine the sensitivity of the biodegradation model to changes in individual parameters. All known or experimentally-estimated parameters were initially used in the model. After the optimal fit was obtained (by varying the initial

biomass and  $K_i^{nit}$ ), the sensitivity analysis was performed. The sensitivity analysis was performed on the following parameters: nitrate inhibition factor ( $K_i^{nit}$ ), biomass decay rate ( $b$ ), and the starting biomass concentration ( $B_0$ ). The sensitivity analysis included the latter two parameters because each varied by more than an order of magnitude during the fitting process. All other parameters were held constant during this analysis. The results of eight simulations are presented in Figures 70 through 77. In each of these simulations, one of the three parameters is varied, while the other two are kept at their "best-fit" value. The best-fit values for the three parameters are:  $K_i^{nit} = 7$  mg/L,  $b = 0.014$  hr<sup>-1</sup>, and  $B_0 = 500$  mg/L.

In Figures 70 through 73, the starting biomass concentration ( $B_0$ ) is varied, while the nitrate inhibition factor ( $K_i^{nit}$ ) remains constant at 7 mg/L and the decay rate ( $b$ ) is set at 0.014 hr<sup>-1</sup>. At  $B_0 = 30$  mg/L (Figure 70), the biomass curve is linear, and very little nitrate or perchlorate degradation is observed. Degradation of both compounds improves when  $B_0$  is increased to 100 mg/L (Figure 71), and the biomass curve remains relatively linear. At  $B_0 = 300$  mg/L (Figure 72), decay begins to dominate when nitrate and perchlorate are depleted. At  $B_0 = 500$  mg/L (Figure 73), the model fit with the data is optimal. The model is sensitive to starting biomass concentration, particularly when  $B_0$  is less than 300 mg/L. The starting biomass concentration used in the optimal model simulation (Figure 73) was 500 mg/L.

In Figures 74 and 75, the nitrate inhibition factor ( $K_i^{nit}$ ) is varied, while  $B_0$  is set at 500 mg/L and  $b$  remains constant at 0.014 hr<sup>-1</sup>. In each of these simulations, perchlorate degradation is affected by a change in  $K_i^{nit}$ , while nitrate degradation does not change. In addition, changes in  $K_i^{nit}$  resulted in only slight changes to the biomass curve. At  $K_i^{nit} = 0.7$  mg/L, the modeled perchlorate degradation was slower than the experimental data show (Figure 74). At  $K_i^{nit} = 70$  mg/L, the modeled perchlorate degradation is more rapid than the experimental data suggest (Figure 75). At  $K_i^{nit} = 7$  mg/L (Figure 73) the modeled perchlorate degradation curve gives a close fit to the experimental data. Therefore, the nitrate inhibition factor used in the optimal model simulation was  $K_i^{nit} = 7$  mg/L.

In Figures 76 and 77, the cell decay rate ( $b$ ) was varied, while  $B_0 = 500$  mg/L and  $K_i^{nit} = 7$  mg/L. At  $b = 0.0014$  hr<sup>-1</sup> (Figure 76), perchlorate and nitrate degradation simulated by the model are a close fit to the data with biomass growth and decay dominating the biomass curve. At  $b = 0.14$  hr<sup>-1</sup> neither perchlorate nor nitrate degradation are simulated well by the model, and biomass decay dominates the biomass curve (Figure 77). The decay value used in the optimal model simulation was 0.014 hr<sup>-1</sup>.

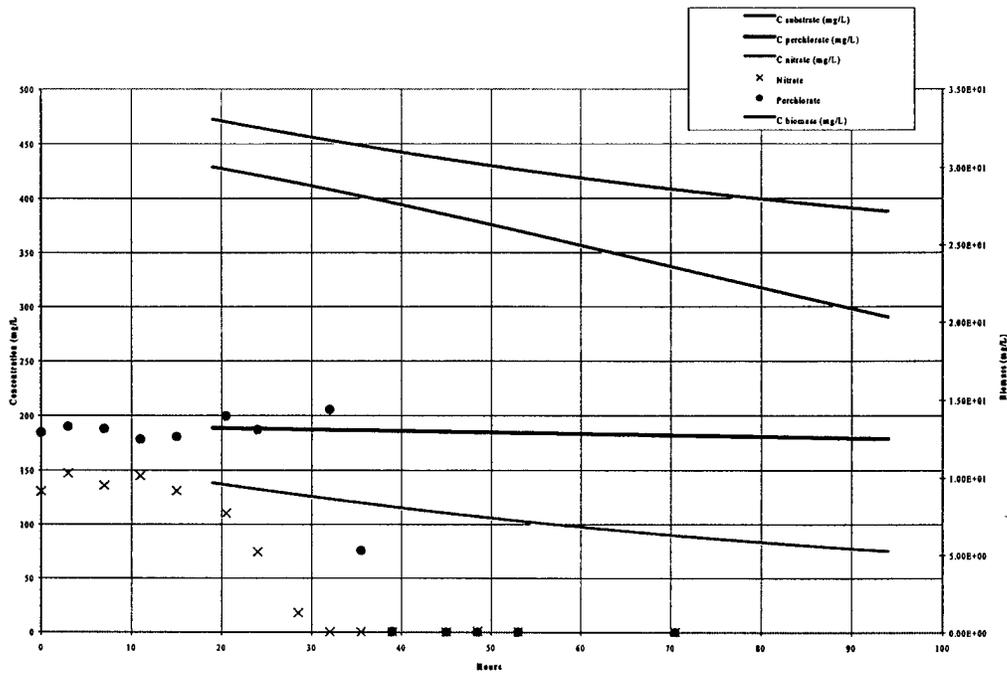


Figure 70. Model Simulation of Perchlorate and Nitrate Biodegradation by *D. suillum* JPLRND in Batch Culture:  $K_i^{nit} = 7$  mg/L,  $B_0 = 30$  mg/L, and  $b = 0.014$  hr<sup>-1</sup>.

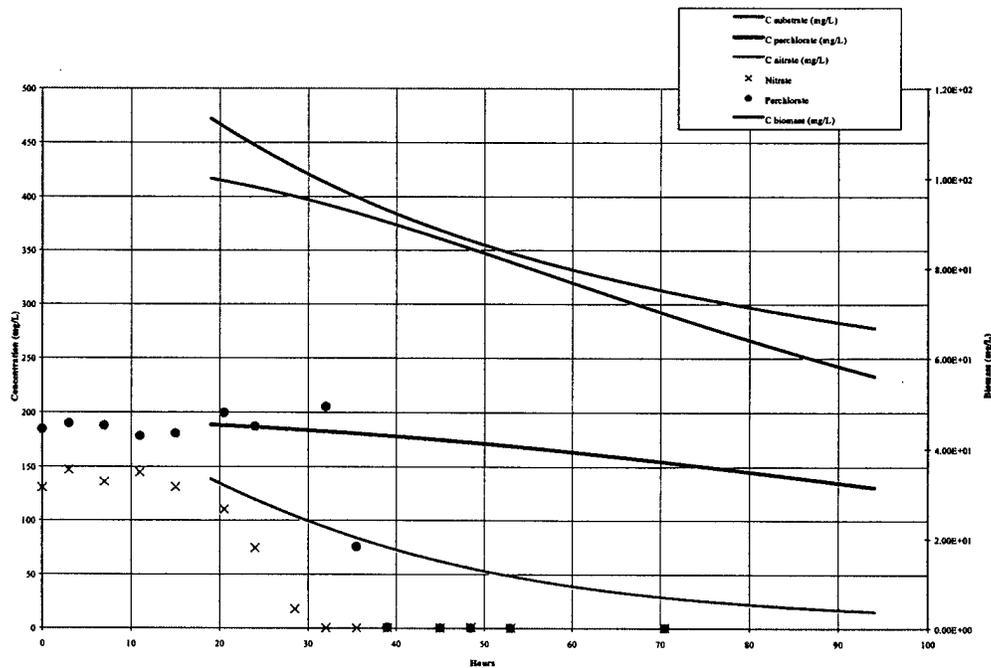


Figure 71. Model Simulation of Perchlorate and Nitrate Biodegradation by *D. suillum* JPLRND in Batch Culture:  $K_i^{nit} = 7$  mg/L,  $B_0 = 100$  mg/L, and  $b = 0.014$  hr<sup>-1</sup>.

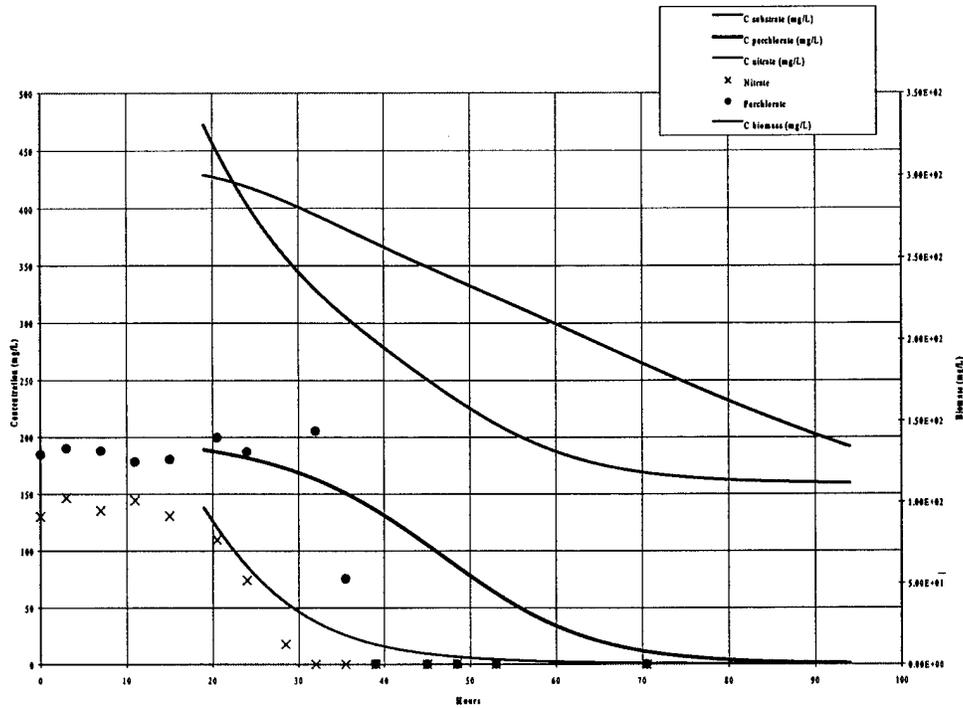


Figure 72. Model Simulation of Perchlorate and Nitrate Biodegradation by *D. suillum* JPLRND in Batch Culture:  $K_i^{nit} = 7$  mg/L,  $B_0 = 300$  mg/L, and  $b = 0.014$  hr<sup>-1</sup>.

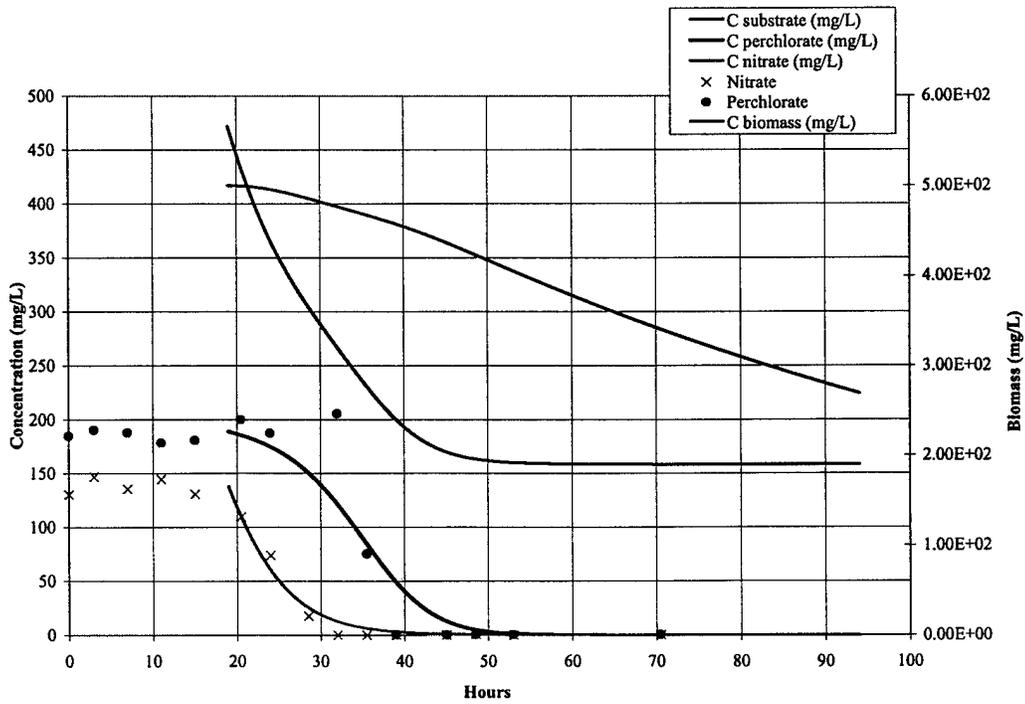


Figure 73. Model Simulation of Perchlorate and Nitrate Biodegradation by *D. suillum* JPLRND in Batch Culture:  $K_i^{nit} = 7$  mg/L,  $B_0 = 500$  mg/L, and  $b = 0.014$  hr<sup>-1</sup>.

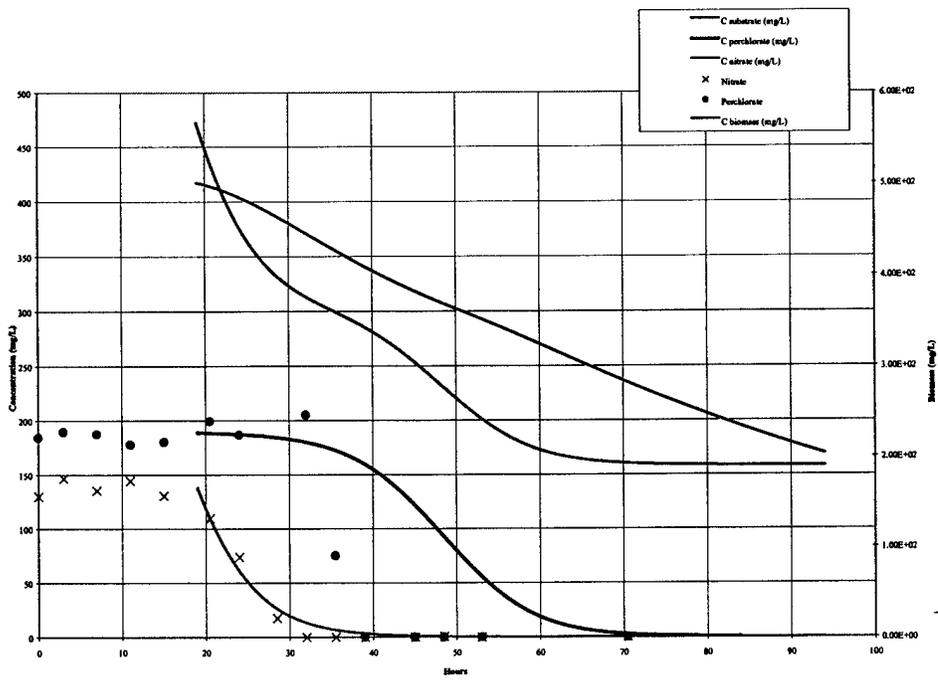


Figure 74. Model Simulation of Perchlorate and Nitrate Biodegradation by *D. suillum* JPLRND in Batch Culture:  $K_i^{nit} = 0.7 \text{ mg/L}$ ,  $B_0 = 500 \text{ mg/L}$ , and  $b = 0.014 \text{ hr}^{-1}$ .

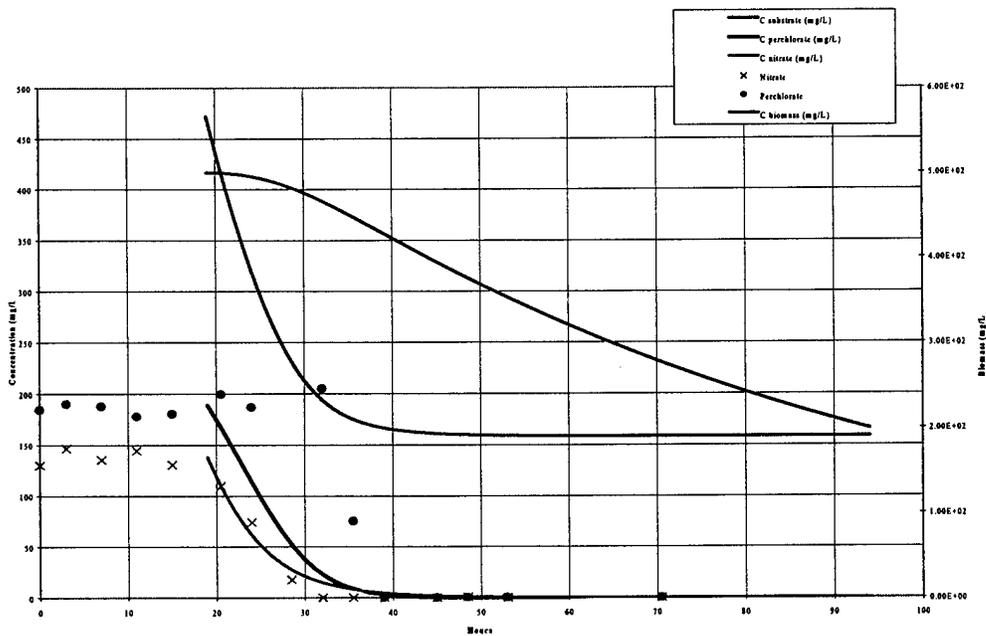


Figure 75. Model Simulation of Perchlorate and Nitrate Biodegradation by *D. suillum* JPLRND in Batch Culture:  $K_i^{nit} = 70 \text{ mg/L}$ ,  $B_0 = 500 \text{ mg/L}$ , and  $b = 0.014 \text{ hr}^{-1}$ .

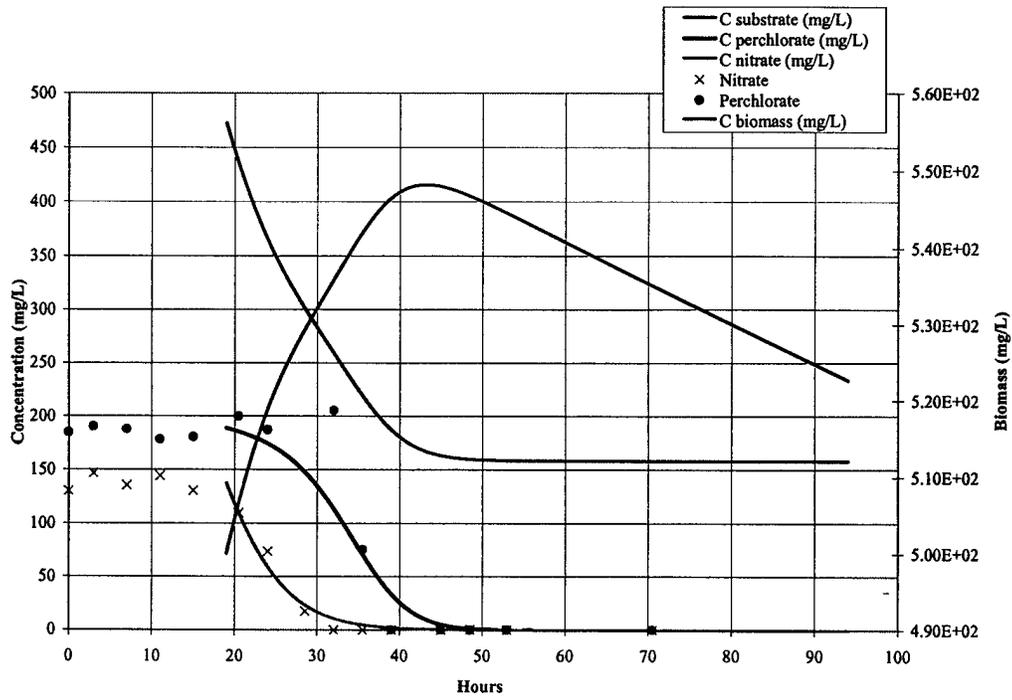


Figure 76. Model Simulation of Perchlorate and Nitrate Biodegradation by *D. suillum* JPLRND in Batch Culture:  $K_i^{nit} = 7$  mg/L,  $B_0 = 500$  mg/L, and  $b = 0.0014$  hr<sup>-1</sup>.

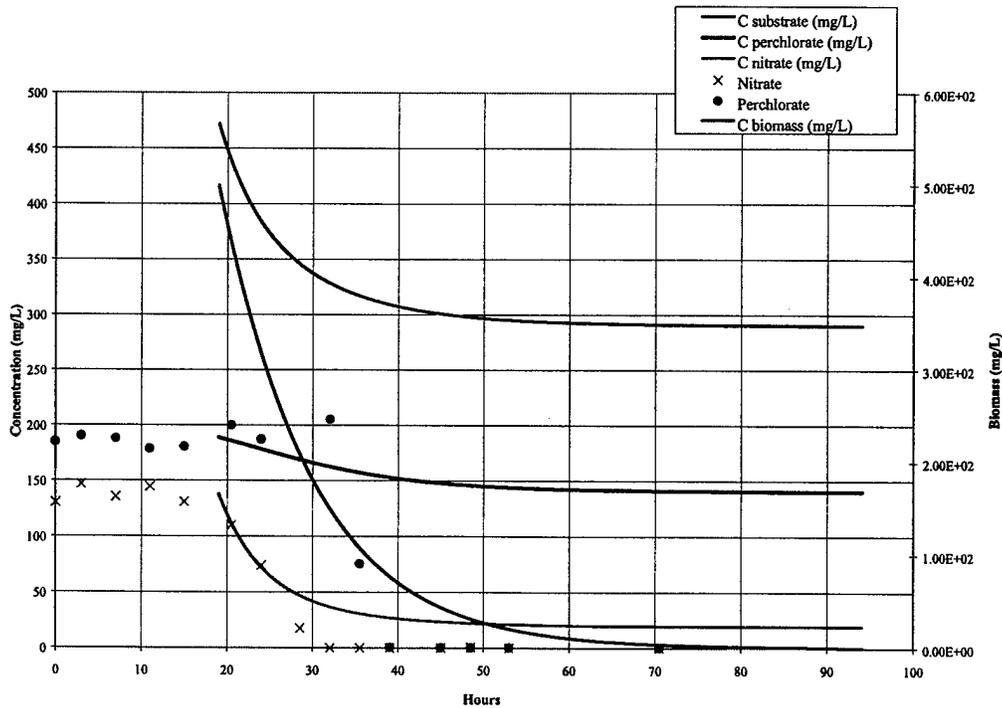


Figure 77. Model Simulation of Perchlorate and Nitrate Biodegradation by *D. suillum* JPLRND in Batch Culture:  $K_i^{nit} = 7$  mg/L,  $B_0 = 500$  mg/L, and  $b = 0.14$  hr<sup>-1</sup>.

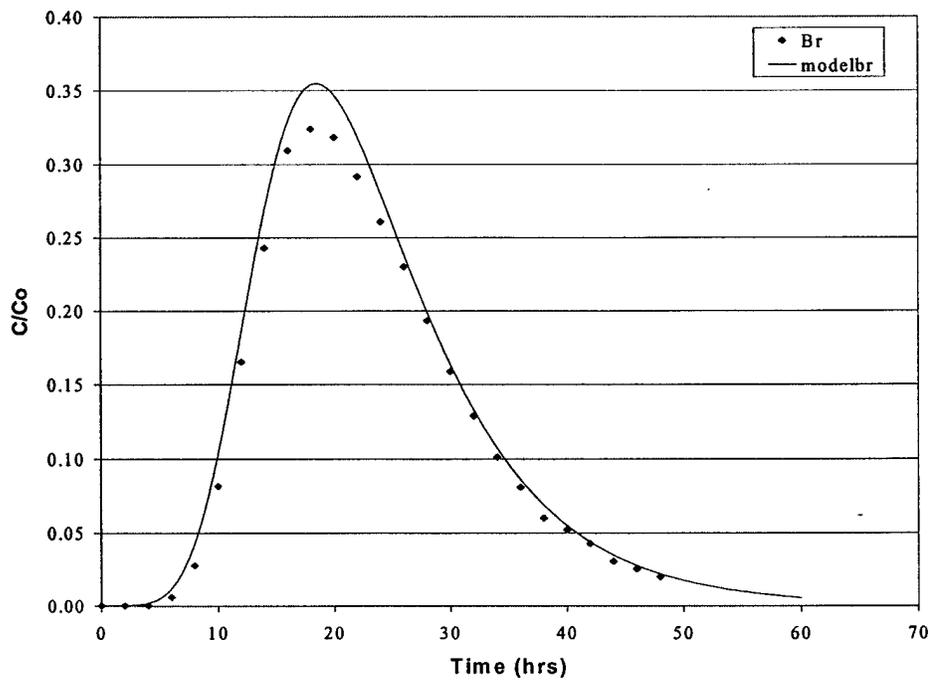
## 4.6 PERCHLORATE TRANSPORT MODEL

### 4.6.1 MODEL SIMULATION OF PERCHLORATE AND BROMIDE TRANSPORT IN THE MODEL AQUIFER

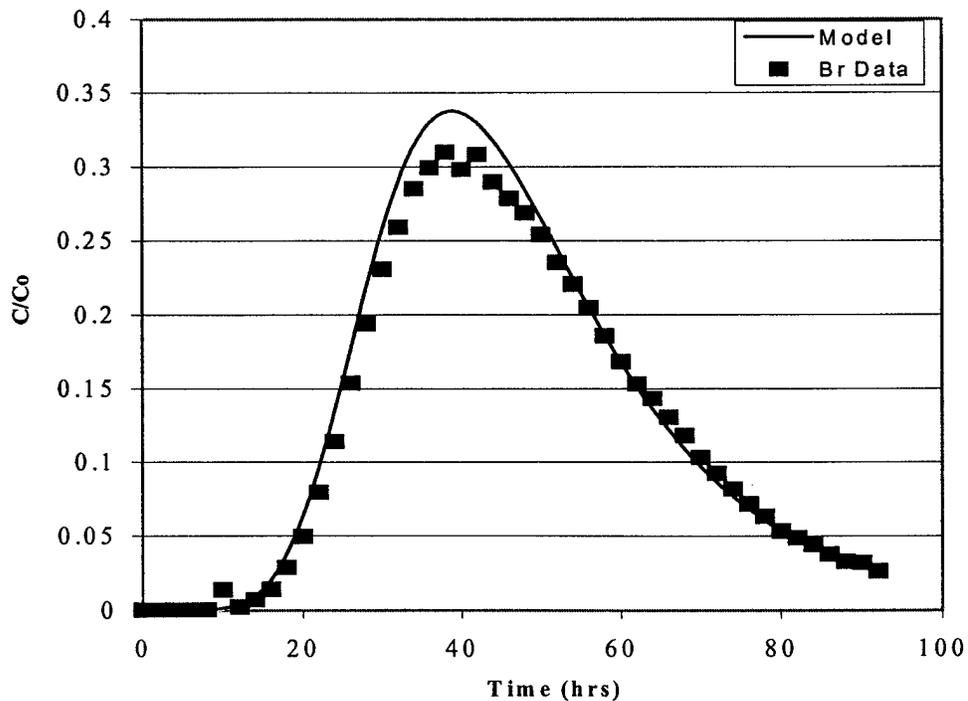
The software HydroBioGeoChem123D (HBGC123D) was used to describe the one-dimensional transport of bromide and perchlorate in a 50-cm laboratory column. This software was chosen because of its capability to describe the transport and consumption of multiple electron acceptors in groundwater. Several conservative transport experiments using sand and aquifer sediments were conducted using the 50-cm column prior to commencing biodegradation studies, as described in Section 4.4.3.

The transport of perchlorate in two column experiments was simulated using HBGC123D. For each of these experiments, the 50-cm column was packed with sediments from LHAAP. In the first experiment, the groundwater flow rate was 42 mL/hr and the pulse of perchlorate and bromide (added together at 50 mg/L each) was 7 hrs. In the second study, the flow was decreased by half to 21 mL/hr, and the addition of bromide and perchlorate lasted 13 hrs. The conservative transport of perchlorate and bromide was nearly identical in these studies. The following parameters were measured or calculated and used for modeling chemical breakthrough curves from each experiment: column length = 50 cm; column diameter = 7.3 cm; cross-sectional area = 42 cm<sup>2</sup>; bulk density = 1.41 g/cm<sup>3</sup>; and porosity = 0.47.

To describe the bromide and perchlorate breakthrough curves, the dispersion coefficient of these compounds through the columns is needed. This parameter is related to the average pore velocity according to the equation  $D = a \cdot v$ , where  $D$  is the dispersion coefficient (cm<sup>2</sup>/hr),  $a$  is the dispersivity (cm); and  $v$  is the average pore velocity (cm/hr). The average pore velocity is calculated by the model based upon the water flux, the column cross-sectional area, and the porosity. To obtain the best fits between the model and observed data, the dispersivity,  $a$ , was varied in HBGC123D. Model fits for the two experiments are provided in Figures 78 and 79, respectively. The bromide data are presented in the figures, but perchlorate data were identical and are simulated by the same model fits. The dispersivity obtained for each curve fit is also given in the figures. These results represent the initial curve fitting exercise with HBGC123D. As seen in the figures, model simulations compared very well with the data, although the maximum breakthrough concentration for each experiment was overestimated slightly by the model.



**Figure 78. Model Fit of Bromide Breakthrough Curves in Experiment 1 (42 ml/hr) with a Dispersivity of 7 cm.**



**Figure 79. Model Fit of Bromide Breakthrough Curves in Experiment 2 (21 ml/hr) with a Dispersivity of 5.5 cm.**

#### **4.7. COUPLED TRANSPORT AND BIODEGRADATION MODEL FOR PERCHLORATE**

Column transport experiments were conducted where perchlorate utilization as an electron acceptor was promoted inside the column. Perchlorate, nitrate, and oxygen were fed into a 50-cm soil column packed with sediments collected from LHAAP (see section 4.4). After measured inlet and outlet perchlorate concentrations were similar (i.e., steady-state concentration conditions), acetate was added to the influent. Perchlorate concentrations were measured at the sampling ports along the length of the column and at the outlet of the column. The software HBGC123D was used to model the transport and biodegradation of acetate, oxygen, nitrate, and perchlorate during these experiments. This software has the capability of modeling the transport and biodegradation of multiple electron donors and acceptors in ground water. In HBGC123D, chemical biodegradation can be described using Monod kinetics and biomass growth. Further, this software can describe inhibition of the consumption of one electron acceptor (e.g., perchlorate) due to the presence of other electron acceptors (e.g., oxygen or nitrate).

##### **4.7.1. EXPERIMENTAL APPROACH**

The biodegradation function described above and presented in Appendix B was incorporated into HBGC123D to describe the transport and biodegradation of perchlorate in the 50-cm soil column experiment. As described previously (Section 4.4.3), the column was packed using soil materials collected from the Longhorn Army Ammunition Plant (LHAAP). During these experiments, perchlorate was added to influent groundwater at 25 mg/L, nitrate was added at 16 mg/L, and oxygen was present at approximately 8 mg/L. These additions represent approximately equimolar quantities (0.25 mM) of each of these three electron acceptors. Acetate (electron donor) was not initially added. After reaching steady-state conditions for nitrate and perchlorate, (i.e., equal influent and effluent concentrations), acetate was added to the inflow water. The concentration of acetate in the inflow water was set at 80 mg/L using a separate syringe pump. In the model, the time when acetate was first added is designated as  $t = 0$ . Data collected during this experiment include the concentrations of acetate, oxygen, nitrate and perchlorate in influent and effluent water, and at sampling ports along the column.

##### **4.7.2. MODEL PARAMETERS**

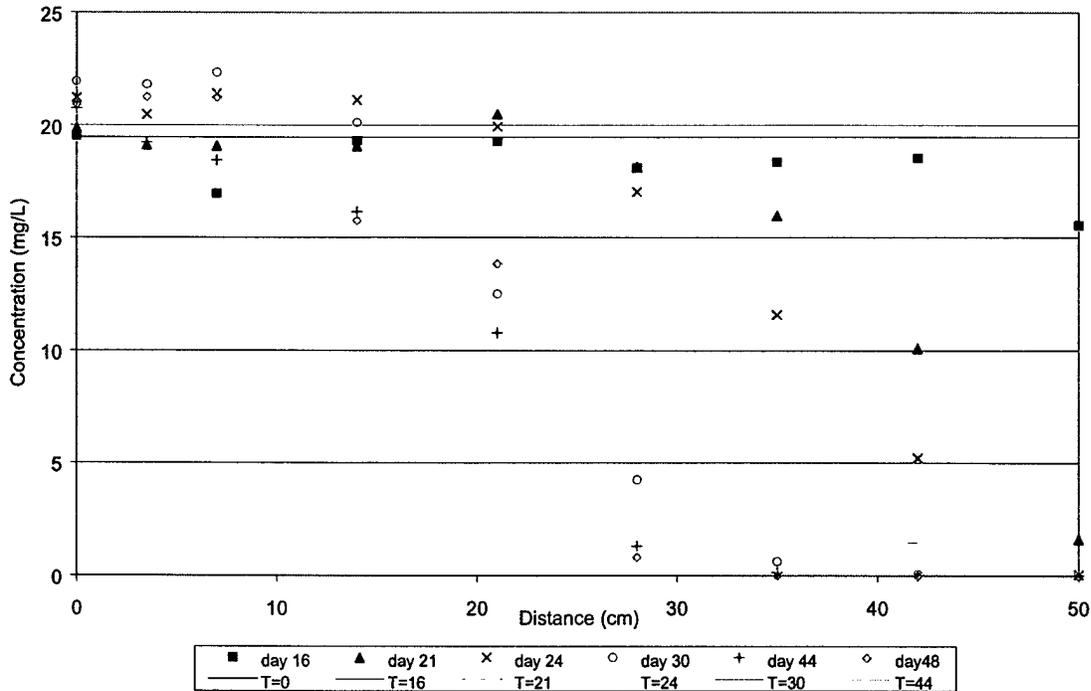
The input parameters used in HBGC123D to simulate the column data are summarized in Table 7. These parameters were measured either directly from the column or obtained from the batch experiments conducted during this project.

**Table 7. Input Parameters for Coupled Model**

	Parameter	Value	Units	Method of Determination
<b>Physical Parameters</b>	Darcy velocity	10	cm/hr	Calculated as the volume of water input to column divided by the column cross-sectional area.
	Dispersivity	6.25	cm	Average of values fit to the bromide breakthrough curve.
	Bulk density	1.41	g/cm <sup>3</sup>	Calculated using the mass of dry soil added to the column and the total volume of the column.
	Porosity	0.47	cm <sup>3</sup> water/cm <sup>3</sup> total	Calculated using the bulk density and assuming the density of the soil particles as 2.65 g/cm <sup>3</sup> .
<b>Biological Parameters</b>	$k_{max}$	0.165	1/hr	Average of $k_{max}^{don/oxy}$ , $k_{max}^{don/nit}$ and $k_{max}^{don/per}$ values fit to batch data (see Table 5).
	$K_s^{don}$	93.3	mg/L	Average of $K_s^{don/oxy}$ , $K_s^{don/nit}$ and $K_s^{don/per}$ values fit to batch data (see Table 5).
	$K_s^{oxy/don}$	1	mg/L	Assumed.
	$K_s^{nit/don}$	180	mg/L	Value fit to batch data (see Table 6)
	$K_s^{per/don}$	150	mg/L	Value fit to batch data (see Table 6)
	$b$	0.014	1/hr	Average of values fit to batch data in Section 4.5.6.2
	$Y$	0.236	g biomass/g acetate	Average of values fit to batch data in Section 4.5.6.2
	Initial biomass, $B_0$	0.01	mg biomass/g soil	Calculated based on an initial cell population of $1 \times 10^7$ cells/g soil and assuming a cell density of 1 g/cm <sup>3</sup> and a cell volume of 1 $\mu\text{m}^3$

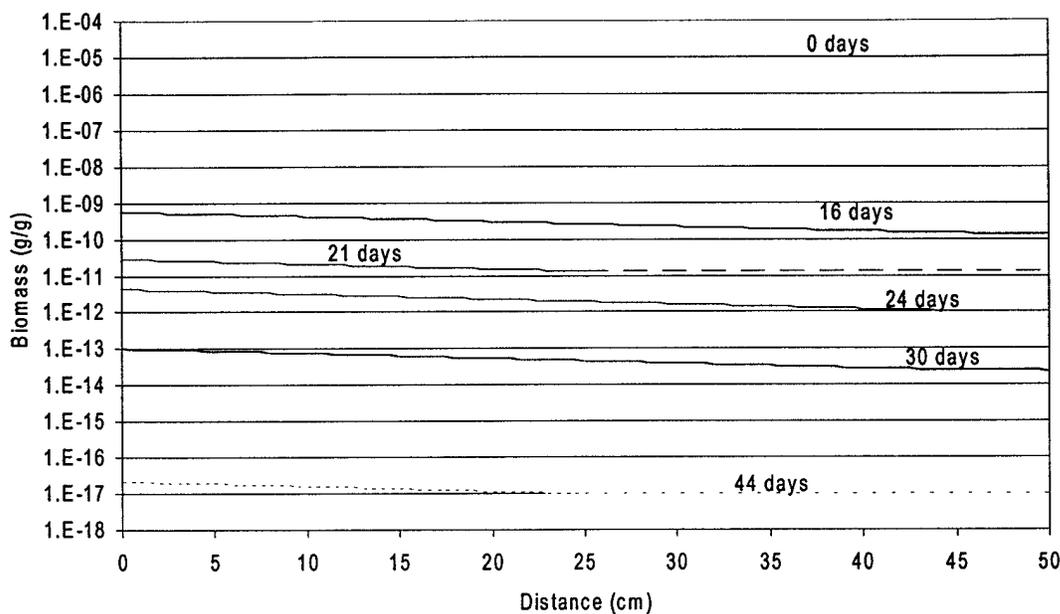
**4.7.3. MODEL RESULTS**

Model simulations predict that no significant biodegradation occurs inside the column. Modeled acetate breakthrough curves show that the concentration front moves through the column with little or no detectable decrease. Also, no detectable decreases in oxygen, nitrate or perchlorate concentrations were calculated in the column simulations. A comparison between measured and modeled perchlorate concentrations is shown in Figure 80.



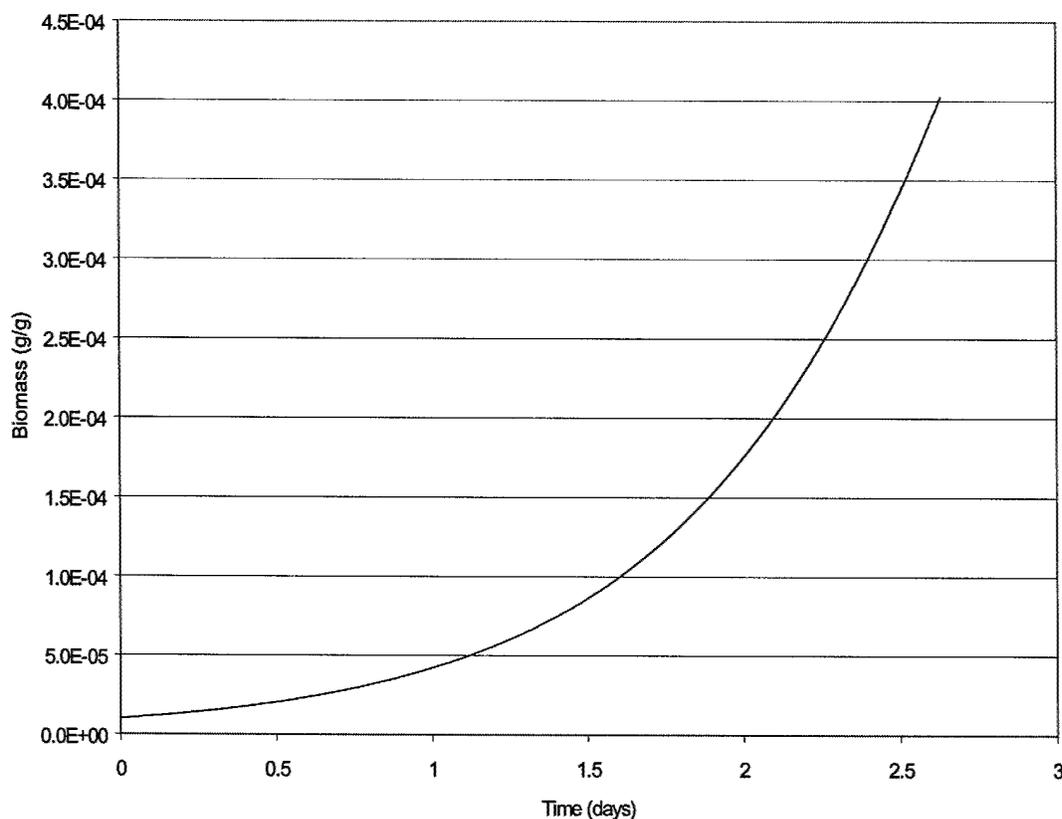
**Figure 80. Comparison between Model Simulation and Measured Perchlorate Profiles in the 50-cm Column Experiment at Different Times.**

Inspection of model results showed that the calculated biomass within the column decayed much faster than it grew. This phenomenon appears to account for the absence of biodegradation of acetate or any of the three electron acceptors within the column. The modeled biomass profiles in the column at different times are presented in Figure 81a. As can be seen in the figure, the modeled microbial population decreased by five orders of magnitude during the first 16 days. The initial biomass concentration in the column was estimated to be  $1 \times 10^7$  cells/g, which is equal to  $1 \times 10^{-5}$  g/g. Because the model calculated fast decay of the microbial population, the model predicted that insignificant consumption of acetate and perchlorate over time would occur. In the actual column experiment, biomass in the column was able to sustain activity and degrade acetate, oxygen, nitrate and perchlorate during the experiment. The difference between the data and model suggests that some of the biomass modeling assumptions were not valid or were critically violated (see below).



**Figure 81a. Modeled Biomass Levels Across the 50-cm Column.**

In an attempt to prevent the calculated microbial population from rapidly decreasing to zero, the biomass decay rate was decreased by a factor of 10 (i.e., the parameter  $b$  was decreased to  $0.0014 \text{ hr}^{-1}$ ) and additional simulations were performed. After simulating approximately 2.5 days, the model failed to converge and the simulation stopped. This occurred because, after 2.5 days, the net rate of biomass growth resulted in a rapid increase in microbial populations causing the numerical iterative scheme within the model to fail to reach convergence. Figure 81b shows the simulated biomass over time at a point 0.5 cm from the column inlet. The calculated biomass increased by 1.5 orders of magnitude during the first 2.5 days of simulation time. The sharp increase in biomass that was observed in the column simulations but not in microcosm simulations reflects the constant feed of acetate to the column. Thus, in the column simulations, the bacteria are allowed to grow indefinitely as long as acetate is being supplied. In reality, the growth of high bacterial populations will be limited eventually by the availability of substrates and nutrients on the microscale, and by physical space on the soil particles.



**Figure 81b. Modeled Biomass Levels at a Point 2-cm from the Column Inlet.**

A violation of one or more of the following assumptions most likely contributed to the inability of the fully coupled model to simulate column data:

1. *The decay rate,  $b$ , in the column is equal to the value determined from the batch experiments.*  
 A wide deviation from this assumption is the most likely reason for simulated biomass in the column to decay quickly to low numbers, and thus for electron donors and acceptors to show no biodegradation in simulations. It was not possible to determine biomass levels or biomass decay in the column study without destructively sampling the sediment matrix. The actual biomass decay rate in the column may be very different from that determined in batch experiments with JPLRND. These two environments are very different, and the decay of organisms in a well-mixed system (batch studies) is likely to differ widely from that of an attached biofilm (sediment column). To determine the “true” biomass decay rate in a soil environment, a new methodology that accounts for the impact of soil on biomass decay needs to be developed.

2. *There is no lag period for biomass activity.* In the model, biomass activity and decay were assumed to occur immediately. This differs from the column data, in which there was a significant lag period prior to perchlorate biodegradation, and a lesser, but measurable lag before nitrate biodegradation was observed. There was also a significant lag period in some of the batch studies performed before the onset of microbial activity and subsequent consumption of perchlorate. Because biomass growth and decay are exponential functions, a short lag period in the column experiment will cause the modeled biomass to quickly diverge from actual values, resulting in incorrect estimates of the magnitude of biodegradation and a large discrepancy between the data and simulations.
3. *The initial biomass in the column is  $1 \times 10^7$  cells/g soil.* The initial microbial population in the column was assumed to be  $1 \times 10^7$  cells/g soil. Though this number is believed to be representative of microbial population in the column, the actual biomass in the soil may be appreciably higher. If this assumption is significantly violated (i.e. actual biomass is 1 or 2 orders of magnitude different than the assumed value) it can result in the observed discrepancy between the model and data.
4. *There is no maximum allowable biomass population in the column.* In the model, biomass growth is limited only by the concentration of acetate, oxygen, nitrate and perchlorate. Given that these components are always abundant at the inlet side of the column, in the absence of a high biomass decay rate, microbial populations will increase indefinitely at column points close to the inlet of the column. In reality, once high microbial populations are present, additional microbial growth will likely be inhibited by the availability of micronutrients and, eventually, physical space on soil particles. To avoid this pitfall, the biodegradation model presented in Appendix B needs to be modified to include a maximum biomass level in soil.

### **Modeling Summary**

In summary, the biodegradation kinetic model for perchlorate was successfully applied to describe consumption of an electron donor (acetate), bacterial growth and decay, and the dynamics of multiple electron acceptors, including consumption, sequential utilization, and inhibition. In addition, the non-reactive transport of perchlorate through natural sediment was successfully simulated using the modeling software HBGC123D. However, when the biodegradation and transport models were coupled using HBGC123D, the simulated kinetics of perchlorate biodegradation under flow conditions failed to describe laboratory data collected from column studies. We have evaluated potential reasons for failure of the

coupled model (see above), and determined that the failure of the model reflects difficulties with coupling HBGC123D with the kinetic model rather than problems with either of these individual components. In addition, gaps in column data, particularly with respect to biomass levels, cell growth, and cell decay, also contributed to the failure of the coupled model. As part of an upcoming field demonstration of *in situ* perchlorate treatment (see section 5.2), we intend to refine the coupling process, collect additional data concerning biomass dynamics, and/or incorporate the biodegradation model into another fate and transport model. The biodegradation model has also been used by researchers at the Air Force Institute of Technology to describe perchlorate biodegradation in a complex flow regime (see section 4.8).

#### **4.8. ADDITIONAL MODEL DEVELOPMENT**

The biodegradation model constructed during this project and the growth parameters obtained from pure culture studies were provided to Lt. Jeffrey Parr at the Air Force Institute of Technology (AFIT). Lt. Parr is a graduate student under the supervision of Dr. Mark Goltz. As part of his Master's Thesis, Lt. Parr incorporated the biodegradation model with a groundwater transport model developed previously by Dr. Goltz. This effort resulted in a new fate and transport model for perchlorate biodegradation. Publications resulting from this effort will be provided to the SERDP Office.

#### **4.9 ANALYTICAL METHOD DEVELOPMENT**

##### **4.9.1 BACKGROUND**

As a partner in this SERDP effort, scientists at the Indian Head Division, Naval Surface Warfare Center (IHDI) evaluated techniques to improve perchlorate detection at low concentrations and in matrices where strong interference is anticipated (e.g., high salinity environments). The method tested during this work, EPA Method SW9058, is an accepted method for analysis of perchlorate in water and wastewater, and is essentially the same ion chromatography procedure as described by EPA Method 314.0 for drinking water.

The recent focus on the presence of perchlorate as a contaminant in groundwater has led to the advent of several methodologies to measure the ion in a variety of matrices. The separation from other matrix bound components and sensitivity of detection afforded by approaches based on ion chromatography have made these analyses the most widely used for perchlorate determination at trace levels. Accordingly, the current EPA method for measurement of perchlorate in groundwater (EPA Method SW9058) uses ion chromatography with chemically suppressed/conductivity detection and an ion exchange separation mode.

The application of SW9058 and similar methods to matrices with high ionic content, apart from the target analyte, has proven difficult due to interference provided by these anionic moieties. While stated detection limits lie in the low parts per billion range (i.e.,  $\mu\text{g/L}$ ), the effective detection is at least ten times higher in more aggressive matrices. The latter resulting in the recent presentation of an amendment to the procedure requiring the dilution of specimens with a high conductivity, due to high ionic content, prior to analysis (Jackson, 2000).

The analysis of specimens taken at different sites at the Naval Surface Warfare Center as part of SERDP Project CU-1163 included groundwater, extracts of soil, brackish water, and extracts of aquatic vegetative and animal matter. Earlier attempts at analysis of some of these matrices with SW9058, and similar methodologies, failed due to the levels of interferants found in the specimens. While the analyses appeared to be capable of detection in the low parts per billion range in the presence of a few hundred parts per million of interferants, some of the matrices contained other ionic moieties at greater than 30,000 parts per million. Interference was due to the overload of the separator used in the system or the earlier eluting species generating signals of such magnitude as to obscure perchlorate detection. Figure 82 shows detection of perchlorate in tap water and in the presence of 300 parts per million sulfate using the current EPA method.

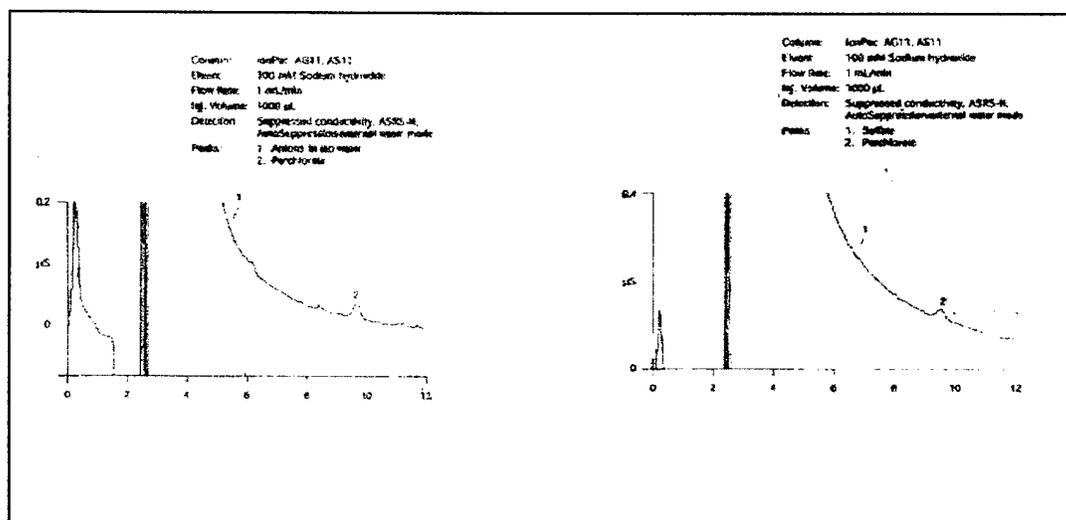
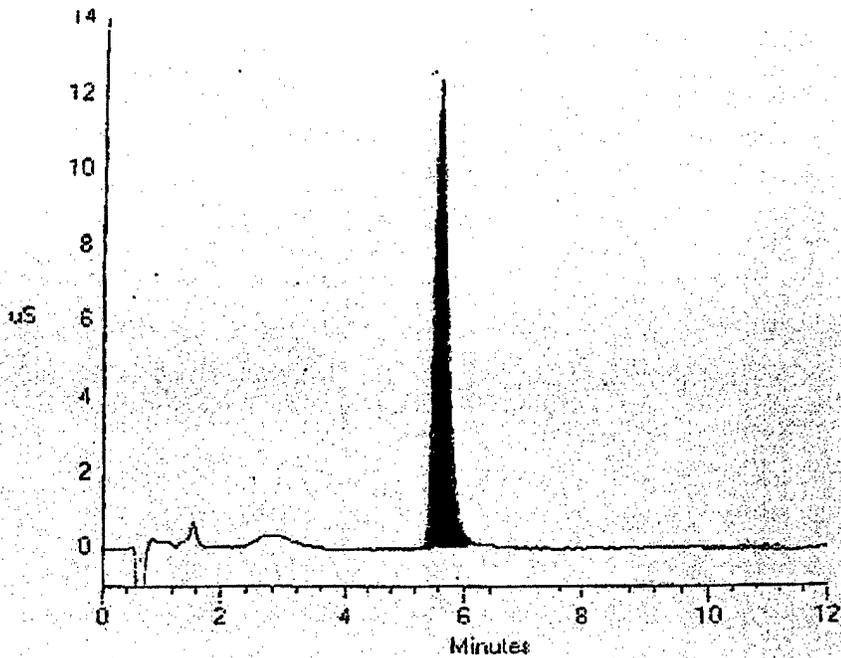


Figure 82. EPA Method SW9058: Chromatograms of Tap Water Sample and Sample with High Sulfate Content.

The figure illustrates the limitation of SW9058 and similar methods (e.g., EPA 314.0). The perchlorate appears as a small signal on the tailing edge of a signal with greater amplitude by several orders of magnitude. The leading signal represents common anions such as fluoride, chloride, nitrate, or sulfate in the range of a few hundred parts per million. An increase in the level of these anions by a factor of two approximately doubled the height and breadth of the signal and effectively masked the signal generated for perchlorate. In the face of tens of thousands parts per million of other ionic species, the entire chromatographic field would be obscured. Dilution of the specimen to lower the intensity of the interferants would have proportionally lowered the perchlorate signal below detection limits.

Methods based on mobile phase ion chromatography (MPIC) have been successfully used in the detection of low levels of perchlorate in environmental matrices (Figure 83) (Basom, 1993). The low background of the eluants, low peak volume, and resistance to interference provide for sensitive detection in specimens with high ionic content. The method, however, possesses a detection limit of approximately 100 parts per billion in typical groundwater and less sensitivity in specimens such as seawater containing several thousand parts per million of ionic content.



**Figure 83. MPIC: Chromatogram of Groundwater Containing Two Parts Per Million Perchlorate.**

The limitations of the aforementioned procedures, in terms of sensitivity in aggressive matrices, prevented their direct use for determining perchlorate at requisite levels (low parts per billion) in the various specimens to be tested in the core project. The development of a procedure with the required capabilities and successful analysis of test specimens were the objectives of this work.

#### **4.9.2. OBJECTIVES OF ANALYTICAL METHOD DEVELOPMENT**

The objective of this phase of research was to develop an analytical methodology capable of detecting perchlorate ion in the low parts per billion range in environmental specimens containing potential interference at concentrations up to  $\sim 1 \times 10^7$  times greater than that of the target analyte. The development of such a methodology is to be used to test the samples collected at the IHDIV installation as part of the core project. The developed method had to meet the following criteria:

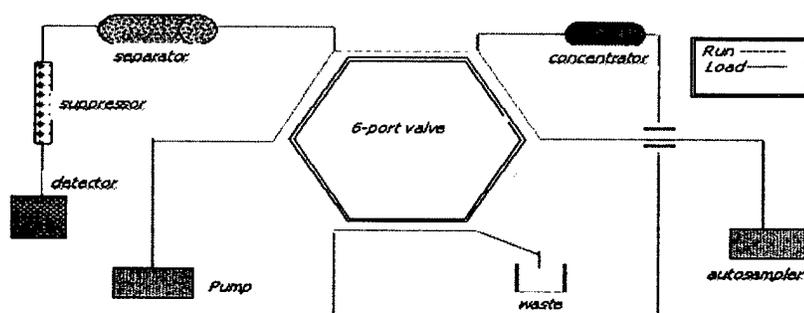
- Detection limits in low parts per billion range (1 - 10 parts per billion)
- Detection not compromised by relatively high levels of interferences including ionic or organic components in specimens
- Durability of approach: system integrity not compromised by repeated analysis of specimens with high levels of contaminants
- High analytical accuracy and precision: to ensure the validity of test results

#### **4.9.3. TECHNICAL APPROACH**

- 1) **Literature review.** Technical journals and other materials were reviewed to provide candidate methods that could perform the required analysis. Literature reviews consisted of materials contained at the laboratory, literature from suppliers of scientific equipment, and database searches by the technical library at IHDIV.
- 2) **Testing of candidate methods.** Candidate methods were initially used on test specimens to determine applicability. Methodologies based on approaches other than ion chromatography were eliminated due to inherent limitations. Eventually, conventional ion chromatographic methods employing ion exchange were eliminated due to limitations imposed by the conductivity of the eluants, the nature of different media in the separator, and other factors.
- 3) **Selection of a "core" analytical approach.** As the candidate methodology with the greatest potential for meeting the previous criteria, test matrices were analyzed using the previously

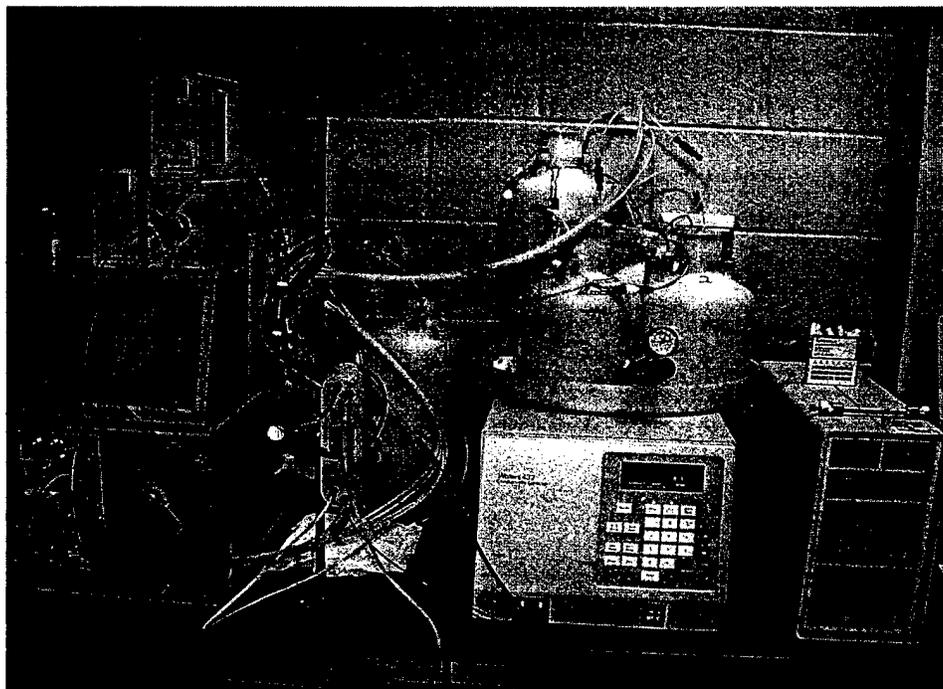
referenced MPIC methodology. Specimens were diluted to lower the levels of interfering anions and to prevent overloading and coelution phenomena. Required detection levels were not achieved; however, the method demonstrated potential as a basis for a hybrid approach coupling MPIC with ancillary technologies.

- 4) **Modification of analytical methodology.** To effectively concentrate the target analyte and lower the levels of interferants, a chromatographic system was configured employing a concentrator column, six-port valve, and pressure assisted autosampler. The system allowed for effective concentration of perchlorate, by a factor of ~500 times versus a fixed volume injection, while reducing the concentration of other ionic species prior to injection. The system was configured to allow for "back-flushing" of the perchlorate onto the separator to prevent band spreading and subsequent reduction in sensitivity. Figure 84 is a schematic of the chromatographic system.



**Figure 84. Diagram of Ion Chromatographic System.**

The solid line in the flow path depicts the valve ports that are interconnected during sample loading and flushing of the concentrator. The broken lines in the flow path depict the valve ports that are interconnected when the concentrator is brought into the liquid circuit and the sample is swept onto the separator column. Figure 85 is a photograph of the system in the depicted configuration.



**Figure 85. Photograph of Ion Chromatographic System.**

Initially, the media used in the concentrator was similar to the media contained in the separator. System instability following injection and other operational problems associated with the hydrophobic media led to the construction of a concentrator using a mixed-bed ion exchange media. The concentration of components in the eluant and other operational parameters were subsequently modified to allow for the use of the concentrator media in the system. Method validation consisting of measurement of accuracy, system recovery, and precision were performed on the system.

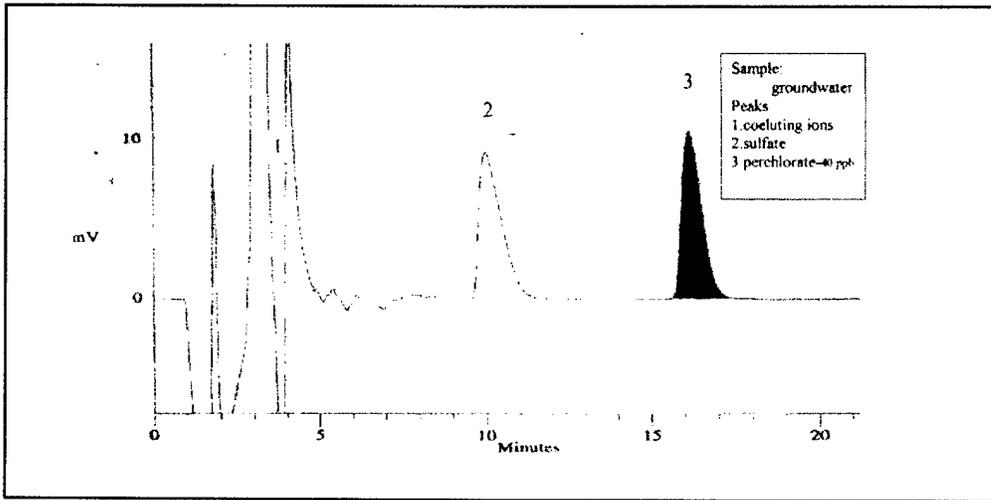
#### ***4.9.4 RESULTS OF ANALYTICAL METHOD***

##### **4.9.4.1. Construction of Analytical System**

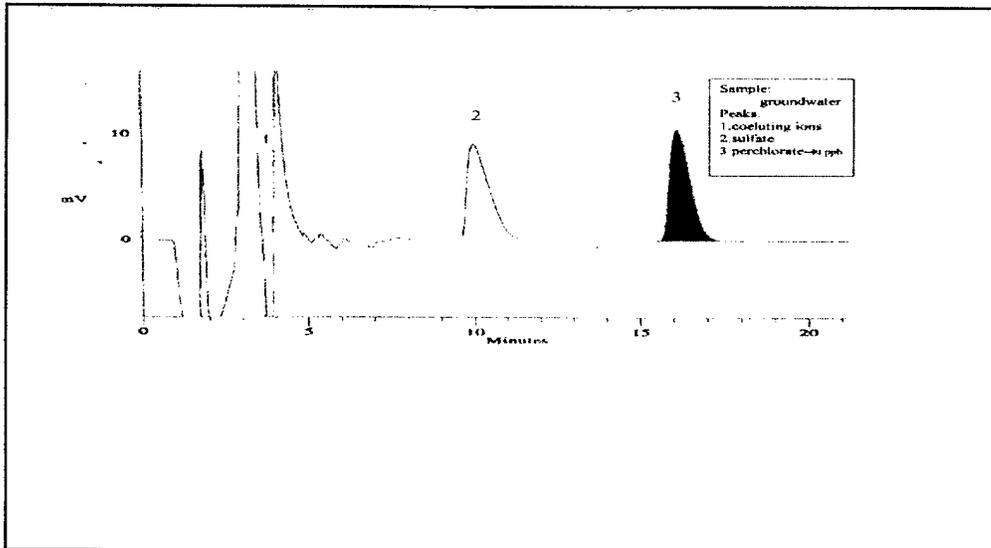
The described system provided for the accurate measurement of perchlorate in the low parts per billion range in samples with ionic content of several thousand parts per million. In-house validation using standards and sample spikes showed the procedure to be accurate (>99% accuracy) and precise (>99% relative precision) when measuring perchlorate at from 5 to ten parts per billion in matrices with up to thirty thousand parts per million of ionic interferants. The detection of the target analyte at these levels in aggressive test matrices rendered the system the most sensitive known for detection of perchlorate in environmental samples.

#### 4.9.4.2. Results and Conclusions from Sample Analysis

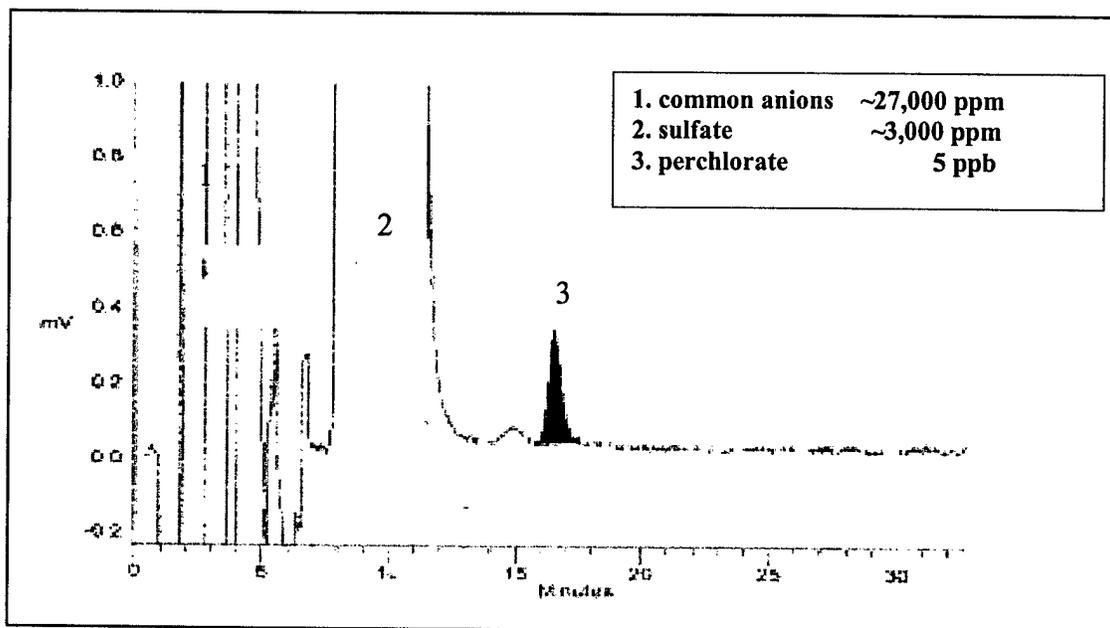
The chromatographic system was used to analyze all samples withdrawn at IHDIV as part of the core project including groundwater and extracts of soil, vegetative, and animal matter with results reported to the liaison on station. None of the interferences displayed by any of the specimens prevented the detection or measurement of perchlorate as determined by sample spikes as all specimens were analyzed for perchlorate at less than or equal to five parts per billion. Figures 86, 87, and 88 are chromatograms of tap, ground, and seawater generated by the system.



**Figure 86. Chromatogram of Perchlorate in Tap Water Using IC Equipped with Perchlorate Concentrator.**



**Figure 87. Chromatogram of Perchlorate in Groundwater Using IC Equipped with Perchlorate Concentrator.**



**Figure 88. Chromatogram of Perchlorate in Seawater Using IC Equipped with Perchlorate Concentrator.**

As observed in the chromatograms, the signal corresponding to perchlorate was well separated from other ionic components and detectable at the low parts per billion level even in matrices with thirty thousand parts per million of ionic content. Unlike chromatograms generated by current methods, the signal appeared as a discrete, symmetrical chromatographic signal which provided for accurate measurement of perchlorate content in all test specimens.

The developed methodology provided accurate measurement of perchlorate in all samples withdrawn from IHDIV during the core project with the results being used for the research into the remediation of perchlorate in subsurface environments. The notable attributes of the method, including sensitivity, accuracy, and resistance to interference, should allow for the analysis to be used in environments in which interfering anions or other constituents in a sample prohibit sensitive perchlorate detection by EPA Methods SW9058 and 314.0.

## 5.0 TRANSITION PLAN - FIELD DEMONSTRATIONS

The laboratory results from this SERDP Project suggest that *in situ* biodegradation of ammonium perchlorate through electron donor addition is likely to be a viable remediation approach at numerous DoD sites. The next step in transitioning this technology is to perform one or more field demonstrations. The data from these demonstrations can then be used to provide cost information on *in situ* perchlorate remediation and to evaluate and resolve potential problems with the technology. Envirogen currently has one *in situ* field demonstration underway and a second demonstration is planned to begin in June, 2002. These two demonstrations will test different technologies for electron donor addition and mixing in subsurface aquifers, and will be performed at sites with very different hydrogeological and geochemical characteristics. A brief description of each field demonstration is provided below.

### 5.1 EVALUATION OF ELECTRON DONOR ADDITION FOR PERCHLORATE TREATMENT AT IHDIV

Based on laboratory results from SERDP Project 1163, the Indian Head Division Naval Surface Warfare Center (IHDIV) provided additional funding for a field demonstration of electron donor injection for perchlorate remediation. This work was contracted to Envirogen through Booze, Allen & Hamilton Consultants, a primary contractor at IHDIV. The field location for this demonstration is located behind Building 1190 (Hog Out Facility) at IHDIV. The laboratory results from this site are provided in section 4.3.2.3. In summary, the data revealed the following: 1) naturally-occurring perchlorate degrading bacteria are present in the groundwater aquifer underlying this site, and 2) these organisms can be stimulated to degrade perchlorate from > 50 mg/L to below detection using acetate or lactate as electron donors but only if the pH of the aquifer is buffered from 4.3 to neutrality. Based on laboratory studies, if the pH of the groundwater is not adjusted, perchlorate biodegradation will not occur. Thus, one of the main technological challenges of this demonstration will be aquifer buffering.

A general description of the field demonstration is provided in Appendix A (Cramer et al., 2002). Characterization work at this site was completed in March, 2002. The field investigation revealed a shallow, narrow plume of perchlorate contamination behind Building 1419. Groundwater analysis from 17 Geoprobe points showed perchlorate levels ranging from below detection to approximately 430 mg/L (Table 8). With a few exceptions, the pH of the site was below 5, and the dissolved oxygen levels were < 2 mg/L. Based on the Geoprobe data, permanent monitoring wells were installed at the site, and pump tests were conducted to characterize groundwater flow and hydraulic conductivity at the site. These data were then used to develop a preliminary system design for the demonstration (see Appendix A; Cramer et al., 2002). Two recirculation cells will be installed at the site. These cells will consist of two extraction wells, three injection wells, and 4 – 6 nested monitoring wells. Groundwater will be removed from each

cell through the extraction wells and reapplied to the aquifer through the injection wells. In the test plot, groundwater will be amended with sodium carbonate as a buffer and lactate as an electron donor prior to reinjection. The control plot will receive neither amendment. Perchlorate, nitrate, pH, and dissolved oxygen will be measured in monitoring wells within each plot during the 6-month demonstration period.

The study is anticipated to reach completion in December, 2002. The data from this demonstration will be used to provide technical guidance and cost information for treating perchlorate in shallow aquifers using a recirculation cell design. The trial will also provide valuable information on the potential for perchlorate treatment in low pH environments using a combination of aquifer buffering and electron donor addition. It is anticipated that the results of this project will be presented to DoD site managers outside of IHDIV and to SERDP/ESTCP personnel.

**Table 8. Groundwater Chemistry at the IHDIV Demonstration Site**

<b>Geoprobe Boring</b>	<b>Perchlorate (mg/L)</b>	<b>Nitrate as N (mg/L)</b>	<b>Sulfate (mg/L)</b>	<b>pH</b>	<b>DO (mg/L)*</b>
GP-1	120	0.6	66	4.67	NA
GP-2	<2.5	3.0	220	8.08	NA
GP-3	8.2	1.9	280	5.23	NA
GP-4	57	0.3	110	4.54	NA
GP-5	65	0.1	130	4.21	1
GP-6	280	11	69	5.62	1
GP-7	35	1.5	66	4.21	0.1
GP-8	430	14	62	4.57	ND
GP-9	73	0.4	56	4.44	0.8
GP-10	300	12	70	4.31	1
GP-11	230	14	72	4.71	0.8
GP-12	55	2.0	110	6.46	ND
GP-13	230	3.8	64	4.61	1.5
GP-14	14	1.5	250	4.97	ND
GP-15	9.8	<0.2	160	5.34	0.2
GP-16	270	2.8	74	4.16	1
GP-17	<5	<0.2	140	4.83	0.2

Notes:

- DO: Dissolved oxygen
- ND: Not determined
- NA: Not analyzed
- \*: Colorimetric field method

## 5.2 EVALUATION OF ELECTRON DONOR ADDITION FOR PERCHLORATE TREATMENT USING HORIZONTAL FLOW TREATMENT WELLS

A second field demonstration is planned to begin in June, 2002. This project, which will be funded by ESTCP, is a collaborative effort among Envirogen, Inc., the Air Force Institute of Technology (AFIT), and the University of New Mexico (UNM). The objective of this technology is to demonstrate that electron donor addition can be used to efficiently and cost-effectively treat perchlorate in subsurface groundwater to below the current minimum detection limit (MDL) of 4  $\mu\text{g/L}$ . One of the most critical issues in adding an electron donor or other amendment to the subsurface is how to achieve mixing of that chemical with contaminated groundwater. If sufficient mixing is not achieved, the treatment technology will be ineffective. Therefore, a recirculating well system (sometimes referred to as a horizontal flow treatment well (HFTW) system) will be tested in this ESTCP Project as a delivery and mixing technology for electron donor addition. A similar system has previously been field tested for the addition of co-substrate (toluene) and oxygen for aerobic remediation of TCE. We believe that this technology will be highly effective for the *in situ* treatment of perchlorate in the subsurface, and will be widely applicable at many DoD sites.

### 5.2.1 TECHNICAL DESCRIPTION, SCHEDULE, AND TECHNOLOGY TRANSFER FOR ESTCP DEMONSTRATION

The site for this ESTCP demonstration has not yet been selected. The project will demonstrate and validate the combined use of two innovative technologies: (1) bioremediation of perchlorate contaminated groundwater through electron donor addition, and (2) horizontal flow treatment wells to achieve *in situ* mixing of the electron donor with the perchlorate-contaminated water, and delivery of the mixture to indigenous perchlorate-degrading bacteria. An HFTW system combines the best features of pump-and-treat and funnel-and-gate technologies to contain and treat contaminated groundwater. As an *in situ* technology, contaminant destruction occurs below ground, and there is no need to pump contaminated water to the surface for treatment. On the other hand, since the HFTW system uses pumping wells, the contaminant plume is actively contained, and the limitations of funnel-and-gate systems (restricted to relatively shallow contamination depths, potential for plume to bypass the treatment system) are overcome. In the field evaluation proposed for this study, two treatment wells will be installed (Figure 89). Each treatment well will have two screens, one an injection screen, the other an extraction screen, with one well pumping in an upflow mode and the other in a downflow mode, so that the water will circulate between the wells. Note that in the HFTW system, due to hydraulic conductivity anisotropy such as is typically seen in aquifers, groundwater flow between the injection and extraction screens of a well pair is horizontal. This is in contrast to conventional groundwater circulation wells (GCWs) that

depend on vertical flow between the injection and extraction screens of a single well. With each pass of perchlorate-contaminated water through a treatment well, electron donor will be added through an in-well static mixer. The donor-amended water will be injected into the aquifer, where a bioactive zone is established and indigenous microorganisms will degrade the donor, using perchlorate as the electron acceptor. Disinfectant may also be added into the in-well mixer to control biogrowth at the injection screens. Due to the circulation between wells, the contaminated water is treated multiple times, so that perchlorate removal efficiencies (comparing concentrations upgradient and downgradient of the treatment wells) can be greatly increased over the removal achieved by a single-pass of perchlorate-contaminated water through the reactor.

The proposed test will demonstrate whether or not perchlorate can be successfully bioremediated in the field for a prolonged period using electron donor addition. To our knowledge, no field demonstrations of *in situ* perchlorate remediation for deep subsurface sites have been conducted over a sufficient length of time to demonstrate and validate the application of this technology. The performance issues that will be documented and validated with the HFTW system include the following: (1) *in situ* biological perchlorate treatment is feasible in the field using electron donor addition; (2) perchlorate can be treated for a sustained period to  $< 4 \mu\text{g/L}$ ; (3) the zone of influence and efficiency of the HFTW are sufficient to make the system a viable, cost-effective option at many sites; (4) biofouling can be effectively controlled by one or several measures that are easily implemented; and (5) co-contaminants, including nitrate and VOCs, can be treated using the same HFTW technology (optional based on site conditions). As with any full-scale technology demonstration, a main objective of this field project is to collect and document information that is relevant to site managers and regulators who are responsible for choosing and implementing technologies. The demonstration is designed to validate the use of HFTWs and electron donor addition for *in situ* perchlorate treatment and to determine the potential problems and costs associated with implementation. This information will be made available to interested DoD and regulatory personnel through technology transfer efforts.

The proposed project will be performed over a period of 24 months, including a 1-year field demonstration. During the initial 6 months of the project, a field site will be selected and characterized as required based on existing hydrogeological data. Samples from the site will be collected and assayed to confirm the existence of naturally-occurring perchlorate-degrading bacteria, to determine the most effective electron donors for perchlorate degradation, and to estimate electron donor consumption and perchlorate degradation kinetics. A conceptual and complete system design will be developed for the field site during this period. In addition, a fate and transport model designed to simulate perchlorate biodegradation at the field site will be developed during this period. The HFTW System will be installed and tested during the second half of Year 1. The field demonstration will begin in Month 11 of Year 1

and continue for 12 months. Data collection and analysis, and model testing and verification will occur during this period. During the demonstration, system modifications will be made as indicated by the field data.

After this demonstration, Envirogen with AFIT and UNM will prepare and submit a technology protocol document at the completion of the project. This document will provide information that can be used to assess the hydrogeological, technical, and design requirements for pilot- or full-scale *in situ* perchlorate treatment using HFTW technology. A cost-benefit comparison with competing technologies will also be provided. The objective of this document will be to provide all necessary information so that the technology can be applied by others throughout the DoD. The document may be supplemented by user-friendly software. Such software has been shown to help remedial project managers select innovative technologies that may be appropriate for their sites. An example of the above described documentation and software may be found at the following website: <http://en.afit.edu/env/geem/insitubio.htm>, where similar products were prepared for the *in situ* aerobic cometabolic bioremediation technology and made available both within and outside of DoD. The above technology transfer material will be in addition to "traditional" avenues of technology transfer, such as publication in peer-reviewed journals and presentation at conferences, which will also be pursued.

### **5.3 OTHER MEANS OF TECHNOLOGY TRANSFER**

In addition to the planned field demonstrations, the laboratory data resulting from this SERDP Project have been presented at seven different conferences (see Appendix A). A portion of the data have been published in a recent journal article, and at least two additional publications will be submitted to appropriate journals in 2002. The results of this project have also been presented to numerous aerospace and chemical companies and/or their primary environmental consultants (including Boeing, Aerojet, Thiokol, Kerr-McGhee, Lockheed-Martin, and Environmental Chemical Corporation) as well as personnel involved in the restoration of perchlorate-contaminated government/military sites, including the Longhorn Army Ammunition Plant, the Massachusetts Military Reservation, the Indian Head Division Naval Surface Warfare Center, and Jet Propulsion Laboratories. These presentations are anticipated to lead to one or more additional pilot demonstrations and/or full-scale *in situ* perchlorate remediation efforts.

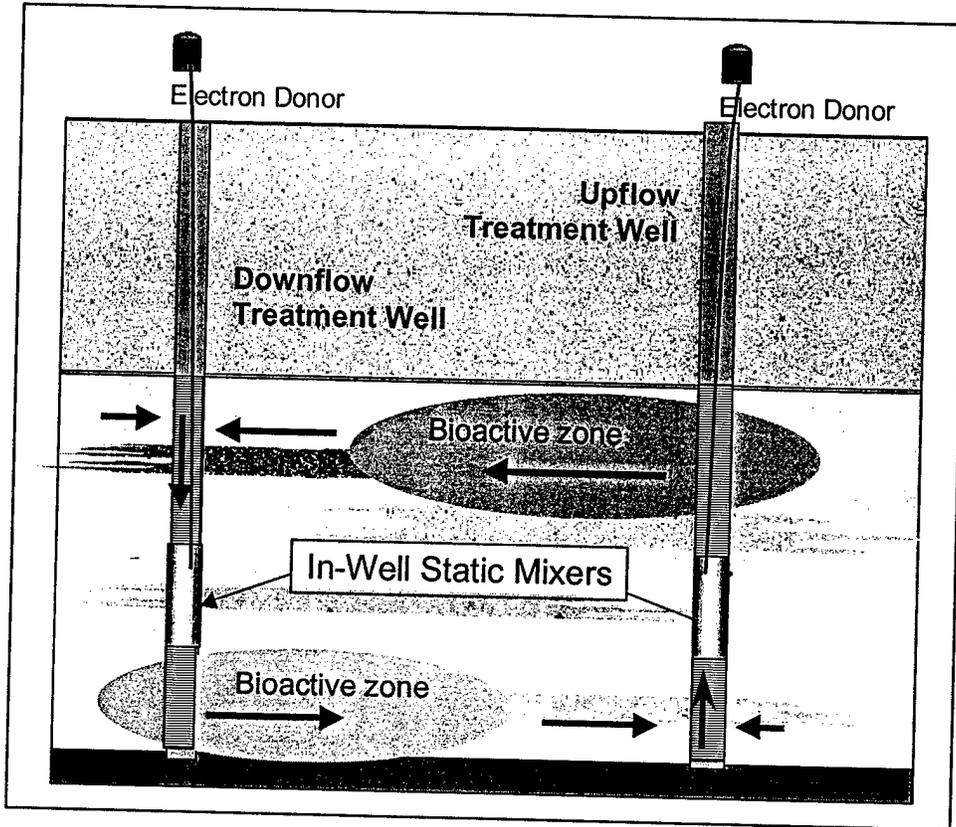


Figure 89. Diagram of Paired Horizontal Flow Treatment Wells.

## 6.0 REFERENCES CITED

- Achenbach, L. A., Michaelidou, U., Bruce, R. A., Fryman, J., and Coates, J. D. (2001). *Dechloromonas agitata* gen. nov., sp. nov. and *Dechlorosoma suillum* gen. nov., sp. nov., two novel environmentally dominant (per)chlorate-reducing bacteria and their phylogenetic position. *International Journal of Systematic and Evolutionary Microbiology*, 51, 527-533.
- Alexander, M. (1994). *Biodegradation and Bioremediation*, Academic Press, New York.
- Atlas, R. M. (1995). *Handbook of Media for Environmental Microbiology*. CRC Press, Inc., New York.
- Attaway, H. and Smith, M. (1994). Propellant wastewater treatment process. US Patent 5302285.
- Attaway, H., and Smith, M. (1993). Reduction of perchlorate by an anaerobic enrichment culture. *Journal of Industrial Microbiology*, 12, 408-412.
- Basom, K. (1993) Analysis of perchlorate by ion chromatography, JANAFF Proceedings, 1993.
- Boopathy, R., and Manning, J. (1998). A laboratory study of the bioremediation of 2,4,6-trinitrotoluene-contaminated soil using aerobic/anoxic soil slurry reactors. *Water Environment Research*, 70, 80-86.
- Boopathy, R., Wilson, M., and Kulpa, C. (1993). Anaerobic removal of 2,4,6-trinitrotoluene (TNT) under different electron accepting conditions: laboratory study. *Water Environment Research* 65, 271-275.
- Burt, J. (1999). Explosives detected in well at demolition area. *Cape Cod Times*, January 27, 1999.
- CDHS; California Department of Health Services. (2002a). California's experience with perchlorate in drinking water. Website: <http://www.dhs.cahwnet.gov/ps/ddwem/chemicals/perchl/perchlindex.htm>.
- CDHS; California Department of Health Services. (2002b). Perchlorate's drinking water action level and regulations. Website: <http://www.dhs.ca.gov/ps/ddwem/chemicals/perchl/actionlevel.htm>.
- CDHS; California Department of Health Services. (1997). Determination of perchlorate by ion chromatography. Website: <http://www.dhs.ca.gov/ps/ddwem/chemicals/perchl/clo4meth.pdf>.
- Coates, J. D., Michaelidou, U., Bruce, R. A., O'Conner, S. M., Crespi, J. N., and Achenbach, L. A. (1999). The ubiquity and diversity of dissimilatory (per)chlorate-reducing bacteria. *Applied and Environmental Microbiology*, 65, 5234-5241.
- Cramer, R. J., Yates, C. A., Hatzinger, P. B., Diebold, J., and Giovanelli, M. (2002). Field demonstration of *in situ* perchlorate bioremediation at NSWC Indian Head. Joint Army-Navy-NASA-Air Force (JAANF) Interagency Propulsion Committee, 30<sup>th</sup> Propellant Development and Characterization Subcommittee Meeting, Colorado Springs, CO, March 18 - 21. (proceedings paper *in press*).
- Damian, P., and Pontius, F. W. (1999). From rockets to remediation: the perchlorate problem. *Environmental Protection*, June, 24-31.
- Goleman, W. L., Urquidi, L. J., Anderson, T. A., Smith, E. E., Kendall, R. J., and Carr, J. A. (2002). Environmentally relevant concentrations of ammonium perchlorate inhibit development and metamorphosis in *Xenopus laevis*. *Environmental Toxicology and Chemistry*, 21:424-430.
- Greene, M. R., and Pitre, M. P. (2000). Treatment of groundwater containing perchlorate using biological fluidized bed reactors with GAC or sand media. pp. 241-256, In E.T. Urbansky (Ed), *Perchlorate in the environment*. Kluwer Academic/Plenum Publishers, New York.
- Gu, B., Brown, G. M., Alexandratos, S. D., Ober, R., Dale, J. A., and Plant, S. (2000). Efficient treatment of perchlorate (ClO<sub>4</sub><sup>-</sup>)-contaminated groundwater by bifunctional anion exchange resins. pp. 165-176, In E.T. Urbansky (Ed), *Perchlorate in the environment*. Kluwer Academic/Plenum Publishers, New York.
- Gu, B., Y-K Ku, and G. M. Brown. (2002). Treatment of perchlorate-contaminated groundwater using highly selective, regenerable ion-exchange technology: a pilot-scale demonstration. *Remediation*, 12:51 - 68.

- Gulick, R. W., Lechevallier, M. W., and Barhorst, T. S.** (2001). Occurrence of perchlorate in drinking water sources. *Journal of the American Water Works Association*, 93:66-77.
- Hareland, W. A., Crawford, R. L., Chapman, P. J., and Dagley, S.** (1975). Metabolic function and properties of 4-hydroxyphenylacetic acid 1-hydroxylase from *Pseudomonas acidovorans*. *Journal of Bacteriology*, 121, 272-285.
- Hatzinger, P. B., Greene, M. R., Frisch, S., Togna, A. P., Manning, J., and Guarini, W. J.** (2000). Biological treatment of perchlorate-contaminated groundwater using fluidized bed reactors. pp. 115-122. In G. B. Wickramanayake et al. (Eds). *Case studies in the remediation of chlorinated and recalcitrant compounds*, Battelle Press, Columbus, OH.
- Hatzinger, P. B., Whittier, M. C., Arkins, M. D., Bryan, C. W., and Guarini, W. J.** (2002). *In-situ* and *ex-situ* bioremediation options for treating perchlorate in groundwater. *Remediation*, 12, 69-86.
- Hawari, J., Halasz, A., Sheremata, T., Beaudet, S., Groom, C., Paquet, L., Rhofir, C., Ampleman, G. and Thiboutot, S.** (2000). Characterization of metabolites during biodegradation of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) with municipal anaerobic sludge. *Applied and Environmental Microbiology*, 66:2652.
- Hurley, J. A., Wallace, W., and Coppola, E.** (1996). Prototype demonstration of ammonium perchlorate biodegradation. *Civil Engineering US Air Force*, 4,3.
- Jackson, P.** (2000). 5<sup>th</sup> Annual Joint Services Pollution Prevention and Hazardous Waste Management Conference, August 21-24.
- Kengen, S. W. M., Rikken, G. B., Hagen, W. R., van Ginkel, C. G., and Stams, A. J. M.** (1999). Purification and characterization of (per)chlorate reductase from chlorate-respiring strain GR-1. *Journal of Bacteriology*, 181, 6706-6711.
- Lamm, S. H. and M. Doemland.** 1999. Has perchlorate in drinking water increased the rate of congenital hypothyroidism? *Journal of Occupational and Environmental Medicine*, 41, 409-413.
- Lawrence, J. E., Lamm, S. H., and Braverman, L. E.** (2001). Low dose perchlorate (3 mg daily) and thyroid function. *Thyroid*, 11, 295.
- Lawrence, J. E., Lamm, S. H., Pino, K., Richman, K. and Braverman, L. E.** (2000). The effect of short-term low-dose perchlorate on various aspects of thyroid function. *Thyroid*, 10: 659-663.
- Logan, B. E.** (2001). Assessing the outlook for perchlorate remediation, *Environmental Science and Technology*, 35, 483A-487A.
- Logan, B. E.** (1998). A review of chlorate- and perchlorate-respiring microorganisms. *Bioremediation Journal*, 2, 69-79.
- Manzon, R. G., and Youson, J. H.** (1997). The effects of exogenous thyroxine (T4) or triiodothyroxine (T3), in the presence and absence of potassium perchlorate, on the incidence of metamorphosis and on serum T4 and T3 concentrations in larval sea lampreys (*Petromyzon marinus L.*). *General Comparative Endocrinology*, 106, 211-220.
- McCarty, P. L., Goltz, M. N., Hopkins, G.D., Dolan, M. E., Allan, J. P., Kawakami, B.T., and Carrothers, T. J.** (1998). Full-scale evaluation of *in situ* cometabolic degradation of trichloroethylene in groundwater through toluene injection. *Environmental Science and Technology*, 32, 88-100.
- Miller, J. P. and Logan, B. E.** (2000). Sustained perchlorate degradation in an autotrophic, gas-phase, packed-bed bioreactor. *Environmental Science and Technology*, 34, 3018-3022.
- OEHHA; Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.** (2002). Public health goal for perchlorate in drinking water, external review draft, March, 2002.
- Renner, R.** (2001) Fertilizers not a source of perchlorate. *Environmental Science and Technology*, 35, 359a.
- Rikken, G. B., Kroon, A. G. M., and van Ginkel, C. G.** (1996). Transformation of (per)chlorate into chloride by a newly isolated bacterium: reduction and dismutation. *Applied Microbiology and Biotechnology*, 45, 420-426.

- Schumacher, J., Lindley, C., and F. Anderson. (1992). Migration of nitroaromatic compounds in unsaturated soil at the abandoned Weldon Springs Ordnance Works, St. Charles County, Missouri. Sixteenth Annual Army Research and Development Symposium. 173.
- Sheremata, T., Halasz, A., Paquet, L., Thiboutot, S., Ampleman, G., and Hawari, J. (2001). The fate of the cyclic nitramine explosive RDX in natural soil. *Environmental Science and Technology* 35:1037.
- Smith, P. N., Theodorakis, C. W., Anderson, T. A., and Kendall, R. J. (2001). Preliminary assessment of perchlorate in ecological receptors at the Longhorn Army Ammunition Plant (LHAAP), Karnack, Texas. *Ecotoxicology*, 10, 305-313.
- Stahl, J. D., Van Aken, B., Cameron, M. D., and Aust, S. D. (2001). Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) biodegradation in liquid and solid-state matrices by *Phanerochaete chrysosporium*. *Bioremediation Journal*, 5, 13-25.
- Urbansky, E. T. (1998). Perchlorate chemistry: implications for analysis and remediation. *Bioremediation Journal*, 2, 81-95.
- USEPA; U.S. Environmental Protection Agency. (2002a). Perchlorate environmental contamination: Toxicological review and risk characterization, external review draft, NCEA-1-0503, January 16, 2002.
- USEPA; U.S. Environmental Protection Agency. (2002b). Perchlorate update. U.S. Environmental Protection Agency, Region IX, San Francisco, CA, March, 2002.
- USEPA; U.S. Environmental Protection Agency. (2001a). Perchlorate. Office of Water, Website: <http://www.epa.gov/safewater/ccl/perchlor/perchlo.html>.
- USEPA; U.S. Environmental Protection Agency. (2001b). Survey of fertilizers and related materials for perchlorate ( $\text{ClO}_4^-$ ). Office of Research and Development, Cincinnati, OH. EPA/600/R-01/049.
- USEPA; U.S. Environmental Protection Agency. (2000). Technical background information for the unregulated contaminant monitoring regulation. Office of Water, Washington, D. C. EPA/815/R-99/007.
- USEPA; U.S. Environmental Protection Agency. (1999). Region 9 perchlorate update. U.S. Environmental Protection Agency, Region IX, San Francisco, CA.
- USEPA; U.S. Environmental Protection Agency. (1998). Perchlorate environmental contamination: toxicological review and risk characterization based on emerging information, external review draft, NCEA-1-0503, National Center for Environmental Assessment (NCEA), December 31, 1998.
- van Ginkel, C. G., Rikken, G. B., Kroon, A. G. M., Kengen, S. W. M. (1996). Purification and characterization of a chlorite dismutase: a novel oxygen-generating enzyme. *Archives of Microbiology*, 166, 321-326.
- van Ginkel, C. G., Plugge, C. M., Stroo, C. A. (1995). Reduction of chlorate with various energy substrates and inocula under anaerobic conditions. *Chemosphere*, 31, 4057-4066.
- Wallace, W., Ward, T., Breen, A., and Attaway, H. (1996). Identification of an anaerobic bacterium which reduces perchlorate and chlorate as *Wolinella succinogenes*. *Journal of Industrial Microbiology*, 16, 68 - 72.
- Wallace, W., Beshear, S., Williams, D., Hospadar, S., and Owens, M. (1998). Perchlorate reduction by a mixed culture in an up-flow anaerobic fixed bed bioreactor. *Journal of Industrial Microbiology and Biotechnology*, 20, 126-131.
- Wolff, J. (1998). Perchlorate and the thyroid gland. *Pharmacology Review*, 50, 89-105.
- Wu, J., Unz, R. F., Zhang, H., and Logan, B. E. (2001). Persistence of perchlorate and the relative numbers of perchlorate- and chlorate-respiring microorganisms in natural waters, soils, and wastewater. *Bioremediation Journal*, 5, 119-130.
- York, R. G., Brown, W. R., Girard, M. F., and Dollarhide, J. S. (2001). Oral (drinking water) developmental toxicity study of ammonium perchlorate in New Zealand white rabbits. *International Journal of Toxicology*, 20, 199-205.

## 7.0 APPENDICES

## 7.1. APPENDIX A: TECHNICAL PRESENTATIONS, PUBLICATIONS, AND ABSTRACTS

### 7.1.1. CONFERENCES AND SYMPOSIA

The research resulting from this SERDP project has been presented at seven conferences in 2000 - 2002. The conference citations are listed below. Published abstracts and papers from these meetings are provided where applicable.

1. **Hatzinger, P. B.** 2000. Biotreatment of Perchlorate in Groundwater. Partners in Environmental Technology Symposium and Workshop. Arlington, VA. November 28 – 30, 2000., pp. 38.
2. **Hatzinger, P. B.** 2000. *In situ* Bioremediation of  $\text{ClO}_4^-$  in Groundwater. Fifth Annual Joint Services Pollution Prevention & Hazardous Waste Management Conference. San Antonio, TX. August 21-24, 2000, available on CD-ROM.
3. **Hatzinger, P. B., M. D. Arkins, Y. H. Farhan, and R. J. Steffan.** 2001. *In situ* Bioremediation of Perchlorate in Groundwater. Partners in Environmental Technology Symposium and Workshop. Washington, D. C. November 27 – 29, 2001, pp. 45.
4. **Hatzinger, P. B., M. D. Arkins, M. Tugusheva, and R. J. Steffan.** 2001. *In situ* Bioremediation of Perchlorate in Groundwater. *In situ* and On-Site Bioremediation. The Sixth International Symposium, San Diego, CA. June 4-7, 2001.
5. **Hatzinger, P., M. Arkins, W. Guarini, and J. Manning.** 2001. *In situ* Bioremediation of Perchlorate in Groundwater. Society of Environmental Toxicology and Chemistry (SETAC) 22<sup>nd</sup> Annual Meeting, Baltimore, MD. November 11 – 15, pp. 313.
6. **Togna, A. P. and P. B. Hatzinger.** 2002. Perchlorate: Bioremediation of Perchlorate in Groundwater and Soil. AFCEE Cleanup Technology Transfer Workshop, San Antonio, TX. March 4 – 7, 2002.
7. **Cramer, R. J., C. A. Yates, P. B. Hatzinger, J. Diebold, and M. Giovanelli.** 2002. Field Demonstration of *In situ* Perchlorate Bioremediation at NSWC Indian Head. Joint Army-Navy-NASA-Air Force (JAANF) Interagency Propulsion Committee, 30<sup>th</sup> Propellant Development and Characterization Subcommittee Meeting, Colorado Springs, CO, March 18 – 21. (proceedings paper *in press*).

### 7.1.2. JOURNAL ARTICLES

One journal paper has been published from this work. Two additional papers are currently being prepared for journal submission in 2002. The citations for these papers are provided below. The full text of the published manuscript is also included.

1. **Hatzinger, P. B., W. C. Whittier, M. Arkins, and C. W. Bryan.** 2002. In-situ and Ex-situ Bioremediation Options for Treating Perchlorate in Groundwater. *Remediation* 12:69-85.
2. **Hatzinger, P. B., J. Pollock, M. Arkins, and J. R. Coates.** 2002. Potential for *In situ* Bioremediation of Perchlorate-Contaminated Groundwater. *Environmental Science and Technology (in preparation)*.

3. **Farhan, Y. H., M. Arkins, C. Condee, and P. B. Hatzinger.** 2002. Development of a Kinetic Model for Describing Perchlorate Degradation in the Presence of Competing Electron Acceptors. *Journal of Environmental Quality* (*in preparation*).

**7.1.3. REPRINTS OF PUBLISHED JOURNAL ARTICLES, CONFERENCE PROCEEDINGS, AND ABSTRACTS**

The following section contains reprints and/or preprints of journal articles, conference proceedings, and abstracts from this project.

# In-Situ and Ex-Situ Bioremediation Options for Treating Perchlorate in Groundwater

---

---

---

Paul B. Hatzinger

M. Casey Whittier

Martha D. Arkins

Chris W. Bryan

William J. Guarini

Perchlorate has been identified as a water contaminant in 14 states, including California, Nevada, New Mexico, Arizona, Utah, and Texas, and current estimates suggest that the compound may affect the drinking water of as many as 15 million people. Biological treatment represents the most-favorable technology for the effective and economical removal of perchlorate from water. Biological fluidized bed reactors (FBRs) have been tested successfully at the pilot scale for perchlorate treatment at several sites, and two full-scale FBR systems are currently treating perchlorate-contaminated groundwater in California and Texas. A third full-scale treatment system is scheduled for start-up in early 2002. The in-situ treatment of perchlorate through addition of specific electron donors to groundwater also appears to hold promise as a bioremediation technology. Recent studies suggest that perchlorate-reducing bacteria are widely occurring in nature, including in groundwater aquifers, and that these organisms can be stimulated to degrade perchlorate to below the current analytical reporting limit ( $< 4 \mu\text{g/l}$ ) in many instances. In this article, in-situ and ex-situ options for biological treatment of perchlorate-contaminated groundwater are discussed and results from laboratory and field experiments are presented. © 2002 Wiley Periodicals, Inc.

## INTRODUCTION

Ammonium perchlorate ( $\text{NH}_4\text{ClO}_4$ ) is the primary oxidant used in the propellant for many solid rocket motors and boosters, including those providing propulsion for space shuttles and intercontinental ballistic missiles. A single rocket booster for the space shuttle contains approximately 500,000 kg of propellant, of which 70 percent is ammonium perchlorate. Perchlorate salts are also used in munitions, explosives, fireworks, matches, and air bags, as well as in leather tanning, electroplating, and lubrication oils (Gulick et al., 2001; USEPA, 2001a). The only confirmed natural source of perchlorate is Chilean caliche, a nitrate salt that is mined in that country for use in agricultural fertilizers (USEPA, 2001b). Most fertilizers in the United States, however, are not produced with this material, and do not appear to contain significant levels of perchlorate. Rather, the primary sources of perchlorate groundwater contamination are related to the manufacture of the compound for military applications, testing and disposal of rocket motors and munitions, and the periodic removal and replacement of solid fuels in missiles and rockets. The latter procedure, which is referred to as "hog-out," is required because perchlorate fuels have a limited shelf life and must be periodically replaced. During fuel replacement, solid propellant is washed from the missile casing using water under high pressure. The wastewater resulting from this operation contains high concentrations of perchlorate. Improper disposal of this water, as well as disposal practices during per-

chlorate manufacturing and testing, has resulted in substantial perchlorate contamination in several states including Texas, California, Utah, New Mexico, and Nevada.

The California Department of Health Services (CDHS) developed a sensitive detection method for perchlorate in 1997 (CDHS, 1997). Because this technique has only been available for a few years, the total scope of perchlorate contamination in the United States is not yet clear. However, perchlorate has now been detected in 14 states, and current estimates suggest that the drinking water of as many as 15 million people may be affected by this compound (USEPA, 1999; Logan, 2001). For example, as of November 2001, CDHS had sampled 570 public water systems in California and found 65 (11 percent) with detectable perchlorate ( $> 4 \mu\text{g}/\text{l}$ ; CDHS, 2001). Of the 3,434 nonpublic drinking water sources tested by the agency, 226 (6.6 percent) tested positive for the oxidant. Perchlorate has been manufactured or used in 44 states nationwide, so groundwater pollution may extend beyond recent reports (USEPA, 2001a). There is currently no federal action level for perchlorate in groundwater. However, several states, including Arizona, California, Nevada, and Texas, have set provisional action levels ranging from 4 to 31  $\mu\text{g}/\text{l}$  (ppb), and site-specific cleanup levels of 1.5  $\mu\text{g}/\text{l}$  and below have been set by regulators. Perchlorate has also been placed on the contaminant candidate list (CCL) of the EPA (Urbansky & Schock, 1999).

... perchlorate has now been detected in 14 states, and current estimates suggest that the drinking water of as many as 15 million people may be affected by this compound...

The public health concern regarding ammonium perchlorate is based largely upon the effect of the perchlorate anion on thyroid function. Perchlorate blocks the production of thyroid hormone by inhibiting the transport of iodide into the thyroid gland (Wolff, 1998). Because of this inhibitory action, perchlorate salts have been used therapeutically in large doses to treat hyperthyroid conditions, such as that resulting from Graves' disease. The potential risks of low levels of perchlorate exposure to humans through drinking water are not fully understood. However, the EPA has recently evaluated the human health risks associated with perchlorate contamination, and is expected to issue a revised reference dose for the compound in the near future. A tentative reference dose of 0.9  $\mu\text{g}/\text{kg}/\text{d}$  was proposed by the EPA in a draft toxicological document in 1999, but a review panel determined that additional information was required before a final level could be established (Logan, 2001; USEPA 2001a). There have been a few recent papers concerning the potential for toxicological effects of perchlorate on terrestrial and aquatic species (York et al., 2001; Smith et al., 2001; Manzon & Youson, 1997). However, much more research is necessary to evaluate the potential ecological effects of this contaminant. Thus, the environmental and human health effects resulting from long-term exposure to low levels of perchlorate remain largely unknown.

Perchlorate salts are highly soluble in water (e.g., ammonium perchlorate is soluble to 200 g/l) and dissociate completely. The resulting perchlorate anion is nonvolatile, highly mobile, and chemically stable in aqueous systems under normal conditions present in groundwater and surface water. As a result, in areas where substantial quantities of perchlorate salts have been disposed, large groundwater plumes of perchlorate are often observed. Because of its physical characteristics (i.e., low reactivity, low volatility, high solubility), water treatment technologies including ultrafiltration, air stripping, carbon adsorption, and advanced oxidation are not effective options for perchlorate removal from groundwater (Damian & Pontius, 1999; Logan, 1998; USEPA, 2001a). Ion exchange using one or more selective resins is a viable approach for removing low concentrations of perchlorate from water (e.g., Gu et al., 2000). However, the perchlorate anion is not destroyed during the ion-exchange process, but rather is reversibly bound to the resin. The exchange resins eventually become saturated with the perchlorate

(and other anions which also bind to the resin) and must then be replaced or regenerated using a high-strength salt solution (Urbansky, 1998; Logan, 2001). If the latter procedure is used, the waste brine from the regeneration procedure contains concentrated perchlorate, which then must undergo additional treatment or disposal. Because of the necessity for regeneration or periodic replacement of ion-exchange resins, the operation and maintenance of ion-exchange treatment systems can be expensive compared to other options.

Unlike abiotic approaches, biological treatment represents a promising technology for the effective and economical removal of perchlorate from water (Logan, 2001; Urbansky, 1998). A number of bacteria have been isolated which are able to degrade perchlorate to the harmless products chloride and water (Rikken et al., 1996; Wallace et al., 1996; Coates et al., 1999; Achenbach et al., 2001). These bacteria grow through anaerobic respiration. During this process, the bacteria require an organic or inorganic electron donor (e.g., ethanol, acetate, hydrogen gas) for growth and utilize the perchlorate molecule as a terminal electron acceptor. A (per)chlorate reductase enzyme appears to catalyze an initial two-step reduction of perchlorate ( $\text{ClO}_4^-$ ) to chlorate ( $\text{ClO}_3^-$ ) and then chlorite ( $\text{ClO}_2^-$ ) (Kengen et al., 1999). The chlorite is then further reduced by the enzyme chlorite dismutase to chloride ( $\text{Cl}^-$ ) and oxygen ( $\text{O}_2$ ) (van Ginkel et al., 1996). Thus, microbial degradation of perchlorate yields two innocuous products, chloride and oxygen. Perchlorate respiration is similar to denitrification, in which bacteria utilize a substrate and reduce nitrate as the terminal electron acceptor to nitrogen gas.

Several different types of bioreactor systems have been evaluated for perchlorate treatment during the past several years. An initial bioreactor design was developed and tested in the early 1990s by researchers at Tyndall Air Force Base to treat heavily contaminated wastewater from hog-out and other operations. This stirred-tank reactor utilizes the bacterium *Wolinella succinogenes* HAP-1 for perchlorate reduction (Attaway & Smith, 1994; Hurley et al., 1996). This design works well for low-flow, high-concentration perchlorate wastes, and has been applied at full-scale for this application.

However, the reactor design is not well suited for high-flow groundwater applications, in which perchlorate concentrations are likely to be in the  $\mu\text{g}/\text{l}$  (ppb) to low  $\text{mg}/\text{l}$  (ppm) range, and flow rates of thousands of gallons per minute may be required. Several researchers have tested laboratory-scale and pilot-scale packed-bed bioreactors for perchlorate treatment (e.g., Miller & Logan, 2000; Wallace et al., 1998). These systems appear to show promise at the laboratory scale. However, one traditional problem with packed-bed systems is the potential for clogging and channeling with long-term use. Because there is no efficient mechanism to remove biomass from the packed bed, if clogging occurs, the media in the reactor must be replaced. To date, no full-scale packed-bed systems for perchlorate treatment in groundwater have been constructed, so the reliability, treatment efficiency, and cost of these systems at the field scale are not known.

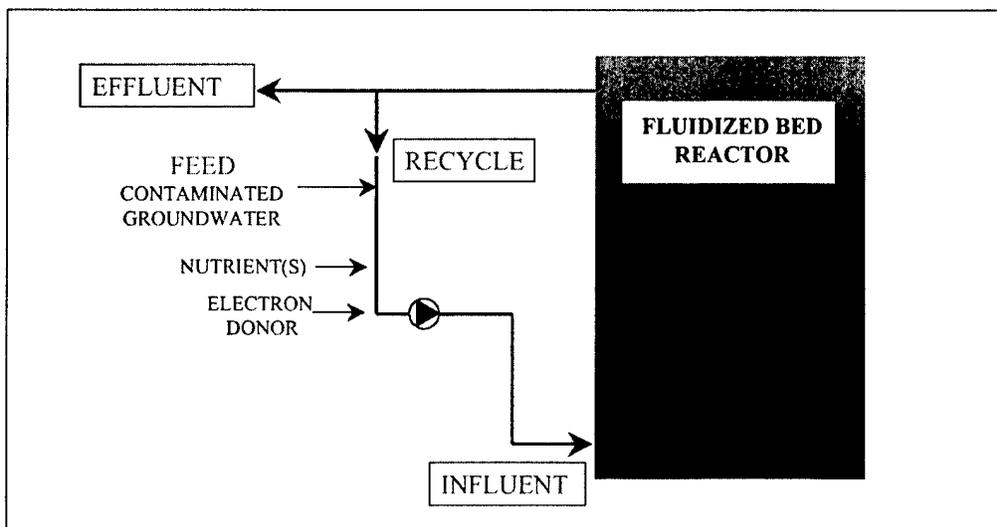
The third biological reactor design that has been tested for perchlorate is the fluidized bed reactor (FBR). Envirogen and USFilter Envirex Products have performed laboratory and pilot-scale tests at several sites across the country. The data from one of these tests is described herein. In addition, two full-scale FBR systems are currently treating perchlorate-contaminated groundwater in California and Texas, respectively, and a third system is under construction. To our knowledge, these are the only full-scale bioreactors currently being used to remediate perchlorate-contaminated groundwater in the United States. The design and treatment efficiency of these systems will be briefly discussed.

A number of bacteria have been isolated which are able to degrade perchlorate to the harmless products chloride and water.

In addition to ex-situ biological treatment using FBRs, in-situ bioremediation of perchlorate through electron donor addition also appears to hold promise for groundwater remediation. For in-situ treatment to be successful, perchlorate-reducing bacteria must be present in contaminated aquifers, and these bacteria must be stimulated to degrade perchlorate from existing levels to below regulatory requirements. A few recent studies show that chlorate- and perchlorate-reducing bacteria are present in soils, sediments, sludges, wastewater, animal waste, and other environments (Coates et al., 1999; Wu et al., 2001). Recent data from our laboratory suggest that these organisms are also native to many groundwater aquifers. In addition, it appears that specific electron donors can be used to promote perchlorate reduction by these bacteria, although the most-effective donors may vary by site. A case study of the effectiveness of electron donor addition for perchlorate and nitrate removal from groundwater is discussed and potential in-situ remediation alternatives are described.

### EX-SITU GROUNDWATER TREATMENT FOR PERCHLORATE USING FLUIDIZED BED REACTORS

Biological fluidized bed reactors (FBRs) have been used for the treatment of nitrate in wastewater beginning in the 1970s (Sutton & Mishra, 1994). Since this time, FBRs have been successfully applied for the treatment of a variety of organic chemicals as well, including petroleum hydrocarbons and pentachlorophenol. An FBR system is a highly efficient, fixed-film bioreactor (Exhibit 1). It consists of a reactor vessel containing media with a large surface area (usually sand or granular activated carbon (GAC)) that is colonized by a film of active bacterial biomass. This media is “fluidized” by the upward flow of wastewater or groundwater into the vessel, with the lowest density particles (those with highest attached biomass) moving to the top. Fluidization is achieved by passing influent water through a distribution system at the bottom of the bed. This system provides a uniform upflow velocity with a flow rate sufficient to achieve a 25–30 percent expansion of the sand or GAC media within the FBR. As biomass grows on the media, the particles become less dense and the bed expands further. A control system is used to remove excess biomass and, thus, maintain the height of the expanded bed. To



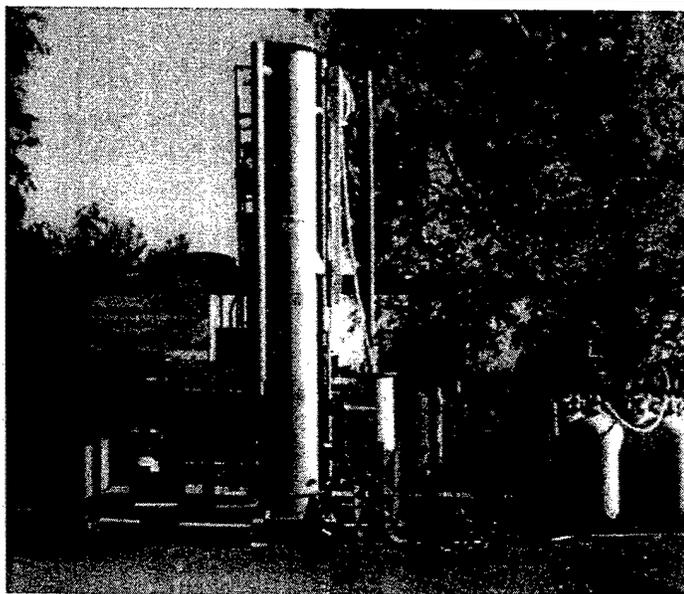
**Exhibit 1.** Process Schematic for a Fluidized Bed Reactor

achieve the required upflow velocity of water for proper fluidization of the media, influent groundwater can be combined with recycled (i.e., treated) water from the reactor. The high biomass maintained within the FBR bed makes it significantly more efficient for water treatment than many other types of biological systems, and allows reactors to be considerably smaller (USEPA, 1993). In addition, the fluidization of the media combined with the presence of effective systems of biomass control prevents clogging and/or channeling in the reactor, allowing efficient performance over long time periods.

## FBR DEMONSTRATION

### *Materials and Methods*

A field pilot test was conducted at a perchlorate-contaminated site in southern California. This study was designed to evaluate reactor performance under site conditions and to develop parameters necessary to size and cost a full-scale system at the site. The pilot FBR system used for the demonstration consisted of a single stainless steel FBR vessel that was 15 feet tall by 20 inches in diameter (Exhibit 2). GAC was used as the fluidization media, and the expanded bed volume was approximately 25 cubic feet. The unit included a complete fluidization system, a biomass control device, media separator, pumps and controls required for addition of the electron donor and nutrients, and online pH control. In addition to the FBR unit for perchlorate treatment, GAC vessels were used to remove low concentrations of volatile organic compounds (VOCs) from the groundwater, a filter was used to remove suspended solids, and a post-aeration tank was supplied to aerate effluent from the FBR. Ethanol (9 percent solution) was used as the electron donor for biological perchlorate reduction. In addition, nitrogen and phosphorus (soluble nutrients necessary for bacterial growth) were added such that a small residual amount of each was detected in the FBR effluent.



**Exhibit 2.** Pilot-Scale Fluidized Bed Reactor

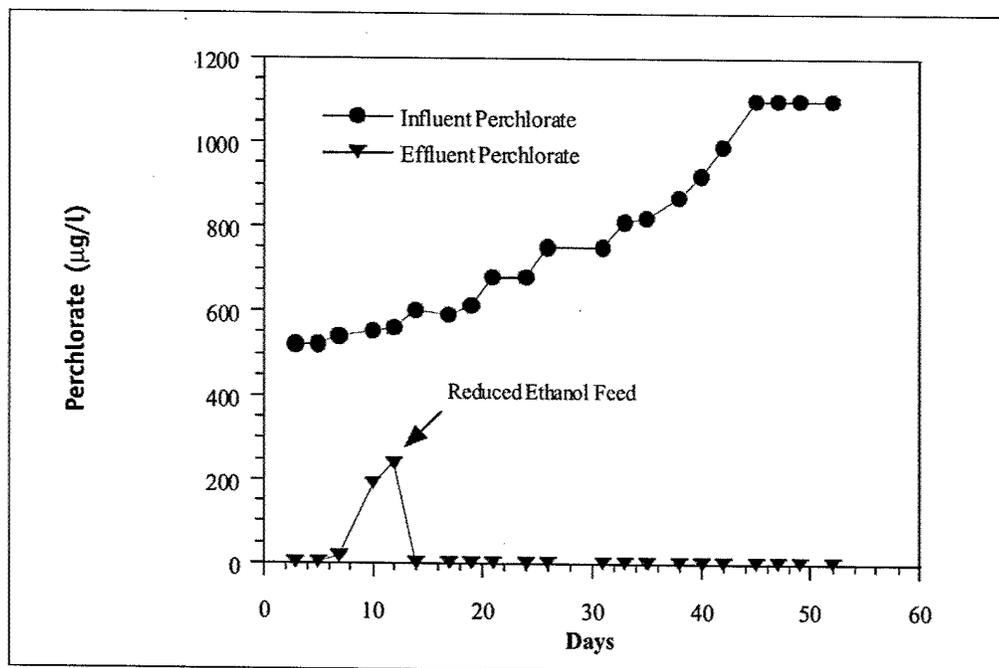
The initial start-up of the FBR system consisted of mechanical start-up, inoculation with a biological seed material, and water flow through the FBR system. The seed material consisted of 20 gallons of GAC media from a full-scale operating FBR that is currently treating perchlorate at the Aerojet Corporation in Rancho Cordova, California. Initial adsorption of perchlorate by the GAC system (used to remove low levels of VOCs in the influent water) and delays in state permitting postponed the steady introduction of perchlorate-contaminated groundwater to the FBR for approximately seven weeks. The FBR was fed groundwater from the site for the initial few weeks of this period, then the unit was operated in recycle mode and fed doses of ethanol (growth substrate) and nutrients daily to sustain biological growth. Air was periodically added to the recycled water by pumping it through the post-aeration tank and back to the FBR. This provided the microbial biomass with oxygen as an alternate electron acceptor. The FBR was spiked with perchlorate prior to beginning steady flow of groundwater to saturate the GAC media with the anion. An effluent sample collected from the FBR after the spike of perchlorate showed a level of 1,100 µg/l, suggesting that the GAC was saturated with the anion.

FBR systems usually require two to three weeks after start-up before perchlorate levels in effluent reach target levels.

During the demonstration, aqueous samples were collected from the influent to the FBR and from the effluent line. The samples were analyzed for perchlorate using EPA Method 314.0 (ion chromatography) and for nitrate by EPA Method 300.0. In addition, selected samples were analyzed for chemical oxygen demand (COD) as a measure of ethanol concentration by EPA Method 410.4; for total phosphorus by Method E365.1; and for ammonia nitrogen (NH<sub>3</sub>-N) by EPA Method 350.1. Laboratory analyses were performed by Montgomery Watson Laboratories in Pasadena, California. The groundwater well pump feeding the FBR pilot operated at maximum capacity throughout the pilot study. The maximum flow rate achieved was 5.3 gallons per minute (gpm) and the minimum flow rate was 3.6 gpm. This water was combined with recycle flow from the FBR to maintain a fluidization flow of approximately 30 gpm. The ethanol feed rate was varied based on the influent flow rate and the influent nitrate and perchlorate concentrations. Once steady groundwater flow was initiated (day zero), the pilot test was conducted for 52 days.

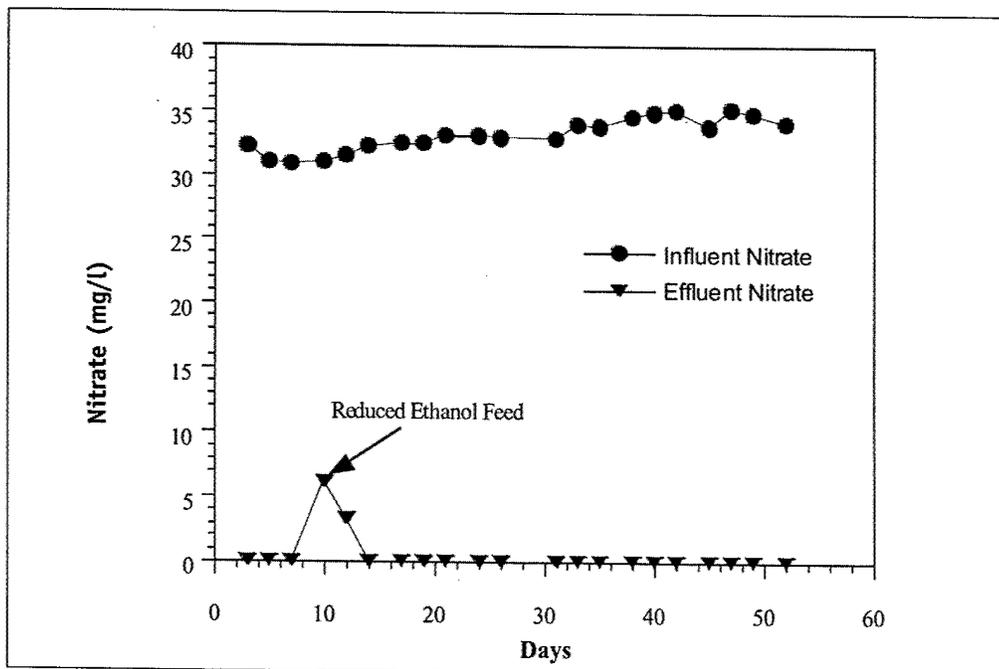
## **Results and Discussion**

There was no appreciable lag period in perchlorate treatment once groundwater flow was initiated (Exhibit 3). Based on previous pilot- and full-scale experience, FBR systems usually require two to three weeks after start-up before perchlorate levels in effluent reach target levels. Rapid colonization of media with microbial biomass occurs during the period. However, it is likely that such biomass growth occurred during the initial period that the reactor was operated and during the period that it was fed in recycle. The results of the FBR effluent analysis after three days of operation showed 520 µg/l of perchlorate in the influent and less than 4 µg/l in the effluent. The level of nitrate (NO<sub>3</sub>) in the influent was 32.3 mg/l at the same time, and the effluent concentration was below 0.4 mg/l (Exhibit 4). To demonstrate that biological treatment rather than adsorption by the GAC media was reducing levels of nitrate and perchlorate, the ethanol feed rate was reduced by 16 percent (from 2.5 to 2.1 ml/min) on day seven. The perchlorate in the FBR effluent increased from below detection (< 4 µg/l) to 15 µg/l, 190 µg/l, and 240 µg/l, during the next three sampling events (days seven, ten, and 12, respectively). The levels of nitrate in the effluent water increased from less than 0.4 mg/l to 6.11 and 3.32 mg/l on day ten and day 12, respectively. The break-



**Exhibit 3.** Influent and Effluent Concentrations of Perchlorate during the Pilot FBR Test

through of both nitrate and perchlorate when the ethanol feed was reduced verifies that biological reduction rather than GAC adsorption was responsible for the removal of perchlorate and nitrate within the FBR. The ethanol feed rate was increased on day 13 and the FBR effluent levels of perchlorate and nitrate returned to less than 4 µg/l and less than 0.4 mg/l, respectively, by day 14. This consistent level of treatment was maintained for the remainder of the study. The influent flow to the reactor was discontinued after 52 days of steady-state operation.



**Exhibit 4.** Influent and Effluent Concentrations of Nitrate during the Pilot FBR Test

As illustrated in Exhibit 3, the FBR received a steady increase in perchlorate concentration during the pilot demonstration. The perchlorate concentration in the influent groundwater increased from 360  $\mu\text{g/l}$  to 1.10  $\text{mg/l}$  and then leveled off. The concentrations of  $\text{NO}_3$  in the influent water also increased marginally during the test period. The increase in influent concentrations occurred naturally as the pumping progressed at the site. The FBR consistently reduced both perchlorate and nitrate to below detection during the entire test period (after the initial ethanol dosing test) irrespective of changes in the influent concentration of the two contaminants.

The average influent nitrate and perchlorate concentrations for the pilot test were 33.2  $\text{mg/l}$  and 770  $\mu\text{g/l}$ , respectively. The average influent flow rate and ethanol feed rate over the same period were 4.1  $\text{gpm}$  and 3.9  $\text{ml/min}$ , respectively. The calculated ethanol feed rate of the 9 percent solution is 1.2 pounds per day and the  $\text{NO}_3$  loading rate is 1.64 pounds per day. The amount of ethanol required is largely based on the nitrate loading because it is more than 30 times that of the perchlorate.

The data from the pilot demonstration suggest that an FBR is a viable technology for treating both nitrate and perchlorate in groundwater at the test site. The FBR system consistently reduced both contaminants to below detection throughout the 52-day treatment period (except when the ethanol dose was intentionally reduced for testing). These test data support findings at several other sites where pilot tests with FBRs have been conducted (Hatzinger et al., 2000; Greene & Pitre, 2000). In addition, there are currently two full-scale FBR systems treating perchlorate-contaminated groundwater in the United States. The first system, which is in operation at the Aerojet facility in Rancho Cordova, California, consists of four FBR units, each 14 feet in diameter by 22 feet high (Exhibit 5). This system has been treating perchlorate ( $\sim 3.5 \text{ mg/l}$ ) and nitrate ( $\sim 6.5 \text{ mg/l}$ ) in groundwater to below detection limits for more than two years. The design flow rate for this system is 4,000  $\text{gpm}$ . A second system has been effectively treating perchlorate (15–35  $\text{mg/l}$  influent) at the Longhorn Army Ammunition Plant, in Karnack, Texas, for more than nine months. The design flow of this system is 50  $\text{gpm}$ . A third FBR



**Exhibit 5.** Full-Scale Fluidized Bed Reactor System Treating Perchlorate in Groundwater

system is currently under construction for perchlorate treatment in groundwater at a U.S. naval facility in Texas. This system is expected to be in operation in early 2002.

## IN-SITU REMEDIATION OF PERCHLORATE IN GROUNDWATER

Three separate projects were funded by the Strategic Environmental Research and Development Program (SERDP) of the Department of Defense (DOD) beginning in 2000 to evaluate the potential for in-situ remediation of perchlorate in groundwater. These projects were designed to assess the occurrence and diversity of perchlorate-reducing bacteria in groundwater, to evaluate the most-effective substrates to stimulate biological perchlorate reduction and the geochemical parameters that may influence the process, and to design and test applicable field techniques for in-situ remediation of the propellant. As a recipient of one of these SERDP projects, we have examined the potential for in-situ remediation of perchlorate at several sites across the United States. These studies have included evaluations of the following: (1) the occurrence of perchlorate-reducing bacteria in groundwater; (2) the most-effective electron donors for the stimulation of these bacteria; and (3) the influence of alternate electron acceptors (e.g., nitrate, chlorate, and oxygen) and environmental conditions on perchlorate degradation. The laboratory results from these studies suggest that perchlorate-reducing bacteria are widespread in groundwater aquifers and that, with addition of specific electron donors, these bacteria can be stimulated to degrade perchlorate from existing levels to below current detection limits. However, environmental conditions including low pH, high salinity, and the presence of co-contaminants can influence the rates and extents of degradation. Laboratory data generated using aquifer samples collected from a site in southern California are presented in the following section. This site is at the same location where the previously described FBR pilot test was conducted. In-situ and ex-situ remediation options are being considered together for this location.

... these studies suggest that perchlorate-reducing bacteria are widespread in groundwater aquifers and that, with addition of specific electron donors, these bacteria can be stimulated to degrade perchlorate from existing levels to below current detection limits.

### Materials and Methods

Groundwater was collected from a monitoring well at the southern California site. Aseptic sampling techniques and sterile sample containers were used to prevent contamination of groundwater with non-native bacteria. Microcosms to evaluate the effectiveness of different substrates for promoting in-situ perchlorate degradation were prepared in sterile, 160-ml serum bottles. All experimental work was performed in a Coy Environmental Chamber with a nitrogen headspace. Groundwater was amended with a sterile stock of diammonium phosphate to provide nitrogen (5 mg/l as  $\text{NH}_4$ ) and phosphorus (4.5 mg/l as P) as nutrients for bacterial growth, then 120-ml volumes were added to the serum bottles. Triplicate bottles were amended with acetate, yeast extract, methanol, or molasses as electron donors (i.e., growth substrates) to 200 mg/l. Triplicate samples were prepared without substrate, and triplicate bottles received formaldehyde (1 percent) to inhibit all biological activity. All bottles were crimp-sealed with sterilized Teflon-lined septa and incubated at 15°C to approximate in-situ temperatures. After various incubation times, a 20-ml volume was removed from each bottle. The samples were analyzed for perchlorate and nitrate by ion chromatography (EPA Method 314.0 and 300.0, respectively).

Additional microcosm studies were conducted to assess the relative reduction kinetics of alternate electron acceptors including nitrate and nitrite, and to evaluate the

influence of these anions on perchlorate reduction. The microcosms were prepared as described in the previous section (160-ml serum bottles, 120-ml groundwater). Ethanol was added as the electron donor to 100 mg/l, and diammonium phosphate was provided as a source of nitrogen and phosphorus. A separate study (data not presented) showed that ethanol was an effective electron donor for microbial perchlorate reduction in site samples. In experiments conducted to evaluate the relative kinetics of nitrate and perchlorate degradation, the perchlorate concentration in the groundwater was brought to 115 mg/l in some samples and others were left at the site level of 310  $\mu\text{g/l}$ . Duplicate microcosms at each perchlorate concentration then received either no additional nitrate or 100 mg/l of nitrate ( $\text{NO}_3^-$ ) in solution. In addition, one set of microcosm bottles containing perchlorate at 310  $\mu\text{g/l}$  received 10 mg/l of nitrite ( $\text{NO}_2^-$ ) in solution, and two additional bottles received oxygen rather than nitrogen in the headspace to examine perchlorate reduction under oxic conditions. A killed control for each treatment was prepared by adding 1 percent formaldehyde to the groundwater samples. The samples were incubated at 15°C, and aqueous subsamples were removed periodically and tested for perchlorate (EPA 314.0), nitrate (EPA 300.0), and nitrite (EPA 300.0).

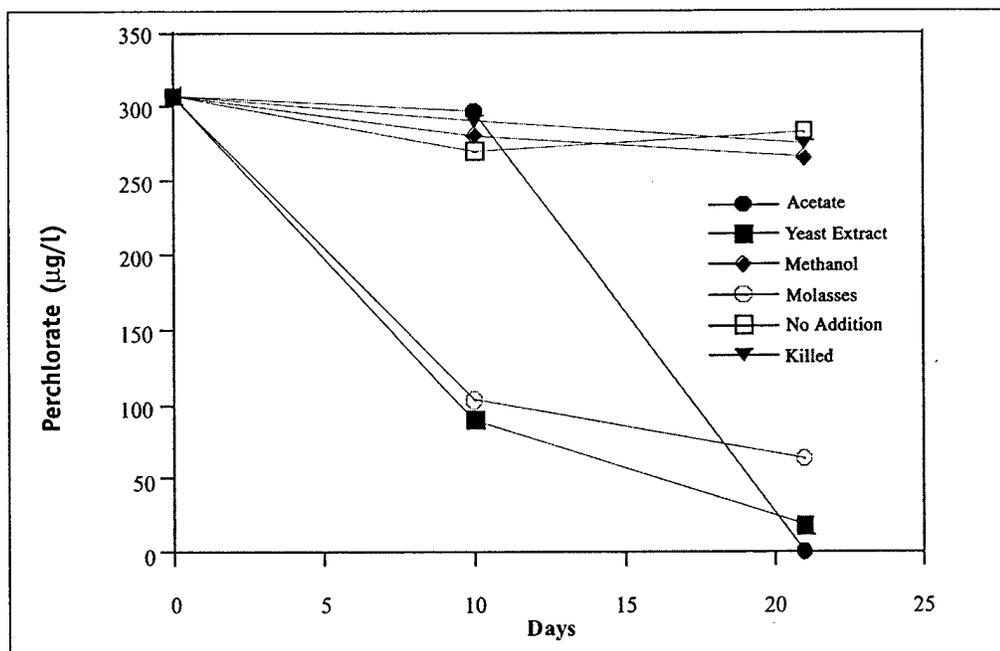
### Results and Discussion

The groundwater initially collected from the site contained perchlorate at 310  $\mu\text{g/l}$ , nitrate at 18.6 mg/l, sulfate at 44 mg/l, 140 mg/l of alkalinity (as  $\text{CaCO}_3$ ), and dissolved oxygen at 2.6 mg/l. The initial pH was 7.6. In microcosms prepared to evaluate the effectiveness of different electron donors, after 21 days of incubation perchlorate was below  $< 5 \mu\text{g/l}$  in triplicate samples amended with acetate (Exhibit 6). Appreciable degradation of perchlorate was also observed in samples amended with yeast extract and those receiving molasses. After 21 days, samples amended with yeast extract had an average of 18  $\mu\text{g/l}$  of perchlorate remaining, while those receiving molasses had 64  $\mu\text{g/l}$ . Perchlorate was not appreciably degraded in samples with methanol added as an electron donor or in those without an electron donor. The killed samples (1 percent formaldehyde) also showed no loss of perchlorate.

The results from this microcosm study reveal the following: (1) indigenous bacteria capable of degrading perchlorate are present in the aquifer underlying the site (see additional information below); (2) these bacteria can be stimulated to degrade perchlorate by the addition of specific electron donors; and (3) perchlorate levels can be reduced to below 5  $\mu\text{g/l}$  through biostimulation with some substrates. A perchlorate-degrading bacterium was subsequently isolated from the groundwater at this location by traditional microbial enrichment and plating techniques. This pure culture was then identified as *Dechlorosoma suillum* strain JPLRND by 16S rRNA analysis (Acculabs, Newark, Delaware). Similar perchlorate-degrading strains of this species were recently identified by researchers at Southern Illinois University (Achenbach et al., 2001). Additional experiments are ongoing to determine kinetic parameters and to evaluate the influence of environmental variables and alternate electron acceptors on perchlorate degradation by this strain.

In experiments conducted to assess the relative reduction kinetics of nitrate and perchlorate in site samples, nitrate was consistently degraded before perchlorate in groundwater microcosms, irrespective of the initial concentrations of the two anions. For example, in the samples spiked with nitrate (100 mg/l) and perchlorate (115 mg/l),

... perchlorate levels can be reduced to below 5  $\mu\text{g/l}$  through biostimulation with some substrates.



**Exhibit 6.** Biodegradation of Perchlorate in Groundwater Microcosms Amended with Different Electron Donors

nitrate was reduced to below detection after only four days of incubation, with no apparent lag period (Exhibit 7). Nitrite, which is the initial product in biological denitrification and nitrate reduction, was detected in samples at day four, but this anion was also degraded to below detection by day seven. A lag period of approximately 16 days occurred before perchlorate degradation commenced in these microcosms, then perchlorate was rapidly reduced to below detection. A similar pattern was observed in samples with nitrate at 100 mg/l and perchlorate at the initial concentration of 310 µg/l; nitrate was degraded within a few days, whereas perchlorate showed an initial lag period of approximately two weeks prior to degradation (data not shown).

The addition of nitrate (100 mg/l) or nitrite (10 mg/l) to groundwater did not appreciably influence the rate of perchlorate degradation in site samples. The data for samples containing 115 mg/l of perchlorate, with or without amendment with additional nitrate (100 mg/l), are presented in Exhibit 8. In fact, perchlorate reduction may have been stimulated slightly by the addition of nitrate. Conversely, the degradation of perchlorate was completely inhibited by the presence of oxygen in aquifer samples (Exhibit 9). This result confirms previous findings that perchlorate degradation occurs only under anoxic conditions (e.g., Attaway & Smith, 1993; Rikken et al., 1996). However, if enough of the electron donor was added for the indigenous bacteria to consume all of the oxygen in the samples via aerobic respiration, it is likely that perchlorate reduction would soon follow.

The data from these experiments suggest that nitrate and nitrite are degraded preferentially to perchlorate in this subsurface environment. It is possible that this pattern of degradation reflects a larger population of denitrifying bacteria in the groundwater samples compared to perchlorate-reducers. Most known perchlorate-reducing strains can also grow using nitrate as an electron acceptor, but the reverse is not true. It is also possible that nitrate and/or nitrite physiologically inhibit biological perchlorate degradation in perchlorate-reducing strains, and that perchlorate reduction cannot commence until

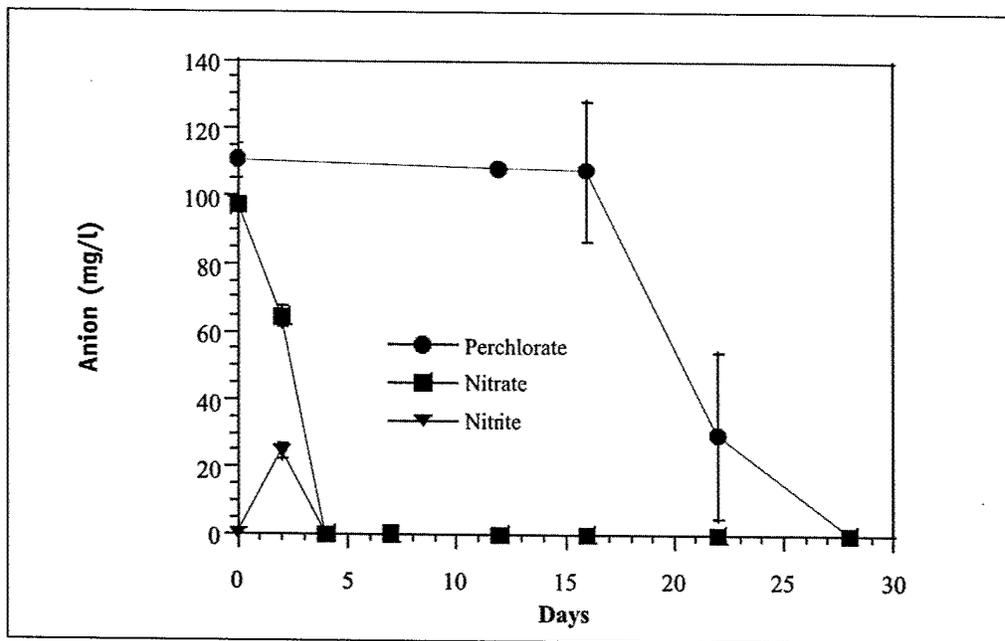


Exhibit 7. Biodegradation of Perchlorate and Nitrate in Groundwater Microcosms

these molecules have been reduced below a certain concentration. Nitrate has been shown to inhibit chlorate degradation in enrichment cultures (van Ginkel et al., 1995). Recent studies in our laboratory with the *D. suillum* strain isolated from this site have shown that the rate of perchlorate reduction can be reduced by the addition of nitrate when the culture is actively degrading perchlorate, and that the amount of reduction is dependent on nitrate concentration (unpublished data). This finding suggests that nitrate may be a competitive inhibitor of perchlorate reduction in this bacterium.

An understanding of the relationship between perchlorate and other electron acceptors (e.g., oxygen, nitrate, ferric iron, sulfate) is important because these molecules

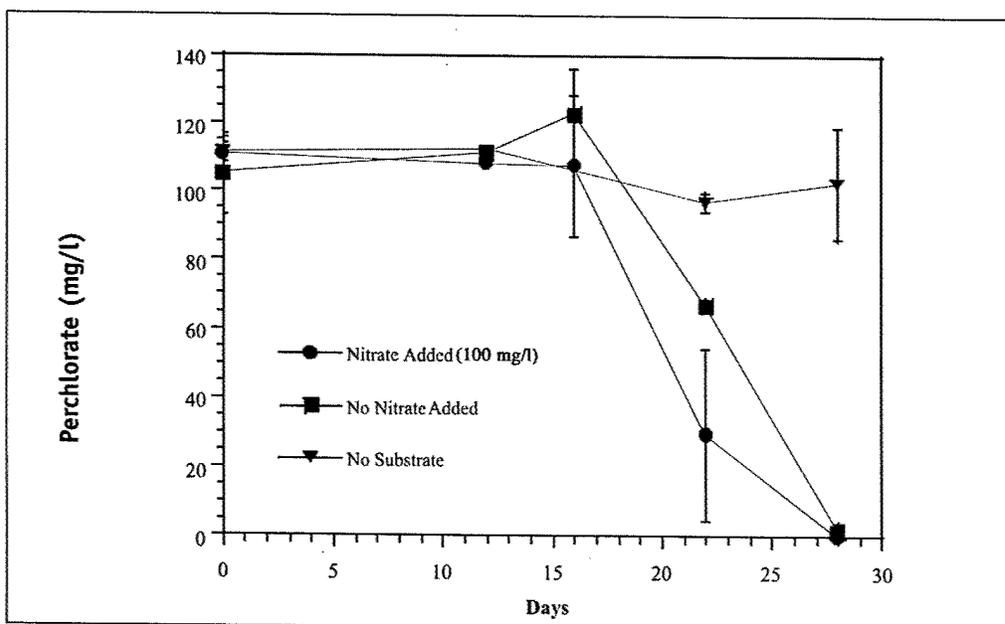
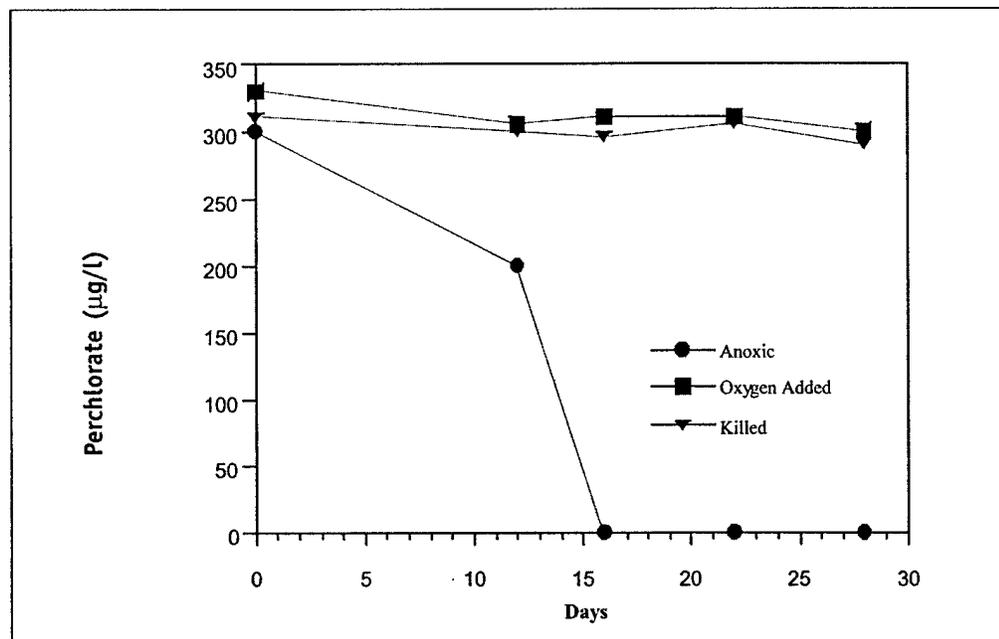


Exhibit 8. Influence of Nitrate on Perchlorate Biodegradation in Groundwater Microcosms



**Exhibit 9.** Influence of Oxygen on Perchlorate Biodegradation in Groundwater Microcosms

frequently occur with perchlorate in groundwater. For example, the groundwater collected from the southern California site contained 18.6 mg/l of nitrate but only 310 µg/l of perchlorate. This situation is not uncommon due to nitrate contamination of groundwater from agricultural and other sources. Therefore, an understanding of whether nitrate influences perchlorate degradation (e.g., due to enzyme inhibition or other factors) may be important in evaluating, designing, and applying treatment options at some contaminated sites.

The data from microcosm studies suggest that in-situ bioremediation of perchlorate through electron donor addition may be an option for perchlorate treatment at this location. Data collected from other sites during this project have generally supported these data. Overall, the results have shown that perchlorate-degrading bacteria are widely distributed in groundwater environments, and that these organisms can be stimulated to degrade perchlorate by several different electron donors, although the most-effective donors may vary by location.

There are currently few published data concerning the effectiveness of in-situ perchlorate treatment in groundwater at the pilot- or field-scale. One of the significant challenges for in-situ perchlorate treatment to be an effective and cost-competitive technology at many locations is the development of methods to effectively deliver and mix the electron donor with groundwater. Much of the perchlorate-contaminated groundwater in California, Utah, New Mexico, and other western states is present in deep aquifers (100 to 700 feet below surface); therefore, many current in-situ technologies that work well in shallow groundwater, such as treatment trenches and barrier walls, are unlikely to be applicable or cost-effective. The addition of slow-release substrates (e.g., vegetable oil, polylactate) is also unlikely to be economical or effective at many of these sites. Drilling depths greater than 100 feet can be prohibitively expensive if many wells are required for injection, as would likely be the case with poorly dispersed oils or other slow-release substrates. In addition, poor mixing of these electron donors with perchlo-

rate-contaminated groundwater is likely to lead to ineffective treatment of large plumes.

Systems that effectively meter and mix the electron donor with a large zone of influence are anticipated to be the most-effective in-situ remediation options for perchlorate. One design, which has been tested at the pilot-scale with promising results at the Aerojet site in Rancho Cordova, California, is a groundwater injection-extraction system (Cox et al., 2001). In a field demonstration, contaminated groundwater was pumped up from the aquifer and mixed with the electron donor. The water with the electron donor was then reinjected through a second well into the aquifer, creating a treatment zone between the injection and extraction wells. The injection and extraction wells were placed perpendicular to groundwater flow. The study results showed rapid biodegradation of perchlorate in situ, with concentrations of perchlorate declining from 15 mg/l to less than 4  $\mu\text{g/l}$  within 15 feet of the electron-donor delivery well. In a second phase of testing, a system consisting of two extraction wells and one injection well is being tested as a means to capture the core of a perchlorate plume (a width of about 600 feet). In this case, groundwater is pumped through the two extraction wells, amended with the electron donor (ethanol), and then recharged to the aquifer via the single recharge well. In initial data from this test, perchlorate concentrations have been reduced from approximately 8 mg/l to less than 4  $\mu\text{g/l}$  within 35 feet of the electron-donor delivery wells.

A second design which holds promise for the treatment of perchlorate in deep sites is a horizontal flow treatment well (HFTW) system, such as that applied by McCarty et al. (1998) for remediation of TCE at Edwards Air Force Base. The HFTW system employs dual-screened treatment wells placed in pairs to create a recirculation cell within a contaminated aquifer (i.e., water is not brought to the surface). The electron donor can then be mixed with groundwater passing through each well to promote perchlorate treatment within the recirculation zone. A field demonstration of this technology for perchlorate treatment will be conducted by Envirogen in collaboration with the University of New Mexico and the Air Force Institute of Technology beginning in 2002.

In-situ and ex-situ biological treatment technologies represent the most-promising alternatives for cost-effective treatment of perchlorate in groundwater.

## SUMMARY AND CONCLUSIONS

Perchlorate has been detected in water supplies in 14 states, including California, Arizona, Nevada, Utah, and Texas. In-situ and ex-situ biological treatment technologies represent the most-promising alternatives for cost-effective treatment of perchlorate in groundwater. Fluidized bed reactors (FBRs) have proven to be an effective reactor design for ex-situ treatment of perchlorate in groundwater. In the study reported herein, an ethanol-fed FBR consistently reduced perchlorate concentrations from influent levels averaging 770  $\mu\text{g/l}$  to below the analytical reporting limit ( $< 4 \mu\text{g/l}$ ). The FBR also consistently treated nitrate from 33.2 mg/l to nondetectable levels ( $< 0.4 \text{ mg/l}$ ). These performance data are consistent with those from two full-scale FBR systems treating perchlorate in groundwater and from several other pilot tests. The high biomass maintained within an FBR system, its ability to efficiently handle high groundwater flow rates and changing concentrations of perchlorate and nitrate, and effective mechanical devices to prevent biological fouling and channeling make the FBR an optimal reactor design for perchlorate treatment in groundwater.

In addition to bioreactor technologies such as the FBR, in-situ treatment of perchlorate-contaminated groundwater through electron donor addition is likely to be a viable remediation option at many sites. Laboratory data suggest that perchlorate-reducing bacteria are widely occurring in natural environments, including groundwater aquifers, and

that these organisms can be stimulated to degrade perchlorate to below detection through addition of specific electron donors. Pilot-scale or full-scale field data are presently inadequate to evaluate the cost and effectiveness of different in-situ treatment options for perchlorate in groundwater. However, initial pilot tests of in-situ perchlorate bioremediation conducted at the Aerojet site in California are showing promising results, and several additional demonstrations of technologies for perchlorate treatment are planned beginning in 2002 (funded through the Environmental Security Technology Certification Program (ESTCP)). These field tests should provide the necessary cost and performance data to evaluate the applicability and economics of in-situ treatment technologies for perchlorate at full scale.

Based on current information, it is likely that both in-situ and ex-situ bioremediation will be employed at many sites as part of an overall strategy for treatment of perchlorate in groundwater. The facilities where perchlorate-containing fuels have been manufactured, tested, or replaced frequently have several different sources of groundwater contamination, including testing grounds, burn areas, and hog-out facilities. The factors that influence perchlorate remediation options at these sites are varied, and include the characteristics of the perchlorate plume (i.e., concentration, depth, extent), the presence of co-contaminants (such as chlorinated solvents and heavy metals, and existing systems to remove these contaminants), the necessity to protect public or private drinking water wells from plume migration, regulatory requirements, and cost. In cases where well protection is required, where existing pump-and-treat systems are already in place, or where plumes are very deep and/or expansive, ex-situ treatment is likely to be the bioremediation option of choice. Conversely, in well-defined source areas, shallow or narrow zones of contamination, and/or regions where drinking water is unlikely to be affected, in-situ perchlorate treatment may prove to be the best treatment option.

## ACKNOWLEDGMENTS

This research was supported in part by the Strategic Environmental Research and Development Program (SERDP Project CU-1163). We also wish to thank Bryan Harre of the Naval Facilities Engineering Service Center for providing site samples, and Evan Cox for supplying in-situ field results.

## REFERENCES

- Achenbach, L.A., Michaelidou, U., Bruce, R.A., Fryman, J., & Coates, J.D. (2001). *Dechloromonas agitata* gen. nov., sp. nov. and *Dechlorosoma suillum* gen. nov., sp. nov., two novel environmentally dominant (per)chlorate-reducing bacteria and their phylogenetic position. *International Journal of Systematic and Evolutionary Microbiology*, 51, 527–533.
- Attaway, H., & Smith, M. (1994). Propellant wastewater treatment process. U.S. Patent 5302285.
- Attaway, H., & Smith, M. (1993). Reduction of perchlorate by an anaerobic enrichment culture. *Journal of Industrial Microbiology*, 12, 408–412.
- California Department of Health Services (CDHS). (1997). Determination of perchlorate by ion chromatography [Online]. Available: <http://www.dhs.ca.gov/ps/ddwem/chemicals/perchl/clo4meth.pdf>.

- California Department of Health Services (CDHS). (2001). California's experience with perchlorate in drinking water [Online]. Available: <http://www.dhs.cahwnet.gov/ps/ddwem/chemicals/perchl/perchlindex.htm>.
- Coates, J.D., Michaelidou, U., Bruce, R.A., O'Conner, S.M., Crespi, J.N., & Achenbach, L.A. (1999). The ubiquity and diversity of dissimilatory (per)chlorate-reducing bacteria. *Applied and Environmental Microbiology*, 65, 5234–5241.
- Cox, E.E., McMaster, M., & Neville, S.L. (2001). Perchlorate in groundwater: Scope of the problem and emerging remedial solutions. In *Proceedings of the 36th annual engineering geology and geotechnical engineering symposium*, Las Vegas, Nevada (pp. 27–32). Pocatello, ID: Idaho State University. (Available from Engineering Geology and Geotechnical Engineering Symposium, Business Office, P.O. Box 8060, Pocatello, ID 83209.)
- Damian, P., & Pontius, F.W. (1999, June). From rockets to remediation: The perchlorate problem. *Environmental Protection*, 24–31.
- Greene, M.R., & Pitre, M.P. (2000). Treatment of groundwater containing perchlorate using biological fluidized bed reactors with GAC or sand media. In E.T. Urbansky (Ed.), *Perchlorate in the environment* (pp. 241–256). New York: Kluwer Academic/Plenum Publishers.
- Gu, B., Brown, G.M., Alexandratos, S.D., Ober, R., Dale, J.A., & Plant, S. (2000). Efficient treatment of perchlorate ( $\text{ClO}_4^-$ )-contaminated groundwater by bifunctional anion exchange resins. In E.T. Urbansky (Ed.), *Perchlorate in the environment* (pp. 165–176). New York: Kluwer Academic/Plenum Publishers.
- Gulick, R.W., Lechevallier, M.W., & Barhorst, T.S. (2001). Occurrence of perchlorate in drinking water sources. *Journal of the American Water Works Association*, 93, 66–77.
- Hatzinger, P.B., Greene, M.R., Frisch, S., Togna, A.P., Manning, J., & Guarini, W.J. (2000). Biological treatment of perchlorate-contaminated groundwater using fluidized bed reactors. In G.B. Wickramanayake et al. (Eds.), *Case studies in the remediation of chlorinated and recalcitrant compounds* (pp. 115–122). Columbus, OH: Battelle Press.
- Hurley, J.A., Wallace, W., & Coppola, E. (1996). Prototype demonstration of ammonium perchlorate biodegradation. *Civil Engineering U.S. Air Force*, 4, 3.
- Kengen, S.W.M., Rikken, G.B., Hagen, W.R., van Ginkel, C.G., & Stams, A.J.M. (1999). Purification and characterization of (per)chlorate reductase from chlorate-respiring strain GR-1. *Journal of Bacteriology*, 181, 6706–6711.
- Logan, B.E. (2001). Assessing the outlook for perchlorate remediation. *Environmental Science and Technology*, 35, 483A–487A.
- Logan, B.E. (1998). A review of chlorate- and perchlorate-respiring microorganisms. *Bioremediation Journal*, 2, 69–79.
- Manzon, R.G., & Youson, J.H. (1997). The effects of exogenous thyroxine (T4) or triiodothyroxine (T3), in the presence and absence of potassium perchlorate, on the incidence of metamorphosis and on serum T4 and T3 concentrations in larval sea lampreys (*Petromyzon marinus* L.). *General Comparative Endocrinology*, 106, 211–220.
- McCarty, P.L., Goltz, M.N., Hopkins, G.D., Dolan, M.E., Allan, J.P., Kawakami, B.T., & Carrothers, T.J. (1998). Full-scale evaluation of in situ cometabolic degradation of trichloroethylene in groundwater through toluene injection. *Environmental Science and Technology*, 32, 88–100.
- Miller, J.P., & Logan, B.E. (2000). Sustained perchlorate degradation in an autotrophic, gas-phase, packed-bed bioreactor. *Environmental Science and Technology*, 34, 3018–3022.

- Rikken, G.B., Kroon, A.G.M., & van Ginkel, C.G. (1996). Transformation of (per)chlorate into chloride by a newly isolated bacterium: reduction and dismutation. *Applied Microbiology and Biotechnology*, 45, 420–426.
- Smith, P.N., Theodorakis, C.W., Anderson, T.A., & Kendall, R.J. (2001). Preliminary assessment of perchlorate in ecological receptors at the Longhorn Army Ammunition Plant (LHAAP), Karnack, Texas. *Ecotoxicology*, 10, 305–313.
- Sutton, P.M., & Mishra, P.N. (1994). Activated carbon based biological fluidized beds for contaminated water and wastewater treatment: a state-of-the-art review. *Water Science and Technology*, 29, 309–317.
- Urbansky, E.T. (1998). Perchlorate chemistry: Implications for analysis and remediation. *Bioremediation Journal*, 2, 81–95.
- Urbansky, E.T., & Schock, M.R. (1999). Issues in managing the risks associated with perchlorate in drinking water. *Journal of Environmental Management*, 56, 79–95.
- U.S. Environmental Protection Agency (USEPA). (2001a). Perchlorate [Online]. Available: <http://www.epa.gov/safewater/ccl/perchlor/perchlo.html>.
- U.S. Environmental Protection Agency (USEPA). (2001b). Survey of fertilizers and related materials for perchlorate ( $\text{ClO}_4^-$ ) (EPA/600/R-01/049). Cincinnati, OH: Office of Research and Development.
- U.S. Environmental Protection Agency (USEPA). (1999). Region 9 perchlorate update [Online]. Available: <http://www.epa.gov/safewater/ccl/perchlor/r9699fac.pdf>.
- U.S. Environmental Protection Agency (USEPA). (1993). Nitrogen control manual (EPA/625/R-93/010). Washington, DC: Office of Research and Development.
- van Ginkel, C.G., Plugge, C.M., & Stroo, C.A. (1995). Reduction of chlorate with various energy substrates and inocula under anaerobic conditions. *Chemosphere*, 31, 4057–4066.
- van Ginkel, C.G., Rikken, G.B., Kroon, A.G.M., & Kengen, S.W.M. (1996). Purification and characterization of a chlorite dismutase: A novel oxygen-generating enzyme. *Archives of Microbiology*, 166, 321–326.
- Wallace, W., Beshear, S., Williams, D., Hospadar, S., & Owens, M. (1998). Perchlorate reduction by a mixed culture in an up-flow anaerobic fixed bed bioreactor. *Journal of Industrial Microbiology and Biotechnology*, 20, 126–131.
- Wallace, W., Ward, T., Breen, A., & Attaway, H. (1996). Identification of an anaerobic bacterium which reduces perchlorate and chlorate as *Wolinella succinogenes*. *Journal of Industrial Microbiology*, 16, 68–72.
- Wolff, J. (1998). Perchlorate and the thyroid gland. *Pharmacology Review*, 50, 89–105.
- Wu, J., Unz, R.F., Zhang, H., & Logan, B.E. (2001). Persistence of perchlorate and the relative numbers of perchlorate- and chlorate-respiring microorganisms in natural waters, soils, and wastewater. *Bioremediation Journal*, 5, 119–130.
- York, R.G., Brown, W.R., Girard, M.F., & Dollarhide, J.S. (2001). Oral (drinking water) developmental toxicity study of ammonium perchlorate in New Zealand white rabbits. *International Journal of Toxicology*, 20, 199–205.

---

**Paul B. Hatzinger, Ph.D.**, is an environmental microbiologist with Envirogen Inc., in Lawrenceville, New Jersey. His research interests include the in-situ and ex-situ bioremediation of perchlorate and MTBE in groundwater.

**Martha D. Arkins** is a project engineer at Envirogen with several years of experience in the development and application of remediation technologies.

**M. Casey Whittier** is the FBR products manager with USFilter Envirex Products and is responsible for evaluation and design of all FBR applications.

**Chris W. Bryan** is a field process engineer with USFilter Envirex. He is responsible for piloting and optimization of biological treatment processes.

**William J. Guarini, M.E.**, is a chemical engineer and the vice president of government programs at Envirogen.

---

## Field Demonstration of In Situ Perchlorate Bioremediation at NSWC Indian Head

Randall J. Cramer\*, Carey A. Yates  
Indian Head Division Naval Surface Warfare Center  
101 Strauss Avenue  
Indian Head, MD 20640-5035

Paul B. Hatzinger, Jay Diebold, Matt Giovanelli  
Envirogen, Inc.  
4100 Quakerbridge Road  
Lawrenceville, NJ 08648

### ABSTRACT

Biological treatment of ammonium perchlorate is a promising technology for remediation of ground and surface water. A wide variety of microbial strains have been isolated with the ability to degrade perchlorate to chloride and water. These organisms require an electron donor (substrate) for growth and utilize the perchlorate molecule as a terminal electron acceptor. The key to utilizing perchlorate-reducing bacteria for *in situ* bioremediation is the understanding and control of the conditions that promote the activity in subsurface environments. As part of a SERDP-funded research project, laboratory microcosm and column studies were conducted using aquifer samples collected from several different perchlorate-contaminated sites across the United States. These studies were designed to evaluate the most effective substrates for stimulating biological perchlorate reduction and to assess the influence of environmental variables on the process. Perchlorate-degrading bacteria were found to be widespread in subsurface aquifers, and pure cultures of the genera *Dechlorosoma* and *Dechlorospirillum* were isolated. Several substrates, including acetate, lactate, molasses, ethanol, and hydrogen effectively stimulated perchlorate reduction in aquifer microcosms. Starting perchlorate levels ranging from 0.31 mg/L to greater than 100 mg/L were reduced to below detection (< 0.004 mg/L) in aquifer samples amended with appropriate electron donors. The laboratory studies revealed that *in situ* bioremediation is a promising technology for perchlorate treatment at many DoD sites. In order to build upon the successful laboratory studies, a field demonstration of *in situ* bioremediation of perchlorate is planned for 2002 at Naval Surface Warfare Center Indian Head Division's Building 1419, otherwise known as the Hogout Facility. Laboratory studies as well as the geological and hydrogeological conditions observed at this site indicate that it is likely to be suitable for *in situ* bioremediation. Laboratory results from this site and an overview of the planned field demonstration are presented.

### INTRODUCTION

Ammonium perchlorate is extensively used as an oxidizer in solid rocket motor and booster propellant formulations and has been found as a contaminant in the environment.<sup>1</sup> The perchlorate salts are quite soluble in water and exceedingly mobile in aqueous systems. The  $\text{ClO}_4^-$  anion is stable and can persist for many decades due to its low reactivity with other constituents. The current database on the health effects and toxicity of  $\text{ClO}_4^-$  anion is very limited.<sup>2</sup> However, current data confirm the potential of perchlorate for disrupting thyroid hormones. The National Center for Environmental Assessment (NCEA) has recently issued a draft toxicological risk assessment based on a reevaluation of the toxicological data for this compound.

Since perchlorate is very unreactive with most reducing agents, the development of suitable remediation and treatment technologies is difficult. However, specific types of bacteria have been found to metabolize perchlorate as a terminal electron acceptor during growth on either organic or inorganic substrates (e.g.,<sub>3</sub> lactate, acetate, hydrogen gas), subsequently reducing perchlorate completely to chloride ion and oxygen. Biological treatment technologies for remediation of groundwater with perchlorate are based on the use of these naturally-occurring microbes.<sup>4</sup>

Distribution authorized to U.S. government agencies and their U.S. contractors only. Critical Technology, May 2000. Other requests for this document should be referred to Commander Indian Head Division Naval Surface Warfare Center, 101 Strauss Ave, Indian Head, MD 20640-5035 Code PM4A via IS.

Both *ex situ* and *in situ* groundwater and soil remediation techniques have been evaluated to some extent.<sup>5,6</sup> Full-scale fluidized bed bioreactors are currently being used successfully to remediate perchlorate-contaminated groundwater at several sites in the United States.<sup>6</sup> In addition, application of appropriate substrates (electron donors) to subsurface aquifers to stimulate indigenous perchlorate-degrading bacteria holds promise as an *in situ* technology for perchlorate remediation. As part of a SERDP-funded research effort, the potential for *in situ* perchlorate remediation at several different sites across the United States was evaluated. The occurrence of perchlorate-reducing bacteria at these sites was tested, the effectiveness of various donor substrates for stimulating perchlorate reduction by these bacteria was quantified, and the influence of environmental variables, including groundwater pH and the presence of co-contaminants, on the rate of microbial perchlorate degradation was determined. Data from this research effort were then used to design a pilot-scale system for a field demonstration of *in situ* bioremediation of perchlorate in groundwater at NSWC Indian Head.

## METHODS, RESULTS AND DISCUSSION

### Site Selection

Biological treatment of ammonium perchlorate is a promising technology for remediation of groundwater. Several microbial strains with the ability to degrade perchlorate by using the molecule as a terminal electron acceptor have been isolated. The enzymatic pathways involved in perchlorate reduction have yet to be fully studied. However, it appears that a perchlorate reductase enzyme catalyzes an initial two-step reduction of perchlorate ( $\text{ClO}_4^-$ ) to chlorate ( $\text{ClO}_3^-$ ) and then chlorite ( $\text{ClO}_2^-$ ).<sup>7</sup> The chlorite is further reduced by chlorite dismutase to chloride ( $\text{Cl}^-$ ) and oxygen ( $\text{O}_2$ ). Thus, microbial degradation of perchlorate yields two innocuous products, chloride, and oxygen. In addition, the reduction of perchlorate to chloride is a very favorable process from a thermodynamic perspective. Thus, bacteria capable of using perchlorate are likely to have a distinct ecological advantage in contaminated environments.

The key in utilizing perchlorate-reducing bacteria for *in situ* bioremediation is to understand the conditions that limit their activity in subsurface environments and then effectively devise technologies that overcome these limitations, subsequently stimulating perchlorate degradation activity. The presence and occurrence of perchlorate-reducing microbes, the ability to stimulate perchlorate degradation with the appropriate electron donors, and the potential factors which may inhibit metabolic degradation of perchlorate have been evaluated during this study. Results from studies at NSWC Indian Head are reported herein.

Two sites where perchlorate use and disposal activities prominently existed were selected for this study. Core and aquifer samples were obtained near the location of a large propellant (300-gallon) mixer facility, and near a facility where water washout of perchlorate propellant rocket motors was performed. The results of the chemical analysis of site samples are shown in Table 1. Slurry samples are a mixture of groundwater and site sediments. Other data are from groundwater only.

Table 1. Chemical Characteristics of Site Samples

	Hogout Facility Bldg. 1419	300-Gallon Mixer Bldg. 1190
Depth	6 - 13 ft (BLS)	4 - 12 (BLS)
Perchlorate	45 mg/L (slurry)	<0.004 mg/L (slurry)
pH	4.3 (slurry)	6.1 (slurry)
Alkalinity	19 mg/L	40 mg/L
Sulfate	88 mg/L	12 mg/L
Nitrate	<0.4 mg/L	<0.2 mg/L
Nitrite	<0.4 mg/L	<0.4 mg/L
Chloride	26 mg/L	43 mg/L
Co-Contamination	NA (binder/metals)	Fuel?

The groundwater was shallow at each of these sites. Although a large quantity of perchlorate has been used and disposed of at the mixer site (Bldg. 1190), perchlorate was not detected in groundwater near this facility. Samples from this location were amended with perchlorate to perform microcosm studies, but the site was dropped from consideration for a field demonstration. Perchlorate was detected in groundwater and sediment samples near the Hogout facility at approximately 45 mg/L. Additional site characterization work has shown perchlorate levels in shallow groundwater exceeding 300 mg/L in specific locations near this facility. Therefore, this area has been identified for use as the primary field demonstration site.

### Microcosm Studies

Aquifer microcosm studies were performed with samples from the above sites to determine the effectiveness of various electron donors for stimulation of perchlorate degradation. To prepare microcosms, groundwater and homogenized sediment from the sites was added to 160-mL serum bottles (100-mL groundwater and 30-g sediment) in a Coy Environmental Chamber with a nitrogen headspace. The groundwater was initially amended with a nutrient solution to provide nitrogen and phosphorus, then the serum bottles received one of several different substrates, including acetate, ethanol, molasses, and lactate. Some bottles were amended with hydrogen as an inorganic substrate for perchlorate reduction. Killed controls received acetate as a substrate and 1% formaldehyde to inhibit microbiological activity. The bottles were sealed with sterile septa and incubated at 15°C with gentle shaking. At various times, aqueous subsamples were collected and analyzed for perchlorate by ion chromatography using EPA Method 314.0.

The results from the Building 1190 site are shown in Figure 1. As previously noted, perchlorate was not detected in samples from this site. Therefore, perchlorate was added to microcosms at a starting concentration of approximately 125 mg/L. After 11 days, perchlorate levels were below detection in microcosms amended with hydrogen gas, and samples that received acetate declined to 3 mg/L perchlorate during this time. After 34 days, perchlorate was below detection in samples treated with molasses or acetate, as well as those receiving hydrogen. No perchlorate loss was evident in samples receiving ethanol or in acetate-amended microcosms that were treated with formaldehyde to inhibit biological activity. The latter result shows that the decline in perchlorate levels was due to biodegradation rather than any abiotic process.

In a separate study using samples from the Hogout facility, there was no significant loss of perchlorate during more than 2 months of incubation in any of the aquifer microcosms, irrespective of substrate added (ten different substrates were tested) (*data not shown*). The most obvious difference between the two sets of samples was the much lower pH of the Hogout site compared to Building 1190 (pH 4.3 vs. 6.1 in slurries, respectively). Therefore, a second study was conducted in which some of the Hogout samples were amended with acetate, then brought to a pH of 7.0 using sodium carbonate. When the pH was increased, perchlorate degradation was observed in microcosms from this site (Figure 2). Perchlorate was below detection by day 28 in samples at pH 7.0, whereas little decline was observed in acetate-amended samples that remained at pH 4.3 or in formaldehyde-killed controls. Thus, the data suggest that perchlorate-degrading bacteria are present at the site, but that low pH is inhibiting perchlorate degradation by these strains.

Figure 1. Influence of Electron Donors on Perchlorate Levels in Aquifer Microcosms from Building 1190

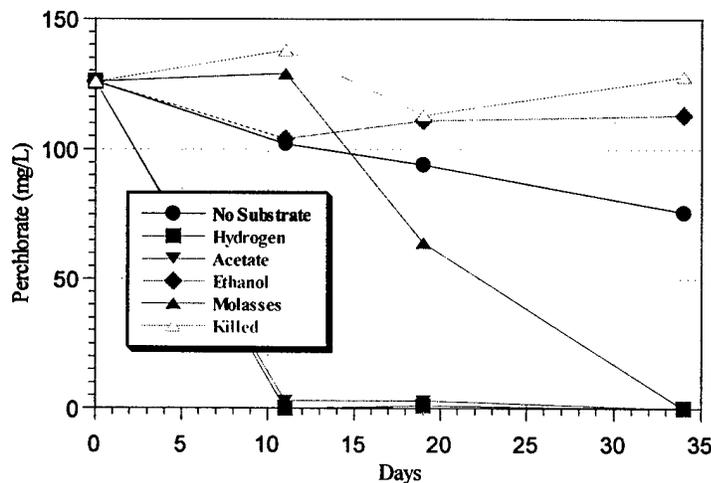
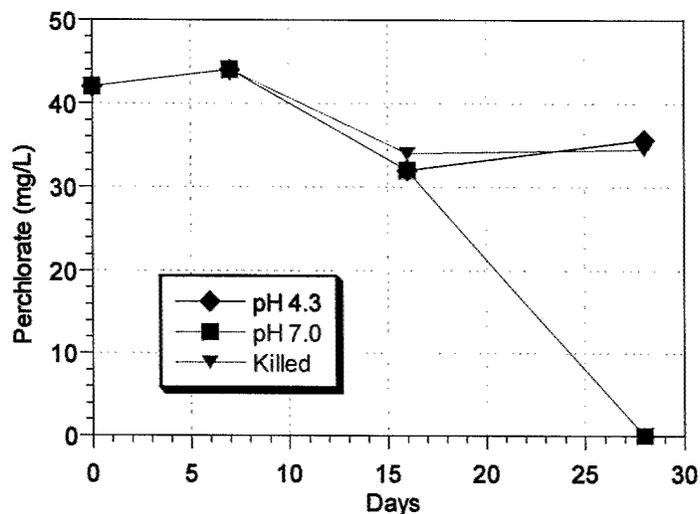


Figure 2. Influence of pH on Perchlorate Degradation in Aquifer Microcosms from the Hogout Facility



The results of microcosm studies performed at Indian Head suggest the following: (1) perchlorate-reducing bacteria are naturally present in the shallow aquifer underlying the facility; (2) these bacteria can be stimulated to biodegrade perchlorate from high mg/L levels to at or below current reporting limits for the compound ( $\sim 0.004$  mg/L) using specific substrates; and (3) low pH is inhibitory to perchlorate biodegradation at the Hogout facility. The information gained during the laboratory phase of this research is currently being applied in the field. An *in situ* treatment system has been designed and is currently being installed at the Hogout facility. As described in the next section, this system will provide both buffer and substrate to the shallow groundwater to stimulate perchlorate treatment at this location. This is one of only a few field demonstrations of *in situ* perchlorate treatment that have been attempted, and the only one at a low pH site.

#### In Situ Treatment System

The objective of this project is to build upon the microcosm results by conducting a field demonstration of *in situ* bioremediation of perchlorate at NSW Indian Head Division's Hogout facility. The observed geological and hydrogeological conditions at this site indicate that it is a suitable candidate for *in situ* bioremediation. Based on the results of laboratory microcosm studies, this site will require pH adjustment and substrate amendment to promote *in situ* bioremediation of perchlorate. The site will need to be buffered to increase pH levels into a range suitable for microbial perchlorate degradation ( $> 6.0$ ). Preliminary studies indicated that the low pH of the Hogout site (4.3) is inhibiting the biological breakdown of perchlorate. The ability to maintain a buffered subsurface reaction zone is critical in maintaining the biological destruction of perchlorate. Injection wells will be used to supply both buffer and substrate. Lactate or acetate will be added as substrates. Preliminary results indicate these compounds are suitable electron donors for supporting the biological breakdown of perchlorate at the Hogout site. A recirculation cell design will be applied at the site to add and mix substrate and buffer into groundwater (Figure 3). Two plots will be installed, a test plot in which substrate and buffer will be applied and a control plot in which neither amendment is added. If the initial demonstration is successful, and perchlorate levels in the test plot are reduced below detection and sustained at this level, additional studies will be performed using the control plot. In particular, a novel hydrogen-generating system (low-voltage proton reduction) will be tested at this site to determine if it can be used to provide hydrogen gas as a substrate for perchlorate reduction. If this demonstration is successful, this type of system could be applied at this or other sites as a flow-through biobarrier with alternating injection and extraction wells, as shown in Figure 4.

Figure 3. Plan View of Field Demonstration Recirculation Cells

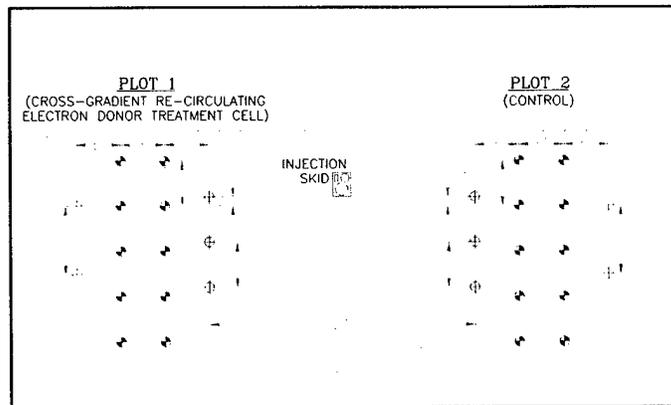
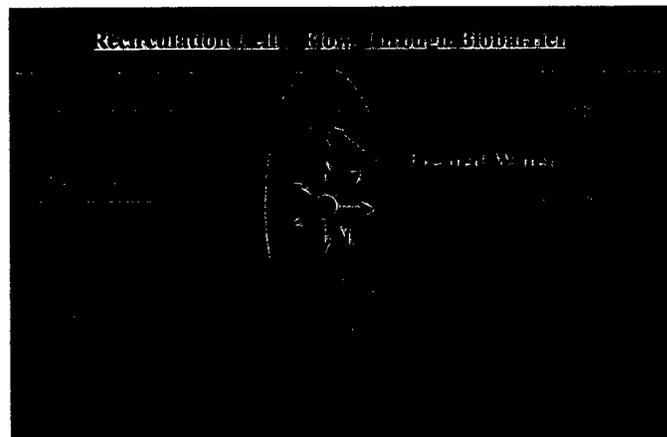


Figure 4. Flow-through Biobarrier for Full-Scale Perchlorate Treatment



This field demonstration conducted at NSWC Indian Head will test the effectiveness of a simple injection/extraction system to supply and mix an electron donor in groundwater, to adjust subsurface pH to optimal levels, and to subsequently promote and maintain microbial breakdown of perchlorate. The effectiveness of the recirculating cell system to supply a buffering agent combined with a low voltage proton reduction system to produce hydrogen gas as a substrate for perchlorate reduction will also be evaluated. This data will provide the field scale scientific as well as the practical knowledge required for the design and implementation of full-scale remediation efforts at perchlorate-contaminated sites. The demonstration system, if successful, is designated to become part of a full-scale system for *in situ* perchlorate remediation at the Hogout site

#### SUMMARY AND CONCLUSIONS

A low cost and effective method for remediation of groundwater containing the propellant formulation ingredient perchlorate is needed. Laboratory studies have shown that naturally-occurring microorganisms can be stimulated to reduce perchlorate to chloride and oxygen. This microbial activity requires the addition of an appropriate electron donor, and can be influenced by a variety of environmental factors. A field

demonstration of *in situ* perchlorate bioremediation is underway at the NSWC Indian Head, at a site in which perchlorate ion has been detected in shallow groundwater. This system uses a recirculating cell design equipped with injection wells for introducing electron donor and buffer. The data from this demonstration will provide the knowledge required for the design and implementation of full-scale *in situ* remediation efforts at perchlorate-contaminated sites.

#### REFERENCES

1. U. S. Environmental Protection Agency, "Perchlorate Environmental Contamination: Toxicological Review And Risk Characterization", 2002 External Review Draft.
2. U. S. Environmental Protection Agency, Perchlorate; Ground Water and Drinking Water, February 2000.
3. Coates, John, D., "In Situ Bioremediation and Removal of Ammonium Perchlorate", Strategic Environmental Research Program Cleanup CU-1162, Annual Report, 2000.
4. Hatzinger, P.B., "In Situ Bioremediation of Perchlorate", Strategic Environmental Research Program Cleanup CU-1163, Annual Report, 2000.
5. Cowan, D., "Innovative Abatement and Remediation of Perchlorate at McGregor, Texas Weapons Plant Site", Soil Sediment & Groundwater, June/July 2000.
6. Hatzinger, P.B.; Whittier, M. C.; Arkins, M. D.; Bryan, C. W.; Guarini, W. "In Situ and Ex situ Bioremediation Options for Treating Perchlorate In Groundwater", Remediation, Vol 12. 2002 (*in press*).
7. Rikken, G. B.; Kroon, A. G. M.; van Ginkel, C. G. "Transformation of (Per)chlorate into Chloride by a Newly Isolated Bacterium: Reduction and Dismutation. Applied Microbiology and Biotechnology, 45:420-426, 1996.

**Society of Environmental Toxicology and Chemistry**

**ABSTRACT BOOK**



**SETAC 22nd Annual Meeting**

***Changing Environmental Awareness:  
Societal Concerns and Scientific Responses***

**11 - 15 November 2001  
Baltimore, Maryland**

in various size and density fractions of the Sunflower River dredged materials. Overall, the results were used to synthesize and correlate data to assess the availability and treatability of DDT in dredged sediments.

**W265 *In situ* Bioremediation of Perchlorate in Groundwater.** Hatzinger, P.<sup>1</sup>, Arkins, M.<sup>1</sup>, Guarini, W.<sup>1</sup> and Manning, J.<sup>1</sup> <sup>1</sup>Envirogen, Inc.. Ammonium perchlorate (NH<sub>4</sub>ClO<sub>4</sub>) has been used since the 1940s as an oxidizer in solid propellants and explosives. In recent years, perchlorate contamination of groundwater has been reported in fourteen states, including California, Utah, Nevada, and Texas. Traditional groundwater remediation methods, such as carbon adsorption, stripping, and chemical oxidation have proven to be ineffective for perchlorate remediation. However, several microbial strains have been isolated that can utilize and subsequently degrade the molecule to chloride and water. The objective of this research is to explore the potential for *in situ* bioremediation of perchlorate and to determine factors influencing biodegradation of the compound in subsurface environments. Laboratory microcosm studies were conducted using aquifer samples collected from several locations throughout the United States. Rapid perchlorate degradation was observed by indigenous bacteria in substrate-amended aquifer samples from five of the seven sites tested, but the most effective substrates varied by site. For example, in aquifer samples from a site in Utah, amendment with lactate, sucrose, or molasses caused perchlorate concentrations to decline from 57 mg/L to less than 0.1 mg/L in 14 days. However, several other electron donors, including hydrogen gas and benzoate, did not stimulate perchlorate degradation. Experimental data showed that perchlorate biodegradation is inhibited at pH values below 6 and declines rapidly with increasing salinity. Oxygen inhibits perchlorate reduction, and nitrate appears to be preferentially degraded to perchlorate, but it is currently unclear whether nitrate actually inhibits microbial perchlorate reduction. The results suggest that *in situ* biostimulation is a promising technology for perchlorate remediation at many sites.

**W266 Biodegradation of Jet Fuel in a Karst Aquifer.** Byl, T.D.<sup>1,3</sup>, Allison, A.<sup>2,3</sup>, Minor, K.<sup>3</sup>, Roy, S.<sup>3</sup>, Haynes, S.<sup>3</sup>, Darlington, R.<sup>3</sup>, Morris, N.<sup>3</sup>, Elliot, L.<sup>3</sup> and Geymang, D.<sup>3</sup> <sup>1</sup>U.S. Geological Survey, Nashville, TN. <sup>2</sup>U.S. Army Corps of Engineers, Nashville, TN. <sup>3</sup>Tennessee State University, Nashville, TN. Complex hydrogeologic conditions coupled with poorly understood biodegradation processes in karst aquifers have led many to believe that the potential for natural attenuation of petroleum fuel hydrocarbons is limited. This research addressed the capacity for biodegradation processes in a karst aquifer. Ground-water samples were collected for bacteria and geochemical analysis from two monitoring wells (MCI-1 and MCI-4) in a karst bedrock aquifer. Water from the MCI-1 well has consistently tested positive for fuel contamination during the past 3 years of semi-annual monitoring. Water from MCI-4 has been relatively uncontaminated during the same time period. Bacteria concentrations were five-times greater in ground-water samples from the fuel-contaminated well. The bacteria community in the clean well was dominated by gram-positive cocci bacteria, whereas, the bacteria community in the contaminated well was dominated by gram-negative, flagellated rods. Additional tests indicate the rod-shaped bacteria are Pseudomonads. Additionally, bacteria isolated from the fuel-contaminated ground-water samples readily grew in Petri dishes with dissolved toluene and benzene as the only source of food. Water from the less contaminated MCI-4 well had a greater dissolved oxygen concentration (6.4 milligrams per liter) than the fuel-contaminated water (dissolved oxygen less than 0.1 milligrams per liter). Also, where the oxygen concentrations were diminished, geochemical evidence indicated that anaerobic processes were active. This evidence includes elevated levels of ammonia, sulfide, and ferrous iron in the fuel-contaminated ground-water samples. Microcosms set up using water from the contaminated well established a half-life of 7 days for toluene and benzene. Based on these results, biodegradation of fuel constituents in the karst aquifer is indicated, and therefore, natural attenuation should not be disregarded because of preconceptions about low microbial activity in karst aquifers.

**W267 Biodegradation of Chlorinated Contaminants Using Gel Encapsulated Bacterial Cultures.** Govind, R.<sup>1</sup> and Tian, F.<sup>1</sup> <sup>1</sup>Chemical Engineering, University of Cincinnati. Chlorinated chemicals, such as chlorinated aliphatic hydrocarbons (CAHs) and chlorinated aromatics, have been used widely for a variety of industrial applications, such as degreasing of aircraft engines, automobile parts, electronic components, and clothing and in transformer heat transfer fluids. Due to water solubilities exceeding drinking water standards and densities higher than water, these compounds migrate downward through soils and water bodies contaminating ground water, sediments, and penetrate deeply into aquifers forming dense non aqueous phase liquids (DNAPLs) on aquifer bottoms. Ground water toxicity problems associated with CAHs occur at over 358 major hazardous waste sites and many minor sites across the nation. Chlorinated contaminants, such as PCBs, are also found in sediments. Most of the CAHs are aerobically degradable. Some CAHs, such as TCE require cometabolites or specialized organisms for aerobic degradation. Full-scale field applications of cometabolic destruction of CAHs are greatly limited by the availability, cost, and potential adverse environmental impacts of the secondary substrates needed for induction of cometabolic activity. In this paper, the use of specially formulated silica gel beads with active biomass encapsulated within the bead, has been shown to biodegrade TCE without any organic substrates. Bench-scale experimental studies have shown high rates of TCE degradation without any release of intermediates, such as vinyl chloride. Kinetic models have been developed to obtain the kinetic coefficients from experimental data.

**W268 Biomonitoring of an Oil Terminal Effluent; Baseline Studies.** Roddie, B.D.<sup>1</sup> <sup>1</sup>ERT Caspian. The recent re-development of the oil and gas industry in Azerbaijan has led to an increasing amount of onshore activity to provide oil reception and transportation facilities. The most extensive development to date is the Sangachal oil terminal, operated by BP. This terminal currently receives oil and gas from the Chirag platform, and further developments at this location are planned to accommodate output from the Shah Deniz field. Terminal expansion inevitably implies increased waste generation and discharges, and it was considered important to establish baseline conditions in the receiving waters in advance of any further developments. Baseline coastal marine and fisheries surveys have been conducted to establish the current status of the receiving environment. However, BP wished to implement a more proactive approach to effluent control, and commissioned the Caspian Environmental Laboratory to implement a programme of work aimed at a) establishing a procedure for determining end of pipe ecotoxicity for the current effluent discharges from the terminal b) conducting baseline end-of-pipe toxicity tests c) developing and implementing an *in situ* biomonitoring approach based on the use of sublethal effects assessment in field-deployed bivalves. Both programmes of work were completed in 2000, and provide a baseline for effluent toxicity and receiving water quality against which future impacts can be evaluated. Both methodologies are practical, robust and require no expensive or sophisticated technology. They will, in future, provide a cost-effective method of monitoring effluent impact in real time, and will offer the possibility of detection and intervention before any harm is done to the environment.

**W269 Bioavailability of Particle and Sediment-sorbed PAH in Unionid Mussels.** Thorsen, W.A.<sup>1</sup>, Shea, D.<sup>1</sup> and Cope, G.<sup>1</sup> <sup>1</sup>North Carolina State University. Unionid Mussels (*Elliptio spp.*) were deployed in two different freshwater sites in Gaston County, North Carolina. One site was a fast-flowing system with low polycyclic aromatic hydrocarbon (PAH) concentrations and low sediment organic carbon (f<sub>oc</sub> 0.64%). The second site was a more stagnant wetland site with higher PAH concentrations and higher sediment organic carbon (f<sub>oc</sub> 3.23%). Mussels were collected at various time intervals along with samples of water, sediment,

**"Building on Past Successes  
to Address Emerging  
Issues"**

**Partners in  
Environmental Technology  
Technical Symposium & Workshop**

**November 27 - 29, 2001  
Marratt Wardman Park Hotel  
Washington, D.C.**

**Sponsored by  
the Strategic Environmental Research and Development Program (SERDP)  
and  
the Environmental Security Technology Certification Program (ESTCP)**



**SERDP**



**Program Guide**

## IN SITU BIOREMEDIATION OF PERCHLORATE IN GROUNDWATER

DR. PAUL B. HATZINGER

Envirogen, Inc.,  
4100 Quakerbridge Road  
Lawrenceville, NJ 08648  
(609) 936-9300  
hatzinger@envirogen.com

Co-Performers: Martha D. Arkins; Dr. Yassar H. Farhan; Dr. Robert J. Steffan

Ammonium perchlorate ( $\text{NH}_4\text{ClO}_4$ ) has been used since the 1940s in the United States as an oxidizer in solid propellants and explosives. The discharge of contaminated effluents from the manufacture of this compound and from the replacement of outdated fuels in military missiles and rockets has resulted in perchlorate contamination in groundwater in at least 14 states, including California, Utah, Texas, New Mexico, and Nevada. Biological treatment represents the most promising and cost-effective technology for remediation of perchlorate in groundwater. A variety of microbial strains have been isolated with the ability to degrade perchlorate to the innocuous products chloride and water. These organisms require an organic or inorganic electron donor (substrate) for growth and utilize the perchlorate molecule as a terminal electron acceptor. Two full-scale fluidized bed bioreactor systems have been successfully implemented for *ex situ* treatment of perchlorate-contaminated groundwater in California and Texas. The objective of this SERDP-funded research is to explore factors influencing perchlorate bioremediation in the subsurface, and to develop an effective technology for *in situ* treatment of this energetic compound.

Laboratory microcosm and column studies were conducted using aquifer samples collected from several different perchlorate-contaminated sites across the United States. These studies were designed to evaluate: (1) the occurrence of indigenous perchlorate-degrading bacteria in subsurface environments; (2) the most effective electron donors for stimulating perchlorate reduction by these bacteria; and (3) the influence of alternate electron acceptors and environmental variables on biological perchlorate reduction. Perchlorate-degrading bacteria were found to be widespread in subsurface aquifers, and pure cultures of the genera *Dechlorisoma* and *Dechlorospirillum* were isolated from samples during the studies. Several electron donors, including acetate, lactate, molasses, ethanol, and hydrogen effectively stimulated perchlorate reduction in aquifer microcosms, although the most effective amendments varied by site. Starting perchlorate levels ranging from 0.31 mg/L to greater than 100 mg/L were reduced to below detection ( $< 0.004$  mg/L) in aquifer samples amended with appropriate electron donors. Oxygen, nitrate, and nitrite were degraded prior to perchlorate in microcosm and column studies. Other electron acceptors, including ferric iron and sulfate, were reduced after perchlorate and did not influence its rate or extent of degradation. Perchlorate biodegradation was not observed in acidic aquifer samples (pH values below 5.7), but the process could be rapidly stimulated through pH adjustment. The laboratory studies conducted during this SERDP project reveal that *in situ* bioremediation is a promising technology for perchlorate treatment at many DoD sites. A field demonstration of *in situ* perchlorate bioremediation is planned for Spring 2002.

**POSTER ABSTRACTS**

# In Situ and On-Site Bioremediation

The Sixth International Symposium  
June 4-7, 2001  
Sheraton Hotel and Marina  
San Diego, California

Sponsor:



**Battelle**

*... Putting Technology To Work*

Co-Sponsors:

*the* **ti**group

**PARSONS**



**REGENESIS**



**GEOMATRIX**

## IN SITU REMOVAL OF PERCHLORATE FROM GROUNDWATER

W. J. Hunter (USDA-ARS, Fort Collins, Colorado, USA)

Perchlorate is a groundwater contaminant that affects over 20 million people in the southwestern US. Laboratory column studies suggest that *in situ* barriers might be used to remove perchlorate from groundwater. Previously, we demonstrated that when a vegetable oil emulsion is injected onto a sand column the oil became trapped in the matrix and formed a stationary organic zone or barrier. Native denitrifying bacteria removed nitrate from the contaminated groundwater when the water was pumped through sand columns injected with vegetable oil. The present laboratory scale study shows that the same process works with perchlorate. For this study a moderately-hard water containing 20 ppm (0.2 mM) perchlorate was pumped, at a rate of ~25 ml/day, through 1.5 by 30 cm columns containing sand as a matrix. The water supplied to the columns was fully oxygenated. No attempt was made to remove oxygen from the supply water. At the start of the study all columns were inoculated with bacteria from a soil extract. After 14 days operation 0.47 mg of soybean oil was injected onto one group of columns, the treatment group, while a second group of columns, the control group, received no oil. Water containing perchlorate was pumped through both groups of columns and samples of the effluent water were collected at regular intervals and analyzed for chloride and perchlorate. In the control columns, perchlorate was present in the column effluents throughout the study. In the treatment columns, perchlorate in the effluent decreased by ~99% over a 17 week period following the addition of the vegetable oil. Also, the concentration of chloride in the treatment column effluents increased by ~0.2 mM after the addition of oil indicating the stoichiometric conversion of perchlorate to chloride. In the control columns perchlorate levels remained high and chloride levels low throughout the study. These results suggest that permeable barriers containing innocuous vegetable oils, other carbon substrates, or other electron donors might be used *in situ* to remove perchlorate from contaminated groundwater.

## IN SITU BIOREMEDIATION OF PERCHLORATE IN GROUNDWATER

Paul B. Hatzinger, Martha D. Atkins, Marina Tugusheva, and Robert J. Steffan  
(Envirogen, Inc., Lawrenceville, NJ, USA)

Biological treatment represents a promising technology for perchlorate remediation in subsurface environments. Several microbial strains have been isolated with the ability to degrade perchlorate to the innocuous products chloride and water. These organisms require an organic or inorganic electron donor (e.g., ethanol, acetate, hydrogen gas) for growth and utilize the perchlorate molecule as a terminal electron acceptor. Full-scale bioreactor systems have been successfully developed and implemented for *ex situ* perchlorate treatment. The objective of this research is to explore factors influencing perchlorate bioremediation in the subsurface, and to develop effective methods for *in situ* treatment of this contaminant.

Laboratory microcosm studies were performed using subsurface samples collected from the Jet Propulsion Laboratory (JPL) in Pasadena, CA, the Indian Head Division Naval Surface Warfare Center (IHDIV) in Indian Head, MD, and a commercial facility in the Rocky Mountains. These studies were designed to evaluate: (1) the most effective electron donors (substrates) for growth of indigenous perchlorate-degrading bacteria, (2) the requirement for addition of exogenous perchlorate-degrading bacteria to aquifer samples, and (3) the influence of alternate electron acceptors (e.g., oxygen, nitrate, nitrite, sulfate) and environmental conditions on biological perchlorate reduction. Several electron donors rapidly stimulated perchlorate degradation by indigenous bacteria in JPL site samples. Perchlorate levels were reduced from 0.31 mg/L to less than the MDL (0.005 mg/L) in 10 days. Oxygen completely inhibited perchlorate degradation in these samples. Nitrate and nitrite were degraded prior to perchlorate and did not appreciably influence its rate of degradation. Perchlorate biodegradation was completely inhibited at pH values below 6.0, and declined appreciably with increasing salinity. Perchlorate was readily degraded in one set of subsurface samples collected from IHDIV when hydrogen gas or acetate (but not ethanol) were added as electron donors. Conversely, perchlorate degradation was not observed in a second set of subsurface samples from IHDIV after amendment with ten different electron donors or a culture of perchlorate-degrading bacteria. Experiments are underway to evaluate the factors inhibiting perchlorate biodegradation at this location. In samples from the Rocky Mountain site, bioaugmentation was found to provide the most rapid removal of perchlorate from groundwater. Lactate and sucrose, but not several other electron donors, also stimulated perchlorate degradation in these samples. Thus, current data from microcosm studies show that *in situ* bioremediation is a promising technology for perchlorate remediation, but that the remediation approach, including the choice of electron donors, may vary by site.

**"Environmental Challenges  
for the Next Decade"**

**Partners in  
Environmental Technology  
Technical Symposium & Workshop**

**Hyatt Regency Crystal City  
Arlington, Virginia**



**Symposium & Workshop Program Guide**

**November 28 - 30, 2000**

## BIOTREATMENT OF PERCHLORATE IN GROUNDWATER

PAUL B. HATZINGER, PH.D.

Envirogen, Inc.

4100 Quakerbridge Road

Lawrenceville, NJ 08648

(609) 936-9300

hatzinger@envirogen.com

Biological treatment represents the most promising approach for perchlorate remediation in groundwater. Several microbial strains have been isolated with the ability to degrade perchlorate to the innocuous products chloride and water. These organisms require an organic or inorganic electron donor (e.g., ethanol, acetate, hydrogen gas) for growth and utilize the perchlorate molecule as a terminal electron acceptor. Full-scale bioreactor systems have been successfully developed and implemented for ex situ perchlorate treatment. The design and operational data from one such treatment system, a fluidized bed reactor treating groundwater in California, will be presented.

With support from SERDP, research is being conducted to develop effective methods for in situ treatment of perchlorate in subsurface environments. Laboratory microcosm studies were performed using subsurface samples collected from the Jet Propulsion Laboratory (JPL) in Pasadena, CA, the Indian Head Division Naval Surface Warfare Center (IHDIIV) in Indian Head, MD, a commercial facility in the Rocky Mountains, and a pristine site in Virginia. These studies were designed to evaluate: (1) the most effective electron donors (substrates) for growth of indigenous perchlorate-degrading bacteria, (2) the requirement for addition of exogenous perchlorate-degrading bacteria to aquifer samples, and (3) the influence of environmental conditions on biological perchlorate reduction. Rapid perchlorate biodegradation was observed in substrate-amended aquifer samples from three of the sites. The most effective substrates for stimulating perchlorate reduction varied by site. For example, in samples from the Rocky Mountain site, amendment with lactate, sucrose, or molasses caused perchlorate concentrations to decline from 57 mg/L to less than 0.1 mg/L in 14 days. However, several other electron donors, including hydrogen gas and benzoate, did not stimulate perchlorate degradation in these microcosms, even after several weeks of incubation. Perchlorate biodegradation was not observed in subsurface samples from a one location at IHDIIV after amendment with ten different electron donors or a culture of perchlorate-degrading bacteria. Experiments are underway to evaluate the factors inhibiting perchlorate biodegradation at this location. The current data show that in situ biotreatment is a promising technology for perchlorate remediation, but that the remediation approach, including the choice of electron donors, may vary by site. An assessment of appropriate applications for in situ and ex situ biotreatment technologies will be given.

## **7.2 APPENDIX B**

### **Kinetic Model to Describe Perchlorate Biodegradation**

#### ***7.2.1. MODEL DESCRIPTION***

This appendix presents the mathematical model developed by Envirogen to describe the kinetics of perchlorate biodegradation. Based on laboratory data, perchlorate is used as an electron acceptor by microorganisms during consumption of available carbon and electron sources in soil. The model presented below describes the biodegradation kinetics of perchlorate in the presence of other, more favorable, electron acceptors.

The model links the dynamics of the microbial population to the consumption of electron donor and acceptors. The model for the microbial population describes bacterial growth and decay. Biodegradation of the electron donor (which is also the growth compound), and consumption of multiple electron acceptors are described using a modified Monod model. Within the hierarchy of electron acceptor use, perchlorate is typically utilized after oxygen and nitrate and before sulfate. Thus, in environments where oxygen or nitrate is present, perchlorate utilization may be reduced and/or inhibited until these electron acceptors are consumed.

#### ***7.2.2 MODEL DEVELOPMENT***

##### **7.2.2.1 Electron Donor**

The model describes sequential degradation of electron donor in the presence of oxygen, nitrate, and perchlorate. The rate of utilization of the electron donor per unit biomass is described by equations (1a, b, c, and d). Essentially, the rate of utilization of electron donor is equal to the sum of the donor degradation rates due to each electron acceptor (Eq. 1a). For simplification purposes, it is assumed that mass is expressed in units of milligrams (mg), volume in units of liters (L), and time in units of hours. Also, it is assumed that the compounds described by the equations below do not volatilize into air or sorb onto soil.

The specific rate of electron donor consumption ( $r_{donor}$ ) is:

$$r_{donor} = \frac{1}{B} \times \frac{dC^{don}}{dt} = r_{don,oxy} + r_{don,nit} + r_{don,per} \quad (1a)$$

where:

$$r_{don,oxy} = k_{max} \left[ \frac{C^{don}}{K_S^{don} + C^{don}} \right] \times \left[ \frac{C^{oxy}}{K_S^{oxy} + C^{oxy}} \right] \quad (1b)$$

$$r_{don,nit} = k_{max} \left[ \frac{C^{don}}{K_S^{don} + C^{don}} \right] \times \left[ \frac{C^{nit}}{K_S^{nit} + C^{nit}} \right] \times \left[ \frac{K_i^{oxy}}{K_i^{oxy} + C^{oxy}} \right] \quad (1c)$$

$$r_{don,per} = k_{max} \left[ \frac{C^{don}}{K_S^{don} + C^{don}} \right] \times \left[ \frac{C^{per}}{K_S^{per} + C^{per}} \right] \times \left[ \frac{K_i^{oxy}}{K_i^{oxy} + C^{oxy}} \right] \times \left[ \frac{K_i^{nit}}{K_i^{nit} + C^{nit}} \right] \quad (1d)$$

and

$r_{don,oxy}$  is the specific rate of electron donor consumption using oxygen as an electron acceptor (mg donor/mg biomass/hr);

$r_{don,nit}$  is the specific rate of electron donor consumption using nitrate as an electron acceptor (mg donor/mg biomass/hr);

$r_{don,per}$  is the specific rate of electron donor consumption using perchlorate as an electron acceptor (mg donor/mg biomass/hr);

$k_{max}$  is the maximum specific growth rate (mg donor/mg biomass/hr);

$C^{don}$  is the concentration of the electron donor (acetate) (mg/L);

$C^{oxy}$  is the concentration of oxygen (mg/L);

$C^{nit}$  is the concentration of nitrate (mg/L);

$C^{per}$  is the concentration of perchlorate (mg/L);

$K_S^{don}$  is the half saturation constant for the electron donor (acetate) (mg/L);

$K_S^{oxy}$  is the half saturation constant for oxygen (mg/L);

$K_S^{nit}$  is the half saturation constant for nitrate (mg/L);

$K_S^{per}$  is the half saturation constant for perchlorate (mg/L);

- $K_i^{oxy}$  is the oxygen inhibition coefficient;  
 $K_i^{nit}$  is the nitrate inhibition coefficient;  
 $B$  is the concentration of biomass (mg/L); and  
 $t$  is time (hours).

### 7.2.2.2 Microbial Populations

Two primary processes were expected to influence changes in the microbial populations during our experiments: population growth due to electron donor consumption and indigenous cell decay. These two processes are mathematically represented by the two terms on the right hand side of Equation (2), respectively.

$$\frac{1}{B} \times \frac{dB}{dt} = Y_{biomass} r_{don} - b \quad (2)$$

where:

$Y_{biomass}$  is the biomass produced per mass of donor consumed (mg biomass/mg electron donor)

$b$  is the biomass decay rate (1/hour)

### 7.2.2.3 Electron Acceptors

Changes in the electron acceptor concentrations are directly linked to the consumption of the electron donor. The relationships linking consumption of electron donor and oxygen, nitrate, and perchlorate are given in Equations 3.

Oxygen:

$$r_{oxy} = \frac{1}{B} \times \frac{dC^{oxy}}{dt} = Y_{oxy} r_{don,oxy} \quad (3a)$$

Nitrate:

$$r_{nit} = \frac{1}{B} \times \frac{dC^{nit}}{dt} = Y_{nit} r_{don,nit} \quad (3b)$$

Perchlorate:

$$r_{per} = \frac{1}{B} \times \frac{dC^{per}}{dt} = Y_{per} r_{don,per} \quad (3c)$$

where

- $r_{oxy}$  is the specific rate of oxygen consumption (mg oxygen/mg biomass/hr);  
 $r_{nit}$  is the specific rate of nitrate consumption (mg nitrate/mg biomass/hr);  
 $r_{per}$  is the specific rate of perchlorate consumption (mg perchlorate/mg biomass/hr);  
 $Y_{oxy}$  is the yield coefficient for the donor-oxygen reaction (mg oxygen/mg donor);  
 $Y_{nit}$  is the yield coefficient for the donor-nitrate reaction (mg nitrate/mg donor); and  
 $Y_{per}$  is the yield coefficient for the donor-perchlorate reaction (mg perchlorate/mg donor).

These coefficients were determined theoretically and compared to observations in the laboratory.

### **7.3 MODEL ASSUMPTIONS**

Some of the basic assumptions made to develop the model include:

1. Maximum specific growth rate and the half saturation constant do not significantly change with the different electron acceptors.
2. Cell yield does not change with different electron acceptors.
3. Competition among the different electron acceptors is a continuous function, i.e., not based on "threshold concentrations".
4. The electron donor and electron acceptors described do not volatilize into air or sorb onto soil.
5. Any lag periods observed during the microcosm studies are due to microbial growth only.
6. Biomass may decay to zero or grow indefinitely.

### **7.4 PARAMETER DETERMINATION**

Batch experiments were conducted to determine the parameters needed for the equations above.

#### 7.4.1 Absence of Inhibition

##### Acetate (Electron Donor)

To determine  $k_{max}$  and  $K_S^{don}$ , a series of batch experiments were conducted using a range of starting donor concentrations where oxygen is not limiting. Bacteria in these experiments were pre-grown on the electron donor. By determining the maximum rate of bacterial growth and measuring the electron donor concentrations in each experiment, a curve of specific growth rate versus donor concentration was constructed. The maximum specific growth rate on this curve is  $k_{max}$ .  $K_S^{don}$  is equal to the donor concentration value where the specific growth rate is half the  $k_{max}$  value.

To estimate  $Y_{biomass}$  the change in biomass in the batch experiments due to a given change in donor concentration was measured. In turn,  $Y_{biomass}$  was estimated by taking the ratio of the change in biomass to the change in donor concentration. The decay coefficient,  $b$ , was estimated by monitoring the decay of a given microbial population over time. This was also done in a batch experiment.

##### Oxygen

To determine  $K_S^{oxy}$ , batch experiments can be conducted using a range of starting oxygen concentrations where donor was not limiting. By measuring the change in oxygen concentrations and microbial populations over time a curve of specific growth rate versus oxygen concentration may be constructed. The maximum specific growth rate value on this curve should equal  $k_{max}$ , thus providing a check for the value determined during the donor experiments, and  $K_S^{oxy}$  is equal to the oxygen concentration value where the specific growth rate is equal half the  $k_{max}$  value. However, because it was experimentally difficult to accurately measure oxygen levels in the microcosm experiments,  $K_S^{oxy}$  was assumed to be 1 mg/L during this work.

### Nitrate

For  $K_S^{nit}$ , batch experiments were conducted using a range of starting nitrate concentrations where donor was not limiting and oxygen was not present. By measuring the change in nitrate concentrations and microbial populations over time a curve of specific growth rate versus nitrate concentration was constructed. The maximum specific growth rate on this curve is  $k_{max}$ , which is assumed/expected not to be significantly different from the  $k_{max}$  value determined from the donor experiments.  $K_S^{nit}$  is equal to the nitrate concentration value where the specific growth rate is half the  $k_{max}$ .

### Perchlorate

To determine  $K_S^{per}$ , batch experiments were conducted using a range of perchlorate concentrations where donor was not limiting and both oxygen and nitrate were absent. By measuring the change in perchlorate concentrations and microbial populations over time a curve of specific growth rate versus perchlorate concentration was constructed. The maximum specific growth rate on that curve is  $k_{max}$  (which is also a check of the second assumption made) and  $K_S^{per}$  is equal to the perchlorate concentration where the specific growth rate is half the  $k_{max}$  value.

## **7.4.2 Modeling Electron Acceptor Competitive Inhibition**

### Oxygen

The set of experiments described above for perchlorate were repeated with the addition of constant concentrations of oxygen to assess the role of oxygen inhibition on perchlorate utilization. The approach for these experiments was to be as follows:

- a) Four or five oxygen concentrations that would be suspected to cause varying degrees of perchlorate inhibition were chosen.
- b) Each oxygen concentration was to be inputted along with a range of perchlorate concentrations in batch experiments to construct a curve of specific growth rate versus perchlorate concentration in the presence of the starting oxygen concentration. Four or five such curves were to be obtained.

- c) These curves were to be mathematically described by maintaining  $k_{max}$  constant and allowing  $K_S^{nit}$  to vary. According to the formulation given in Eq. (1b), oxygen will inhibit perchlorate utilization by reducing the effective rate of perchlorate consumption.

The above experiments assessing the role of oxygen inhibition on perchlorate utilization were not completed, as described in the Final Report text.

#### Nitrate

The set of experiments described above for perchlorate was repeated with the addition of constant concentrations of nitrate to assess the role of nitrate inhibition on perchlorate utilization.

The approach for these experiments was as follows:

- a) Four or five nitrate concentrations that would be suspected to cause varying degrees of perchlorate inhibition were chosen.
- b) Each nitrate concentration was inputted with a range of perchlorate concentrations to batch experiments to construct a curve of specific growth rate versus perchlorate concentration at each chosen nitrate concentration.
- c) These curves were mathematically described by maintaining  $k_{max}$  constant and allowing  $K_S^{per}$  to change. According to the formulation given in Eq. (1c), nitrate will inhibit perchlorate utilization by decreasing the effective rate of perchlorate utilization.

**Naval Ordnance Safety and Security Activity  
Naval Sea Systems Command**

Indian Head, MD 20640-5555

---

---

**NOSSA-TR-2004-001** 22 January 2004  
Ordnance Environmental Support Office  
Technical Report

**Field Demonstration of In Situ  
Perchlorate Bioremediation at  
Building 1419**

By Randall J. Cramer and Carey Yates  
Indian Head Division  
Naval Surface Warfare Center

Paul Hatzinger and Jay Diebold  
Shaw Environmental, Inc.



---

Approved for public release; distribution is unlimited.

---

# Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419

Randall J. Cramer and Carey Yates

*Indian Head Division  
Naval Surface Warfare Center*

Paul Hatzinger and Jay Diebold

*Shaw Environmental, Inc.*

Prepared for  
Naval Ordnance Safety and Security Activity  
Ordnance Environmental Support Office

22 January 2004



Approved for public release; distribution is unlimited.

## FOREWORD

Biological treatment of perchlorate in the environment represents a promising technology for remediation of ground and surface water. Naturally occurring microbial strains with the ability to degrade perchlorate by using the molecule as a terminal electron acceptor have been identified in site samples from the Indian Head Division, Naval Surface Warfare Center at Indian Head, MD. To build upon successful laboratory studies, a field demonstration of in situ bioremediation of perchlorate was conducted in 2002 at Indian Head's Building 1419, otherwise known as the Hog-out Facility. The publication includes the field trial results of buffering the aquifer pH to make it suitable for microbial perchlorate degradation, methods for addition of an electron donor, such as acetate, and the perchlorate biodegradation data over a 6-month period.

This publication reflects the personal views of the authors and does not suggest or reflect the policy, practices, programs, or doctrine of the U.S. Navy or Government of the United States. The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.



## EXECUTIVE SUMMARY

As part of a research project (CU-1163) funded by the Strategic Environmental Research and Development Program, laboratory studies were conducted using site samples from the Indian Head Division, Naval Surface Warfare Center (IHDIV) in Indian Head, MD. The site studies revealed the following:

- Naturally occurring perchlorate-degrading bacteria are present in the groundwater aquifer underlying IHDIV.
- These organisms can be stimulated to degrade perchlorate from more than 50 mg/L to below detection using lactate as a food source (electron donor).
- The pH of the aquifer must be buffered to achieve optimal perchlorate biodegradation.

Based on the above, a field demonstration of in situ perchlorate treatment was performed at IHDIV on a shallow, narrow plume of perchlorate-contaminated groundwater behind IHDIV Building 1419, known as the Hog-out Facility. Analysis of samples from this site showed the perchlorate levels ranged from 8 to 430 mg/L with an average of approximately 170 mg/L, and nitrate levels were at 4 to approximately 50 mg/L. The groundwater pH measured in several locations was generally below pH 5.0 with some values as low as pH 4.2.

A pilot system employing a recirculation cell design was engineered based on site geochemical and hydrogeologic data. Two field plots, a test plot and a control plot, were installed; each consisted of two extraction wells, two injection wells, and nine groundwater monitoring wells. In the test plot, groundwater was extracted from the site, amended with electron donor (lactate) and buffer (carbonate/bicarbonate mixture), then re-injected into the aquifer. Groundwater was extracted and re-injected without substrate or buffer amendment in the control plot.

During the first 15 weeks of the study, approximately 20,000 gallons of groundwater was recirculated through each plot. The injected buffer elevated the pH to greater than 5.9 in all test plot wells, and perchlorate was steadily degraded during the demonstration.

Over the 20-week period, the perchlorate levels were reduced by more than 95% in eight of nine monitoring wells in the test plot, with five wells reaching less than 1 mg/L and two wells reaching below 5 µg/L. Nitrate levels in all wells were reduced to less than 1 mg/L, and seven of nine wells showed non-detectable levels within 7 weeks.

Conversely, there was no significant change in pH or reduction of either perchlorate or nitrate within the control plot.

The data from this demonstration show in situ biostimulation using lactate and buffer addition was a successful remediation option for treating high levels of perchlorate in the shallow aquifers. The results suggest that in situ perchlorate bioremediation would be a viable approach for treatment of perchlorate in aquifers containing localized, high concentrations of the oxidant.

# CONTENTS

<i>Heading</i>	<i>Page</i>
Foreword.....	iii
Executive Summary.....	v
Introduction.....	1
Summary of Laboratory Results.....	3
Site Characterization.....	12
Site Geology and Hydrogeology.....	16
Slug and Pump Test Results.....	24
Field Demonstration.....	26
Field Demonstration Results.....	31
Analytical Methods and Results.....	34
Conclusions.....	45
References.....	47
Appendix A. Typical Well Construction and Soil Boring Logs.....	A-1
Appendix B. Slug Test and Pump Test Curves.....	B-1
Appendix C. Rainfall Data.....	C-1

## Tables

I. Perchlorate Degradation in Aquifer Microcosms from the Building 1419 Site.....	4
II. Enumeration of Perchlorate Reducing Bacteria from Site Samples at IHDIV.....	4
III. Groundwater Chemistry at the Demonstration Site.....	22
IV. Groundwater Chemistry and Perchlorate Concentrations in Monitoring Wells 1 through 6.....	22
V. Bromide Values in the Test Plot with Time.....	31
VI. pH in the Test Plot with Time.....	35
VII. pH in the Control Plot with Time.....	36
VIII. Alkalinity Values in the Test Plot with Time.....	37
IX. Alkalinity Values in the Control Plot with Time.....	37
X. Lactate Values in the Test Plot with Time.....	38
XI. Perchlorate Concentrations in the Test Plot with Time.....	40
XII. Perchlorate Concentrations in the Control Plot with Time.....	41
XIII. Nitrate-N Concentrations in the Test Plot with Time.....	42
XIV. Nitrate-N Concentrations in the Control Plot with Time.....	43
XV. Sulfate Concentrations in the Test Plot with Time.....	44
XVI. Sulfate Concentrations in the Control Plot with Time.....	44

## CONTENTS—Continued

<i>Heading</i>	<i>Page</i>
<b>Figures</b>	
1. Carbonate Titration Curve for Sediment Slurries from the Building 1419 Site .....	5
2. Influence of pH on Perchlorate Degradation in Aquifer Microcosms from the Building 1419 Site .....	6
3. Influence of Different Electron Donors on Nitrate Biodegradation in Buffered Site Samples .....	7
4. Perchlorate Levels in Aquifer Microcosms Receiving Lactate (pH 4.5 or 7.3) or No Electron Donor .....	8
5. Influence of Bicarbonate/Carbonate Mixtures on pH of Sediment Slurries from the Demonstration Area .....	10
6. Influence of Bicarbonate and Carbonate/Bicarbonate Mixtures on Groundwater pH .....	10
7. Site Location Map .....	13
8. Site Plan View .....	14
9. Geologic Map of Charles County .....	17
10. Boring Location and Cross-Section Plan View .....	17
11. Geologic Cross Section A-A' .....	18
12. Geologic Cross Section B-B' .....	19
13. Groundwater Potentiometric Surface .....	20
14. Groundwater Perchlorate Distribution .....	22
15. Recirculation Cell Layouts and Schematic Cross-Section View .....	27
16. Control Panel and Treatment Skid .....	29
17. Recirculation Cells and Components .....	30
18. Groundwater Volumes Recirculated through the Test Plot and the Control Plot During the Demonstration .....	31
19. pH Values in Deep TPMWs During the Field Demonstration .....	33
20. pH Values in Shallow TPMWs During the Field Demonstration .....	34
21. pH Values in the CPMWs During the Field Demonstration .....	35
22. Perchlorate Levels in Deep TPMWs During the Field Demonstration .....	38
23. Perchlorate Levels in Shallow TPMWs During the Field Demonstration .....	38
24. Perchlorate Levels in CPMWs During the Field Demonstration .....	39
25. Nitrate Levels in the Test Plot During the Field Demonstration .....	41
26. Nitrate Levels in the Control Plot During the Field Demonstration .....	42
27. Sulfate Levels in the Test Plot During the Field Demonstration .....	43

## INTRODUCTION

### Background

Ammonium perchlorate ( $\text{NH}_4\text{ClO}_4$ ) has been used since the 1940s in the United States as an oxidizer in solid propellants and explosives. Discharges during the manufacture of this compound and from the demilitarization of outdated solid fuels in military missiles and rockets have resulted in substantial perchlorate contamination in groundwater in several states, including California, Texas, Utah, and Nevada (Urbansky, 1998; Damian and Pontius, 1999; Betts, 2000). Because a sensitive detection method for perchlorate was not available until 1997 (CDHS, 1997), the total scope of perchlorate contamination in the United States is not yet known. However, it is currently estimated that the drinking water of more than 15 million people may be impacted (Wu et al., 2001). According to data compiled by the California Department of Health Services (CDHS), perchlorate has been detected in 80 of 912 public water supplies tested in the state, and 292 of 5,205 private drinking water sources sampled contained measurable levels of the pollutant (CDHS, 2003). Based on current data, California has established a provisional action level of 4  $\mu\text{g}/\text{L}$  for perchlorate in drinking water. Several other states, including Nevada, Maryland, Massachusetts, and Texas have also instituted advisory levels for the oxidant, and it is expected that the Environmental Protection Agency (EPA) will establish a reference dose for the compound in the near future.

Standard water treatment technologies, such as sedimentation, air-stripping, carbon adsorption, and advanced oxidation, are generally not effective at removing perchlorate from water because the compound is nonreactive and nonvolatile, its salts are highly soluble, and it cannot be reduced by common reducing agents (Urbansky, 1998; Logan, 1998; USEPA, 2001). Unlike abiotic approaches, however, biological treatment represents a promising technology for the remediation of ground and surface water. In the past few years, a wide variety of microbial strains have been isolated with the ability to degrade perchlorate by using the molecule as a terminal electron acceptor (Achenbach et al., 2001; Coates et al., 1999; Rikken et al., 1996; Logan, 1998). The enzymatic pathways involved in perchlorate reduction have yet to be fully elucidated. However, it appears that a perchlorate reductase enzyme catalyzes an initial two-step reduction of perchlorate ( $\text{ClO}_4^-$ ) to chlorate ( $\text{ClO}_3^-$ ) and then chlorite ( $\text{ClO}_2^-$ ) (van Ginkel et al., 1996; Kengen et al., 1999). The chlorite is further reduced by chlorite dismutase to chloride ( $\text{Cl}^-$ ) and oxygen ( $\text{O}_2$ ) (Coates et al., 1999). Thus, microbial degradation of perchlorate yields two innocuous products, chloride and oxygen.

Ex situ biological treatment systems have been successfully developed to treat perchlorate-contaminated groundwater (Greene and Pitre, 2000; Hatzinger et al., 2000, 2002; Logan, 2001; Miller and Logan, 2000). Electron donors, such as ethanol and acetate, are supplied to perchlorate-reducing bacteria in these reactors to promote biological reduction of the propellant. The success of ex situ biological treatment of perchlorate suggests that in situ treatment through

electron donor addition may also be possible. Research data suggest that perchlorate reducing bacteria are naturally occurring in various environments, including soils, sludge, and raw wastewater, as well as in groundwater aquifers (Coates et al., 1999; Wu et al., 2001; Hatzinger et al., 2002; Hatzinger, 2002). The key to utilizing perchlorate-reducing bacteria for in situ remediation is understanding the conditions that limit their activity in subsurface environments and then devising effective technologies to overcome these limitations and subsequently stimulate perchlorate degradation.

Until recently, little research had been conducted to develop an in situ technology for bioremediation of perchlorate in groundwater. However, in 2000, Shaw Environmental, Inc. and the Indian Head Division, Naval Surface Warfare Center (IHDIW) were awarded a Strategic Environmental Research and Development Program (SERDP) project to evaluate fundamental questions concerning the potential for in situ perchlorate treatment. The results from this project revealed the following:

1. Perchlorate-degrading bacteria are widely distributed in groundwater aquifers.
2. These organisms can be stimulated to biodegrade perchlorate under anoxic conditions using a variety of different electron donors, although the most effective donors vary on a site-specific basis.
3. Perchlorate biodegradation is inhibited in aquifers where the pH is naturally below approximately 5.5.

The detailed report from this project (CU-1163) is available from the SERDP Office, 901 N. Stuart St., Suite 303, Arlington, VA 22203. Based on the successful SERDP study, the Naval Ordnance Safety and Security Activity funded a field-pilot demonstration to evaluate the potential for in situ perchlorate treatment in a shallow aquifer behind IHDIW Building 1419, the Hog-out Facility. This document details the results of this demonstration.

## SUMMARY OF LABORATORY RESULTS

As part of the SERDP-funded study (CU-1163) and as a prelude to performing the field-pilot demonstration, samples were collected from the area immediately behind Building 1419, and a series of microcosm studies were conducted to determine whether perchlorate-reducing bacteria were present at the site and which electron donors were most effective at stimulating them to degrade perchlorate in the underlying aquifer. Microcosms were prepared by mixing sediment and groundwater from the Building 1419 site under anoxic conditions. The starting perchlorate concentration in the mixed groundwater and sediment was approximately 45 mg/L. Serum bottles were amended with the following electron donors at 200 mg/L: methanol, ethanol, acetate, benzoate, lactate, sucrose, molasses, or a mixture of ethanol and yeast extract (100 mg/L each). Bottles were also prepared with hydrogen gas or propane in the headspace as gaseous substrates or with the perchlorate-degrading enrichment culture FBR2 (isolated from a fluidized bed bioreactor treating perchlorate in California). Bottles were incubated at 15 °C and samples were collected at 11, 20, 36, and 71 days of incubation for perchlorate analysis by EPA Method 314.0.

There was no appreciable loss of perchlorate during the 71-day incubation period in any of the microcosms prepared from the hog-out site samples (Table I). Ten different electron donors did not stimulate perchlorate biodegradation in the samples. These results differ from those with Building 1190 samples collected from IHDIV, where several electron donors quickly stimulated perchlorate degradation (data not shown). One possibility for this absence of biological perchlorate reduction was the absence of a native microbial population capable of carrying out this process at the Building 1419 site. However, microbial analyses conducted in the laboratory of Dr. John Coates at Southern Illinois University (Hatzinger, 2002) revealed that such bacteria are present in samples from the aquifer as well as at other locations on the IHDIV facility (Table II). The observation that bioaugmentation with an exogenous perchlorate degrading culture (FBR2) also did not reduce perchlorate levels confirmed that the absence of such organisms was not the most likely cause of the persistence of perchlorate. Rather, a geochemical factor or environmental co-contaminant was hypothesized to be the factor preventing perchlorate biodegradation.

The most apparent difference between the hog-out samples and those from Building 1190 was the comparatively low pH of the microcosms from hog-out compared to those from the second site (pH of 4.3 versus 7.0). An experiment was subsequently conducted to assess the influence of pH on perchlorate degradation in the hog-out samples. A titration curve using samples from the Building 1419 area showed that approximately 240 mg/L of carbonate was required to increase the pH of the slurry from approximately 4.3 to 7.0 (Figure 1). To evaluate the influence of pH on perchlorate degradation, groundwater and sediment were added to 160-mL bottles at a ratio of approximately 3:1 (100 mL groundwater and 30 g sediment), and acetate was added as the electron donor at 75 mg/L. In eight of the fourteen bottles prepared, the pH was increased from 4.3 to approximately 7.0 by adding sodium carbonate. The pH of the

remaining six microcosms was not adjusted (i.e., pH 4.3). Three of the bottles at pH 4.3 and three at pH 7.0 were inoculated with the perchlorate-degrading culture FBR2, and three bottles at each pH remained uninoculated. Two bottles were treated with formaldehyde to inhibit all microbial activity. The bottles were incubated on a rotary shaker at 15 °C and periodically sampled for perchlorate analysis.

**Table I. Perchlorate Degradation in Aquifer Microcosms from the Building 1419 Site**

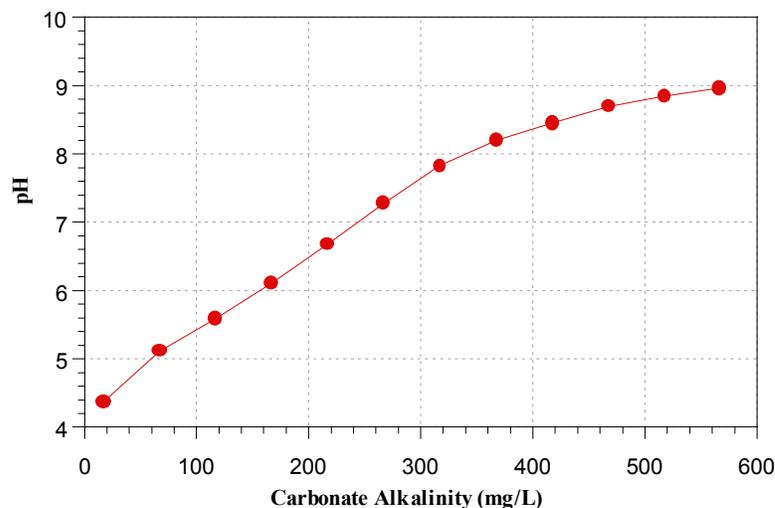
Treatment	Perchlorate concentration <sup>a</sup> (mg/L)				
	Day 0	Day 11	Day 20	Day 36	Day 71
Electron donors					
Killed control	42 ± 4	41 ± 1	44 ± 2	36 ± 4	37 ± 2
No substrate	42 ± 4	37 ± 1	36 ± 4	38 ± 1	39 ± 5
Nutrients only	42 ± 4	38 ± 2	41 ± 4	42 ± 1	34 ± 1
Hydrogen	42 ± 4	38 ± 2	40 ± 4	32 ± 5	35 ± 2
Propane	42 ± 4	38 ± 1	39 ± 2	34 ± 2	37 ± 2
Ethanol	42 ± 4	39 ± 2	41 ± 2	36 ± 4	36 ± 3
Methanol	42 ± 4	41 ± 2	41 ± 1	32 ± 2	34 ± 2
Acetate	42 ± 4	39 ± 1	42 ± 2	33 ± 1	37 ± 1
Benzoate	42 ± 4	40 ± 1	43 ± 0	32 ± 1	38 ± 1
Lactate	42 ± 4	38 ± 3	43 ± 3	33 ± 2	37 ± 2
Molasses	42 ± 4	43 ± 2	43 ± 2	28 ± 1	36 ± 2
Sucrose	42 ± 4	44 ± 1	45 ± 0	31 ± 0	35 ± 0
Yeast extract/ethanol	42 ± 4	43 ± 2	44 ± 2	35 ± 3	37 ± 2
Bioaugmentation					
Inoculum FBR2+ ethanol	42 ± 4	41 ± 1	44 ± 3	36 ± 2	36 ± 2

<sup>a</sup>Values are the mean ± standard deviation from triplicate microcosms.

**Table II. Enumeration of Perchlorate Reducing Bacteria from Site Samples at IHDIV**

Sample <sup>a</sup>	Mean practical No.	CKB type	RCB type	PS type
Pristine soil	7.5 ± 3.4 × 10 <sup>3</sup>	Negative	Negative	Negative
Bldg. 1419 soil	9.3 ± 4.2 × 10 <sup>4</sup>	Negative	Positive	Negative
Bldg. 1419 water	4.3 ± 2.1 × 10 <sup>1</sup>	Negative	Positive	Positive
Bldg. 1170 soil	9.3 ± 4.2 × 10 <sup>4</sup>	Positive	Positive	Negative
Bldg. 1170 stream	2.4 ± 1.7 × 10 <sup>3</sup>	Negative	Negative	Negative
Bldg. 1170 water	4.3 ± 2.1 × 10 <sup>5</sup>	Negative	Positive	Positive
Bldg. 760 soil (ditch)	1.5 + 0.6 × 10 <sup>7</sup>	Positive	Positive	Negative

<sup>a</sup>Data courtesy of Dr. John Coates, currently at UC Berkeley.

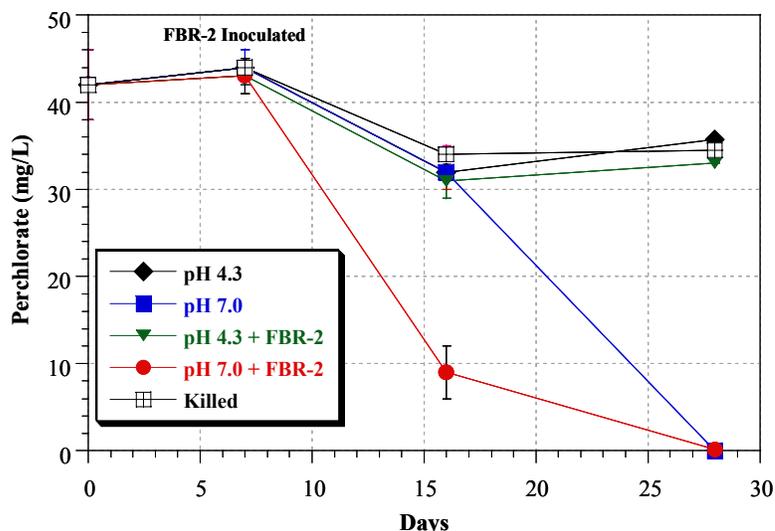


**Figure 1. Carbonate Titration Curve for Sediment Slurries from the Building 1419 Site**

The perchlorate levels in the samples at pH 4.3 did not decline appreciably during the study, regardless of whether the samples were bioaugmented (Figure 2). Conversely, the samples in which the pH was increased to 7.0 all showed perchlorate biodegradation. Perchlorate levels in samples receiving *Dechlorospirillum* sp. FBR2 declined from 43 to 9 mg/L from day 7 to day 16, and then to 0.16 mg/L by day 28. The perchlorate concentrations in samples that were brought to pH 7.0 but not augmented with the culture declined more slowly, but perchlorate was below detection by day 28 of the experiment. Thus, the data suggest that low pH was inhibiting perchlorate degradation in the hog-out site samples. It is interesting that indigenous perchlorate-degrading microorganisms could be stimulated to degrade the anion at a pH of 7.0 but not at a pH of 4.3. These bacteria are obviously able to survive at the low pH, which occurs naturally at this site, yet appear not to degrade perchlorate at this pH. The results suggest that (1) there may be a pH below which perchlorate biodegradation is physiologically inhibited; or (2) some other geochemical factor (e.g., heavy metal toxicity or trace metal unavailability) prevents perchlorate biodegradation at low pH.

Additional laboratory studies were conducted just prior to commencing system installation at the IHDIV site to confirm previous SERDP studies. These experiments were performed to

- (1) Confirm that perchlorate degradation did not occur in unbuffered samples
- (2) Determine if any electron donors other than acetate were effective for stimulating perchlorate reduction in buffered samples
- (3) Quantify the expected lag period prior to the onset of perchlorate biodegradation after electron donor addition
- (4) Assess whether nutrient addition would increase the rate of perchlorate reduction.



**Figure 2. Influence of pH on Perchlorate Degradation in Aquifer Microcosms from the Building 1419 Site**

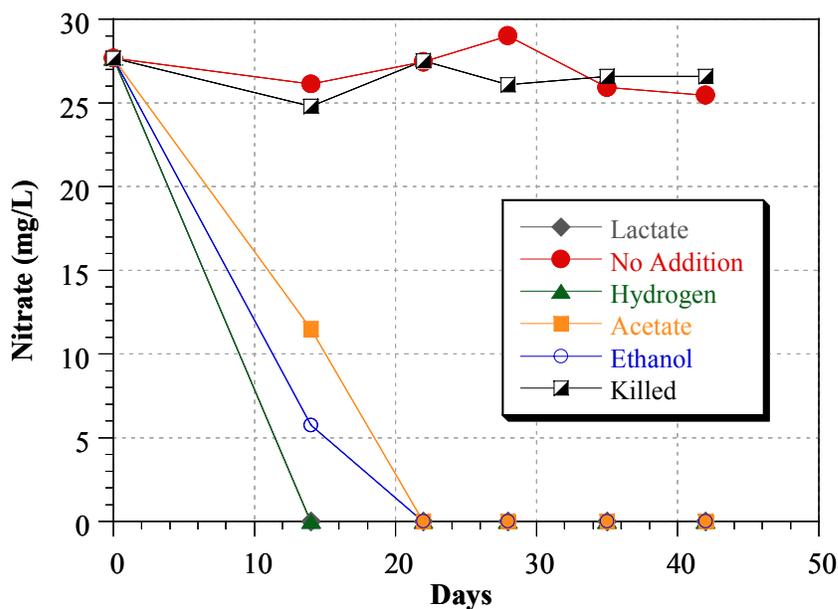
Aquifer solids and groundwater were collected from the test plot area in January 2002 during the initial site assessment (see the “Site Characterization” section). Sediments were obtained from several points behind Building 1419 using a Geoprobe rig. The levels of perchlorate in groundwater samples from each Geoprobe location were determined, and, based on these results as well as the physical conditions at the site (presence of utilities, buildings, etc.), a general test plot area was designated. To conduct laboratory studies, groundwater collected from three different Geoprobe points within the test plot area (GP-1, GP-11, GP-13) was mixed in a large, sterile glass container. Sediments from two of these points (GP-1 and GP-11) were also combined and thoroughly homogenized. The sediments from GP-1 were obtained from 13 to 20 ft below surface, and those from GP-11 were obtained from 11 to 16 ft below surface. Samples from two or three Geoprobe locations were combined to obtain the most representative groundwater and sediment conditions within the test plot area.

Microcosms were prepared in sterile, 160-mL serum bottles. Groundwater and sediment were added to each 160-mL bottle at a ratio of 3:1 (75 mL groundwater and 25 g sediment). One group of bottles was amended with 14 mg of carbonate to bring the slurry pH to approximately 7.3. The other set of bottles received no buffer and remained at a pH of 4.5. Acetate, ethanol, lactate, or hydrogen gas was added to four bottles, two at each pH (i.e., duplicate bottles at site pH and duplicates adjusted to pH 7.3). The liquid electron donors (ethanol, acetate, lactate) were added at a concentration of 250 mg/L, and hydrogen (a gaseous donor) was added to the bottle headspace in a 5-mL volume. In addition, two microcosm bottles at each pH received no electron donor and two adjusted to pH 7.3 received 1% formaldehyde to inhibit all microbial activity (killed controls). The killed samples also received acetate as an electron donor. All samples were prepared in a Coy Environmental Chamber with a nitrogen headspace. The bottles were incubated on a rotary shaker at 15 °C. At various times of incubation, an 8-mL subsample of groundwater was removed from each bottle. The water was then passed through a 0.22-µm syringe filter to remove bacteria and sediment fines and placed at 4 °C until analysis. The

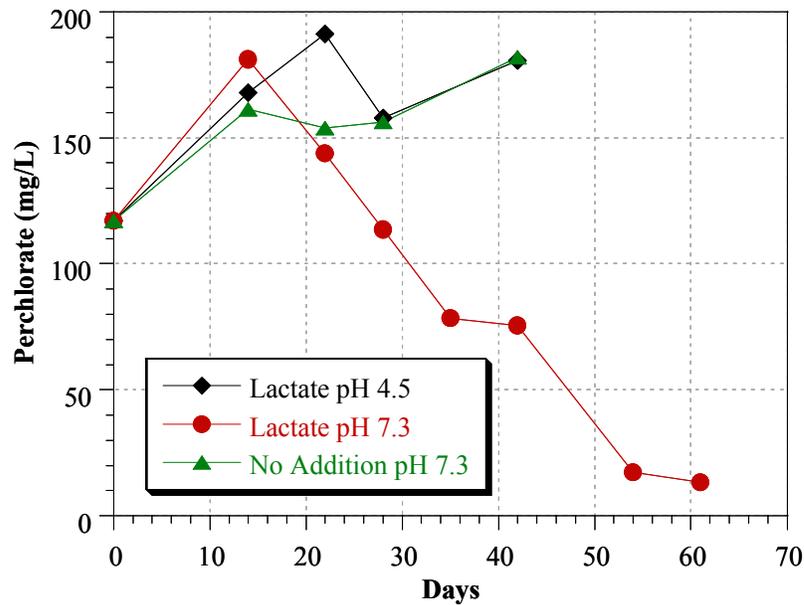
samples were analyzed for perchlorate by EPA Method 314.0 and for nitrate and sulfate by EPA 300.0 series methods.

The initial perchlorate levels in the microcosms at day 0 averaged 116 mg/L, and the starting nitrate concentration was 27.7 mg/L. The level of perchlorate in the microcosms increased from 116 mg/L at day 0 (immediately after slurry preparation) to approximately 170 mg/L at day 14. This increase was consistent among samples and appears not to reflect an analytical error or inconsistency. Therefore, it is likely that this increase reflects perchlorate desorbing from the site sediments into solution. There was no degradation of perchlorate or nitrate in any of the microcosms that remained at pH 4.5, irrespective of the type of electron donor added (data not shown). This finding confirms results from previous studies conducted at Shaw Environmental with samples from IHDIV and the Longhorn Army Ammunition Plant which suggest that low pH (< 5.7) is inhibitory to biological perchlorate reduction. The data also suggest that the low pH is inhibitory to biological nitrate reduction at the hog-out site.

In the samples adjusted to pH 7.3, nitrate was biodegraded to below detection (< 2 mg/L) within 22 days in samples amended with ethanol, acetate, lactate, or hydrogen gas (Figure 3). Nitrate biodegradation was not observed in samples that did not receive an electron donor or in killed control samples. Biodegradation of perchlorate was apparent in pH-adjusted microcosms amended with lactate (Figure 4). Perchlorate concentrations declined from a high of 181 mg/L at day 14 to less than 14 mg/L by day 61 (the last sample collected) in the microcosms receiving lactate. The pH-adjusted microcosms receiving acetate, ethanol, and hydrogen gas did not show appreciable perchlorate reduction during the course of the study. Perchlorate levels also did not decline in microcosms without added electron donor or in killed controls.



**Figure 3. Influence of Different Electron Donors on Nitrate Biodegradation in Buffered Site Samples**



**Figure 4. Perchlorate Levels in Aquifer Microcosms Receiving Lactate (pH 4.5 or 7.3) or No Electron Donor**

The data from this microcosm experiment generally support previous laboratory studies conducted by Shaw Environmental and IHDIV from several sites across the country. The data show the following:

- (1) Naturally occurring bacteria capable of degrading perchlorate are present in the test plot location.
- (2) These bacteria can be stimulated to degrade perchlorate using lactate as an electron donor.
- (3) Adjustment of pH from 4.5 to neutrality will be required for perchlorate reduction to occur.

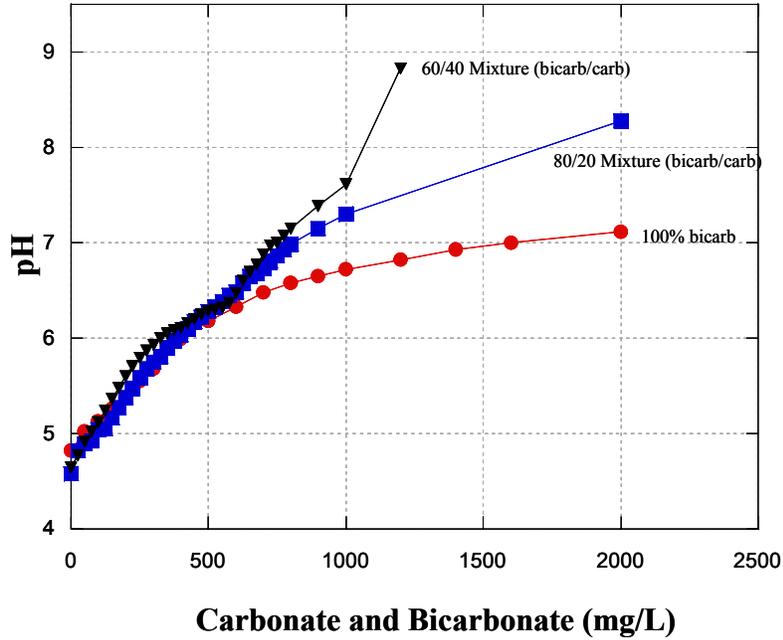
However, the laboratory results differed slightly from previous findings in a couple of ways. First, the rate of perchlorate reduction in the pH-adjusted microcosms receiving lactate was somewhat slower than anticipated based on results from previous studies at the Building 1419 location. This may reflect the high perchlorate concentration in the designated test plot area or a low starting density of indigenous perchlorate-reducing bacteria in the aquifer in this area. A limitation in inorganic nutrients (phosphate in particular) could also account for the slow rate of perchlorate reduction. However, such a nutrient limitation was ruled out in an additional microcosm study. The data from this study showed that ammonium and phosphate addition did not appreciably enhance perchlorate reduction in the lactate-amended aquifer samples (pH 7.3) (data not shown). The data from this study also differed from that in the previous SERDP study

in that acetate was observed to be a suitable electron donor for perchlorate reduction in pH-adjusted samples in the study with samples from Building 1419 (see Figure 3). Acetate did not support perchlorate reduction in this study. The samples for the first SERDP study were obtained in August 2000 at a location much closer to Building 1419 than those used for the current study. Therefore, it is possible that the geochemistry and microbiology differ somewhat between the two locations. Based on the most recent laboratory study, lactate was chosen for use in the field pilot study.

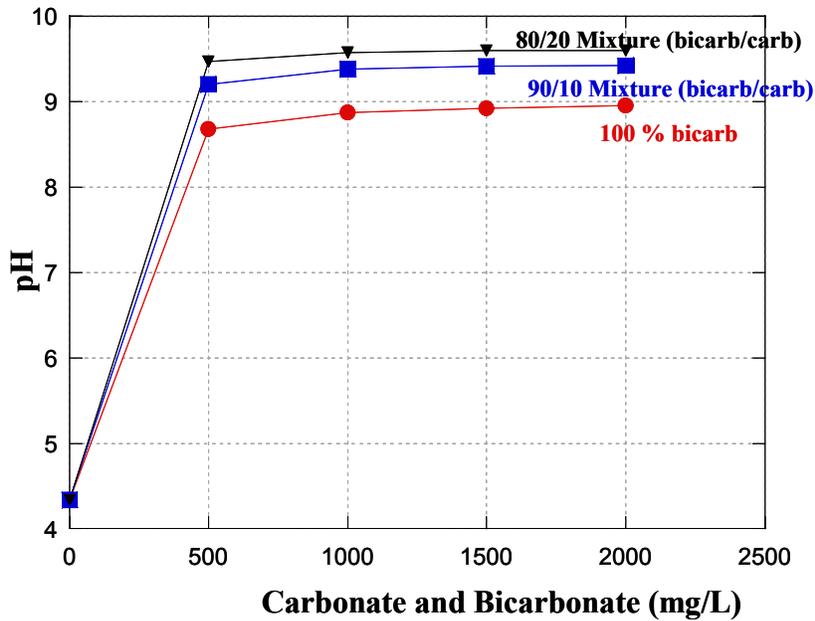
In addition to biodegradation studies, experiments were conducted with site samples to evaluate the most effective buffer for the demonstration. The addition of pure sodium carbonate to the IHDIV groundwater was anticipated to raise the pH of that water to more than 10.0, which is inhibitory to bacterial growth. Although the added alkalinity was expected to be quickly consumed by the sediments, it was possible that the initially high pH near the injection wells would inhibit microbial growth and subsequently perchlorate reduction. Because of this possibility, laboratory studies were performed in sediment/groundwater slurries and in groundwater only to evaluate pH adjustment using sodium bicarbonate ( $\text{NaHCO}_3$ ) and various carbonate/bicarbonate mixtures.

As described for previous microcosm experiments, sediment and groundwater collected within the demonstration area were combined and homogenized for these studies. Titrations were performed with sediment/groundwater slurries using sodium bicarbonate only, a mixture of 20% sodium carbonate and 80% sodium bicarbonate, and a mixture of 40% sodium carbonate and 60% sodium bicarbonate. To conduct these experiments, 50 g of site sediment and 50 mL of groundwater were mixed, the bicarbonate or bicarbonate/carbonate mixture was added in small increments, and the pH of the slurry was measured after each addition of buffer. In addition, the influence of the bicarbonate solution and carbonate/bicarbonate mixtures on the pH of groundwater only was examined.

The titration curves for bicarbonate and two carbonate/bicarbonate mixtures in the aquifer sediment slurries are provided in Figure 5. The quantity of buffer required to reach a pH of 7.0 was appreciably higher when bicarbonate alone was used (1,600 mg/L) compared to a 80/20 mixture or a 60/40 mixture of bicarbonate/carbonate (800 mg/L and 750 mg/L, respectively). However, the pH of the aquifer sediments increased only gradually beyond 7.0 with continued amendment with bicarbonate only. The pH of the sediment slurry was only 7.12 after addition of 2,000 mg/L of bicarbonate (the highest dose tested). The pH of aquifer samples receiving 20% carbonate and 80% bicarbonate reached 7.0 after addition of 800 mg/L of buffer, and the pH achieved after addition of 2,000 mg/L was 8.3. The 60/40 mixture of bicarbonate/carbonate brought the sediment slurry to a pH of 8.8 after addition of 1,200 mg/L. The pH response of site groundwater amended with the three different buffer solutions is presented in Figure 6. After addition of 2,000 mg/L of each buffer, the pH of the groundwater was 8.95 for bicarbonate only, 9.42 for a 90/10 mixture, and 9.60 for an 80/20 mixture of bicarbonate/carbonate, respectively.



**Figure 5. Influence of Bicarbonate/Carbonate Mixtures on pH of Sediment Slurries from the Demonstration Area**



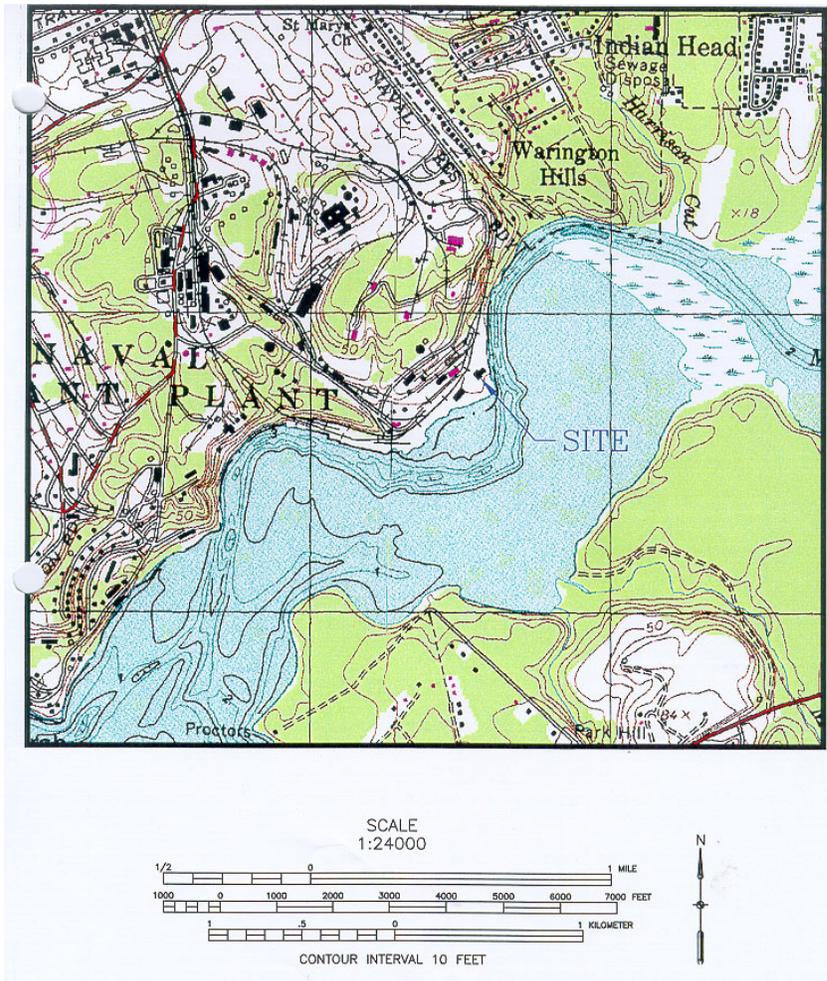
**Figure 6. Influence of Bicarbonate and Carbonate/Bicarbonate Mixtures on Groundwater pH**

The equilibrium chemistry for carbon dioxide, bicarbonate, and carbonate in natural waters is complicated and is affected by the geology and geochemistry of the system. Based on equilibrium curves published for carbon dioxide/bicarbonate/carbonate, the maximum pH in an aqueous solution containing only bicarbonate should be approximately 8.5 to 9.0 (Wetzel, 1975). The final pH of the site groundwater amended with bicarbonate only was within this range. As the ratio of carbonate/bicarbonate increases, pH will increase accordingly, exceeding 12 when carbonate only is in solution. Thus, while carbonate is more effective than bicarbonate for neutralizing acidity, the potential for increasing aqueous pH to levels beyond those which are optimal for the activity of perchlorate-reducing bacteria (6.0–8.0) is also higher when using a carbonate solution compared to bicarbonate. These factors must be taken into account when attempting to buffer an acidic aquifer. Based on these results and the expected consumption of alkalinity during aquifer buffering, a concentrated solution (6.67%) of 80% bicarbonate and 20% carbonate was initially chosen for the concentrated buffer to be used during the demonstration. The pH of the water in the monitoring wells was closely monitored to determine the effectiveness of buffering, and adjustments were made to the buffer mixture based on these data.

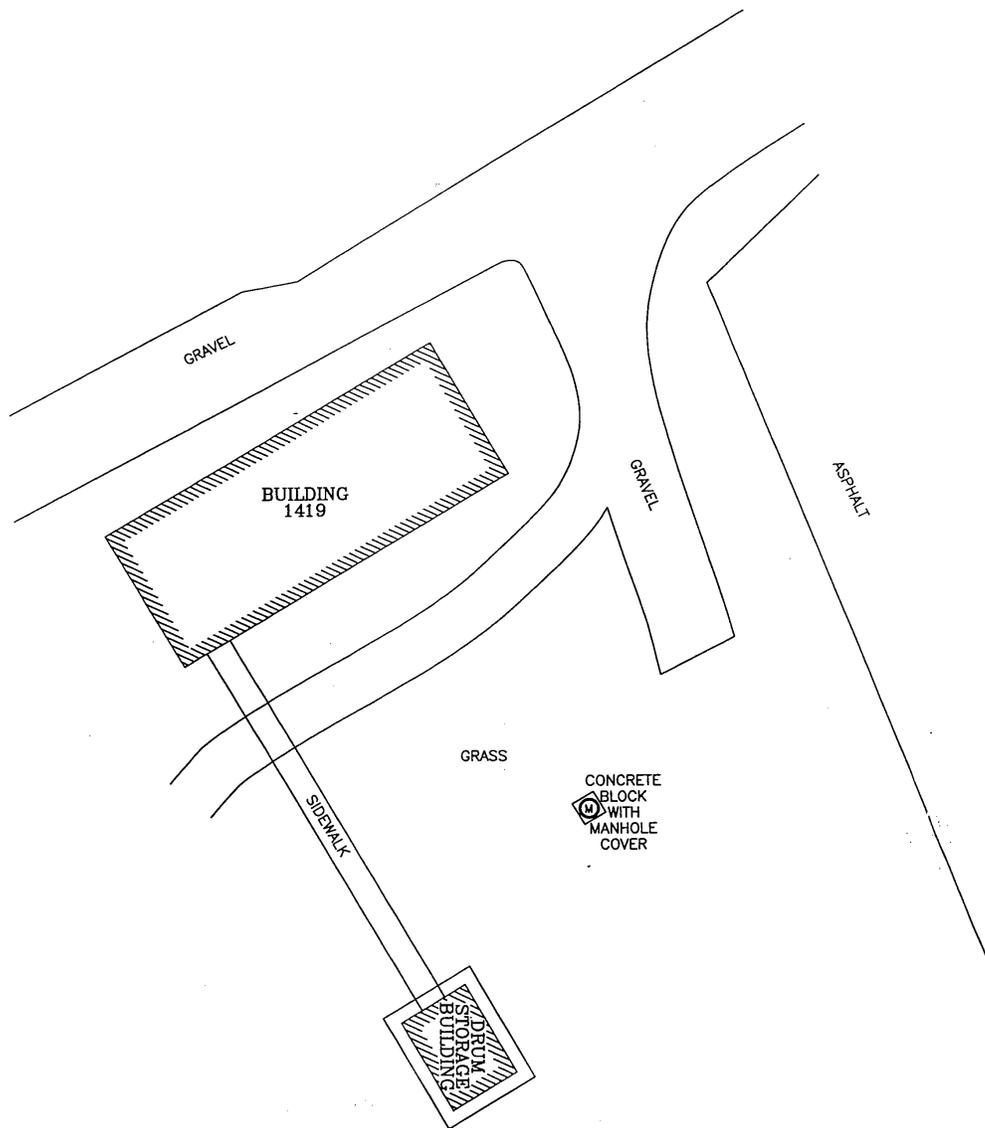
## **SITE CHARACTERIZATION**

### **Site Background**

The Indian Head Division is located near Indian Head, Maryland. Geographically the site is located at 38°35'05" N latitude, 77°09'50" W longitude in Charles County, Maryland (United States Geological Survey [USGS] Indian Head, MD-VA 15' Quadrangle, 1982). Figure 7 shows the site location. The study area is located on the southeast side of IHDIV Building 1419, also known as the Hog-out Facility. Figure 8 shows the site plan view. Building 1419 is used to clean out or "hog out" solid propellant containing ammonium perchlorate from various devices, including rockets and ejection seat motors, that have exceeded their useful life span. The hog-out process and former waste handling methods have impacted the groundwater near Building 1419.



**Figure 7. Site Location Map**



**Figure 8. Site Plan View**

**Procedures**

Field characterization of the demonstration area behind Building 1419 was performed in January and February 2002. A direct-push (Geoprobe) rig was used to collect continuous sediment cores for geological analysis. Standard Geoprobe penetrations were conducted with a vehicle-mounted rig. Geoprobe penetration was performed by the pneumatic hammering action of a 1-inch outside diameter steel rod. For the pneumatic advancement of the Geoprobe extensions, a 2- to 4-ft-long, 2-inch-diameter, split-barrel sampler was mounted on the leading end of the penetration probe rod. The sampler and probe rods were then advanced into the

ground, allowing soil to enter the sample barrel. The sample barrel assembly was then removed, and the soil sample was extruded for analysis. A total of 17 Geoprobe borings were installed. Following the completion of each boring, a temporary 1-inch inner diameter (I.D.) polyvinyl chloride (PVC) well casing with a screened (0.010-inch slot) lower section was inserted into the open Geoprobe hole. Groundwater samples were then collected from each borehole for geochemical analysis using a peristaltic pump and plastic tubing.

Based on the groundwater analysis from the 17 Geoprobe points, six permanent groundwater monitoring wells were initially installed in the demonstration area. Drilling activities were conducted in general accordance with ASTM:D1586. Borings were advanced using hollow-stem auger/split-spoon sample drilling methods. Split-spoon soil samples were collected at 2.5-ft intervals from each boring ahead of the hollow-stem auger. The six borings were then completed as groundwater monitoring wells. The monitoring wells were constructed using 2-inch I.D. schedule 40 PVC risers and 10-ft well screens (0.010-inch slot). The bottom of the screened section was set approximately 1 ft into the gray clay layer. A sand pack was placed around each screen section. A bentonite plug was placed above the sand pack to prevent surface water from entering the sand pack. Copies of typical boring logs and well construction forms are given in Appendix A.

The wells were developed using a submersible pump. During development, at least ten well volumes were purged from each well. The purpose of the development process was to remove fine-grained sediment from the sand pack and to provide a proper hydraulic connection between the well and the surrounding aquifer. Groundwater samples were then collected from each of the monitoring wells for geochemical analysis using a peristaltic pump and plastic tubing.

A mark was placed on the top of each monitoring well casing for use as a reference point when measuring water elevations. Water levels are recorded to the nearest 0.01 ft in each monitoring well using an electronic sensing device. The water level indicator was decontaminated after each measurement to prevent cross contamination. The top-of-casing (TOC) elevation of each well was then surveyed to the nearest 0.01 ft and referenced to a site datum. The water level is referenced to the TOC elevation to determine the water table elevation.

## SITE GEOLOGY AND HYDROGEOLOGY

### Regional Geology

Surficial geology in the general area of the IHDIV site is composed of Pleistocene lowland deposits. These deposits consist of gravel, sand, silt, and clay. Medium- to coarse-grained sand and gravel, cobbles, and boulders are located near the base of the formation. The deposits commonly contain reworked Eocene glauconite, varicolored silts and clays, and brown to dark gray lignitic silty clay. Estuarine to marine fauna are found in some areas. The thickness of the formation varies from 0 to 150 ft.

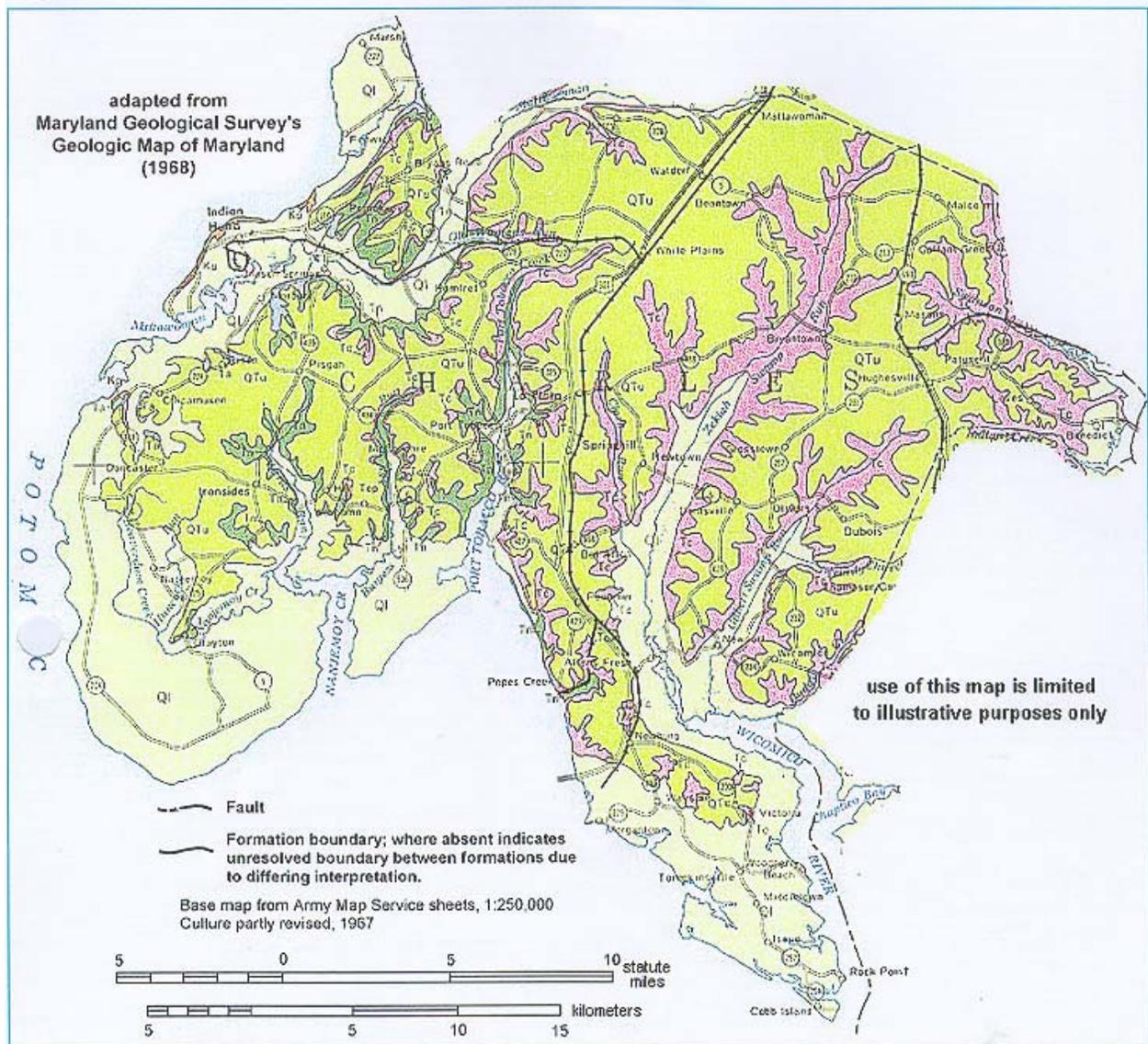
The Cretaceous Potomac Group is located adjacent to the Potomac River (and covers almost the entire peninsula between the Mattawoman Creek and the Potomac River). This formation consists of interbedded quartzose gravels, protoquartzitic to orthoquartzitic argillaceous sands, and white, dark gray, and multicolored silts and clays. The thickness of the formation varies from 0 to 800 ft. The dark gray clays of this formation likely underlie the site. The surficial geologic map for Charles County is shown in Figure 9.

### Local Geology

The field demonstration area is located southeast of Building 1419 and is approximately 300 ft from the Mattawoman Creek. The surficial geology of the test plot area was derived from soil samples collected from 17 Geoprobe borings and six test borings that ranged in depth from 16 to 20 ft below the ground surface (bgs). The top 2 to 4 ft consisted of fill material including organic material, gravel, and silty sand. The underlying 11 to 13 ft consisted of mottled light to olive brown clay to sandy silts. The clay and sand fraction of the silts varied horizontally and vertically. Fine grained sand seams 1 to 2 inches in thickness were seen in many of the boring locations, but these seams were not continuous from boring to boring. At a depth of approximately 15 ft bgs, a 1- to 1-1/2-ft-thick layer of sand and gravel was encountered. This layer was found to be continuous throughout the area near the test plot. The sand and gravel layer is underlain by a gray clay layer, which extends to a depth of at least 20 ft bgs, the deepest extent of the Geoprobe and test borings. This is likely the clays of the Potomac Group. Figures 10, 11, and 12 show the Geoprobe and well locations, cross-section plan view, and geologic cross sections A-A' and B-B' for the demonstration area.

## Local Hydrogeology

Groundwater elevations measured in the six monitoring wells in the demonstration area indicate a groundwater flow direction to the southeast toward the Mattawoman Creek. The flow direction basically follows the surface topography. Depth to groundwater ranged from approximately 6.5 to 10.25 ft below the ground surface. The average hydraulic gradient, as measured between wells MW-1 and MW-3, was 0.023 ft/ft. The groundwater potentiometric surface in the demonstration area is shown in Figure 13.



**Figure 9. Geologic Map of Charles County**

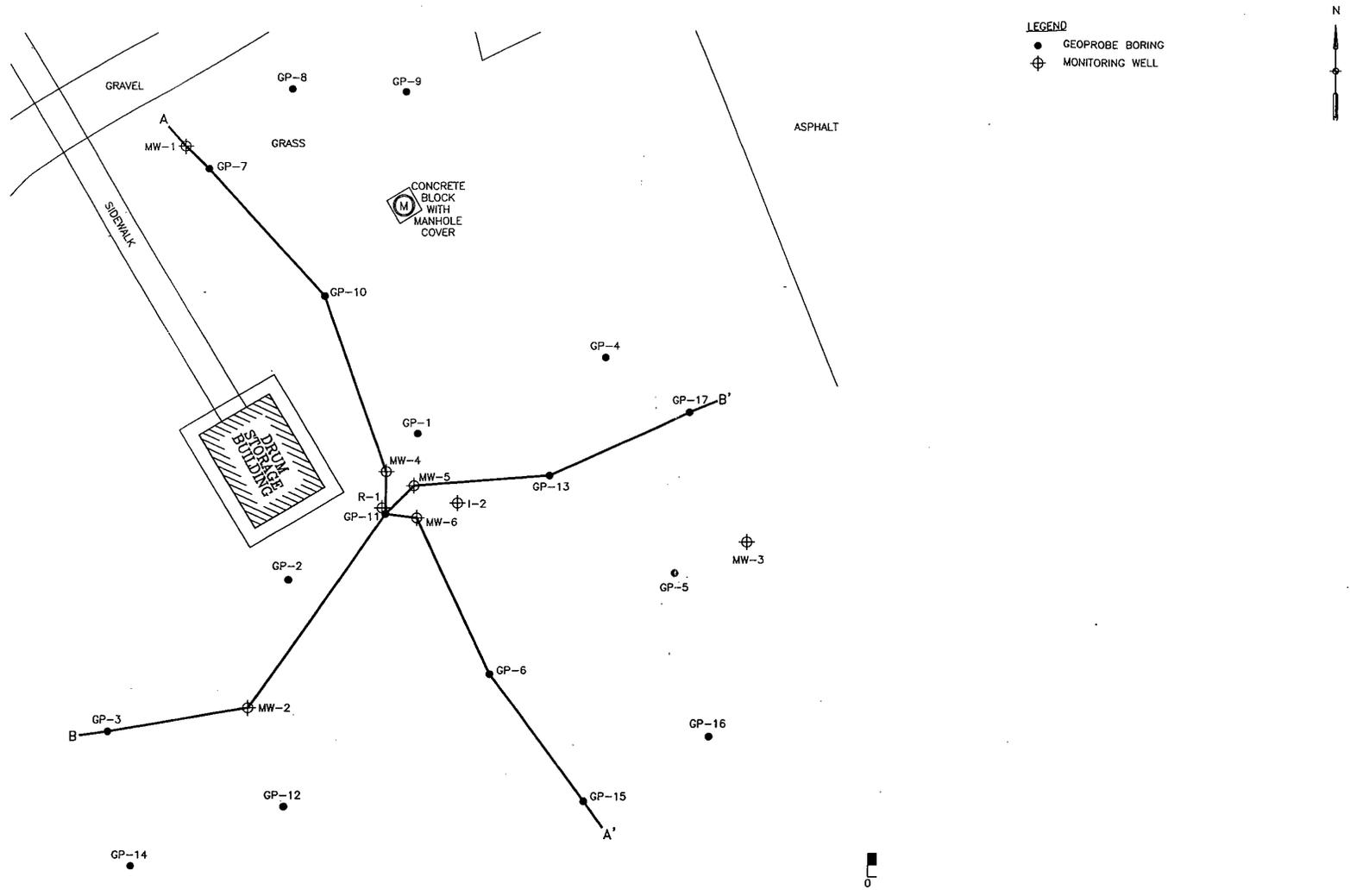


Figure 10. Boring Location and Cross-Section Plan View

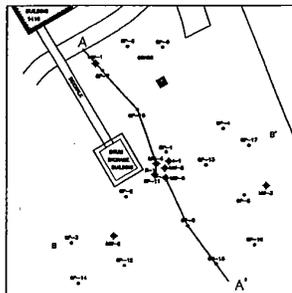
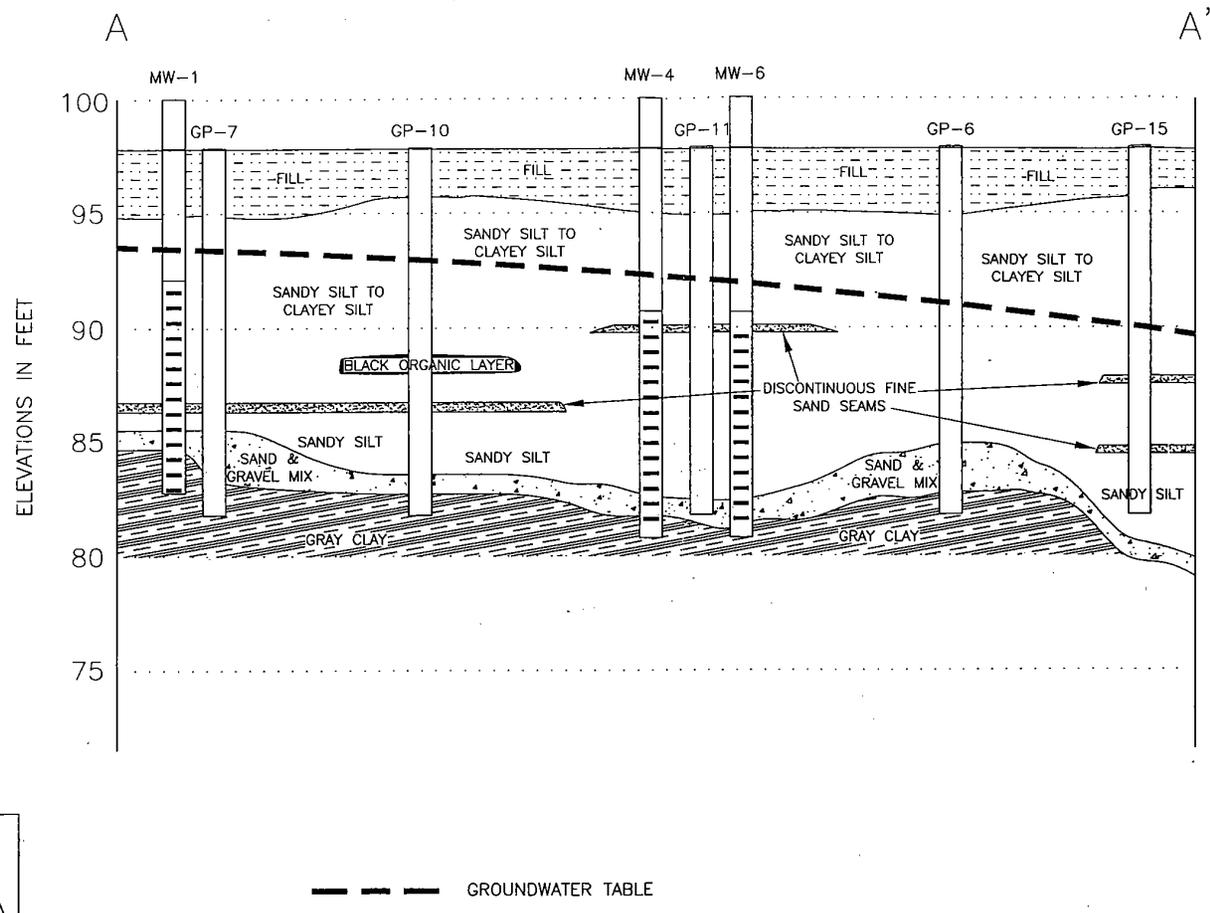


Figure 11. Geologic Cross-Section A-A'

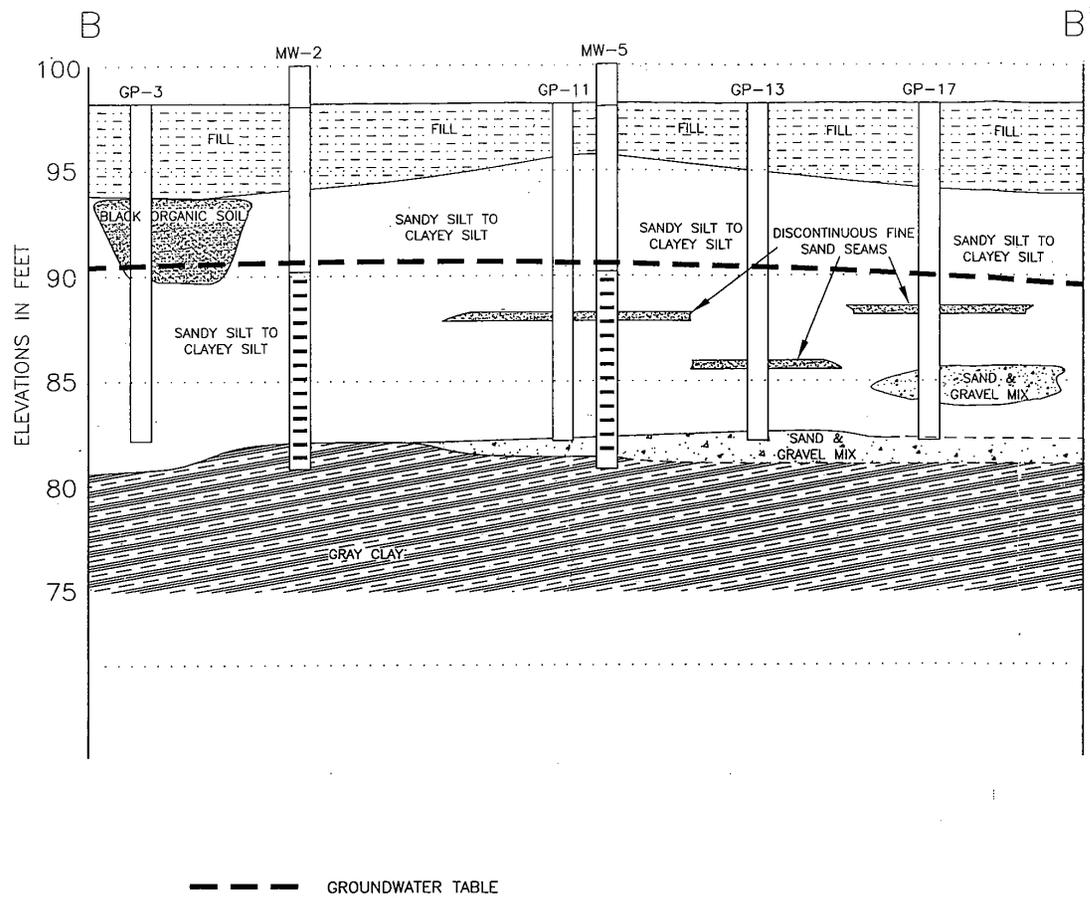
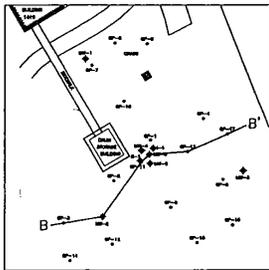


Figure 12. Geologic Cross-Section B-B'



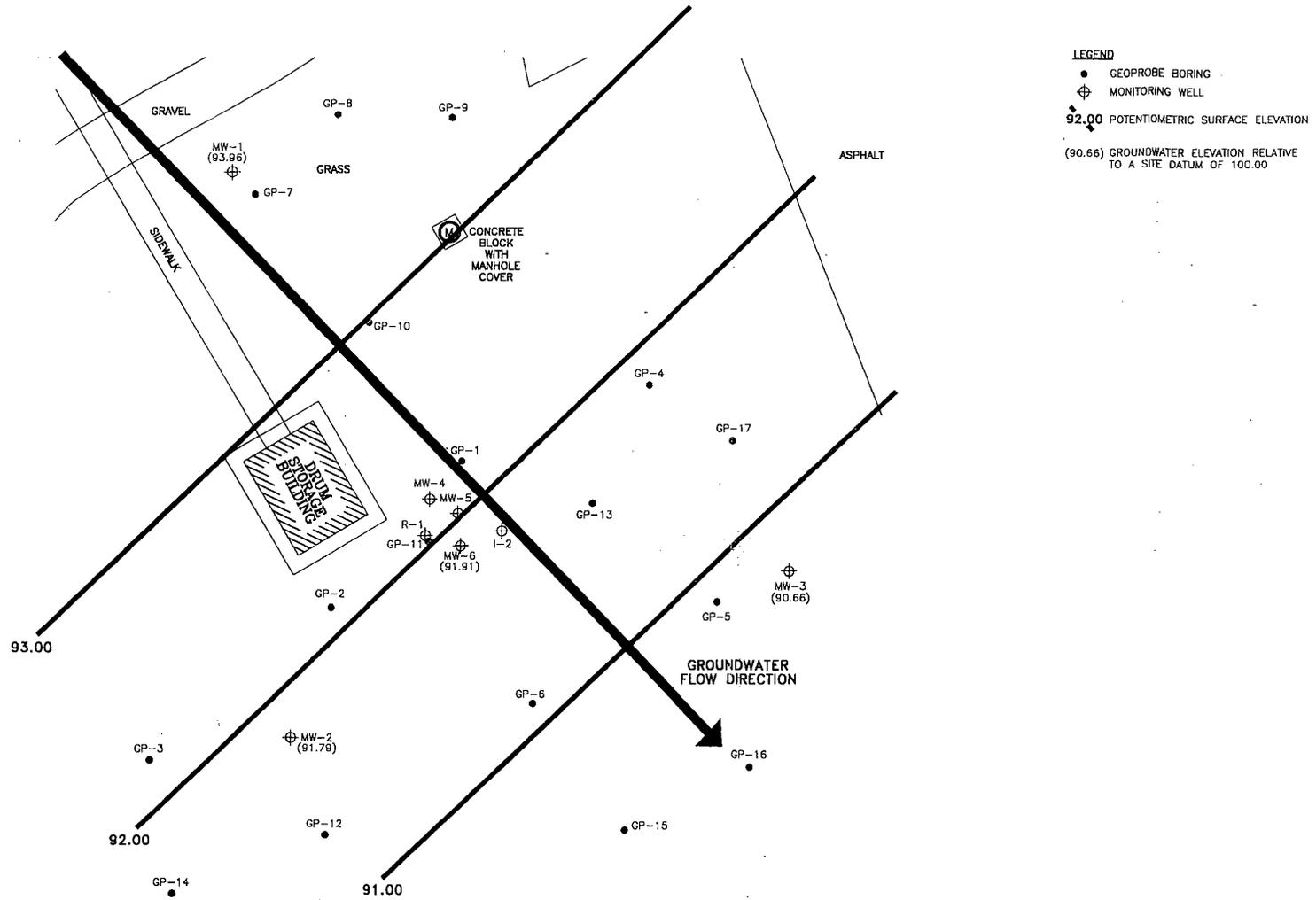


Figure 13. Groundwater Potentiometric Surface

## Geochemical Results

Groundwater samples were collected from the 17 Geoprobe borings on 22 and 24 January 2002, and from the six monitoring wells on 5 and 6 February 2002. The groundwater samples collected from the Geoprobe borings were analyzed for perchlorate, nitrate, sulfate, pH, and dissolved oxygen (DO). Results of the chemical analyses from the Geoprobe borings are provided in Table III. Groundwater samples collected from the six monitoring wells were analyzed for perchlorate, pH, and DO. Results of the chemical analyses are provided in Table IV. The distribution of perchlorate in groundwater based on the Geoprobe and monitoring well sample results are shown in Figure 14. As shown, the field investigation revealed a shallow, narrow plume of perchlorate contamination behind Building 1419 with levels ranging from below detection to approximately 430 mg/L. With a few exceptions, the pH of the site was below 5, and the dissolved oxygen levels were less than 2 mg/L.

**Table III. Groundwater Chemistry at the Demonstration Site**

Geoprobe boring	Perchlorate (mg/L)	Nitrate as N (mg/L)	Sulfate (mg/L)	pH	Dissolved oxygen (mg/L) <sup>a,b</sup>
GP-1	120	0.6	66	4.67	NA
GP-2	< 2.5	3.0	220	8.08	NA
GP-3	8.2	1.9	280	5.23	NA
GP-4	57	0.3	110	4.54	NA
GP-5	65	0.1	130	4.21	1
GP-6	280	11	69	5.62	1
GP-7	35	1.5	66	4.21	0.1
GP-8	430	14	62	4.57	ND
GP-9	73	0.4	56	4.44	0.8
GP-10	300	12	70	4.31	1
GP-11	230	14	72	4.71	0.8
GP-12	55	2.0	110	6.46	ND
GP-13	230	3.8	64	4.61	1.5
GP-14	14	1.5	250	4.97	ND
GP-15	9.8	< 0.2	160	5.34	0.2
GP-16	270	2.8	74	4.16	1
GP-17	< 5	< 0.2	140	4.83	0.2

<sup>a</sup>Analysis performed by colorimetric field method (Chemets).

<sup>b</sup>NA: Not analyzed; ND: Not determined.

**Table IV. Groundwater Chemistry and Perchlorate Concentrations in Monitoring Wells 1 through 6**

Monitoring well	Perchlorate (mg/L)	pH	Dissolved oxygen (mg/L)
MW-1	84.7	5.02	1.49
MW-2	1.9	6.75	5.50 <sup>a</sup>
MW-3	1.6	4.13	6.60 <sup>a</sup>
MW-4	181	5.00	1.64
MW-5	82.8	6.20	1.13
MW-6	142.4	5.03	1.33

<sup>a</sup>DO meter recalibrated — results may not reflect site conditions.

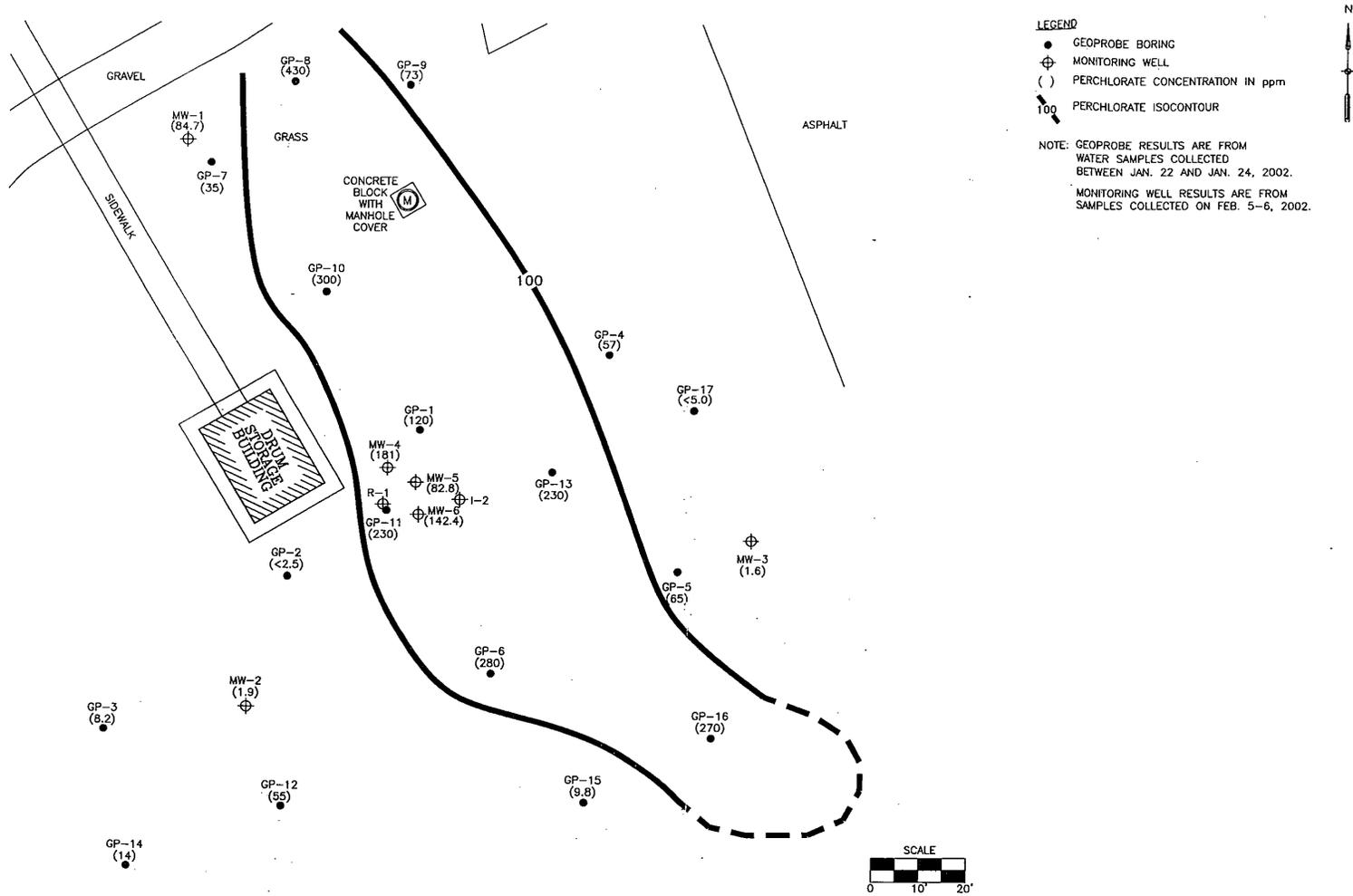


Figure 14. Groundwater Perchlorate Distribution

## SLUG AND PUMP TEST RESULTS

### Slug Testing

Slug testing was performed on monitoring wells MW-4, MW-5, and MW-6. These wells were selected due to their proximity to the planned test plot area. All slug test results were reduced using the Bower-Rice unconfined aquifer method. Appendix B contains copies of the slug test graphs and curve fit lines. The slug test results indicated an average hydraulic conductivity ( $K$ ) of approximately 0.012 ft/min within the aquifer.

### Pump Testing

An aquifer-pumping test was completed at the site during early March 2002. The goal of the aquifer pumping test was to determine how the aquifer in the area of the pilot study responded to actual groundwater pumping scenarios. Using the results of the slug testing as a starting point, a stepped test was performed to determine the optimum flow rate for the pump test. During the stepped test the flow rate was varied between 0.13 and 0.528 gal/min. Based on the results of the stepped test (data not shown) it was estimated that a flow rate of less than 0.25 gal/min would be required to allow for continuous steady-state pumping throughout the pump test.

Using this information a 12-hour pump test was conducted. An initial flow rate of approximately 0.2 gal/min was used at the start. However, based on the observed rate of drawdown within the extraction well, which indicated the well would be pumped dry, the flow rate was adjusted down to approximately 0.15 gal/min after approximately 4.5 hours of pumping. This reduction in flow rate stabilized the rate of decline in water level within the extraction well, allowing for continuous pumping throughout the test.

Drawdown levels were logged in the extraction well and several nearby monitoring wells throughout the pump test to determine the influence on the aquifer of pumping in the vicinity of the extraction well. The drawdown data were reduced and analyzed using the Theis method for unconfined aquifers. Based on the curve data,  $K$  value estimates ranged from 0.011 to 0.044 ft/min. Appendix B contains copies of the drawdown curves and curve fit lines for the recovery and observation wells.

## **Re-injection Testing**

Following the completion of the pump test, a brief re-injection test was completed using waters collected during the pump test. The purpose of the re-injection test was to ensure that the planned injection wells would be capable of reintroducing the amended water into the formation at the anticipated flow rates and to obtain design parameters such as flow rates and injection pressures. The injection well was able to sustain an injection rate of slightly over 1.2 gal/min at less than 3.5-psi pressure.

## FIELD DEMONSTRATION

### Demonstration Objectives

The objectives of this demonstration were as follows:

1. Demonstrate that the IHDIV aquifer can be effectively buffered using a mixture of carbonate and bicarbonate.
2. Show that electron donor (lactate) can be effectively distributed throughout the contaminated aquifer using a groundwater extraction-injection design.
3. Demonstrate that perchlorate and nitrate can be biodegraded in the buffered aquifer using lactate as an electron donor, with minimal reduction of sulfate.
4. Quantify the time required for perchlorate biodegradation and the levels of degradation achievable.
5. Identify key design and operational factors that influence full-scale application of in situ perchlorate bioremediation at this and other sites.

### Recirculation Cell Design

A simple single-layer numeric model was developed to represent site conditions. The model was calibrated by simulating the pump test conditions and adjusting the  $K$  value for the aquifer until the drawdown levels observed in the model at distance were similar to those measured in the field at the 12-hour interval. This information was utilized to assess recirculation well layouts and anticipate operating conditions associated with the final field scale design.

The final recirculation cell layouts comprised two injection wells and two recovery wells installed 12 ft apart. The extraction and injection wells were installed cross-gradient to the natural groundwater flow direction. The relatively close spacing was chosen to allow for faster pore volume turnover rates and to minimize the amount of formation to be buffered during the study. Two sets of well nests were installed between each set of injection/recovery well pairs located at 4-ft intervals. Each of the four well nests included one well screened within the saturated zone of the clayey silt layer and above the gravel layer, and one well with a screened interval intersecting the coarse sand and gravel layer located above the underlying clay soils found at the 13- to 16-ft depth interval. The two screened sections overlapped approximately 6 inches to ensure that no sand lenses were missed. This nested configuration was chosen to allow the spread of buffer agent and electron donor within both the upper clayey silt layer and

the highly conductive sand and gravel layer to be monitored separately. In addition to the four nested wells, one fully screened well was installed in the center of each cell.

The treatment and control cells (test plot and control plot) were located 20 ft apart to ensure that similar perchlorate concentrations were present in both cells. The injection wells were installed to the depth of the gravel/clay interface. The recovery wells were set 4 ft into the clay layer. The control plot was located to the west of the test plot. In the test plot, the injection wells were on the west side of the cell (nearest the control plot) and the recovery wells on the east side of the cell (away from the control plot). This layout was reversed for the control plot. This configuration resulted in cross-gradient flow patterns within each cell (east to west in the control plot and west to east in the test plot) and groundwater flow in each cell that was moving in an opposite direction to that in the adjacent cell. The mounding created by the injection wells in the control plot prevented the amendments from the test plot from being introduced into the control plot cell. The final location, layout, and cross-sectional schematic of the control and test plot cells are shown in Figure 15.

An injection skid was designed to be integrated with the wells. The injection skid had separate transfer tanks, injection pumps, flow meters, and associated valves for the control and test plots. In addition, the test plot had two metering pumps installed to inject a pH solution and an electron donor-reagent to promote optimal aquifer conditions and stimulate biological activity. The injection skid was located between the control and test plots.

## **Pilot System Installation**

The injection and recovery wells were installed using a standard hollow stem auger drilling rig equipped with 10.25-inch outside diameter augers. Both the injection and recovery wells were constructed using 6-inch I.D. schedule 40 PVC. The injection wells were installed with approximately 8 ft of screen (0.010-inch slot) set at the gravel/clay interface. The recovery wells were installed with approximately 15-ft screens (0.010-inch slot) set 4 ft into the clay layer. A sand pack was placed around each screened section, and a bentonite plug (approximately 2 ft thick for the recovery wells and 4 to 5 ft thick for the injection wells) was placed above the sand pack. The extra seal thickness was used for the injection wells to ensure that the injected fluid was not rejected up the annular space of the borehole and was directed into the formation.

The nested and fully penetrating monitoring wells were installed using the same hollow stem auger drilling and installation methods as described previously for monitoring wells MW-1 through MW-6. The wells were constructed using 2-inch I.D. schedule 40 PVC well casing and screen materials. Screen lengths (0.010-inch slot) varied from approximately 7 to 8 ft long for the shallow nested wells, 2.5 to 3 ft long for the deep nested wells, and 10 to 11 ft long for the fully penetrating wells. A sand filter pack was placed around the screened sections and a 2-ft-thick bentonite seal was placed around the upper portion of the well casing to prevent fluid infiltration or loss.

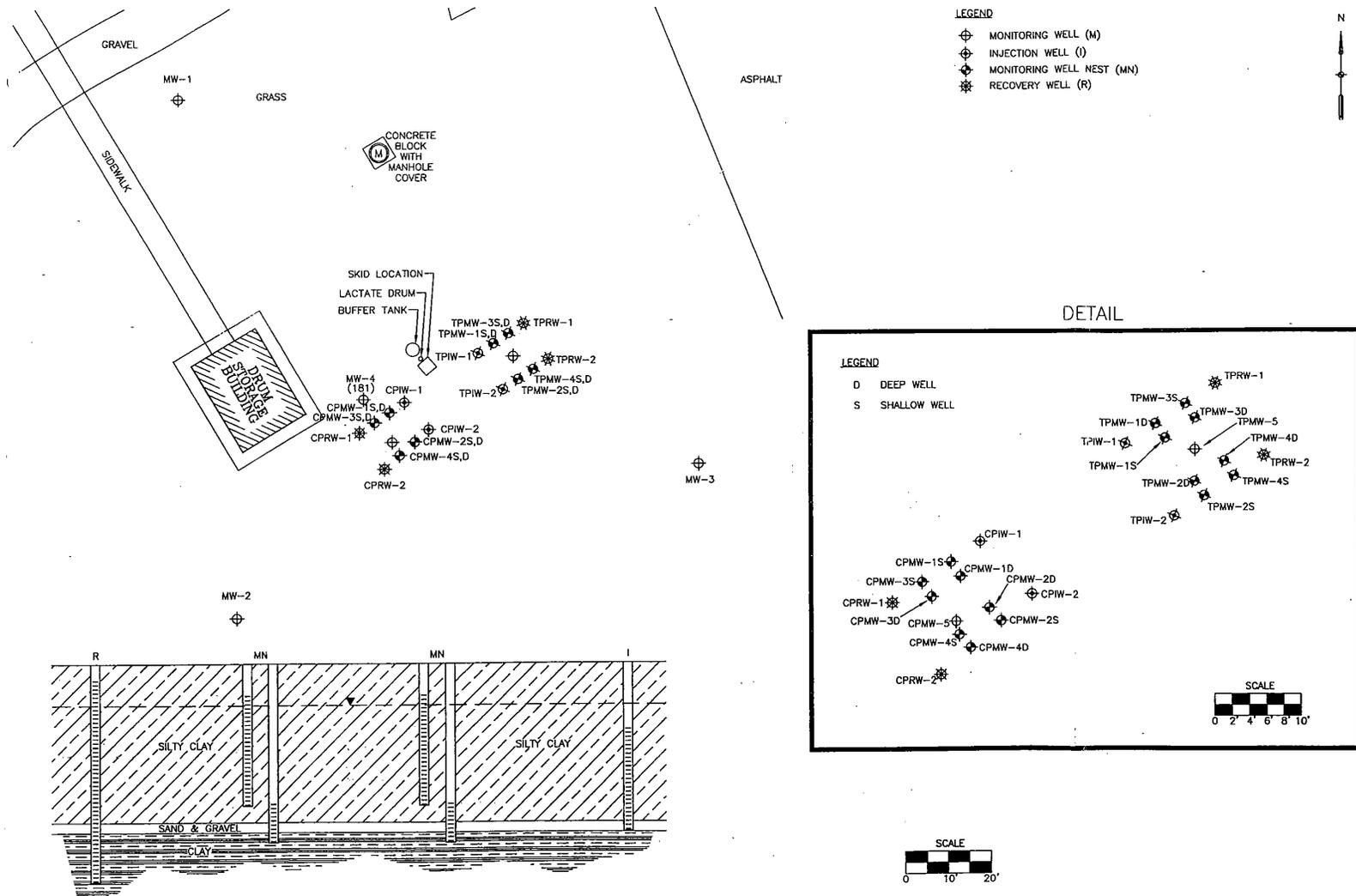


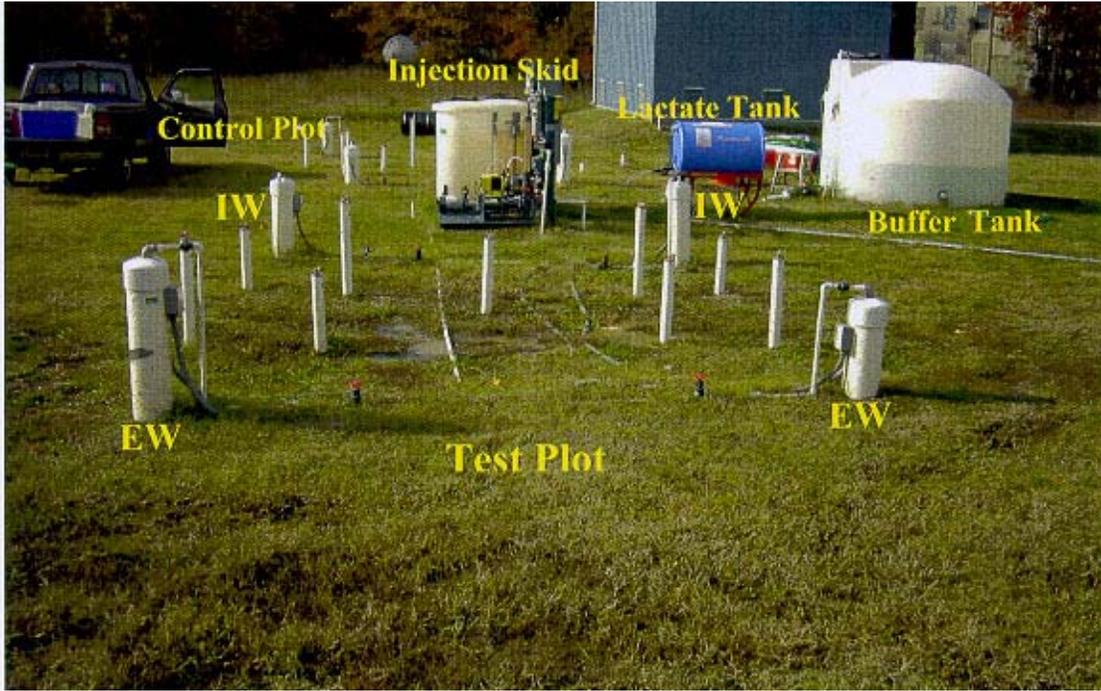
Figure 15. Recirculation Cell Layouts and Schematic Cross-Section View

The injection skid was fabricated off-site and delivered to the site in early July 2002. One-inch PVC piping was used to connect all the extraction/injection wells to the injection skid. The groundwater extraction pumps were installed and adjusted to pump at approximately 0.25 gal/min each. High-level and low-level floats were installed in each well to turn the pumps on and off if the extraction rate exceeded the recharge rate, causing significant drawdown. The injection pump was set to operate at approximately 1 gal/min per injection well.

The pH buffer tank (1,500-gal polyethylene tank) was filled with groundwater extracted from this site. Site water was used to prepare the buffer to ensure that there was no dilution in perchlorate levels in the test plot during buffer injection. A special line was run from the extraction wells to the buffer tank so that water could be periodically diverted to fill the tank. All piping runs and controls were configured to minimize the potential for aeration of the recirculated groundwater. The buffering agents were food-grade sodium bicarbonate and sodium carbonate (see the “System Operation” section). Once the pH buffer tank was filled, the extracted groundwater was diverted to the injection skid and re-injected in the test and control plot areas. The pH buffer tank was connected to the metering pump by 1/2-inch PVC pipe. IHDIV personnel installed the electrical service at the site. A 60-A, 230-V, single-phase service was provided for use on this project. The injection skid and the recirculation cells are shown in Figures 16 and 17.



**Figure 16. Control Panel and Treatment Skid**



**Figure 17. Recirculation Cells and Components**

## FIELD DEMONSTRATION RESULTS

### Tracer Test

A conservative tracer test was performed on 25 July 2002 to determine if each of the monitoring wells installed in the test plot was hydraulically connected with the injection wells where buffer and electron donor were introduced into the formation. To perform this test, approximately 80 gal of groundwater was pumped from the treatment plot into a holding tank and then amended with sodium bromide to achieve a final bromide concentration of 250 mg/L. The bromide solution was then added as a slug to each of the two injection wells at a flow rate of approximately 2 gal/min. Each well received approximately 40 gal of bromide solution. Samples were collected from the bromide tank prior to injection, and then from each of the nine monitoring wells in the test plot (TPMWs) after 1, 5, and 15 days. Samples were also analyzed for bromide during all subsequent groundwater monitoring events. All samples were measured for bromide by ion chromatography (EPA Method 300.0).

The bromide results are presented in Table V. Bromide was detected ( $> 0.2$  mg/L) in four of the nine TPMWs after 1 day and in seven of the nine wells after 5 days of system operation. The remaining two wells showed bromide concentrations above background levels by day 15 and 25 of operation for wells TPMW-4s and TPMW-2d, respectively. Thus, the results of this test suggest that all wells in the test plot are hydraulically connected to the zone where buffer and electron donor are added to the aquifer.

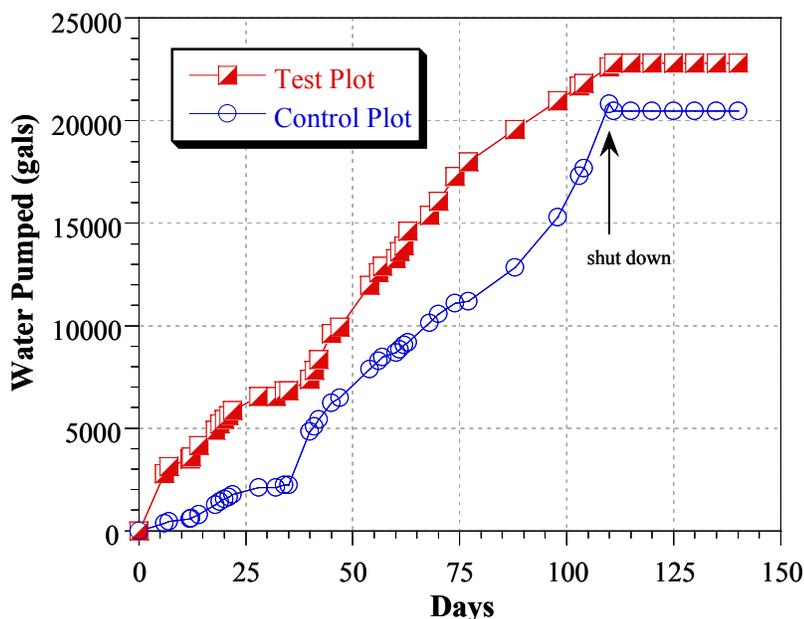
**Table V. Bromide Values in the Test Plot with Time**

Date	Day	Bromide (mg/L)								
		TPMW-1s	TPMW-1d	TPMW-2s	TPMW-2d	TPMW-3s	TPMW-3d	TPMW-4s	TPMW-4d	TPMW-5
7/18/02	-7	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
7/26/02	1	1.6	3.3	< 0.2	< 0.2	1.5	< 0.2	< 0.2	< 0.2	0.77
7/30/02	5	1.1	1.5	2.8	< 0.2	1.5	1.5	< 0.2	0.6	3.9
8/9/02	15	6.8	< 0.2	< 0.2	< 1.0	< 1.0	< 0.2	0.8	< 0.2	1.1
8/19/02	25	0.5	< 0.2	0.3	2.7	7.1	1.8	4.4	33	38
10/3/02	70	< 0.2	< 0.2	2	1.4	< 0.2	< 0.2	1.9	< 0.2	0.7
11/7/02	105	< 0.2	0.64	0.23	< 0.2	0.55	0.6	0.41	0.58	< 0.2
12/12/02	140	0.32	0.54	0.22	< 0.2	0.21	0.28	0.37	0.36	< 0.2

### System Operation

A total volume of approximately 20,000 gal of groundwater was recirculated through each plot during the course of the 140-day demonstration (Figure 18). The recirculation system was shut down after 111 days of operation, and one additional sampling event was performed on day 140 to examine the residual effect of buffer and electron donor added to the aquifer. During

the first month of the demonstration, the rate of water recirculation through the test plot was appreciably higher than through the control plot. During this period, approximately 6,500 gal of water were pumped through the test plot compared to 2,100 gal for the control plot. This difference was based on the yield of the aquifer formation in each of these zones. After this time, however, the rate of pumping of the two plots was reasonably similar, as can be seen from the slope of the curves in Figure 18. Increased rainfall in the late summer and early fall, including more than 2.3 inches on 28 August, caused significant aquifer recharge and subsequently increased pumping rates during the demonstration. On 11 November 2002, the groundwater injection rates could no longer be sustained due to the high water table resulting from rainfall in October and early November (nearly 6 inches of rain fell during this period). The system was shut down at this time, which was near the end of the planned period for the demonstration. Rainfall data at IHDIIV during the course of the demonstration are provided in Appendix C. Over the course of the entire demonstration, approximately 180 gal of water per day was recirculated through each cell.



**Figure 18. Groundwater Volumes Recirculated through the Test Plot and the Control Plot During the Demonstration**

The groundwater pumped from both plots was stored in separate holding tanks until approximately 40 gal was collected, at which time the water was reinjected into the test or control plot at approximately 2 gal/min (~ 1 gal/min per well). The test plot water was amended with electron donor and buffer during the reinjection process. The electron donor was a 60% solution (wt/wt) of food-grade L-(+) lactic acid (sodium salt) supplied by Purac America Inc., Lincolnshire, IL. The sodium lactate syrup, which is neutral in pH, is commonly used as an antimicrobial agent in food products. The concentrated buffer solution consisted of a 6.67% mixture containing either 80% bicarbonate (from NaHCO<sub>3</sub>) and 20% carbonate (from Na<sub>2</sub>CO<sub>3</sub>) or 70% bicarbonate and 30% carbonate. The sodium carbonate and sodium bicarbonate were food-grade products purchased from Seidler Chemical Co., Newark, NJ.

The buffer pump was set to amend each 40 gal of groundwater with approximately 2,500 ppm of the carbonate/bicarbonate mixture during re-injection. At two times during the early operation of the system (on days 19 and 35) approximately 250 gal of buffer was added to the aquifer. After each of these additions, the buffer pump was turned off and water was re-circulated for approximately 1 week through the test plot to disperse the buffer amendment throughout the formation. During the course of the demonstration, 1,175 gal of buffer was added to the aquifer. Approximately 875 gal of this buffer was a 6.67% solution containing 80% bicarbonate and 20% carbonate. The other 300 gal was a 6.67% solution containing a mixture of 70% bicarbonate and 30% carbonate. The latter solution, with a slightly higher ratio of carbonate, was added to the aquifer 1 month after the beginning of the demonstration to increase the rate at which the aquifer was buffered. After the 300-gal addition was complete, the mixture was returned to an 80% bicarbonate and 20% carbonate mixture for the remainder of the demonstration.

The lactate pump was set to supply electron donor at a flow rate of approximately 4.5 mL/min during reinjection of groundwater. Based on an injection time of 20 min per 40 gal of groundwater, the concentration of lactate added to the injected water was expected to be approximately 380 mg/L. This concentration of lactate was calculated to provide a reasonable excess of electron donor in the formation based on the average concentrations of oxygen, nitrate, and perchlorate present throughout the test plot. An additional dose of electron donor (~ 3 gal) was added to the aquifer during the early operation of the system on two occasions (on days 19 and 35) in conjunction with the extra buffer addition. The lactate pump was turned off and the groundwater was recirculated for 1 week to mix the electron donor after each of these additions. A total volume of 91 L (24 gal) of the 60% lactate solution was added to the aquifer during the demonstration period (i.e., an average of 0.22 gal/day). A total weight of 58 kg of lactate was added during the 111-day study.

The pH and alkalinity of the water within the test plot were monitored throughout the demonstration to evaluate the effectiveness of the buffer addition to the aquifer. The concentrations of lactate and perchlorate as well as nitrate and sulfate were measured with time to assess the distribution and effectiveness of electron donor amendment to the aquifer for perchlorate remediation. The analytical results are summarized in the “Analytical Methods and Results” section.

## **Groundwater Sampling**

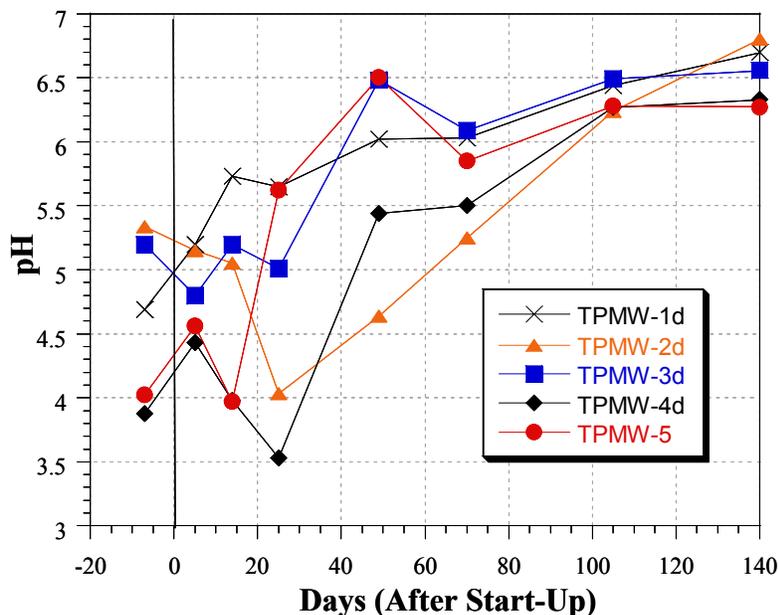
Baseline groundwater samples were collected from the test and control plots 69 days (10 weeks) and 7 days (1 week) prior to the startup of the injection system. During the demonstration, samples were taken from all nine monitoring wells in the test plot on days 14, 25, 49, 70, 105, and 140. The control plot wells were sampled on days 14, 49, 105, and 140. Each well received dedicated sampling tubing at the start of the demonstration. The wells were sampled using a peristaltic pump, and each well was purged for 25 to 30 min prior to sampling. During most of the sampling events, a YSI 600 XL water quality meter with a flow cell was used to determine that key parameters (e.g., pH, conductivity) were stable prior to sample collection.

## ANALYTICAL METHODS AND RESULTS

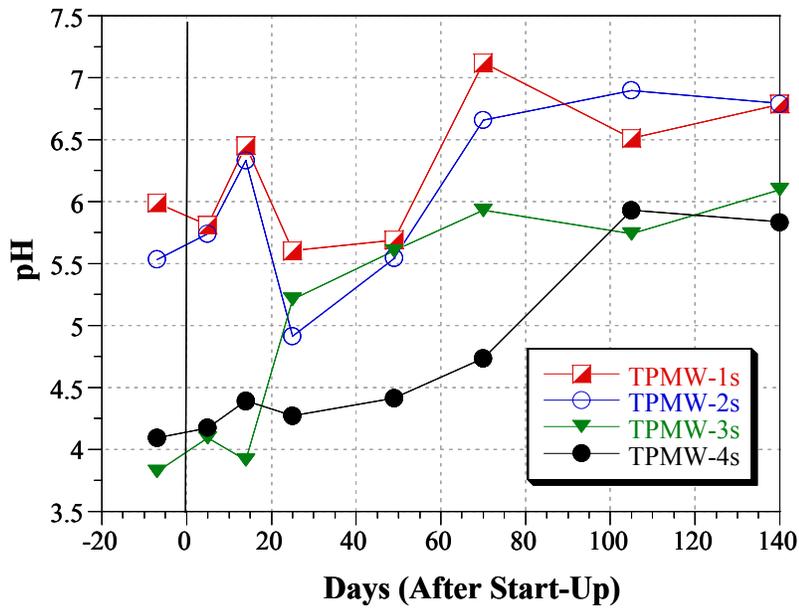
Summary results for each significant parameter measured are provided in subsequent sections.

### pH and Alkalinity

The pH of groundwater in the test and control plots was measured using a field probe (YSI 600XL water quality meter) during sample collection and in the laboratory by EPA Method 150.1. Alkalinity was measured by titration according to EPA Method 310.1. The pH of the groundwater in each of the nine TPMWs was observed to increase significantly during the course of the 140-day demonstration (Figures 19 and 20 and Table VI). For example, the pH in TPMW-5 increased from 4.02 seven days before the start of the demonstration to 6.28 at day 105, just before the system was shut down. At day 140, 4 weeks after the injection system was shut off, the pH in this well remained at 6.27. Conversely, there was no appreciable and consistent change in the pH of the control plot monitoring wells (CPMWs) during the active demonstration (Figure 21 and Table VII).



**Figure 19. pH Values in Deep TPMWs During the Field Demonstration**

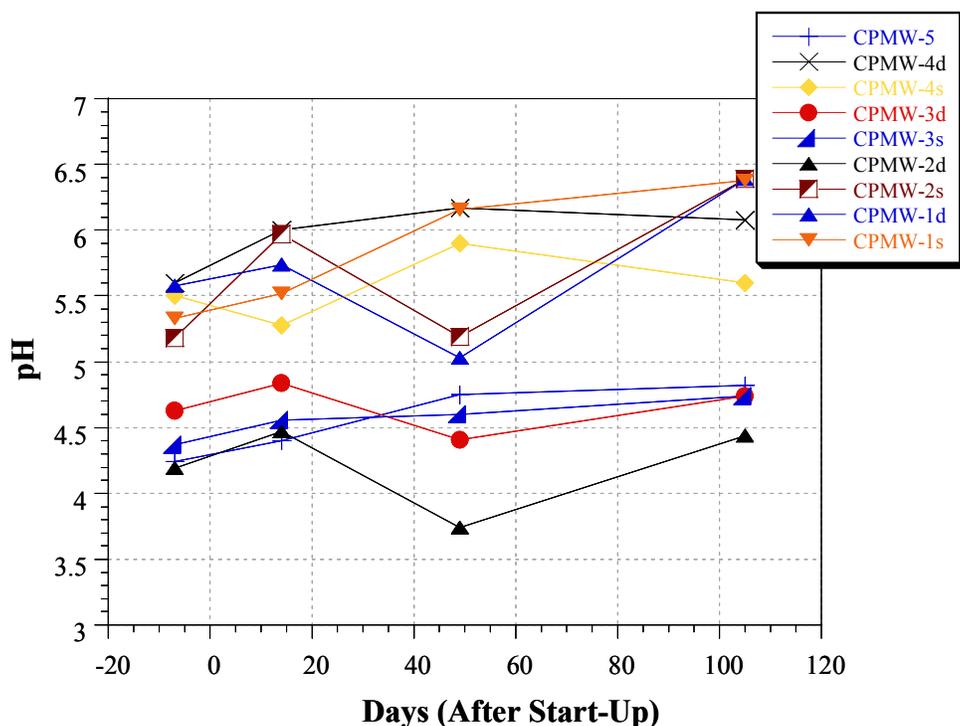


**Figure 20. pH Values in Shallow TPMWs During the Field Demonstration**

**Table VI. pH in the Test Plot with Time**

Date	Day	pH <sup>a</sup> at—								
		TPMW-1s	TPMW-1d	TPMW-2s	TPMW-2d	TPMW-3s	TPMW-3d	TPMW-4s	TPMW-4d	TPMW-5
7/18/02	-7	5.99	4.69	5.53	5.34	3.82	5.2	4.09	3.88	4.02
7/30/02	5	<b>5.81</b>	<b>5.2</b>	<b>5.74</b>	<b>5.15</b>	<b>4.09</b>	<b>4.8</b>	<b>4.17</b>	<b>4.43</b>	<b>4.56</b>
8/8/02	14	<b>6.45</b>	<b>5.73</b>	<b>6.33</b>	<b>5.05</b>	<b>3.91</b>	<b>5.2</b>	<b>4.39</b>	<b>3.98</b>	<b>3.97</b>
8/19/02	25	5.6	5.65	4.91	4.03	5.21	5.01	4.27	3.53	5.62
8/19/02	25	<b>6.32</b>	<b>6.14</b>	<b>5.3</b>	<b>4.46</b>	<b>5.54</b>	<b>5.29</b>	<b>4.55</b>	<b>3.85</b>	<b>5.97</b>
9/12/02	49	5.69	6.02	5.54	4.64	5.6	6.48	4.41	5.44	6.5
9/12/02	49	<b>5.78</b>	<b>6.34</b>	<b>5.82</b>	<b>4.62</b>	<b>5.9</b>	<b>6.42</b>	<b>4.79</b>	<b>5.76</b>	<b>6.46</b>
10/3/02	70	7.12	6.03	6.66	5.25	5.93	6.09	4.73	5.5	5.85
11/7/02	105	<b>6.51</b>	<b>6.44</b>	<b>6.9</b>	<b>6.24</b>	<b>5.74</b>	<b>6.49</b>	<b>5.93</b>	<b>6.27</b>	<b>6.28</b>
12/12/02	140	<b>6.79</b>	<b>6.7</b>	<b>6.79</b>	<b>6.8</b>	<b>6.1</b>	<b>6.56</b>	<b>5.83</b>	<b>6.33</b>	<b>6.27</b>

<sup>a</sup>Values in bold are laboratory measurements (EPA 150.1) and those in plain text are field probe values.



**Figure 21. pH Values in the CPMWs During the Field Demonstration**

**Table VII. pH in the Control Plot with Time**

Date	Day	pH <sup>a</sup> at—								
		CPMW-1s	CPMW-1d	CPMW-2s	CPMW-2d	CPMW-3s	CPMW-3d	CPMW-4s	CPMW-4d	CPMW-5
7/18/02	-7	5.33	5.58	5.18	4.19	4.37	4.63	5.5	5.6	4.24
8/8/02	14	<b>5.52</b>	<b>5.74</b>	<b>5.97</b>	<b>4.47</b>	<b>4.56</b>	<b>4.84</b>	<b>5.28</b>	<b>6</b>	<b>4.4</b>
9/12/02	49	6.16	5.03	5.19	3.74	4.6	4.41	5.9	6.17	4.75
9/12/02	49	<b>6.4</b>	<b>5.75</b>	<b>6.08</b>	<b>4.43</b>	<b>5.05</b>	<b>4.6</b>	<b>5.48</b>	<b>5.93</b>	<b>4.6</b>
11/7/02	105	<b>6.38</b>	<b>6.39</b>	<b>6.39</b>	<b>4.44</b>	<b>4.74</b>	<b>4.74</b>	<b>5.6</b>	<b>6.08</b>	<b>4.82</b>
12/12/02	140	<b>6.2</b>	<b>6.43</b>	<b>6.33</b>	<b>5.02</b>	<b>6.28</b>	<b>5.66</b>	<b>5.93</b>	<b>5.8</b>	<b>4.8</b>

<sup>a</sup>Values in bold are laboratory measurements (EPA 150.1) and those in plain text are field probe values.

The alkalinity in each of the wells also showed a marked increase as buffer was added (Tables VIII and IX). The alkalinity in each of the TPMWs reached in excess of 480 mg/L during the course of the study. For example, the alkalinity in TPMW-5 increased from less than 2 mg/L (as CaCO<sub>3</sub>) prior to the demonstration to 1,600 mg/L on day 105. The data show that the addition of the carbonate/bicarbonate buffer caused an appreciable increase in the alkalinity and the pH of the aquifer underlying the test plot.

**Table VIII. Alkalinity Values in the Test Plot with Time**

Date	Day	Alkalinity (mg/L) at—								
		TPMW-1s	TPMW-1d	TPMW-2s	TPMW-2d	TPMW-3s	TPMW-3d	TPMW-4s	TPMW-4d	TPMW-5
7/18/02	-7	92	5.4	60	15	< 2.0	16	< 2.0	< 2.0	< 2.0
8/19/02	25	508	200	91	3.9	130	95	14	< 4.0	640
9/12/02	49	160	530	220	69	240	600	49	470	162
10/3/02	70	3200	370	1670	270	710	690	64	320	410
11/7/02	105	680	390	390	740	250	720	480	1040	1600
12/12/02	140	1240	340	1420	150	590	490	340	510	600

**Table IX. Alkalinity Values in the Control Plot with Time**

Date	Day	Alkalinity (mg/L) at—								
		CPMW-1s	CPMW-1d	CPMW-2s	CPMW-2d	CPMW-3s	CPMW-3d	CPMW-4s	CPMW-4d	CPMW-5
9/12/02	49	150	59	84	20	20	25	34	120	20
11/7/02	105	120	110	89	2	5.9	5.9	26	29	3.9
12/12/02	140	110	110	110	7.9	20	7.9	28	31	7.9

## Lactate

Lactate was measured in groundwater samples collected from the test plot using ion chromatography. The samples were analyzed on a Dionex DX-600 ion chromatograph equipped with a Dionex IonPac AS11-HC column. The sample method utilizes a gradient of sodium hydroxide increasing from 1 to 60 mM over a 40-min run time. Complete method details are described in Dionex Application Note 123 “The Determination of Inorganic Anions and Organic Acids in Fermentation Broths.” To ensure that lactate was not biodegraded prior to analysis, groundwater samples (20-mL volume) were passed through sterile 0.22- $\mu$ m-pore-size cellulose acetate filters in the field. The water was collected in sterile 50-mL conical tubes and stored at 4 °C until analysis.

Lactate was detected in groundwater from seven of nine TPMWs by day 14, and all wells had measurable concentrations of lactate by day 25 (Table X). The lactate levels varied somewhat by well and with time; however, the electron donor was detected consistently above 10 ppm in eight of the nine wells during the course of the demonstration, and each of the eight wells had levels exceeding 100 ppm at one or more sample points. At the end of the demonstration period on day 140, 29 days after system shut-down on Day 111, lactate was below detection in seven of nine TPMWs. Among the test plot wells tested during the demonstration, TPMW-1d generally had the lowest concentration of lactate (< 7 ppm on five of six samplings), and the groundwater collected from this well never exceeded 21 ppm lactate. This was also the one well in which perchlorate levels declined only marginally (43%) during the demonstration (see below) and in which nitrate never declined below 1 ppm. Thus, the data suggest that either

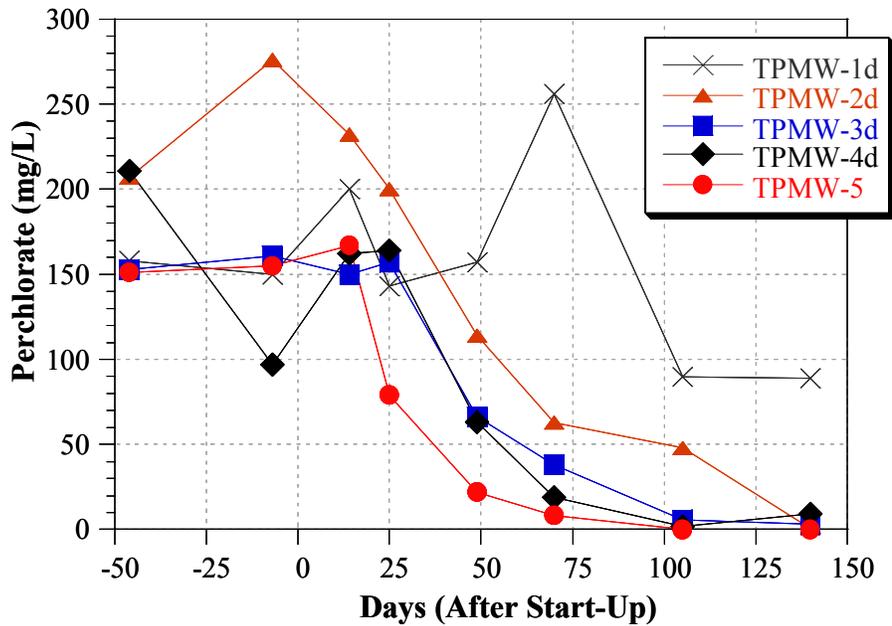
the electron donor did not reach the area surrounding this well at high enough concentrations to support complete reduction of perchlorate, or the electron donor was rapidly consumed by biological processes other than perchlorate reduction (i.e., denitrification and aerobic respiration). The latter process could have occurred if “new” water (containing oxygen and nitrate) was entering the treatment zone preferentially near this well. The presence of oxygen and nitrate would inhibit perchlorate reduction and cause excess consumption of lactate. The close proximity of this well to one of the treatment plot injection wells could have impacted water flow in this region, causing water from outside the treatment area to enter the region surrounding the well preferentially.

**Table X. Lactate Values in the Test Plot with Time**

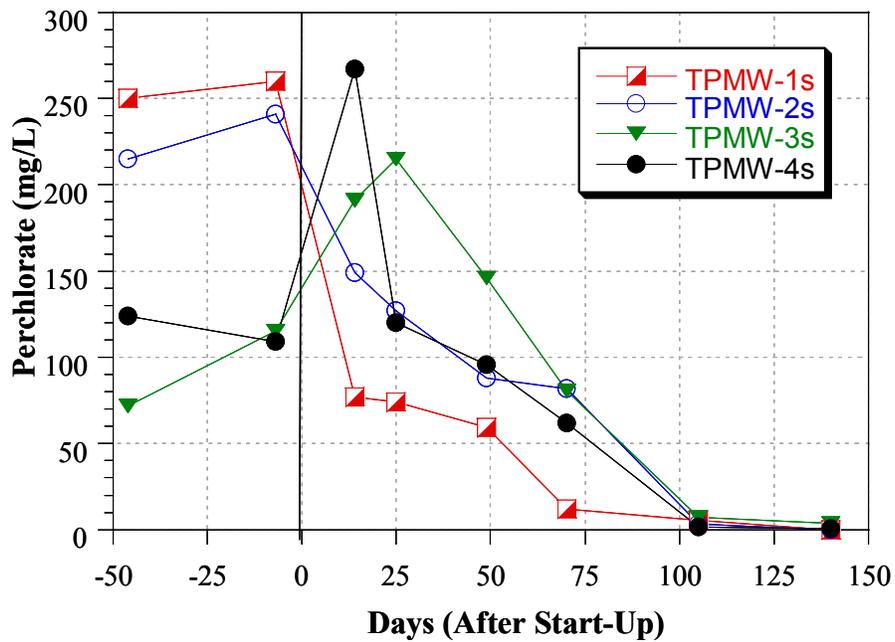
Date	Day	Lactate (mg/L) at—								
		TPMW-1s	TPMW-1d	TPMW-2s	TPMW-2d	TPMW-3s	TPMW-3d	TPMW-4s	TPMW-4d	TPMW-5
8/8/02	14	139	6	34	37	249	249	< 0.5	< 0.5	376
8/19/02	25	15	21	96	35	85	463	652	562	390
9/12/02	49	38	3.8	68	248	97	159	44	297	114
10/3/02	70	410	2.2	170	21	15	130	12	40	11
11/7/02	105	83	0.18	56	16	2.9	35	21	7.1	15
12/12/02	140	110	< 0.5	230	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5

## Perchlorate

Perchlorate in groundwater was analyzed according to EPA Method 314.0. Perchlorate levels throughout the test plot showed a steady decline during the 5-month field demonstration (Figures 22 and 23 and Table XI). During the two baseline sampling events (69 and 7 days before system startup), perchlorate levels ranged from a low of 72 mg/L in well TPMW-3s to a high of 276 mg/L in TPMW-2d. The average perchlorate level in the test plot was 171 mg/L on 10 May (69 days prior to startup) and 174 mg/L on 18 July (7 days prior to startup). By the end of the 20-week demonstration, perchlorate levels in two test wells (TPMW-1s and TPMW-2s) were below the practical quantitation limit (PQL) of 5 µg/L, one well was less than 20 µg/L (TPMW-5), and two additional wells were less than 1 mg/L. The reduction in aqueous perchlorate from the start of the demonstration was in excess of 99% for each of these wells. Of the remaining four wells in the test plot, two displayed perchlorate concentrations of less than 3.7 mg/L (TPMW-3s and TPMW-3d) at the end of the demonstration, and one (TPMW-4d) was less than 10 mg/L. However, perchlorate in groundwater from TPMW-4d had reached levels as low as 2 mg/L during system operation. The percent reduction in perchlorate in each of these wells exceeded 95% from the start to the end of the demonstration. The only well in which perchlorate levels did not decline precipitously during the demonstration was TPMW-1d. Perchlorate levels fell by only 43% in this well, ending at approximately 90 mg/L after 140 days. As previously noted, this well consistently had the lowest concentration of electron donor, and the highest residual nitrate levels during the demonstration. It is likely that the flow pattern in the vicinity of this well continually introduced water from outside of the treatment area.



**Figure 22. Perchlorate Levels in Deep TPMWs During the Field Demonstration**

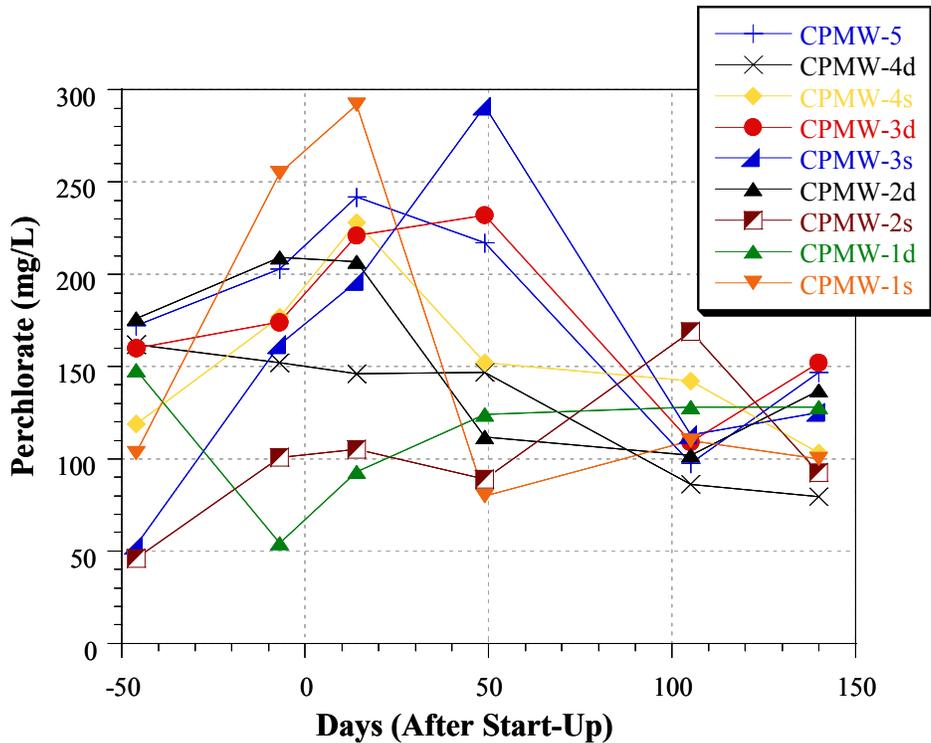


**Figure 23. Perchlorate Levels in Shallow TPMWs During the Field Demonstration**

**Table XI. Perchlorate Concentrations in the Test Plot with Time**

Date	Day	Perchlorate (mg/L) at—								
		TPMW-1s	TPMW-1d	TPMW-2s	TPMW-2d	TPMW-3s	TPMW-3d	TPMW-4s	TPMW-4d	TPMW-5
5/10/02	-69	250	158	215	207	72	153	124	211	151
7/18/02	-7	260	150	241	276	115	161	109	97	155
8/8/02	14	77	200	149	232	191	150	267	161	167
8/19/02	25	74	143	127	190	234	160	125	154	93
9/12/02	49	59.2	157	87.7	114	149	66.3	95.9	63.5	22.2
10/3/02	70	12.1	256	81.6	62.9	80.5	32.7	61.9	19	8.3
11/7/02	105	5.5	89	3.3	64	7.2	10.6	1.7	2	0.2
12/12/02	140	< 0.005	89.9	< 0.005	0.89	3.65	3.3	0.815	9.19	0.0196

Unlike the test plot, there was no consistent reduction in perchlorate levels in any of the wells in the control plot during the demonstration period (Figure 24 and Table XII). The average perchlorate concentration in the nine CPMWs 69 days prior to system startup was 127 mg/L, and after 140 days of system operation, the concentration was 118 mg/L. A similar amount of water was re-circulated through both plots during the demonstration, but the water in the control plot received no amendments.



**Figure 24. Perchlorate Levels in CPMWs During the Field Demonstration**

**Table XII. Perchlorate Concentrations in the Control Plot with Time**

Date	Day	Perchlorate (mg/L) at—								
		CPMW-1s	CPMW-1d	CPMW-2s	CPMW-2d	CPMW-3s	CPMW-3d	CPMW-4s	CPMW-4d	CPMW-5
5/10/02	-69	103	148	46	176	53	160	119	162	172
7/18/02	-7	255	54.5	101	209	162	174	177	152	203
8/8/02	14	292	93.2	105	207	196	221	228	146	242
9/12/02	49	79.9	124	89	112	291	232	152	147	217
11/7/02	105	110	128	169	102	113	109	142	86.3	97.5
12/12/02	140	100	128	92.3	137	125	152	103	79.5	147

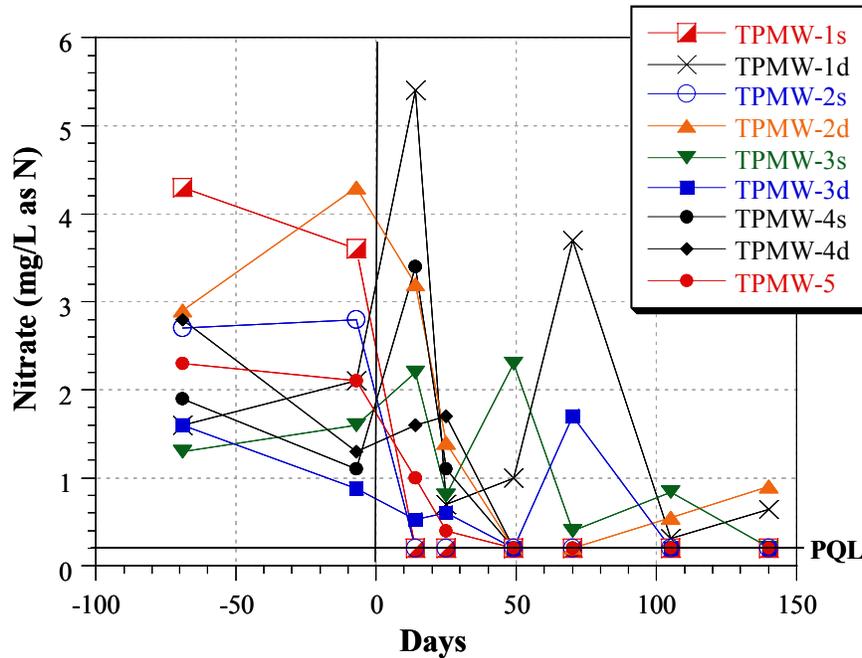
The data from the demonstration clearly show that the addition of buffer and electron donor to the test plot stimulated the microbial reduction of perchlorate in the aquifer. Losses of perchlorate to dilution or any other abiotic process would have been observed in both plots. The data also show that even in an acidic aquifer with extremely high perchlorate levels, in situ biological reduction can effectively reduce perchlorate concentrations to less than 5 µg/L in a reasonably short period. Although a treatment level of 5 µg/L for perchlorate was not achieved in every well, a reduction in perchlorate levels exceeding 95% was observed in eight of the nine TPMWs, including those screened in the shallow, less conductive zone in the aquifer. Based on the trends of perchlorate removal observed during the demonstration, it is likely that many of the other TPMWs would have reached non-detect levels of perchlorate with additional time of system operation.

## Nitrate and Sulfate

Although the focus of this demonstration was the biological reduction of perchlorate, levels of other common electron acceptors, including nitrate and sulfate, were monitored. Nitrate reduction (i.e., denitrification) occurs by a biological process similar to perchlorate reduction and generally occurs prior to perchlorate degradation. Nitrate is a regulated pollutant in the U.S., although the Federal Regulatory Level is 10 ppm, much higher than that anticipated for perchlorate (i.e., 1 to 6 µg/L). The biological reduction of sulfate occurs after perchlorate reduction and produces hydrogen sulfide, which has a “rotten egg” odor that is undesirable in groundwater. Thus, one goal of in situ treatment systems for perchlorate and/or nitrate is to mix and distribute electron donor effectively so that sulfate reduction is minimized after reduction of the previous two electron acceptors is complete. This is readily accomplished in ex situ treatment systems (such as biological reactors), but more difficult in in situ applications.

Nitrate and sulfate were measured in groundwater samples by EPA Method 300. The levels of nitrate in the test plot declined rapidly in several wells (Figure 25 and Table XIII). The levels of this contaminant average slightly above 2 mg/L as nitrate-N prior to the investigation in the test plot. Nitrate was below detection (< 0.2 mg/L nitrate-N) in seven of nine TPMWs by day 49 of the study. As noted for perchlorate, TPMW-1d showed the slowest decline in nitrate concentrations. The starting levels of nitrate in the control plot wells were somewhat higher than in the test plot, averaging above 7 mg/L as nitrate-N at the commencement of the study. However, although there was some variability in nitrate levels from point to point in each well,

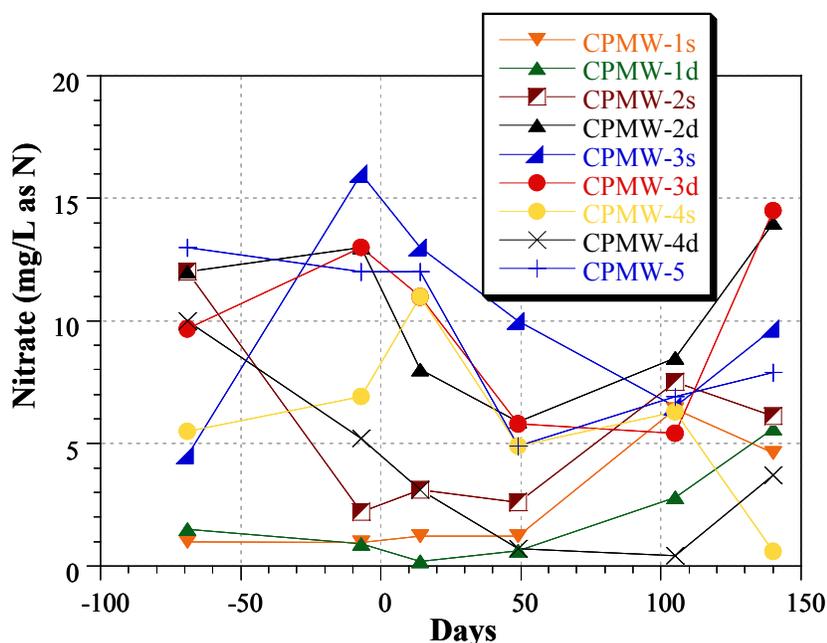
there was no consistent reduction in nitrate levels across the control plot during the demonstration (Figure 26 and Table XIV). After 140 days, the average concentration among the nine wells remained above 7 mg/L as nitrate-N.



**Figure 25. Nitrate Levels in the Test Plot During the Field Demonstration**

**Table XIII. Nitrate-N Concentrations in the Test Plot with Time**

Date	Day	Nitrate-N (mg/L) at—								
		TPMW-1s	TPMW-1d	TPMW-2s	TPMW-2d	TPMW-3s	TPMW-3d	TPMW-4s	TPMW-4d	TPMW-5
5/10/02	-69	4.3	1.6	2.7	2.9	1.3	1.6	1.9	2.8	2.3
7/18/02	-7	3.6	2.1	2.8	4.3	1.6	0.88	1.1	1.3	2.1
8/8/02	14	< 0.2	5.4	< 0.2	3.2	2.2	0.52	3.4	1.6	1
8/19/02	25	< 0.2	0.7	< 0.2	1.4	0.8	0.6	1.1	1.7	0.4
9/12/02	49	< 0.2	1.0	< 0.2	< 0.2	2.3	< 0.2	< 0.2	< 0.2	< 0.2
10/3/02	70	< 0.2	3.7	< 0.2	< 0.2	0.4	1.7	< 0.2	< 0.2	< 0.2
11/7/02	105	< 0.2	0.31	< 0.2	0.55	0.84	< 0.2	< 0.2	< 0.2	< 0.2
12/12/02	140	< 0.2	0.64	< 0.2	0.9	0.21	< 0.2	< 0.2	< 0.2	< 0.2

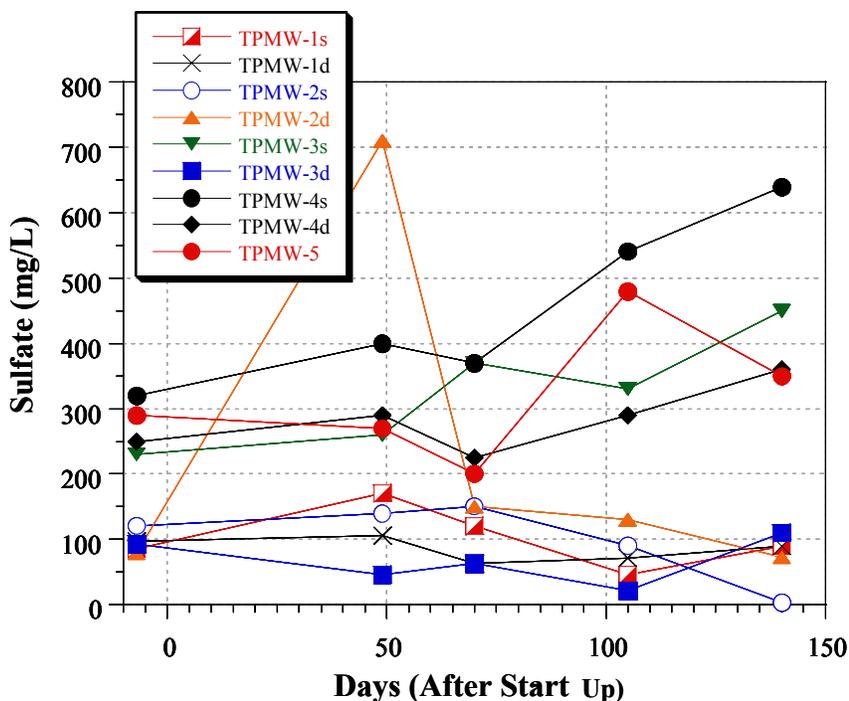


**Figure 26. Nitrate Levels in the Control Plot During the Field Demonstration**

**Table XIV. Nitrate-N Concentrations in the Control Plot with Time**

Date	Day	Nitrate-N (mg/L) at—								
		CPMW-1s	CPMW-1d	CPMW-2s	CPMW-2d	CPMW-3s	CPMW-3d	CPMW-4s	CPMW-4d	CPMW-5
5/10/02	-69	1	1.5	12	12	4.5	9.7	5.5	10	13
7/18/02	-7	0.96	0.9	2.2	13	16	13	6.9	5.2	12
8/8/02	14	1.2	< 0.2	3.1	8	13	11	11	3.1	12
9/12/02	49	1.2	0.61	2.6	5.9	10	5.8	4.9	0.7	4.9
11/7/02	105	6.4	2.8	7.5	8.5	6.5	5.4	6.3	0.42	6.9
12/12/02	140	4.6	5.6	6.1	14	9.7	14.5	0.58	3.7	7.9

There was a slight odor of hydrogen sulfide detected in some of the test plot wells during the demonstration, and the presence of a black precipitate was observed in a few wells on these occasions (presumably iron sulfide). During the short demonstration time, the goal was to supply adequate electron donor to achieve nitrate and perchlorate reduction, rather than to tightly control the process. If the demonstration were conducted for a longer period, the level of excess electron donor could have been minimized further. However, overall, the level of sulfate reduction in the test plot was not significant based on sulfate measurements (Figure 27 and Tables XV and XVI). The average concentration at the start of the demonstration in the nine TPMWs was 174 mg/L, and at the end of the demonstration the average was 240 mg/L. The only well that showed a significant decrease in sulfate concentration was TPMW-2s, but this was based on one point collected at day 140. Levels were normal at the previous sampling time on day 105.



**Figure 27. Sulfate Levels in the Test Plot During the Field Demonstration**

**Table XV. Sulfate Concentrations in the Test Plot with Time**

Date	Day	Sulfate (mg/L) at—								
		TPMW-1s	TPMW-1d	TPMW-2s	TPMW-2d	TPMW-3s	TPMW-3d	TPMW-4s	TPMW-4d	TPMW-5
7/18/02	-7	85	97	120	79	230	93	320	250	290
9/12/02	49	170	106	140	710	260	46	400	290	270
10/3/02	70	120	63	150	150	370	63	370	225	200
11/7/02	105	46	71	91	130	330	21	540	290	480
12/12/02	140	89	89	3.7	72	450	110	640	360	350

**Table XVI. Sulfate Concentrations in the Control Plot with Time**

Date	Day	Sulfate (mg/L) at—								
		CPMW-1s	CPMW-1d	CPMW-2s	CPMW-2d	CPMW-3s	CPMW-3d	CPMW-4s	CPMW-4d	CPMW-5
9/12/02	49	67	89	150	99	60	68	105	77	110
11/7/02	105	99	120	110	99	120	95	130	82	110
12/12/02	140	120	110	150	86	109	74	79	150	120

## CONCLUSIONS

This study represents one of the first successful field demonstrations of in situ perchlorate bioremediation in a groundwater aquifer. To our knowledge, this is the first field trial conducted on the East Coast of the United States, the first trial performed in an acidic aquifer, and the first demonstration that perchlorate levels in excess of 200 mg/L can be treated in situ. Thus, we believe that this project provides new and valuable information concerning the application of bioremediation for in situ perchlorate treatment.

The general conclusions from this field demonstration are as follows:

1. The acidic aquifer in the vicinity of Building 1419 was effectively buffered using an aqueous mixture of carbonate and bicarbonate. The buffer increased local groundwater pH from values as low as 3.8 to values exceeding 5.9 for all test plot wells. The alkalinity in each of the wells reached in excess of 480 mg/L during the study.
2. The system design, which generated a recirculation cell within the aquifer, provided an effective distribution of buffer and electron donor throughout the saturated zone, even though the aquifer was characterized by regions with widely differing geology and conductivity.
3. In situ perchlorate biodegradation was rapidly observed using lactate as an electron donor. Perchlorate levels were reduced by more than 95% in eight of the nine monitoring wells within the test plot during the demonstration. In two wells, with starting perchlorate concentrations in excess of 210 mg/L, final perchlorate levels after 20 weeks of treatment were less than the PQL of 5 µg/L. Conversely, there was no significant reduction in perchlorate levels in the control plot.
4. Nitrate-N levels in the test plot were reduced to below detection in seven of the nine monitoring wells within 7 weeks. The other two wells had nitrate-N concentrations less than 1 mg/L at the end of the 20-week study. There was no significant reduction in nitrate-N in the control plot during the demonstration.
5. Sulfide was detected by odor in some of the test plot monitoring wells during the demonstration. However, analytical data revealed no appreciable reduction in sulfate levels throughout the test plot during the demonstration period. In future work at the site, tests should be performed to optimize electron donor delivery such that sulfate reduction is completely inhibited.

6. The field pilot results suggest that the addition of buffer and electron donor to the shallow aquifer behind Building 1419 using a recirculation cell for mixing and distribution of the amendments is a viable approach for perchlorate remediation at this location. However, groundwater recirculation may have to be interrupted periodically during times of high rainfall due to flooding and a high water table in the area.
7. Data from the demonstration suggest that in situ bioremediation will be a viable option for perchlorate treatment in aquifers containing localized, high concentrations of the oxidant. These include source areas from hog-out operations, demolition and open burn areas, and other regions where perchlorate or perchlorate-laden fuels are discharged.

## REFERENCES

- Achenbach, L.A., Michaelidou, U., Bruce, R.A., Fryman, J., and Coates, J.D. (2001). *Dechloromonas agitata* gen. nov., sp. nov. and *Dechlorosoma suillum* gen. nov., sp. nov., two novel environmentally dominant (per)chlorate-reducing bacteria and their phylogenetic position. *International Journal of Systematic and Evolutionary Microbiology*, 51, 527-533.
- Betts, K.S. (2000). Accelerating perchlorate detection. *Environmental Science and Technology*, 34, 245A-246A.
- CDHS; California Department of Health Services. (1997). Determination of perchlorate by ion chromatography. Website: <http://www.dhs.ca.gov/ps/ddwem/chemicals/perchl/clo4meth.pdf>.
- CDHS; California Department of Health Services. (2003). Perchlorate in California Drinking Water: Monitoring Update. Website: <http://www.dhs.ca.gov/ps/ddwem/chemicals/perchl/monitoringupdate.htm>.
- Coates, J.D., Michaelidou, U., Bruce, R.A., O'Conner, S.M., Crespi, J.N., and Achenbach, L.A. (1999). The ubiquity and diversity of dissimilatory (per)chlorate-reducing bacteria. *Applied and Environmental Microbiology*, 65, 5234-5241.
- Damian, P., and Pontius, F.W. (1999). From rockets to remediation: the perchlorate problem. *Environmental Protection*, June, 24-31.
- Greene, M.R., and Pitre, M.P. (2000). Treatment of groundwater containing perchlorate using biological fluidized bed reactors with GAC or sand media. pp. 241-256, In E.T. Urbansky (Ed), *Perchlorate in the environment*. Kluwer Academic/Plenum Publishers, New York.
- Hatzinger, P.B. (2002). In situ bioremediation of perchlorate. Final Report for SERDP Project CU-1163. Strategic Environmental Research and Development Program, Arlington, VA. 131 pp.
- Hatzinger, P.B., Greene, M.R. Frisch, S., Togna, A.P. Manning, J., and Guarini, W.J. (2000). Biological treatment of perchlorate-contaminated groundwater using fluidized bed reactors. pp. 115-122. In G.B. Wickramanayake et al. (Eds). *Case studies in the remediation of chlorinated and recalcitrant compounds*, Battelle Press, Columbus, OH.
- Hatzinger, P.B., Whittier, M.C., Arkins, M.D., Bryan, C.W., and Guarini, W.J. (2002). In-situ and ex-situ bioremediation options for treating perchlorate in groundwater. *Remediation*, 12, 69-86.

- Kengen, S.W.M., Rikken, G.B., Hagen, W.R., van Ginkel, C.G., and Stams, A.J.M. (1999). Purification and characterization of (per)chlorate reductase from chlorate-respiring strain GR-1. *Journal of Bacteriology*, 181, 6706-6711.
- Logan, B.E. (1998). A review of chlorate- and perchlorate-respiring microorganisms. *Bioremediation Journal*, 2, 69-79.
- Logan, B.E. (2001). Assessing the outlook for perchlorate remediation, *Environmental Science and Technology*, 35, 483A-487A.
- Miller, J.P. and Logan, B.E. (2000). Sustained perchlorate degradation in an autotrophic, gas-phase, packed-bed bioreactor. *Environmental Science and Technology*, 34, 3018-3022.
- Rikken, G.B., Kroon, A.G.M., and van Ginkel, C.G. (1996). Transformation of (per)chlorate into chloride by a newly isolated bacterium: reduction and dismutation. *Applied Microbiology and Biotechnology*, 45, 420-426.
- Urbansky, E.T. (1998). Perchlorate chemistry: implications for analysis and remediation. *Bioremediation Journal*, 2, 81-95.
- USEPA; U.S. Environmental Protection Agency. (2001). Perchlorate. Office of Water. Website: <http://www.epa.gov/safewater/ccl/perchlor/perchlo.html>.
- van Ginkel, C.G., Rikken, G.B., Kroon, A.G.M., Kengen, S.W.M. (1996). Purification and characterization of a chlorite dismutase: a novel oxygen-generating enzyme. *Archives of Microbiology*, 166, 321-326.
- Wetzel, R.G. (1975). *Limnology*. W. B. Saunders Co., Philadelphia, PA.
- Wu, J., Unz, R.F., Zhang, H., and Logan, B.E. (2001). Persistence of perchlorate and the relative numbers of perchlorate- and chlorate-respiring microorganisms in natural waters, soils, and wastewater. *Bioremediation Journal*, 5, 119-130.

**Appendix A**

**TYPICAL WELL CONSTRUCTION AND SOIL BORING LOGS**

Facility/Project Name INDIAN HEAD BUILDING 1419 Utility License, Permit or Monitoring No.	Well Name TPRW-1 Date of Well Installation 05/08/02 M/D/Y
Facility ID 010206	Well Installed By: Name (first, last) & Firm CARL HUGO C.R. HUGO DRILLERS
Type of Well MONITORING WELL	Enf. Stds. Apply <input type="checkbox"/>
Distance from Waste/Source _____ ft.	

- A. Protective pipe, top elevation. N/A
  - B. Well casing, top elevation. N/A
  - C. Land surface elevation. N/A
  - D. Surfaces seal, bottom. 1.5 ft
12. USCS classification of soil near screen:  
 GP  GM  GC  GW  SW  SP   
 SM  SC  ML  MH  CL  CH   
 Bedrock

13. Sieve analysis performed? Yes  No

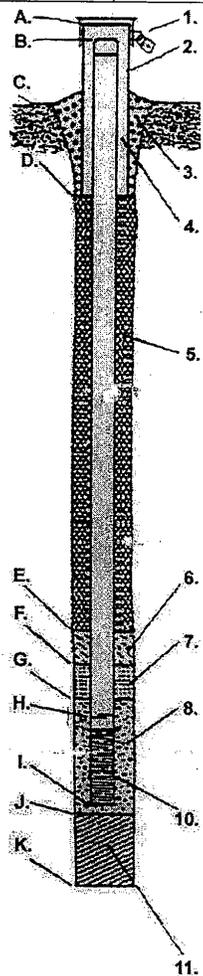
14. Drilling method used:  
 Rotary   
 Hollow Stem Auger   
 Other

15. Drilling fluid used:  
 Water  Air   
 Drilling Mud  None

16. Drilling additives used? Yes  No

Describe \_\_\_\_\_

17. Source of water (attach analysis if required)
- E. Bentonite seal, top 1.5 ft.
  - F. Fine sand, top 3.5 ft.
  - G. Filter pack, top 3.5 ft.
  - H. Screen joint, top 5 ft
  - I. Well bottom 17 ft
  - J. Filter pack, bottom 17 ft
  - K. Borehole, bottom 17 ft
  - L. Borehole, diameter 12.25 in.
  - M. O.D. Well casing 6.33 in.
  - N. I.D. Well casing 6 in



- 1. Cap and lock? NO
- 2. Protective cover pipe:
  - a. Inside diameter: 10 in.
  - b. Length: 1 ft.
  - c. Material: ALUMINUM Steel  Other
  - d. Additional protection? Yes  No
- 3. Surface seal: Bentonite  Concrete  Other
- 4. Material between well casing and protective pipe: Bentonite  Other
- 5. Annular space seal:
  - a. Granular/Chipped Bentonite
  - b. \_\_\_ Lbs/gal mud weight Bentonite-sand slurry
  - c. \_\_\_ Lbs/gal mud weight... Bentonite slurry
  - d. \_\_\_ % Bentonite... Bentonite-cement grout
  - e. 0.68 ft<sup>3</sup> volume added for any of the above
  - f. How installed: Tremie  Tremie pumped  Gravity
- 6. Bentonite seal:
  - a. Bentonite granules
  - b.  ¼ in.  3/8 in.  ½ in. Bentonite chips
  - c. \_\_\_\_\_ Other
- 7. Fine sand material: Manufacturer, product name & mesh size: \_\_\_\_\_
- 8. Filter pack material: Manufacturer, product name & mesh size:
  - a. FILPRO #2 WG
  - b. Volume added 4.59 ft<sup>3</sup>
- 9. Well casing:
  - Flush threaded PVC schedule 40
  - Flush threaded PVC 80
  - Other
- 10. Screen material: PVC
  - a. Screen type: Factory cut  Continuous slot  Other
  - b. Manufacturer \_\_\_\_\_
  - c. Slot size: 0.01 in.
  - d. Slotted length: 12 ft.
- 11. Backfill material (below filter pack) None  Other

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature <u>RIE BILES</u>	Firm ENVIROGEN, INC
-------------------------------	------------------------

Facility/Project Name DIAN HEAD BUILDING 1419 Utility License, Permit or Monitoring No.	Well Name TPIW-1 Date of Well Installation 05/08/02 M/D/Y
Facility ID 010206	Well Installed By: Name (first, last) & Firm CARL HUGO C.R. HUGO DRILLERS
Type of Well MONITORING WELL	Enf. Stds. Apply <input type="checkbox"/>
Distance from Waste/Source _____ ft.	

- A. Protective pipe, top elevation. N/A
- B. Well casing, top elevation. NA
- C. Land surface elevation. N/A
- D. Surfaces seal, bottom. 2 ft

12. USCS classification of soil near screen:  
 GP  GM  GC  GW  SW  SP   
 SM  SC  ML  MH  CL  CH   
 Bedrock

13. Sieve analysis performed? Yes  No

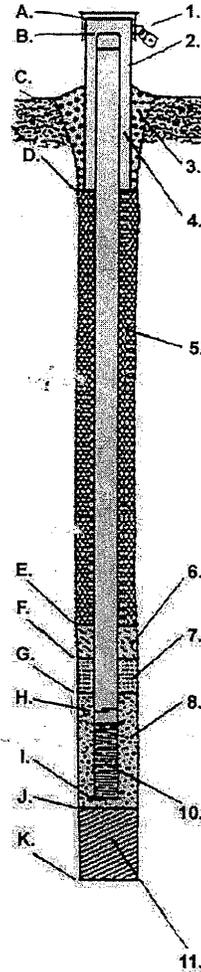
14. Drilling method used:  
 Rotary   
 Hollow Stem Auger   
 Other

15. Drilling fluid used:  
 Water  Air   
 Drilling Mud  None

16. Drilling additives used? Yes  No

Describe \_\_\_\_\_

17. Source of water (attach analysis if required)



- 1. Cap and lock? NO
- 2. Protective cover pipe:
  - a. Inside diameter: 12 in.
  - b. Length: 2 ft.
  - c. Material: Steel  ALUMINUM  Other
  - d. Additional protection? Yes  No
- 3. Surface seal:
  - Bentonite
  - Concrete
  - Other
- 4. Material between well casing and protective pipe:
  - Bentonite
  - Other
- 5. Annular space seal:
  - a. Granular/Chipped Bentonite
  - b. \_\_\_ Lbs/gal mud weight Bentonite-sand slurry
  - c. \_\_\_ Lbs/gal mud weight... Bentonite slurry
  - d. \_\_\_ % Bentonite... Bentonite-cement grout
  - e. 0.68 ft<sup>3</sup> volume added for any of the above
  - f. How installed: Tremie  Tremie pumped  Gravity
- 6. Bentonite seal:
  - a. Bentonite granules
  - b.  1/4 in.  3/8 in.  1/2 in. Bentonite chips
  - c. Other
- 7. Fine sand material: Manufacturer, product name & mesh size:
  - a. FILPRO #2 WG
- 8. Filter pack material: Manufacturer, product name & mesh size:
  - a. FILPRO #2 WG
  - b. Volume added 2.72 ft<sup>3</sup>
- 9. Well casing:
  - Flush threaded PVC schedule 40
  - Flush threaded PVC 80
  - Other
- 10. Screen material: PVC
  - a. Screen type:
    - Factory cut
    - Continuous slot
    - Other
  - b. Manufacturer \_\_\_\_\_
  - c. Slot size: 0.01 in.
  - d. Slotted length: 7 ft.
- 11. Backfill material (below filter pack)
  - None
  - Other

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature RIE BILES	Firm ENVIROGEN, INC
------------------------	------------------------

Facility/Project Name DIAN HEAD BUILDING 1419	Well Name MW-3
Utility License, Permit or Monitoring No.	Date of Well Installation 01/24/01 M/D/Y
Facility ID 010206	Well Installed By: Name (first, last) & Firm STEFAN SMITH TIDE WATER
Type of Well MONITORING WELL	Enf. Stds. Apply <input type="checkbox"/>

- A. Protective pipe, top elevation. N/A
- B. Well casing, top elevation. 100.91
- C. Land surface elevation. N/A
- D. Surfaces seal, bottom. 3 ft

12. USCS classification of soil near screen:  
 GP  GM  GC  GW  SW  SP   
 SM  SC  ML  MH  CL  CH   
 Bedrock

13. Sieve analysis performed? Yes  No

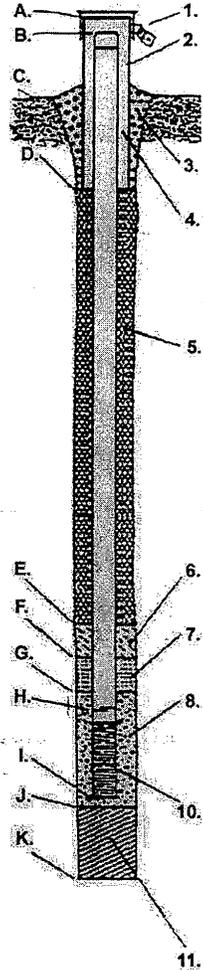
14. Drilling method used:  
 Rotary   
 Hollow Stem Auger   
 Other

15. Drilling fluid used:  
 Water  Air   
 Drilling Mud  None

16. Drilling additives used? Yes  No

Describe \_\_\_\_\_

17. Source of water (attach analysis if required)



- 1. Cap and lock? NO
- 2. Protective cover pipe:
  - a. Inside diameter: 6 in.
  - b. Length: 1 ft.
  - c. Material: ALUMINUM Steel  Other
  - d. Additional protection? Yes  No
- 3. Surface seal:
  - Bentonite
  - Concrete
  - SAND Other
- 4. Material between well casing and protective pipe:
  - Bentonite
  - Other
- 5. Annular space seal:
  - a. Granular/Chipped Bentonite
  - b. \_\_\_ Lbs/gal mud weight Bentonite-sand slurry
  - c. \_\_\_ Lbs/gal mud weight... Bentonite slurry
  - d. \_\_\_ % Bentonite... Bentonite-cement grout
  - e. 0.68 ft<sup>3</sup> volume added for any of the above
  - f. How installed:
    - Tremie
    - Tremie pumped
    - Gravity
- 6. Bentonite seal:
  - a. Bentonite granules
  - b.  1/4 in.  3/8 in.  1/2 in. Bentonite chips
  - c. Other
- 7. Fine sand material: Manufacturer, product name & mesh size:
  - a. FILPRO #2 WG
- 8. Filter pack material: Manufacturer, product name & mesh size:
  - a. FILPRO #2 WG
  - b. Volume added 4.08 ft<sup>3</sup>
- 9. Well casing:
  - Flush threaded PVC schedule 40
  - Flush threaded PVC 80
  - Other
- 10. Screen material: PVC
  - a. Screen type:
    - Factory cut
    - Continuous slot
    - Other
  - b. Manufacturer \_\_\_\_\_
  - c. Slot size: 0.01 in.
  - d. Slotted length: 10 ft.
- 11. Backfill material (below filter pack)
  - None
  - Other

- E. Bentonite seal, top 3 ft.
- F. Fine sand, top 5 ft.
- G. Filter pack, top 5 ft.
- H. Screen joint, top 7 ft.
- I. Well bottom 17 ft.
- J. Filter pack, bottom 17 ft.
- K. Borehole, bottom 17 ft.
- L. Borehole, diameter 8.25 in.
- M. O.D. Well casing 2.33 in.
- N. I.D. Well casing 2 in.

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature <u>RIE BILES</u>	Firm ENVIROGEN, INC
-------------------------------	------------------------

Facility/Project Name LAN HEAD BUILDING 1419	Well Name TPMW-3S
City License, Permit or Monitoring No.	Date of Well Installation 05/08/02 M/D/Y
Facility ID 010206	Well Installed By: Name (first, last) & Firm CARL HUGO C.R. HUGO DRILLERS
Type of Well MONITORING WELL	Enf. Stds. Apply <input type="checkbox"/>
Distance from Waste/Source _____ ft.	

- A. Protective pipe, top elevation. N/A
- B. Well casing, top elevation. N/A
- C. Land surface elevation. N/A
- D. Surfaces seal, bottom. 3.5 ft

12. USCS classification of soil near screen:  
 GP  GM  GC  GW  SW  SP   
 SM  SC  ML  MH  CL  CH   
 Bedrock

13. Sieve analysis performed? Yes  No

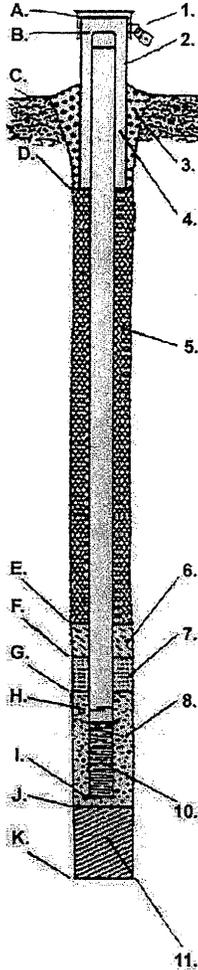
14. Drilling method used:  
 Rotary   
 Hollow Stem Auger   
 Other

15. Drilling fluid used:  
 Water  Air   
 Drilling Mud  None

16. Drilling additives used? Yes  No

Describe \_\_\_\_\_

17. Source of water (attach analysis if required)



- 1. Cap and lock? NO
- 2. Protective cover pipe:
  - a. Inside diameter: 6 in.
  - b. Length: 1 ft.
  - c. Material: Steel  Other  ALUMINUM
  - d. Additional protection? Yes  No
- 3. Surface seal:
  - Bentonite
  - Concrete
  - Other
- 4. Material between well casing and protective pipe:
  - Bentonite
  - Other
- 5. Annular space seal:
  - a. Granular/Chipped Bentonite
  - b. Lbs/gal mud weight Bentonite-sand slurry
  - c. Lbs/gal mud weight... Bentonite slurry
  - d. % Bentonite... Bentonite-cement grout
  - e. 3.91 ft<sup>3</sup> volume added for any of the above
  - f. How installed:
    - Tremie
    - Tremie pumped
    - Gravity
- 6. Bentonite seal:
  - a. Bentonite granules
  - b. 1/4 in.  3/8 in.  1/2 in.  Bentonite chips
  - c. Other
- 7. Fine sand material: Manufacturer, product name & mesh size:
  - a. FILPRO #2 WG
- 8. Filter pack material: Manufacturer, product name & mesh size:
  - a. FILPRO #2 WG
  - b. Volume added 1.7 ft<sup>3</sup>
- 9. Well casing:
  - Flush threaded PVC schedule 40
  - Flush threaded PVC 80
  - Other
- 10. Screen material: PVC
  - a. Screen type:
    - Factory cut
    - Continuous slot
    - Other
  - b. Manufacturer \_\_\_\_\_
  - c. Slot size: 0.01 in.
  - d. Slotted length: 7 ft.
- 11. Backfill material (below filter pack)
  - None
  - Other

- E. Bentonite seal, top 1.5 ft.
- F. Fine sand, top 3.5 ft.
- G. Filter pack, top 3.5 ft
- H. Screen joint, top 4 ft
- I. Well bottom 14 ft
- J. Filter pack, bottom 11 ft
- K. Borehole, bottom 11 ft
- L. Borehole, diameter 8.25 in.
- M. O.D. Well casing 2.33 in.
- N. I.D. Well casing 2 in

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature JIE BILES	Firm ENVIROGEN, INC
------------------------	------------------------

Facility/Project Name DIAN HEAD BUILDING 1419	Well Name TPMW-3D
Facility License, Permit or Monitoring No.	Date of Well Installation 05/08/02 M/D/Y
Facility ID 010206	Well Installed By: Name (first, last) & Firm CARL HUGO C.R. HUGO DRILLERS
Type of Well MONITORING WELL	Enf. Stds. Apply <input type="checkbox"/>
Distance from Waste/Source _____ ft.	

- A. Protective pipe, top elevation. N/A
- B. Well casing, top elevation. N/A
- C. Land surface elevation. N/A
- D. Surfaces seal, bottom. 1.5 ft

12. USCS classification of soil near screen:  
 GP  GM  GC  GW  SW  SP   
 SM  SC  ML  MH  CL  CH   
 Bedrock

13. Sieve analysis performed? Yes  No

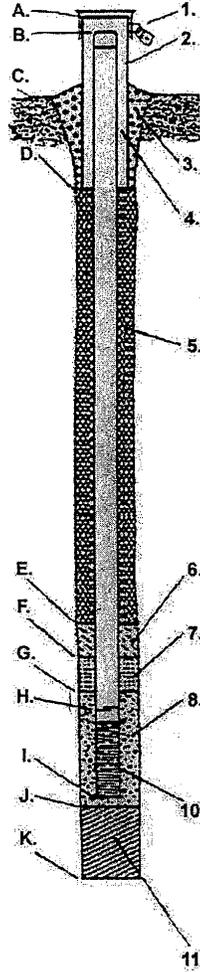
14. Drilling method used:  
 Rotary   
 Hollow Stem Auger   
 Other

15. Drilling fluid used:  
 Water  Air   
 Drilling Mud  None

16. Drilling additives used? Yes  No

Describe \_\_\_\_\_

17. Source of water (attach analysis if required)



- 1. Cap and lock? NO
- 2. Protective cover pipe:
  - a. Inside diameter: 6 in.
  - b. Length: 1 ft.
  - c. Material: Steel  ALUMINUM
  - d. Additional protection? Yes  No
- 3. Surface seal:
  - Bentonite
  - Concrete
  - Other
- 4. Material between well casing and protective pipe:
  - Bentonite
  - Other
- 5. Annular space seal:
  - a. Granular/Chipped Bentonite
  - b. \_\_\_ Lbs/gal mud weight Bentonite-sand slurry
  - c. \_\_\_ Lbs/gal mud weight... Bentonite slurry
  - d. \_\_\_ % Bentonite... Bentonite-cement grout
  - e. 2.21 ft<sup>3</sup> volume added for any of the above
  - f. How installed: Tremie  Tremie pumped  Gravity
- 6. Bentonite seal:
  - a. Bentonite granules
  - b.  ¼ in.  3/8 in.  ½ in. Bentonite chips
  - c. Other
- 7. Fine sand material: Manufacturer, product name & mesh size:
  - a. FILPRO #2 WG
- 8. Filter pack material: Manufacturer, product name & mesh size:
  - a. FILPRO #2 WG
  - b. Volume added 1.7 ft<sup>3</sup>
- 9. Well casing:
  - Flush threaded PVC schedule 40
  - Flush threaded PVC 80
  - Other
- 10. Screen material: PVC
  - a. Screen type:
    - Factory cut
    - Continuous slot
    - Other
  - b. Manufacturer \_\_\_\_\_
  - c. Slot size: 0.01 in.
  - d. Slotted length: 3 ft.
- 11. Backfill material (below filter pack)
  - None
  - Other

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature ARIE BILES	Firm ENVIROGEN, INC
-------------------------	------------------------

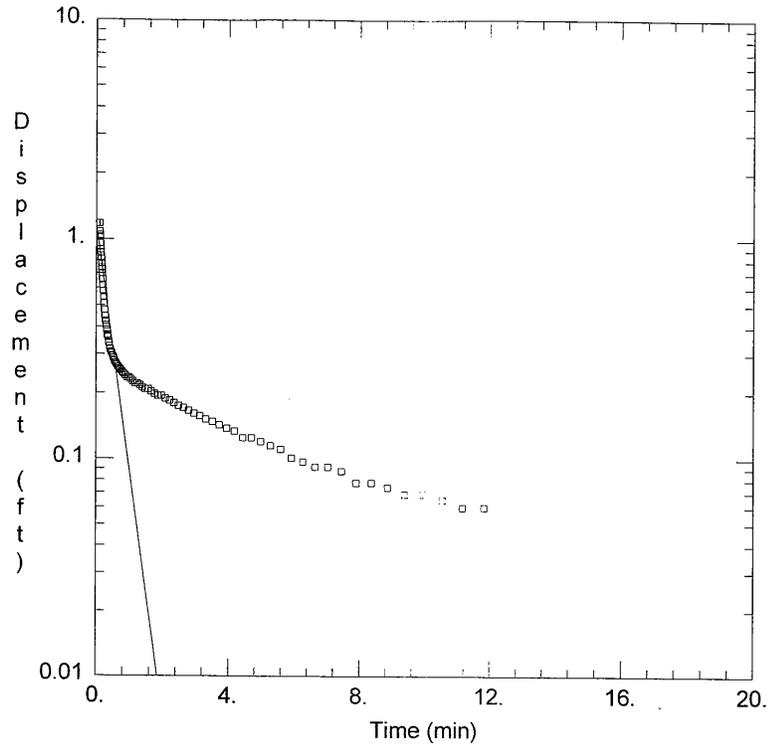
		PROJECT NUMBER		Building 1419		
				Boring Number: GP07		
<b>SOIL BORING LOG</b>						
PROJECT : Indian Head				LOCATION : Indian Head, Maryland		
ELEVATION :				DRILLING CONTRACTOR : Stefen Smith		
DRILLING METHOD AND EQUIPMENT USED : Drill Rig 2" split spoon						
START : 1/23/02		END : 1/23/2002		LOGGER : Mike Cushman		
DEPTH BELOW SURFACE (FT)				CORE DESCRIPTION		COMMENTS
INTERVAL (FT)	RECOVERY (FT)		Moisture Content	Munsell Code	SOIL NAME, COLOR RELATIVE DENSITY OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY.	DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS, AND INSTRUMENTATION
		USCS CODE				
0-4'	2.5'		Damp		FILL: Black gravel material with mixed organics Olive clayey silt at 3.5'	
4-8'	4'		Moist		CLAYEY SILT/SANDY SILT: alternating layers of clayey silt and sandy silt. Colors ranging ranging from olive to light olive brown and mottled.	
8-12'	4'		Saturated		Sand seam at 12'	
12-16'	4'		Saturated		SAND/GRAVEL: 13.5 - 15 feet sand and gravel mix CLAY: gray clay at 15' to end of boring	

END OF BORING AT 16'

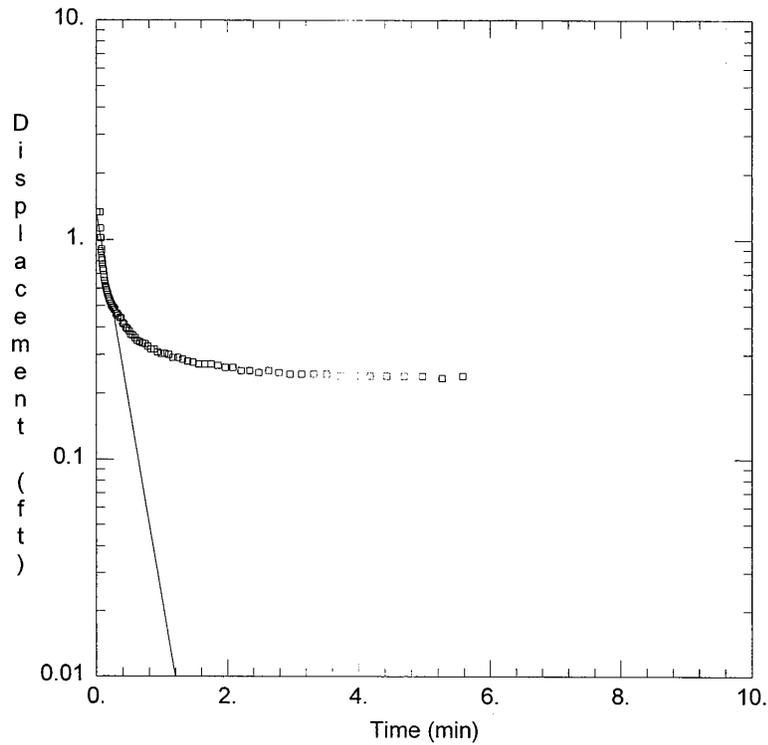
	PROJECT NUMBER		Building 1419			
			Boring Number: GP13			
<b>SOIL BORING LOG</b>						
PROJECT : Indian Head			LOCATION : Indian Head, Maryland			
ELEVATION :			DRILLING CONTRACTOR : Stefen Smith			
DRILLING METHOD AND EQUIPMENT USED : Drill Rig 2" split spoon						
START : 1/23/02		END : 1/23/2002		LOGGER : Mike Cushman		
DEPTH BELOW SURFACE (FT)				CORE DESCRIPTION	COMMENTS	
INTERVAL (FT)	RECOVERY		Moisture Content	Munsell Code	SOIL NAME, COLOR RELATIVE DENSITY OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY.	DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS, AND INSTRUMENTATION
	(FT)	USCS CODE				
0-4'	4'		Damp		FILL: Black gravel material with mixed organics SILTY SAND: mottled olive yellow to olive	
4-8'	4'		Moist			
8-12'	4'		Saturated		CLAYEY SILT: colors ranging from olive to pale olive with some red, mottled	
12-16'	4'		Saturated		SAND/SILT/CLAY: mixture to 15.5 feet, grading into sand with gravel to end of the boring	

END OF BORING AT 16'

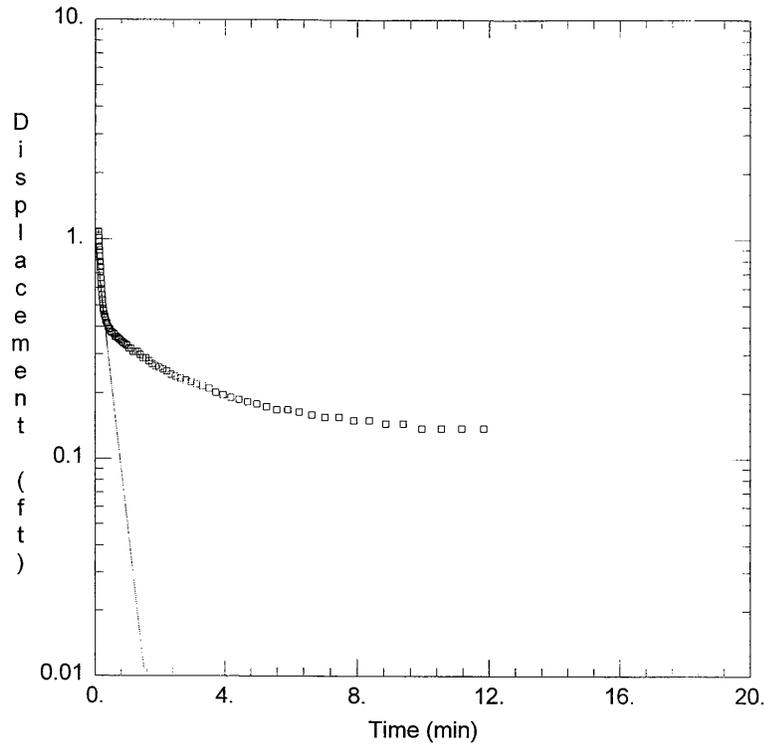
**Appendix B**  
**SLUG TEST AND PUMP TEST CURVES**



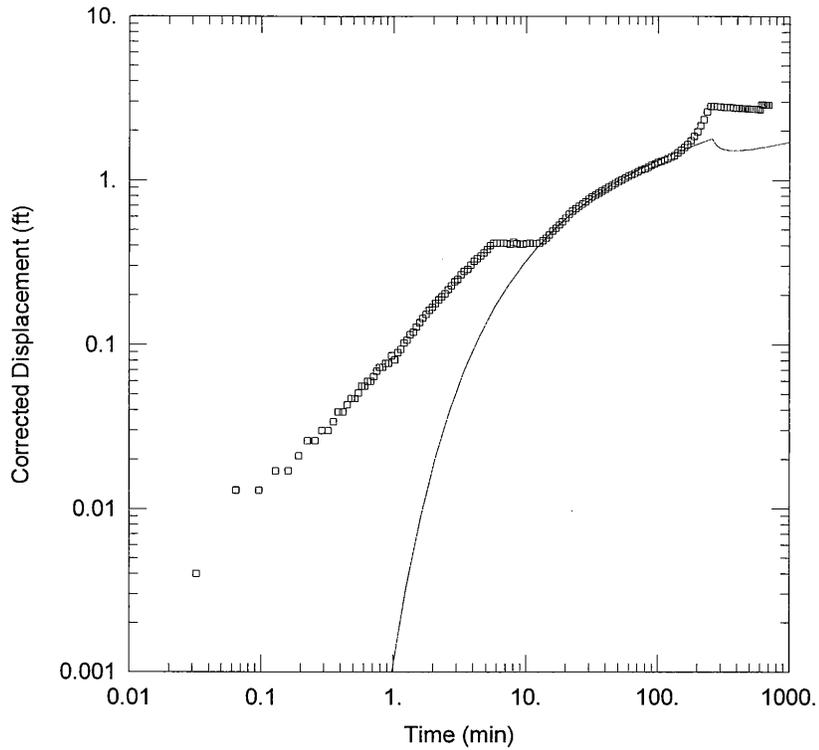
<u>MW-4 RISING HEAD</u>	
Data Set: <u>Q:\APPS\AQTMW4OUT.AQT</u>	Time: <u>16:25:03</u>
Date: <u>03/07/03</u>	
<u>PROJECT INFORMATION</u>	
Test Location: <u>Indian Head, MD</u>	
Test Well: <u>MW-4</u>	
Test Date: <u>2/14/02</u>	
<u>AQUIFER DATA</u>	
Saturated Thickness: <u>11.76</u> ft	Anisotropy Ratio (Kz/Kr): <u>1.</u>
<u>WELL DATA</u>	
Initial Displacement: <u>1.179</u> ft	Water Column Height: <u>11.76</u> ft
Casing Radius: <u>0.086</u> ft	Wellbore Radius: <u>0.344</u> ft
Screen Length: <u>10.</u> ft	Gravel Pack Porosity: <u>0.3</u>
<u>SOLUTION</u>	
Aquifer Model: <u>Unconfined</u>	K = <u>0.01385</u> ft/min
Solution Method: <u>Bouwer-Rice</u>	y0 = <u>1.168</u> ft



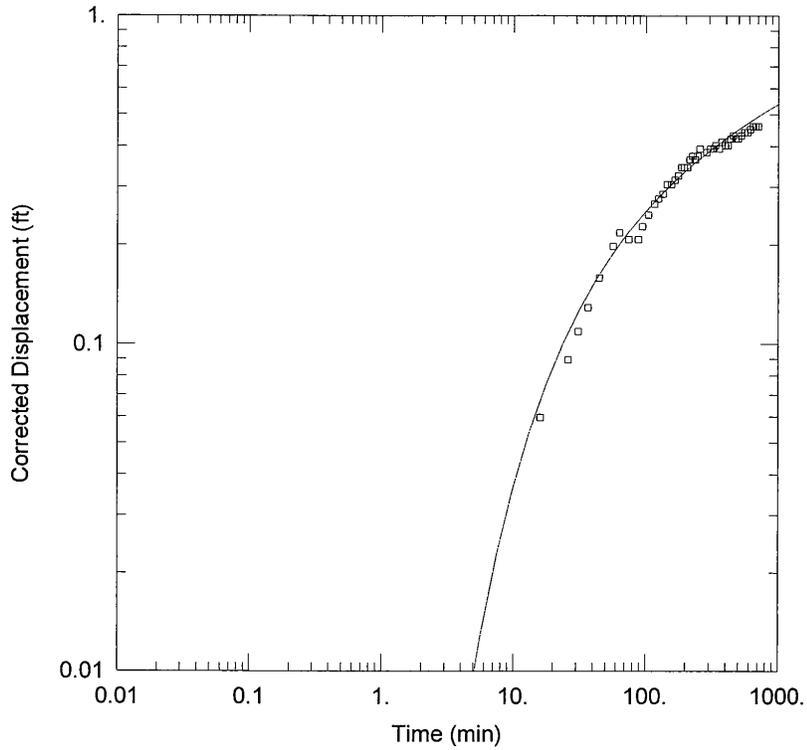
<u>MW-5 RISING HEAD</u>	
Data Set: <u>Q:\APPS\AQTMW5OUT.AQT</u>	Time: <u>16:24:32</u>
Date: <u>03/07/03</u>	
<u>PROJECT INFORMATION</u>	
Test Location: <u>Indian Head, MD</u>	
Test Well: <u>MW-5</u>	
Test Date: <u>2/14/02</u>	
<u>AQUIFER DATA</u>	
Saturated Thickness: <u>11. ft</u>	Anisotropy Ratio (Kz/Kr): <u>1.</u>
<u>WELL DATA</u>	
Initial Displacement: <u>1.333 ft</u>	Water Column Height: <u>11. ft</u>
Casing Radius: <u>0.086 ft</u>	Wellbore Radius: <u>0.344 ft</u>
Screen Length: <u>10. ft</u>	Gravel Pack Porosity: <u>0.3</u>
<u>SOLUTION</u>	
Aquifer Model: <u>Unconfined</u>	K = <u>0.02161 ft/min</u>
Solution Method: <u>Bower-Rice</u>	y0 = <u>1.335 ft</u>



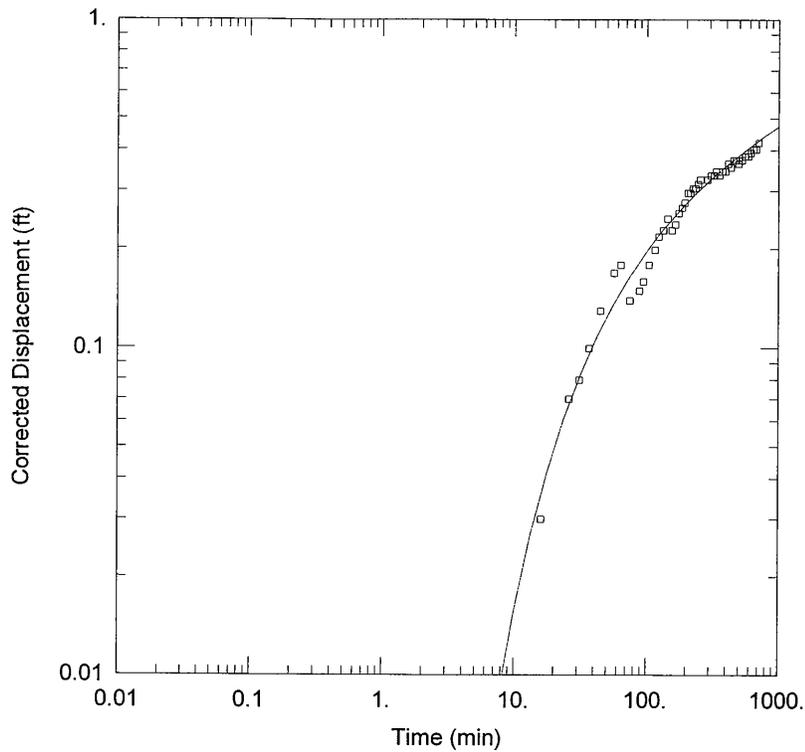
<u>MW-6 RISING HEAD</u>	
Data Set: <u>Q:\APPS\AQTT\MW6OUT.AQT</u>	Time: <u>16:19:27</u>
Date: <u>03/07/03</u>	
<u>PROJECT INFORMATION</u>	
Test Location: <u>Indian Head, MD</u>	
Test Well: <u>MW-6</u>	
Test Date: <u>2/14/02</u>	
<u>AQUIFER DATA</u>	
Saturated Thickness: <u>11.3 ft</u>	Anisotropy Ratio (Kz/Kr): <u>1.</u>
<u>WELL DATA</u>	
Initial Displacement: <u>1.082 ft</u>	Water Column Height: <u>11.3 ft</u>
Casing Radius: <u>0.086 ft</u>	Wellbore Radius: <u>0.344 ft</u>
Screen Length: <u>10. ft</u>	Gravel Pack Porosity: <u>0.3</u>
<u>SOLUTION</u>	
Aquifer Model: <u>Unconfined</u>	K = <u>0.01613 ft/min</u>
Solution Method: <u>Bower-Rice</u>	y0 = <u>1.017 ft</u>



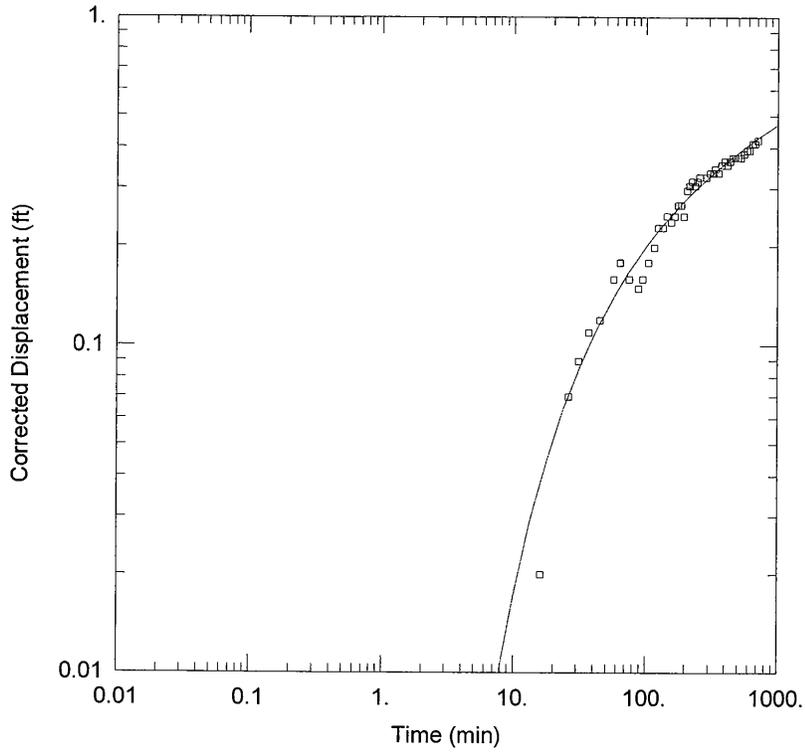
<u>WELL TEST ANALYSIS</u>					
Data Set: <u>Q:\APPS\AQ\TW\PTTLR1.AQT</u>			Time: <u>12:09:43</u>		
Date: <u>02/26/03</u>					
<u>AQUIFER DATA</u>					
Saturated Thickness: <u>11. ft</u>			Anisotropy Ratio (Kz/Kr): <u>1.</u>		
<u>WELL DATA</u>					
Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
R-1	0	0	□ RW-1	0.1	0
<u>SOLUTION</u>					
Aquifer Model: <u>Unconfined</u>			T = <u>0.1163 ft<sup>2</sup>/min</u>		
Solution Method: <u>Theis</u>			S = <u>207.6</u>		



<u>WELL TEST ANALYSIS</u>					
Data Set: <u>Q:\APPS\AQ\TW\PMW4.AQT</u>			Time: <u>15:10:18</u>		
Date: <u>02/26/03</u>					
<u>AQUIFER DATA</u>					
Saturated Thickness: <u>11. ft</u>			Anisotropy Ratio (Kz/Kr): <u>1.</u>		
<u>WELL DATA</u>					
Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
R-1	0	0	mw-4	0	5
<u>SOLUTION</u>					
Aquifer Model: <u>Unconfined</u>			T = <u>0.4673</u> ft <sup>2</sup> /min		
Solution Method: <u>Theis</u>			S = <u>0.63</u>		



<u>WELL TEST ANALYSIS</u>					
Data Set: <u>Q:\APPS\AQTW\PMW5.AQT</u>			Time: <u>15:13:25</u>		
Date: <u>02/26/03</u>					
<u>AQUIFER DATA</u>					
Saturated Thickness: <u>11. ft</u>			Anisotropy Ratio (Kz/Kr): <u>1.</u>		
<u>WELL DATA</u>					
Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
R-1	0	0	□ MW-5	5	5
<u>SOLUTION</u>					
Aquifer Model: <u>Unconfined</u>			T = <u>0.4719 ft<sup>2</sup>/min</u>		
Solution Method: <u>Theis</u>			S = <u>0.5136</u>		



<u>WELL TEST ANALYSIS</u>					
Data Set: <u>Q:\APPS\AQTW\PMW6.AQT</u>			Time: <u>15:14:40</u>		
Date: <u>02/26/03</u>					
<u>AQUIFER DATA</u>					
Saturated Thickness: <u>11. ft</u>			Anisotropy Ratio (Kz/Kr): <u>1.</u>		
<u>WELL DATA</u>					
Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
R-1	0	0	□ MW-6	5	0
<u>SOLUTION</u>					
Aquifer Model: <u>Unconfined</u>			T = <u>0.4803 ft<sup>2</sup>/min</u>		
Solution Method: <u>Theis</u>			S = <u>0.9857</u>		

**Appendix C**  
**RAINFALL DATA**

MONTHLY CLIMATOLOGICAL SUMMARY for JUN. 2002

NAME: Weather 2001 CITY: Indain Head STATE: Maryland  
 ELEV: LAT: 38°34',59 N LONG: 77°11',35 W

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	80.9	90.2	5:45p	72.3	12:00m	0.0	16.3	0.00	3.8	27.0	12:30a	NW
2	78.0	86.5	4:00p	69.6	4:00a	0.0	13.0	0.00	12.3	43.0	2:15p	NW
3	71.5	79.7	6:15p	64.5	6:30a	0.0	7.1	0.00	5.3	29.0	12:15a	NNW
4	73.1	83.5	4:00p	62.2	7:30a	0.0	7.9	0.13	5.9	19.0	7:00p	ESE
5	80.0	91.6	5:45p	72.2	6:15a	0.0	16.9	0.00	3.7	35.0	8:15p	SE
6	76.5	90.0	2:15p	66.8	8:30p	0.0	13.4	0.29	6.2	45.0	6:45p	NW
7	66.9	73.0	4:30p	60.6	10:45p	0.0	1.8	0.00	8.2	25.0	1:30a	NNW
8	65.6	75.7	4:30p	56.0	5:15a	0.0	0.8	0.00	3.0	12.0	4:45p	SE
9	70.3	84.4	6:00p	57.0	5:30a	0.0	5.7	0.00	4.0	13.0	10:30a	SE
10	78.5	91.3	4:15p	65.8	5:15a	0.0	13.6	0.00	2.0	10.0	7:45p	WSW
11	80.8	95.5	5:15p	70.8	6:15a	0.0	18.2	0.00	2.9	14.0	4:45p	SE
12	81.0	89.8	3:15p	72.3	6:15a	0.0	16.1	0.00	4.4	31.0	6:00p	SW
13	72.9	82.6	11:45a	65.5	12:00m	0.0	9.0	0.74	1.9	16.0	3:15p	NE
14	67.4	72.1	5:15p	64.0	7:30a	0.0	3.0	0.03	2.4	11.0	1:15a	NE
15	70.5	78.3	5:00p	63.7	11:45p	0.0	6.0	0.12	7.8	31.0	4:45p	W
16	69.5	79.9	3:45p	61.8	1:00a	0.0	5.9	0.14	4.8	49.0	4:45p	SE
17	71.0	80.8	4:15p	59.8	6:15a	0.0	5.3	0.01	1.9	13.0	4:30p	NNW
18	71.7	83.4	3:45p	61.4	6:30a	0.0	7.4	0.00	3.8	31.0	11:45p	E
19	71.7	79.7	5:00p	61.4	12:30p	0.0	5.5	0.00	3.7	17.0	12:45a	E
20	73.5	84.0	3:45p	63.1	6:15a	0.0	8.5	0.00	2.8	12.0	2:45p	E
21	72.9	84.5	3:30p	60.1	4:45p	0.0	7.3	0.00	2.6	12.0	12:45p	ESE
22	74.2	84.6	6:15p	60.7	12:45a	0.0	7.6	0.00	2.9	12.0	11:00p	WNW
23	76.6	88.3	5:45p	65.1	5:15a	0.0	11.7	0.00	3.5	12.0	1:00p	SE
24	81.1	92.8	3:30p	69.8	5:45a	0.0	16.3	0.00	1.6	9.0	5:30p	WSW
25	82.0	92.7	4:00p	71.0	12:15a	0.0	16.8	0.00	2.3	11.0	5:00p	N
26	82.9	94.7	3:15p	71.3	7:00p	0.0	18.0	0.02	4.4	24.0	6:15p	S
27	80.3	93.0	4:15p	72.2	12:00m	0.0	17.6	0.13	4.8	41.0	6:30p	SSE
28	75.7	84.3	4:45p	71.7	6:30a	0.0	13.0	0.00	3.5	24.0	5:30p	WSW
29	78.9	88.8	4:45p	70.3	12:00m	0.0	14.6	0.00	3.4	13.0	2:30p	NNW
30	77.1	87.4	3:15p	64.7	6:45a	0.0	11.0	0.00	2.9	13.0	3:30p	ESE
-----												
	75.1	95.5	11	56.0	8	0.0	315.4	1.61	4.1	49.0	16	ESE

Max >= 90.0: 9

Max <= 32.0: 0

Min <= 32.0: 0

Min <= 0.0: 0

Max Rain: 0.74 ON 6/13/02

Days of Rain: 8 (>.01 in) 6 (>.1 in) 0 (>1 in)

Heat Base: 65.0 Cool Base: 65.0 Method: (High + Low) / 2

MONTHLY CLIMATOLOGICAL SUMMARY for JUL. 2002

NAME: Weather 2001 CITY: Indain Head STATE: Maryland  
 LEV: LAT: 38°34'59 N LONG: 77°11'35 W

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN		TIME	LOW	TIME	HEAT	COOL	RAIN	AVG		TIME	DOM
	TEMP	HIGH				DEG	DEG		WIND	SPEED		DIR
1	79.9	89.8	5:45p	70.7	5:45a	0.0	15.3	0.00	4.2	13.0	5:00p	SE
2	82.6	92.8	5:00p	72.4	4:45a	0.0	17.6	0.00	2.3	9.0	1:00a	SE
3	86.5	99.3	6:30p	76.2	6:15a	0.0	22.8	0.00	2.4	13.0	9:15a	NW
4	88.9	99.0	4:15p	81.2	6:45a	0.0	25.1	0.00	4.8	16.0	8:45a	NW
5	86.4	94.1	4:00p	76.9	12:00m	0.0	20.5	0.00	8.3	25.0	12:15p	NW
6	78.6	88.5	4:15p	70.3	6:00a	0.0	14.4	0.00	6.9	23.0	10:45a	NNW
7	75.3	86.6	2:00p	63.6	6:15a	0.0	10.1	0.00	3.0	16.0	1:30p	NW
8	77.3	92.0	5:30p	62.9	5:45a	0.0	12.5	0.00	2.9	15.0	11:45p	E
9	83.5	94.8	5:00p	73.0	10:00p	0.0	18.9	0.28	6.0	28.0	9:00p	SW
10	77.9	83.3	6:15p	73.2	3:00p	0.0	13.3	0.55	3.0	21.0	2:30p	WNW
11	72.6	80.0	6:45p	63.1	12:00m	0.0	6.5	0.00	6.7	30.0	2:45a	NNE
12	70.6	83.5	5:45p	56.9	6:30a	0.0	5.2	0.00	2.8	13.0	3:45p	ESE
13	73.3	81.7	6:00p	67.0	6:15a	0.0	9.3	0.00	2.7	11.0	1:00a	SE
14	69.7	75.0	5:30p	66.4	5:00a	0.0	5.7	0.59	2.5	14.0	7:30p	E
15	77.1	87.6	5:15p	66.7	6:00a	0.0	12.1	0.00	3.2	12.0	2:00p	SW
16	82.1	90.8	3:30p	71.8	2:30p	0.0	16.3	0.00	7.7	29.0	2:45p	NW
17	80.8	92.8	5:00p	70.3	3:30a	0.0	16.6	0.00	2.6	11.0	4:00p	N
18	82.1	90.3	1:45p	74.3	4:30a	0.0	17.3	0.00	1.1	11.0	11:15p	ESE
19	82.3	88.9	1:00p	75.5	6:30a	0.0	17.2	0.00	4.4	21.0	7:15p	NW
20	81.3	89.4	4:00p	75.6	7:00a	0.0	17.5	0.00	4.4	15.0	1:30a	NNW
21	81.0	89.7	2:00p	73.5	6:30a	0.0	16.6	0.00	4.3	18.0	10:45p	SE
22	83.8	95.8	4:15p	72.1	6:00a	0.0	19.0	0.00	5.0	18.0	12:00p	SE
23	84.0	95.0	3:15p	76.4	6:00a	0.0	20.7	0.00	6.5	37.0	8:00p	SSW
24	77.3	84.8	4:15p	72.6	12:00m	0.0	13.7	0.00	5.3	19.0	2:30a	N
25	74.1	78.7	4:30p	71.5	6:30a	0.0	10.1	0.00	4.6	17.0	9:15a	E
26	68.9	71.7	12:15a	65.4	8:15a	0.0	3.5	0.54	3.5	13.0	1:00a	E
27	74.3	80.5	2:30p	69.5	12:15a	0.0	10.0	0.54	2.7	42.0	3:45p	ESE
28	82.4	94.1	4:15p	72.7	7:00a	0.0	18.4	0.01	2.4	15.0	7:00p	SW
29	84.0	92.6	3:15p	77.7	5:30a	0.0	20.1	0.43	3.5	46.0	4:30p	SW
30	83.3	91.0	5:30p	75.0	6:15a	0.0	18.0	0.00	8.3	31.0	11:45a	WNW
31	83.9	93.2	4:15p	75.6	2:45a	0.0	19.4	0.00	3.9	18.0	11:15a	NW
-----												
	79.5	99.3	3	56.9	12	0.0	463.7	2.94	4.3	46.0	29	NW

Max >= 90.0: 15  
 Max <= 32.0: 0  
 Min <= 32.0: 0  
 Min <= 0.0: 0  
 Max Rain: 0.59 ON 7/14/02  
 Days of Rain: 6 (>.01 in) 6 (>.1 in) 0 (>1 in)  
 Heat Base: 65.0 Cool Base: 65.0 Method: (High + Low) / 2

MONTHLY CLIMATOLOGICAL SUMMARY for AUG. 2002

NAME: Weather 2001 CITY: Indain Head STATE: Maryland  
 LEV: LAT: 38°34',59 N LONG: 77°11',35 W

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	82.9	94.6	5:00p	73.2	7:15p	0.0	18.9	0.91	4.4	52.0	7:15p	NW
2	83.3	94.7	2:15p	72.1	6:15a	0.0	18.4	0.00	2.4	11.0	1:00a	ESE
3	81.7	94.4	3:45p	74.9	12:00m	0.0	19.7	0.00	4.0	23.0	4:15p	SE
4	82.5	94.6	5:45p	73.2	7:00a	0.0	18.9	0.00	3.9	12.0	9:45p	WSW
5	83.3	96.6	4:00p	75.8	7:00a	0.0	21.2	0.03	4.3	46.0	6:00p	SW
6	78.6	83.6	4:15p	73.8	11:45p	0.0	13.7	0.00	10.8	31.0	8:15a	NNW
7	72.9	81.8	4:15p	63.2	7:00a	0.0	7.5	0.00	7.0	25.0	1:15a	N
8	73.7	84.2	5:30p	63.3	1:15a	0.0	8.7	0.00	5.4	21.0	11:30a	NNW
9	75.4	87.8	6:15p	62.9	4:45a	0.0	10.4	0.00	3.2	13.0	12:15p	NNW
10	77.0	90.2	5:15p	63.3	6:45a	0.0	11.7	0.00	4.7	14.0	2:30p	SE
11	79.5	92.9	5:00p	68.4	6:45a	0.0	15.7	0.00	3.3	12.0	1:30a	SE
12	82.8	96.3	4:30p	70.4	6:45a	0.0	18.4	0.00	2.6	11.0	7:15p	SE
13	86.0	97.8	5:15p	75.8	5:15a	0.0	21.8	0.00	2.9	13.0	11:45p	ESE
14	86.7	98.9	4:00p	78.9	7:15a	0.0	23.9	0.00	6.1	19.0	5:00p	ESE
15	84.3	93.6	3:45p	77.0	6:45a	0.0	20.3	0.00	5.4	18.0	12:00p	WSW
16	82.9	91.9	4:15p	75.6	6:30a	0.0	18.8	0.00	3.3	16.0	2:00a	SSE
17	84.6	93.9	3:45p	78.5	6:45a	0.0	21.2	0.00	2.0	15.0	5:00p	S
18	85.6	95.6	4:30p	76.8	7:00a	0.0	21.2	0.00	3.1	12.0	3:30a	WSW
19	86.4	95.4	6:15p	79.4	3:30a	0.0	22.4	0.00	3.1	11.0	6:30a	N
20	85.4	93.5	4:30p	79.2	7:00a	0.0	21.3	0.00	7.3	20.0	1:45p	NW
21	81.6	90.7	4:00p	74.7	5:15a	0.0	17.7	0.00	4.6	16.0	10:00p	ESE
22	82.7	93.9	3:30p	73.5	4:30a	0.0	18.7	0.00	4.2	16.0	12:45a	SE
23	85.2	93.8	5:00p	76.7	11:30p	0.0	20.3	0.04	4.7	21.0	1:30p	NW
24	77.9	89.2	3:30p	74.0	4:15p	0.0	16.6	0.78	3.3	50.0	3:45p	E
25	80.9	88.5	5:00p	74.8	7:15a	0.0	16.7	0.01	8.1	26.0	4:45a	NW
26	75.4	80.2	1:15p	70.7	5:30a	0.0	10.4	0.00	1.5	15.0	1:30p	ESE
27	76.5	82.8	1:15p	70.5	6:45a	0.0	11.7	0.00	1.5	9.0	1:00p	E
28	67.9	73.6	12:15a	64.5	12:00m	0.0	4.0	2.37	5.8	27.0	7:00p	NNE
29	66.5	71.4	4:15p	61.3	5:30p	0.0	1.4	0.19	7.3	21.0	9:30a	NNW
30	69.5	76.2	3:00p	63.6	6:15a	0.0	4.9	0.00	4.8	13.0	1:30a	N
31	70.2	76.0	2:30p	65.2	1:30a	0.0	5.6	0.00	4.2	20.0	9:45p	N
-----												
	79.7	98.9	14	61.3	29	0.0	481.9	4.33	4.5	52.0	1	NNW

Max >= 90.0: 19

Max <= 32.0: 0

Min <= 32.0: 0

Min <= 0.0: 0

Max Rain: 2.37 ON 8/28/02

Days of Rain: 6 (>.01 in) 4 (>.1 in) 1 (>1 in)

Heat Base: 65.0 Cool Base: 65.0 Method: (High + Low) / 2

MONTHLY CLIMATOLOGICAL SUMMARY for SEP. 2002

NAME: Weather 2001 CITY: Indain Head STATE: Maryland  
 ELEV: LAT: 38°34'59 N LONG: 77°11'35 W

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	66.2	68.2	6:45p	63.3	7:45a	0.0	0.7	0.41	8.4	31.0	1:15p	NNW
2	69.0	76.0	6:30p	64.0	12:00m	0.0	5.0	0.00	6.1	17.0	12:45a	NNW
3	74.5	88.3	5:30p	62.9	6:45a	0.0	10.6	0.00	3.1	12.0	2:00p	N
4	79.1	87.9	4:15p	66.4	4:30p	0.0	12.2	0.00	4.7	18.0	11:30a	NW
5	75.6	85.2	5:15p	67.8	7:30a	0.0	11.5	0.00	5.0	15.0	6:30p	NW
6	71.7	81.3	5:00p	64.1	9:15p	0.0	7.7	0.00	3.2	14.0	8:45a	N
7	70.7	83.2	3:45p	60.7	7:00a	0.0	6.9	0.00	3.0	16.0	2:30p	E
8	71.1	81.3	3:45p	61.3	7:45p	0.0	6.3	0.00	2.9	10.0	12:15p	ESE
9	73.1	89.0	5:00p	60.6	7:00a	0.0	9.8	0.00	2.4	13.0	12:45p	E
10	78.0	89.7	5:00p	59.8	10:30a	0.0	9.7	0.00	3.0	13.0	5:30p	N
11	76.8	80.8	12:45p	69.7	12:00m	0.0	10.3	0.00	16.4	44.0	11:00a	NW
12	69.4	78.8	5:45p	60.7	12:00m	0.0	4.8	0.00	6.7	22.0	4:30a	NW
13	70.4	83.9	5:00p	57.5	7:00a	0.0	5.7	0.00	4.1	16.0	12:45p	SE
14	73.7	82.9	3:30p	66.3	6:00a	0.0	9.6	0.13	4.5	27.0	7:15p	SE
15	74.4	78.9	4:30p	63.0	1:00p	0.0	6.0	0.07	4.8	26.0	11:30p	SE
16	75.0	83.1	3:45p	71.1	4:45a	0.0	12.1	0.28	3.2	19.0	12:30a	WSW
17	72.9	82.9	4:15p	57.8	8:15p	0.0	5.4	0.00	2.4	14.0	12:45a	NW
18	72.8	83.6	4:15p	64.1	6:30a	0.0	8.8	0.00	2.7	10.0	3:00p	SSW
19	73.3	82.1	3:45p	67.6	4:45a	0.0	9.8	0.00	3.9	12.0	2:15p	ESE
20	75.7	84.8	4:45p	68.9	5:00a	0.0	11.9	0.00	4.1	14.0	9:15p	ESE
21	77.4	87.6	4:00p	68.7	7:00a	0.0	13.1	0.00	4.8	15.0	8:30a	SE
22	76.9	85.5	3:00p	70.6	7:30a	0.0	13.0	0.00	4.8	16.0	12:00m	ESE
23	71.4	77.5	5:30p	64.5	12:00m	0.0	6.0	0.02	11.7	32.0	6:15a	NNW
24	67.4	79.1	5:15p	57.9	5:30a	0.0	3.5	0.00	4.2	14.0	6:00p	NNW
25	67.6	75.1	1:15p	58.9	4:00a	0.0	2.0	0.00	3.1	17.0	10:15a	NNE
26	65.4	67.9	12:30a	63.1	8:30p	0.0	0.5	0.75	4.6	17.0	2:45p	NNE
27	72.7	83.2	5:45p	52.8	11:30a	0.0	3.0	0.04	4.8	20.0	3:30p	SE
28	72.5	79.3	12:15a	62.4	12:00m	0.0	5.9	0.01	11.0	35.0	2:00a	NNW
29	66.3	76.8	4:45p	58.6	5:00a	0.0	2.7	0.00	2.6	11.0	11:00a	NNW
30	68.1	77.9	4:00p	59.3	1:00a	0.0	3.6	0.00	2.7	9.0	3:15a	ESE
-----												
	72.3	89.7	10	52.8	27	0.0	218.1	1.71	5.0	44.0	11	SE

Max >= 90.0: 0

Max <= 32.0: 0

Min <= 32.0: 0

Min <= 0.0: 0

Max Rain: 0.75 ON 9/26/02

Days of Rain: 7 (>.01 in) 4 (>.1 in) 0 (>1 in)

Heat Base: 65.0 Cool Base: 65.0 Method: (High + Low) / 2

MONTHLY CLIMATOLOGICAL SUMMARY for OCT. 2002

NAME: Weather 2001 CITY: Indain Head STATE: Maryland  
 ELEV: LAT: 38° 34' 59 N LONG: 77° 11' 35 W

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	71.7	82.6	4:15p	63.0	2:30a	0.0	7.8	0.00	3.2	14.0	12:30p	E
2	73.8	86.1	3:00p	64.1	7:00a	0.0	10.1	0.00	1.4	10.0	2:45p	SSE
3	75.7	87.8	3:15p	66.8	7:30a	0.0	12.3	0.00	0.1	4.0	8:45a	S
4	76.3	84.5	4:00p	69.7	4:45a	0.0	12.1	0.00	5.3	22.0	10:45p	SE
5	78.1	87.7	3:15p	66.9	12:00m	0.0	12.3	0.00	7.6	34.0	6:45p	NNW
6	67.1	74.5	4:45p	59.4	7:15a	0.0	2.0	0.00	5.4	21.0	1:15a	SE
7	69.7	78.7	1:30p	58.1	11:45a	0.0	3.4	0.00	6.6	23.0	2:45p	NNW
8	58.2	66.3	3:30p	46.8	10:45a	8.4	0.0	0.00	5.4	21.0	1:00a	N
9	59.4	64.4	5:00p	51.4	2:45a	7.1	0.0	0.00	0.9	6.0	10:15a	E
10	64.1	67.2	2:30p	61.3	5:00a	0.8	0.0	0.23	1.9	12.0	11:00a	N
11	67.5	70.5	3:00p	65.0	6:00a	0.0	2.8	0.66	1.0	12.0	3:30p	N
12	68.4	73.7	3:00p	54.7	3:00p	0.8	0.0	0.00	4.9	15.0	4:30p	N
13	65.6	69.0	5:15p	61.3	12:00m	0.0	0.1	0.00	5.4	31.0	11:15p	NE
14	55.5	61.6	3:00p	45.8	12:00m	11.3	0.0	0.00	7.8	24.0	8:45a	NNW
15	52.9	60.4	4:00p	43.6	6:00a	13.0	0.0	0.04	3.1	20.0	10:15p	NNE
16	58.3	61.0	5:45p	54.4	10:45p	7.3	0.0	1.33	9.9	27.0	11:00a	N
17	56.2	61.8	3:45p	50.6	8:00a	8.8	0.0	0.03	5.9	30.0	11:30p	NW
18	52.1	62.1	5:00p	41.0	7:30a	13.5	0.0	0.00	5.3	23.0	12:15a	ESE
19	58.0	66.0	4:30p	48.0	5:00a	8.0	0.0	0.00	5.4	24.0	4:30p	SE
20	58.7	64.0	12:15a	56.0	12:00m	5.0	0.0	0.00	2.5	12.0	9:45a	NNW
21	54.8	61.9	5:15p	46.0	11:45p	11.0	0.0	0.00	3.4	13.0	12:15p	N
22	51.1	63.7	4:45p	42.9	5:15a	11.7	0.0	0.01	2.1	7.0	2:45p	E
23	54.7	66.8	2:15p	44.1	7:30a	9.5	0.0	0.00	4.7	18.0	2:15p	ESE
24	50.7	54.3	12:15a	46.8	12:00m	14.5	0.0	0.00	4.6	17.0	7:45a	NE
25	50.3	55.5	11:30p	45.5	3:00a	14.5	0.0	0.56	3.6	16.0	12:15a	N
26	57.7	66.6	4:00p	53.0	7:30a	5.2	0.0	0.11	3.4	16.0	5:30p	NW
27	57.5	67.4	4:30p	48.6	8:00a	7.0	0.0	0.00	2.5	20.0	12:30p	NW
28	51.3	56.2	12:15a	47.8	6:15p	13.0	0.0	0.15	2.1	10.0	1:45a	N
29	45.7	50.9	1:15a	42.1	12:00m	18.5	0.0	0.86	5.7	19.0	5:15a	NNE
30	41.8	43.1	3:30p	40.6	6:30a	23.2	0.0	0.52	9.1	26.0	6:45p	NNW
31	45.0	50.3	4:00p	41.1	5:15a	19.3	0.0	0.02	9.7	25.0	12:15a	NNW
-----												
	59.6	87.8	3	40.6	30	231.3	62.8	4.52	4.5	34.0	5	N

Max >= 90.0: 0

Max <= 32.0: 0

Min <= 32.0: 0

Min <= 0.0: 0

Max Rain: 1.33 ON 10/16/02

Days of Rain: 11 (>.01 in) 8 (>.1 in) 1 (>1 in)

Heat Base: 65.0 Cool Base: 65.0 Method: (High + Low) / 2

MONTHLY CLIMATOLOGICAL SUMMARY for NOV. 2002

NAME: Weather 2001 CITY: Indain Head STATE: Maryland  
 ELEV: LAT: 38°34',59 N LONG: 77°11',35 W

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	46.9	56.1	1:00p	35.7	7:00a	19.1	0.0	0.00	8.8	33.0	9:45p	W
2	43.5	52.3	3:30p	34.9	11:45p	21.4	0.0	0.00	8.4	31.0	2:30a	WNW
3	44.4	54.8	4:15p	34.1	12:30a	20.6	0.0	0.00	4.0	16.0	7:15a	NW
4	47.9	57.1	4:00p	42.4	12:15a	15.3	0.0	0.00	3.3	16.0	6:45p	SE
5	46.9	52.5	11:30a	40.7	7:15a	18.4	0.0	0.60	3.5	14.0	1:30a	ESE
6	50.1	56.7	1:30p	46.6	2:45a	13.4	0.0	0.15	13.7	46.0	4:45p	WNW
7	48.2	53.0	3:30p	39.7	10:45p	18.6	0.0	0.00	12.0	35.0	3:00a	WNW
8	50.4	65.6	3:00p	37.2	6:00a	13.6	0.0	0.00	4.0	15.0	3:30p	SE
9	58.2	69.3	3:00p	44.8	7:00a	7.9	0.0	0.00	4.6	16.0	12:45p	SE
10	67.7	74.1	12:45p	59.3	6:00a	0.0	1.7	0.00	6.1	25.0	10:45a	SE
11	66.0	72.1	6:00a	58.4	9:15p	0.0	0.3	0.48	3.6	27.0	6:00a	SE
12	54.5	60.5	12:30a	51.3	5:00p	9.1	0.0	0.80	7.7	28.0	3:15p	NNW
13	49.1	52.1	1:45p	39.4	11:45p	19.3	0.0	0.01	11.0	36.0	11:15a	NW
14	49.7	63.5	3:00p	36.7	7:00a	14.9	0.0	0.00	2.9	13.0	10:00a	SE
15	52.1	61.9	3:30p	43.9	6:00a	12.1	0.0	0.00	2.4	11.0	2:00a	SE
16	51.6	53.2	1:15p	49.6	12:00m	13.6	0.0	1.34	4.7	18.0	11:30p	N
17	45.3	49.7	12:15a	42.3	10:00p	19.0	0.0	0.53	11.9	34.0	7:45p	NNW
18	45.3	52.1	2:45p	36.9	12:00m	20.5	0.0	0.00	11.9	34.0	10:30a	W
19	43.2	55.9	3:45p	31.5	6:15a	21.3	0.0	0.00	3.0	16.0	10:30a	E
20	43.9	59.8	3:30p	34.5	4:45a	17.9	0.0	0.00	2.3	12.0	4:30p	SE
21	47.3	52.3	12:45p	40.3	4:15a	18.7	0.0	0.00	0.7	7.0	8:45a	ESE
22	48.3	51.1	12:45p	43.9	10:00p	17.5	0.0	0.02	8.6	44.0	11:15p	W
23	44.0	49.0	3:15p	39.8	7:30a	20.6	0.0	0.00	17.9	60.0	2:15a	WNW
24	44.5	61.3	4:15p	32.0	7:00a	18.4	0.0	0.00	1.1	6.0	9:45a	SSW
25	45.7	59.3	3:15p	34.5	7:00a	18.1	0.0	0.00	1.5	15.0	12:00m	N
26	45.7	50.0	12:15a	42.6	7:00p	18.7	0.0	0.01	5.0	21.0	4:45a	N
27	40.5	43.7	1:00p	34.9	12:00m	25.7	0.0	0.01	15.3	35.0	9:45a	NW
28	35.4	42.5	3:45p	29.0	6:45a	29.3	0.0	0.00	6.0	20.0	5:30p	NW
29	41.2	50.7	4:30p	29.7	5:30a	24.8	0.0	0.00	6.9	25.0	8:15p	S
30	47.4	56.4	2:00p	39.0	11:45p	17.3	0.0	0.07	12.7	54.0	8:45p	S
-----												
	48.2	74.1	10	29.0	28	504.9	1.9	4.02	6.8	60.0	23	SE

Max >= 90.0: 0  
 Max <= 32.0: 0  
 Min <= 32.0: 4  
 Min <= 0.0: 0  
 Max Rain: 1.34 ON 11/16/02  
 Days of Rain: 8 (>.01 in) 6 (>.1 in) 1 (>1 in)  
 Heat Base: 65.0 Cool Base: 65.0 Method: (High + Low) / 2

MONTHLY CLIMATOLOGICAL SUMMARY for DEC. 2002

NAME: Weather 2001 CITY: Indain Head STATE: Maryland  
 ELEV: LAT: 38°34',59 N LONG: 77°11',35 W

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	35.1	39.4	12:15a	28.0	11:00p	31.3	0.0	0.00	15.0	42.0	7:00a	WNW
2	41.9	51.8	1:45p	28.8	6:30a	24.7	0.0	0.00	5.0	20.0	5:45p	S
3	31.9	43.5	2:45a	26.3	9:30p	30.1	0.0	0.00	14.7	43.0	4:30a	NNW
4	28.1	33.9	8:00p	23.5	6:30a	36.3	0.0	0.00	4.2	20.0	1:00a	NNW
5	29.2	31.7	9:00p	26.4	1:45a	36.0	0.0	0.00	8.6	24.0	11:45a	NNW
6	30.1	36.1	11:45a	19.6	12:00m	37.2	0.0	0.18	6.2	29.0	12:15p	NW
7	28.8	42.4	3:45p	14.7	7:15a	36.5	0.0	0.20	3.6	14.0	11:30a	NE
8	37.1	50.5	3:00p	25.5	7:30a	27.0	0.0	0.01	6.5	34.0	8:45p	SSE
9	30.6	38.2	12:15a	22.7	5:45p	34.5	0.0	0.00	6.2	29.0	12:15a	N
10	31.5	37.3	3:00p	24.8	12:15a	34.0	0.0	0.00	2.1	10.0	10:15p	E
11	34.7	36.7	12:00m	32.4	4:45a	30.4	0.0	1.37	6.9	22.0	6:45p	NNW
12	34.1	36.7	12:15a	31.8	5:30a	0.0	0.0	0.00	3.1	9.0	1:45a	SW
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
-----												
	32.8	51.8	2	14.7	7	357.9	0.0	1.76	6.8	43.0	3	NW

Max >= 90.0: 0  
 Max <= 32.0: 1  
 Min <= 32.0: 11  
 Min <= 0.0: 0  
 Max Rain: 1.37 ON 12/11/02  
 Days of Rain: 3 (>.01 in) 3 (>.1 in) 1 (>1 in)  
 Heat Base: 65.0 Cool Base: 65.0 Method: (High + Low) / 2

## DISTRIBUTION

<p>COMMANDING OFFICER            NAVAL WEAPONS STA CHARLESTON            ATTN CODE 092            2316 RED BANK RD SUITE 100            GOOSE CREEK SC 29445-8601</p>	1	<p>COMMANDING OFFICER            ATTN CODE 043            NAVAL WEAPONS STATION EARLE            201 HIGHWAY 34 SOUTH            COLTS NECK NJ 07722-5014</p>	1
<p>COMMANDING OFFICER            NAWCWPNDIV            ATTN ENVIRONMENTAL DIRECTOR            1 ADMINISTRATION CIRCLE            CHINA LAKE CA 93555-6001</p>	1	<p>COMMANDING OFFICER            SOUTHWEST DIVISION NAVFACENGCOM            1220 PACIFIC HIGHWAY            SAN DIEGO CA 92132-5190</p>	1
<p>COMMANDING OFFICER            NAVSURFWARCEN DAHLGREN DIV            ATTN CODE CD28            17320 DAHLGREN ROAD            DAHLGREN VA 22448-5100</p>	1	<p>US ARMY ENVIRONMENTAL CENTER            TECHNICAL INFORMATION CENTER            ATTN SFIM-AEC-RMI            E5179 HOADLEY ROAD (E4460)            APG MD 21010-5401</p>	1
<p>COMMANDER            NAVSURFWARCEN CRANE DIV            BUILDING 3260, 300 HIGHWAY 361            CRANE IN 47522-5001</p>	1	<p>US ARMY CORPS OF ENGINEERS            HTRW- CX            12565 WEST CENTER ROAD            OMAHA NE 68144</p>	1
<p>COMMANDER IN CHIEF            ATTN CODE N4652            U.S. PACIFIC FLEET            250 MAKALAPA DRIVE            PEARL HARBOR HI 96860-3131</p>	1	<p>US AIR FORCE            HQ AF CENTER FOR ENVIR EXCELLENCE            ATTN AFCEE/ECP            3207 NORTH ROAD            BROOKS AFB TX 78235-5363</p>	1
<p>COMMANDER            NAVFACENGCOM PACIFIC DIV            ATTN CODE ENV            258 MAKALAPA DRIVE, SUITE 100            PEARL HARBOR HI 96860-3134</p>	1	<p>ARMY ENVIRONMENTAL DIVISION            NATIONAL GUARD BUREAU            ARNG READINESS CENTER NGB-ARE            11 SOUTH GEORGE MASON DRIVE            ARLINGTON VA 22204-1382</p>	1
<p>COMMANDER            NAVFACENGCOM            ATTN CODE ENV            1322 PATTERSON AVE SE SUITE 1000            WASH NAVY YARD DC 20374-5065</p>	1	<p>HEADQUARTERS MARINE CORPS            ATTN CODE LFL            2 NAVY STREET            WASHINGTON DC 20380-1775</p>	1
<p>COMMANDING OFFICER            ATTN CODE 953            NAVAL WEAPONS STATION YORKTOWN            P.O. BOX 160            YORKTOWN VA 23691-0160</p>	1	<p>COMMANDING OFFICER            NAVFACENG SERVICE CENTER            ATTN CODE 40            1100 23RD AVENUE            PORT HUENEME CA 93043-4370</p>	1

DISTRIBUTION 1

For Official Use Only

COMMANDING OFFICER ATTN ENVIRONMENTAL DEPARTMENT SOUTHERN DIVISION NAVFAC 2155 EAGLE DRIVE NORTH CHARLESTON SC 29419-9010	1	JOHNS HOPKINS UNIVERSITY CHEMICAL PROPULSION INFO AGENCY 10630 LITTLE PAT PKWY SUITE 202 COLUMBIA MD 21044-3204	1
COMMANDER US ATLANTIC FLEET ATTN CODE N465 1562 MITSCHER AVENUE SUITE 250 NORFOLK VA 23551-2487	1	NASA HQ ENVIRONMENTAL MANAGEMENT DIVISION CODE JE 300 E ST SW WASHINGTON DC 20546-0001	1
COMMANDING OFFICER ENGINEERING FIELD ACTIVITY NORTHEAST ATTN ENVIRONMENTAL DEPARTMENT 10 INDUSTRIAL HWY LESTER PA 19113-2090	1	SHAW ENVIRONMENTAL INC 4100 QUAKERBRIDGE ROAD LAWRENCEVILLE NJ 08648	1
		<b>Internal:</b>	
		N51 (DOW)	1 CD
		04	1 CD
		071	1
		20T2	1, 1 CD
		20P4	1, 1 CD
		2330I	1, 1 CD
COMMANDER NAVAL SEA SYSTEMS COMMAND ATTN CODE 04RE 614 SICARD STREET SE STOP 7031 WASH NAVY YARD DC 20376-7031	1		
CNO ENVIRONMENTAL READINESS DIV ATTN CODE N453D CRYSTAL PLAZA 5 ROOM 680 2211 SOUTH CLARK PLACE ARLINGTON VA 22202-3735	1		
ASST SECRETARY OF THE AIR FORCE INSTALLATIONS ENVIRONMENT & LOG 1665 AIR FORCE PENTAGON SAF/IEE WASHINGTON DC 20330-1660	1		

DISTRIBUTION 2

For Official Use Only

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestion for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.  
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

<b>1. REPORT DATE (DD-MM-YYYY)</b> 22 January 2004		<b>2. REPORT TYPE</b> Final Report		<b>3. DATES COVERED (From - To)</b>	
<b>4. TITLE AND SUBTITLE</b>  Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419			<b>5a. CONTRACT NUMBER</b>		
			<b>5b. GRANT NUMBER</b>		
			<b>5c. PROGRAM ELEMENT NUMBER</b>		
<b>6. AUTHOR(S)</b>  Randall J. Cramer and Carey Yates Indian Head Division Naval Surface Warfare Center Paul Hatzinger and Jay Diebold Shaw Environmental, Inc			<b>5d. PROJECT NUMBER</b>		
			<b>5e. TASK NUMBER</b>		
			<b>5f. WORK UNIT NUMBER</b>		
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  Indian Head Division Naval Surface Warfare Center Indian Head, MD 20640-5035				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  Naval Ordnance Safety and Security Activity Naval Sea Systems Command Indian Head, MD 20640-5555				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>  NOSSA/OESO	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>  NOSSA-TR-2004-001	
<b>12a. DISTRIBUTION/AVAILABILITY STATEMENT</b>  Approved for public release; distribution is unlimited.					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b>  The Applied Technology Department at the Indian Head Division, Naval Surface Warfare Center and Shaw Environmental, Inc., have just successfully completed a field demonstration of in situ bioremediation of a groundwater aquifer contaminated with perchlorate. Using a recirculation cell design, naturally occurring microorganisms were stimulated to degrade perchlorate by injecting a food source (lactate) and neutralizing the groundwater acidity with a carbonate buffer. Starting with perchlorate concentrations in excess of 210 mg/L, perchlorate levels were reduced by more than 95% in eight of the nine test plot monitoring wells over the 5 months of sampling. In two of the monitoring wells, the perchlorate levels were lowered to less than 5 ppb. In addition to the perchlorate levels and the pH, alkalinity, nitrate, and sulfate concentrations were measured. In situ bioremediation techniques are much less expensive and significantly lower in maintenance than traditional ex situ pump-and-treat systems. This is the first field trial conducted on the east coast of the United States, the first trial performed in an acidic aquifer, and the first demonstration of treating in situ perchlorate levels in excess of 200 mg/L. This project provides new and valuable information concerning the application of bioremediation for in situ perchlorate treatment.					
<b>15. SUBJECT TERMS</b>  Bioremediation Perchlorate					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>  SAR	<b>18. NUMBER OF PAGES</b>  85	<b>19a. NAME OF RESPONSIBLE PERSON</b>
<b>a. REPORT</b>  U	<b>b. ABSTRACT</b>  U	<b>c. THIS PAGE</b>  U			<b>19b. TELEPHONE NUMBER (Include area code)</b>

Evaluation of Potential for Monitored Natural Attenuation of  
Perchlorate in Groundwater

Technology Demonstration Plan  
for  
Building 1419 Site, Naval Surface Warfare Center,  
Indian Head, MD  
ESTCP Project No. ER-0428



Prepared by:



February 2006

## TABLE OF CONTENTS

<b>1.0</b>	<b>Introduction.....</b>	<b>1</b>
1.1	Background.....	1
1.2	Objectives of the Demonstration.....	2
1.3	Regulatory Drivers.....	3
1.4	Stakeholder/End-User Issues .....	3
<b>2.0</b>	<b>Technology Description.....</b>	<b>4</b>
2.1	Technology Development and Application .....	4
2.2	Previous Testing of the Technology .....	4
2.3	Factors Affecting Cost and Performance.....	4
2.4	Advantages and Limitations of the Technology .....	5
2.4.1	Advantages of MNA of Perchlorate .....	5
2.4.2	Limitations of MNA of Perchlorate.....	5
2.4.2.1	Hydrogeology .....	5
2.4.2.2	Groundwater Geochemistry .....	6
2.4.2.3	Commercialization of the Chlorite Dismutase Enzyme Assay .....	6
2.4.2.4	Cleanup Objectives .....	7
<b>3.0</b>	<b>Demonstration Design .....</b>	<b>8</b>
3.1	Performance Objectives .....	8
3.2	Site Selection for Demonstration .....	9
3.3	Test Site History/Characteristics.....	9
3.3.1	Test Site History and Description.....	9
3.4	Present Operations .....	11
3.5	Pre-Demonstration Testing and Analysis.....	12
3.5.1	Pre-Demonstration Testing - Probable Source Area.....	12
3.5.2	Test Site Characterization .....	13
3.5.3	Pre-Demonstration Testing – Mudflats.....	15
3.6	Testing and Evaluation Plan .....	16
3.6.1	Demonstration Set-Up and Start-Up.....	16
3.6.1.1	Monitoring Well Installation for Mass Flux Study.....	16
3.6.1.2	<i>In Situ</i> Biodegradation Study in the Mud Flats.....	18
3.6.1.3	Surveying and Initial Groundwater Sampling .....	19
3.6.2	Period of Operation.....	19
3.6.3	Amount/Treatment Rate of Materials to be Treated .....	20
3.6.4	Residuals Handling.....	20
3.6.5	Operating Parameters for the Technology .....	20
3.6.6	Experimental Design.....	21
3.6.7	Groundwater Sampling Plan.....	21
3.6.7.1	Laboratory Analysis.....	22
3.6.8	Demobilization.....	25
3.6.9	Health and Safety Plan.....	25
3.7	Selection of Analytical/Testing Methods and Laboratory .....	26
3.8	Selection of Analytical/Testing Methods.....	26
3.9	Management and Staffing .....	26
3.10	Demonstration Schedule .....	27
<b>4.0</b>	<b>Performance Assessment.....</b>	<b>30</b>
4.1	Performance Criteria .....	30

4.2	Performance Confirmation Methods.....	31
4.3	Data Analysis, Interpretation and Evaluation .....	33
5.1	Cost Reporting .....	34
5.2	Cost Analysis .....	35
<b>6.0</b>	<b>Implementation Issues.....</b>	<b>36</b>
6.1	Environmental Checklist.....	36
6.2	Other Regulatory Issues.....	36
6.3	End-User Issues .....	36
<b>7.0</b>	<b>References.....</b>	<b>37</b>
<b>8.0</b>	<b>Points of Contact.....</b>	<b>40</b>

## TABLES

<b>Table 3-1</b>	Performance Objectives
<b>Table 3-2</b>	Groundwater Characterization in Selected Monitoring Wells, February 14, 2005
<b>Table 3-3</b>	Groundwater Characterization in Selected Monitoring Wells, September 28, 2005
<b>Table 3-4</b>	Sample Analysis Details
<b>Table 3-5</b>	Groundwater Characterization, November 15 and 16, 2005
<b>Table 3-6</b>	Sample Locations and Designations
<b>Table 3-7</b>	Sample Collection and Analysis Details
<b>Table 3-8</b>	Specialized Laboratory Expertise
<b>Table 3-9</b>	Demonstration Schedule
<b>Table 4-1</b>	Performance Criteria
<b>Table 4-2</b>	Expected Performance and Performance Confirmation Methods
<b>Table 5-1</b>	Cost Tracking
<b>Table 8-1</b>	Points of Contact

## FIGURES

<b>Figure 1-1</b>	Perchlorate Biodegradation Pathway
<b>Figure 3-1</b>	Topographic Site Map
<b>Figure 3-2</b>	Site Map and Well Pair Location Map
<b>Figure 3-3</b>	Cross-Section Locations
<b>Figure 3-4</b>	Geologic Cross-Section A-A'
<b>Figure 3-5</b>	Geologic Cross-Section B-B'
<b>Figure 3-6</b>	Groundwater Potentiometric Surface Map - Shallow Wells (Nov 2005)
<b>Figure 3-7</b>	Perchlorate Isoconcentration Map - Shallow (Nov 2005)
<b>Figure 3-8</b>	Perchlorate Isoconcentration Map - Deep (Nov 2005)
<b>Figure 3-9</b>	Aerial View of Mudflats and Proposed Mudflats Study Area
<b>Figure 3-9A</b>	Proposed Mudflats Study Area
<b>Figure 3-10</b>	Tentative Permanent Monitoring Well Locations
<b>Figure 3-11</b>	Organization Chart
<b>Figure 3-12</b>	Gantt Chart of Project Schedule

## **APPENDICES**

<b>Appendix I</b>	Historical Information
<b>Appendix II</b>	Site-Specific Workplan for Pre-Demonstration Sampling (November 2005)
<b>Appendix III</b>	Boring Logs
<b>Appendix IV</b>	Boring Advancement and Groundwater Sampling
<b>Appendix V</b>	Updated Site-Specific Health and Safety Plan
<b>Appendix VI</b>	Quality Assurance Project Plan
<b>Appendix VII</b>	Laboratory Analytical Results from Pre-Demonstration Sampling (November 2005)

## LIST OF ABBREVIATIONS USED IN THIS DOCUMENT

1. AFCEE – Air Force Center for Environmental Excellence
2. BOD – Biochemical Oxygen Demand
3. CD – Chlorite Dismutase
4. CVOC – Chlorinated Volatile Organic Compound
5. DNA – Deoxyribonucleic Acid
6. DO – Dissolved Oxygen
7. DoD – Department of Defense
8. ESTCP – Environmental Security Technology Certification Program
9. ft bgs – Feet below ground surface
10. HASP – Health and Safety Plan
11. IC – Ion Chromatography
12. IC/MS/MS – Ion Chromatography/Dual Mass Spectroscopy
13. IDW – Investigation-Derived Waste
14. IHDIV – Indian Head Division
15. ITRC – Interstate Technology Regulatory Council
16. K – Hydraulic Conductivity
17. MCL – Maximum Contamination Limits
18. MNA – Monitored Natural Attenuation
19. mRNA – Messenger Ribonucleic Acid
20. MSDS – Material Safety Data Sheet
21. MTBE – Methyl-*tert*-Butyl Ether
22. NPV – Net Present Value
23. NSWC – Naval Surface Warfare Center
24. O&M – Operation and Maintenance
25. ORP – Oxidation-Reduction Potential
26. PI – Principal Investigator
27. PID – Photoionization Detector
28. PPE – Personal Protective Equipment
29. RNA – Ribonucleic Acid
30. TOC – Total Organic Carbon
31. USEPA – United States Environmental Protection Agency

32. VOC – Volatile Organic Compound

## 1.0 Introduction

The purpose of the following Technology Demonstration Plan is to describe how Solutions-IES will evaluate the potential for monitored natural attenuation (MNA) of perchlorate in groundwater at the selected site in Indian Head, Maryland. The demonstration is funded by ESTCP under Project No. ER-0428. This Technology Demonstration Plan details the performance measurements and metrics for success.

### 1.1 Background

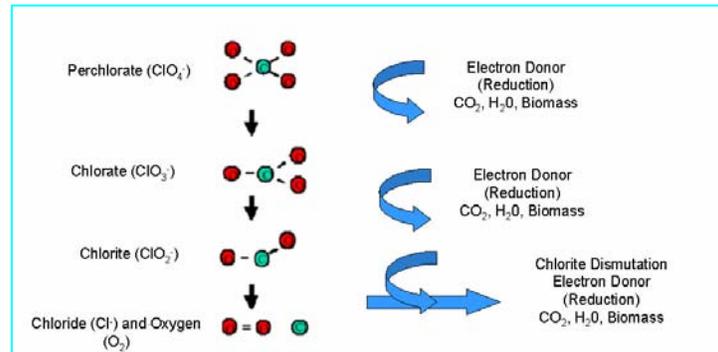
Groundwater and surface water contaminated with perchlorate ( $\text{ClO}_4^-$ ) has become a major environmental issue for the US Department of Defense (DoD) due to the use, release and/or disposal of solid rocket fuel and munitions containing ammonium perchlorate. These releases have resulted in extensive contamination of surface and groundwater supplies. In the western US, over 15 million people consume water with some level of perchlorate. This is a significant concern because high levels of perchlorate interfere with iodide uptake by the thyroid (USACHPPM). Currently, there is no federal cleanup standard for perchlorate in groundwater or soil (US EPA, 2005; ITRC, 2005), however, in January 2006, the USEPA issued "Assessment Guidance for Perchlorate" identifying 24.5  $\mu\text{g/L}$  as the recommended "to be considered" (TBC) value and preliminary remediation goal for perchlorate (USEPA, 2006). Several states have identified advisory levels that range in concentration from 1  $\mu\text{g/L}$  to 52  $\mu\text{g/L}$ . Specifically, the state of Maryland has identified an advisory level of 1  $\mu\text{g/L}$  for perchlorate in drinking water (US EPA, 2005).

Perchlorate is a highly mobile, soluble anion that sorbs poorly to most aquifer material, and can persist for decades under aerobic conditions. As a consequence, discharge of perchlorate to the environment can impact ground and surface water with the potential for human consumption through direct (drinking water) and indirect (crop uptake from irrigation water) pathways. However, recent research has shown that a diverse array of bacteria can anaerobically degrade perchlorate to chloride and oxygen. These organisms appear to be widespread in the environment and can use a variety of different organic substrates as electron donors for perchlorate reduction. This suggests that perchlorate may naturally degrade at some sites without active human intervention.

In recent years, an extensive body of information has been developed demonstrating that a large and diverse population of microorganisms can degrade perchlorate to chloride and oxygen (Coates *et al.*, 1999; Coates and Pollock, 2003). Perchlorate-reducing organisms are widespread in the environment (Coates *et al.*, 1999; Logan, 2001) and can use a variety of different organic substrates (e.g., acetate, propionate, lactate, etc.) as electron donors for perchlorate reduction (Herman and Frankenberger, 1998; Coates *et al.*, 1999). Perchlorate biodegradation can occur under strict anaerobic conditions as well as facultative anaerobic conditions. Facultative anaerobic microorganisms are capable of both aerobic respiration under low oxygen tension and fermentation when anaerobic conditions prevail. This metabolic versatility suggests that environments exist that can support a variety of perchlorate-reducing microbial populations.

Facultative anaerobic metabolism is inhibited by dissolved oxygen concentrations in excess of 2 mg/L (Rikken *et al.*, 1996; Chaudhuri *et al.*, 2002). However, when biodegradable organic substrates are present, the available dissolved oxygen will be consumed and there is a very high probability that perchlorate will biodegrade in the natural environment. The biodegradation pathway of perchlorate is illustrated below (**Figure 1-1**).

**Figure 1-1 Perchlorate Biodegradation Pathway**



Work by Coates *et al.* (1999), Chaudhuri *et al.* (2002), and Bender *et al.* (2002) indicates that the *Dechloromonas* and *Dechlorosoma* groups represent the primary chlorate and perchlorate reducing bacteria in the environment, but more than 30 different strains of perchlorate-reducing microbes have been identified (US EPA, 2005). The rate-limiting step in the three-step degradation process is the conversion of perchlorate to chlorate by a perchlorate reductase enzyme. Subsequent conversion of chlorate to chlorite is also catalyzed by a perchlorate reductase enzyme. Chlorite removal by the chlorite dismutase (CD) enzyme is the final step in perchlorate reduction. Its specificity may be useful as an indicator of perchlorate biodegradation and therefore, provide supporting evidence for MNA of perchlorate at certain sites.

Because there is a strong potential for MNA of perchlorate where site conditions are appropriate, identifying lines of evidence that suggest which sites are amenable to perchlorate MNA is highly important. During an extensive site selection process, lines of evidence were evaluated for use in evaluating perchlorate MNA at sites throughout the United States including sites in Utah, Maryland, Mississippi, Alabama, and California. The Naval Surface Warfare Center (NSWC), Building 1419 site in Indian Head, Maryland site was selected for technical demonstration to confirm that the lines of evidence selected for perchlorate MNA are appropriate for conditions that may be encountered by engineers and scientists in the field. This demonstration should enable Solutions-IES to confirm common characteristics of perchlorate attenuation, and can be utilized to evaluate sites for perchlorate MNA in engineering practice. The characteristics of the demonstration site will be discussed in greater detail in Section 3.

## 1.2 Objectives of the Demonstration

Natural attenuation is defined by the US EPA as the “biodegradation, diffusion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility or volume to levels that are protective of human health and the environment.” The term MNA refers to the reliance on natural attenuation processes, within the context of a carefully controlled and monitored site cleanup, to achieve site-specific remedial goals. There are two overall goals of this project:

1. Provide DoD managers with the tools needed to evaluate whether MNA may be appropriate for management of perchlorate releases on their site(s); and
2. Demonstrate to regulatory agencies that perchlorate MNA is effective for controlling adverse impacts to the environment.

To achieve these goals, the following objective was established for the site selection phase of the project.

- Evaluate the rate and extent of perchlorate biodegradation in aquifer material and groundwater from a variety of sites that potentially received perchlorate through microcosm studies.

During the site selection process, the rate and extent of perchlorate biodegradation was evaluated at seven sites: Little Mountain Test Annex, Utah; ATK-Elkton, Maryland; Stennis Space Center, Mississippi; NSWC Indian Head Division, Maryland; Redstone Arsenal; Alabama; ATK Thiokol, Utah; and Beale Air Force Base, California. This information was used in part to assist Solutions-IES in identifying Indian Head Division, Maryland as a technical demonstration site. The site selection process was also used to indicate which lines of evidence should be tested for eventual use in a MNA protocol.

The objectives for the next phase of the project, the technical demonstration, are:

- Verify biodegradation rates established with microcosm studies that were performed during the site selection process.
- Evaluate the use of the chlorite dismutase (CD) enzyme analysis and isotopic ratios as indicators of perchlorate biodegradation.
- Continue to develop and test multiple lines of evidence established during the site selection process to evaluate the MNA of perchlorate.

Once the technical demonstrations are complete and the lines of evidence are tested in the field, Solutions-IES will:

- Develop a protocol for monitoring the natural attenuation of perchlorate.
- Transfer the knowledge gained about perchlorate MNA to the regulatory community.

### **1.3 Regulatory Drivers**

Currently, there is no federal cleanup standard for perchlorate in groundwater or soil (US EPA, 2005) although a TBC guidance concentration of 24.5 µg/L has been recommended (USEPA, 2006). However, several states have identified advisory levels that range in concentration from 1 µg/L to 52 µg/L. Specifically, the State of Maryland, location of the demonstration site, has identified an advisory level of 1 µg/L for groundwater (ITRC, 2005). The State of Maryland does not have a surface water standard for perchlorate<sup>1</sup>.

### **1.4 Stakeholder/End-User Issues**

An overall objective of this project is to produce a protocol that can be used by scientists and engineers as a guide to implement the MNA of perchlorate as a remedial strategy. Demonstrating MNA of perchlorate may be difficult because of large plume areas, poorly defined source areas, and absence of easily monitored degradation products.

---

<sup>1</sup> Personal communication from John McGillen, Maryland Department of the Environment, to M. Tony Lieberman, Solutions-IES, January 26, 2006.

The technical demonstration at the selected site in Indian Head, MD will allow Solutions-IES to test in the field the lines of evidence identified during the site selection process. Assuming that the demonstration is successful and the lines of evidence evaluated are useful, stakeholders such as local regulators and the general public will gain confidence that MNA of perchlorate is an effective remediation option to implement while protecting the public welfare and environmental health.

End-users may include regulators and consultants who will rely on the protocol that will be supported by the technical demonstration. The protocol will provide end-users with guidance for designing monitoring well networks in locations to optimize gathering useful information about plume movement and attenuation. The protocol will also present guidance for obtaining appropriate analytical data from the site and evaluating the data to understand its meaning with regard to indicating if MNA of perchlorate is the best remedial strategy in whole or in part for the site in question.

## **2.0 Technology Description**

### **2.1 Technology Development and Application**

Currently, Solutions-IES is developing lines of evidence for the MNA of perchlorate that could ultimately be used in a protocol to guide scientists and engineers when they implement the technology. A goal of the demonstration is to test these lines of evidence in the field to verify if they will be adequate for use in the protocol.

Some lines of evidence that we will evaluate during the technical demonstration include:

- Using existing and new monitoring wells to determine the horizontal and vertical distribution of perchlorate and mass flux with distance;
- Observe changes in groundwater bio-geochemistry as supporting evidence for attenuation;
- Confirm and obtain additional microbiological evidence for the *in situ* activity of perchlorate-degrading organisms using an analysis for CD and *in situ* biodegradation study results; and
- Identify changes in isotopic composition of perchlorate as an indicator of biodegradation.

### **2.2 Previous Testing of the Technology**

MNA of perchlorate has not been tested in the field. However, as discussed in Section 1.1, laboratory studies have shown that perchlorate-reducing organisms are widespread in the environment and can use a variety of different organic substrates. One objective of the demonstration is to evaluate which characteristics of perchlorate attenuation that have been tested in the laboratory apply to field sites where perchlorate MNA may be applied.

### **2.3 Factors Affecting Cost and Performance**

The primary capital costs associated with implementing a MNA groundwater strategy associated with chlorinated solvents or petroleum fuels is the installation of a well network to monitor the progress of natural attenuation of the respective constituents. The costs of installing the well network are affected by the subsurface lithology, the depth to groundwater, and the vertical extent of contamination. These same factors will influence the cost of the MNA of perchlorate.

We are also investigating the use of innovative indicator parameters to help identify perchlorate biodegradation, and these will be used during the technical demonstration. These indicator parameters include CD enzyme analysis and stable isotope studies. Using these parameters to identify perchlorate biodegradation will have significant impact on the cost of the technical demonstration, and the frequency that they are used at field sites will have a significant impact to cost where MNA of perchlorate is implemented as a remedy.

Another factor that will effect cost in the technical demonstration and eventually at field sites will be the cost of perchlorate analysis using EPA Method 330 where ion chromatography (IC) is used in tandem with a mass spectrometer detector (MS) in lieu of perchlorate analysis via Method 314, which relies on IC alone. Currently, Solutions-IES expects to collect a large number of samples for perchlorate analysis during the field demonstration and confirm the results of 10% of those samples with IC/MS/MS method. If EPA Method 330 is eventually required for all perchlorate analysis in the perchlorate MNA protocol, it could represent a significant increase in cost to implement the MNA of perchlorate at field sites.

The cost of an MNA project is also influenced by the rate of biodegradation of the contaminant of concern, and the mechanical aspects of attenuation such as dilution and dispersion. It is anticipated that these same factors will influence the cost of implementing a MNA strategy because they will affect the length of time required to monitor a site (i.e., the slower the rate of biodegradation the longer the monitoring time and the higher the cost).

## **2.4 Advantages and Limitations of the Technology**

### **2.4.1 Advantages of MNA of Perchlorate**

The primary advantages of MNA of perchlorate:

- No remediation equipment
- Lower capital costs
- Low maintenance cost
- No artificial impact to groundwater geochemistry and biology

### **2.4.2 Limitations of MNA of Perchlorate**

The use of MNA for perchlorate may be limited by hydrogeology, groundwater geochemistry, high contaminant concentrations, microbiology, and location of receptors.

#### **2.4.2.1 Hydrogeology**

An important part of implementing an MNA remedy is to identify the groundwater flow characteristics and the fate and transport of the contaminant of interest. At sites where hydrogeology is not well understood, it may not be possible to accurately determine the transport mechanisms of perchlorate or its fate in the environment. For example, in a strongly heterogeneous aquifer, it may be difficult to determine whether perchlorate has degraded or if it has been transported to another part of the aquifer system. At the Indian Head site, the hydrogeology should not prevent a clear understanding of the fate and transport of perchlorate. Based on current information, the site geology is fairly consistent with a mixed layer of a clay, silt, sand to a depth of approximately 15 to 16 feet below ground surface (ft bgs), resting upon a layer of gravel, silt, sand mixture less than 2 feet in thickness, resting upon a grey clay confining unit.

### **2.4.2.2 Groundwater Geochemistry**

Perchlorate is known to biodegrade anaerobically, so depletion of dissolved oxygen (DO) and nitrate may be required prior to perchlorate biodegradation. Therefore, high concentrations of DO and nitrate coupled with low concentrations of total organic carbon (TOC) could inhibit biodegradation of perchlorate.

Recent DO concentrations measured at the Indian Head site range from 0.1 to 7.0 ppm; therefore, DO concentrations are not optimal, at all locations, since DO concentrations greater than 2.0 ppm are expected to inhibit perchlorate biodegradation. However, nitrate concentrations are low at the Indian Head site and would not be expected to inhibit perchlorate biodegradation.

### **2.4.2.3 Commercialization of the Chlorite Dismutase Enzyme Assay**

Available information indicates that the CD enzyme is only present in organisms that are actively reducing perchlorate or chlorate. As a consequence, detection of the CD enzyme should provide a direct indication that perchlorate is being degraded under *in situ* conditions, and therefore, use of the enzyme assay would provide another tool to evaluate the potential for MNA of perchlorate. Until recently, methods to detect the presence of the CD enzyme have been available on a limited basis.

During the site selection process previously performed for this project, Solutions-IES evaluated two methods under development. Sediment samples were sent to Dr. John Coates at the University of California-Berkeley, and some were split with Microbial Insights, Inc. in Rockford, TN. Initially, Dr. Coates employed a simple, relatively inexpensive immunoassay to measure RNA activity. However, the test was subject to matrix interference and the results proved generally inconsistent and unreliable. Microbial Insights used a DNA-based assay to determine the presence of the functional gene for chlorite dismutase in the sample matrices. Results from this approach determined if organisms with the genetic potential to degrade perchlorate were present or absent in the groundwater sample provided. However, presence of the organisms alone does not indicate that the bacteria are alive and metabolically active or expressing a particular function.

Concurrent with our site selection activities, both Dr. Coates and Microbial Insights were also working to develop and refine a more reliable RNA-based assay to directly identify perchlorate-reducing activity. While these prototype methods were available during the site selection process on a limited basis, neither was completely ready for commercialization at that time, and the prototype methods were used on a limited basis by Solutions-IES during the site selection phase of the project. However, recently Microbial Insights has completed development of an RNA-based test to identify the expression of a CD gene. Using this approach, RNA, as opposed to DNA, is extracted from the microbial population in the groundwater sample. The RNA is then subject to electrophoresis and the resultant protein band signature is compared with the RNA of known perchlorate-reducing microorganisms. The RNA is used to determine the expression of a particular functional gene based upon the abundance of messenger RNA (mRNA). The perchlorate-reducing microorganisms use the mRNA to assemble the CD enzyme, and its

abundance in the groundwater sample is a direct indication of enzyme activity and, therefore, the active biodegradation of perchlorate.

The mRNA approach is now commercially available from Microbial Insights. Solutions-IES intends to use this method as part of the monitoring program for the field demonstrations that are being planned. However, the RNA approach is still relatively new, and if problems with the analytical method are recognized during our technical demonstration, identifying perchlorate biodegradation would be more difficult, and therefore proving the MNA of perchlorate might be less convincing.

#### **2.4.2.4 Cleanup Objectives**

The use of MNA as a remedial strategy at some sites may be limited to relatively low concentrations of perchlorate. High concentrations would likely require active treatment. In addition, the use of MNA may require a long period of monitoring before perchlorate concentrations are less than remediation goals, so in cases where cleanup goals must be met very quickly because of the use of the property or because of potential receptors, MNA of perchlorate may not be an appropriate strategy for the site.

At the Indian Head site, the regulatory pressure to implement a remedy is not evident at the current time, but that may change as the State of Maryland identifies a remedial goal for perchlorate. After the technical demonstration, the Navy may have the information necessary to show that MNA for perchlorate can be applied as a remedial strategy at the Indian Head site.

### 3.0 Demonstration Design

#### 3.1 Performance Objectives

The overall objective of this demonstration project is to evaluate MNA for remediating perchlorate in groundwater. The performance will be evaluated by monitoring changes in perchlorate concentrations, mass flux, and plume stability. In addition, Solutions-IES will evaluate innovative tools that can be used to determine if biodegradation is occurring and at what rates. The performance objectives are summarized in **Table 3-1** and the performance criteria are discussed in Section 4.0.

<b>Table 3-1 Performance Objectives</b>			
<b>Type of Performance Objective</b>	<b>Primary Performance Criteria</b>	<b>Expected Performance (Metric)</b>	<b>Actual Performance (Objective Met?)</b>
Qualitative	1. Reduce risk	Reduce concentrations and mass flux of perchlorate during downgradient migration.	
	2. Capital costs	<b>Capital costs are significantly lower than active remedial alternatives.</b>	
	3. Maintenance	Maintenance costs are low and are typical of those associated with maintaining a monitoring well network.	
	4. Uncomplicated implementation	Implementation is similar to that of a typical monitoring program.	
	5. Regulatory acceptance	MNA approach is generally accepted by regulatory community, with conditions.	
	6. Monitoring approach	Monitoring approach is consistent with current industry practice. Results are easy to understand and interpret.	
Quantitative	1. Reduce perchlorate concentrations	> 90% reduction in average perchlorate concentration in wells downgradient of the probable source area.	
	2. Reduce mass flux of perchlorate	Reduce mass flux of perchlorate by >75% between source area and the most downgradient line of monitor wells.	
	3. Multiple lines of evidence	Two or more lines of evidence support perchlorate attenuation.	
	4. Stable isotope ratios	Observe statistically significant change in isotopic ratio of perchlorate during downgradient migration.	
	5. Enzyme activity	RNA levels of perchlorate degraders are elevated at some locations in the plume relative to background locations.	
	6. Meet regulatory standards	Perchlorate concentrations are below regulatory levels at compliance point.	

### 3.2 Site Selection for Demonstration

To identify sites for participation in the perchlorate MNA project, three levels of site evaluation were conducted. The first level of site identification (Screening Level 1) was performed in the office and involved gathering information from as many sites across the United States as possible. The second level of site identification (Screening Level 2) included reviewing the gathered information, and selecting up to seven sites for initial and comparative field characterization. The third level of screening (Screening Level 3) included actual collection and analysis of samples from the selected field sites, use of microcosm tests to examine degradation under ambient and augmented conditions, and testing innovative measures of enzyme activity to assist in identifying microbial activity on perchlorate. For a detailed description of the site evaluation process, please refer to the Site Selection Memorandum dated September 20, 2005.

Subsequent to the field work performed during Screening Level 3, a scoring system was devised to assist in the evaluation of the seven sites of interest for technical demonstration. In similar fashion to the Bioscreen model for evaluating the MNA of CVOCs, (AFCEE, 1996), a variety of parameters were assigned scores based on the likelihood that each criterion would be conducive to natural attenuation and a successful technical demonstration. Several criteria were scored including, but not limited to, field parameters such as pH and oxidation-reduction potential (ORP), total organic carbon (TOC) concentration, percent perchlorate removal estimated by microcosm studies, CD analytical results, and long term biological oxygen demand (BOD) studies.

Several additional criteria were also factored into the evaluation. These included site logistics like accessibility, weather, presence of unexploded ordnance, and terrain. Additional criteria included depth and type of drilling required, which relates to cost, and interest of the base managers in supporting the project at their site. The scores were totaled and the site with the highest total score was located at Building 1419 (Indian Head site) at Indian Head, MD. The Indian Head site was selected for technical demonstration and approved by ESTCP in a conference call on October 12, 2005

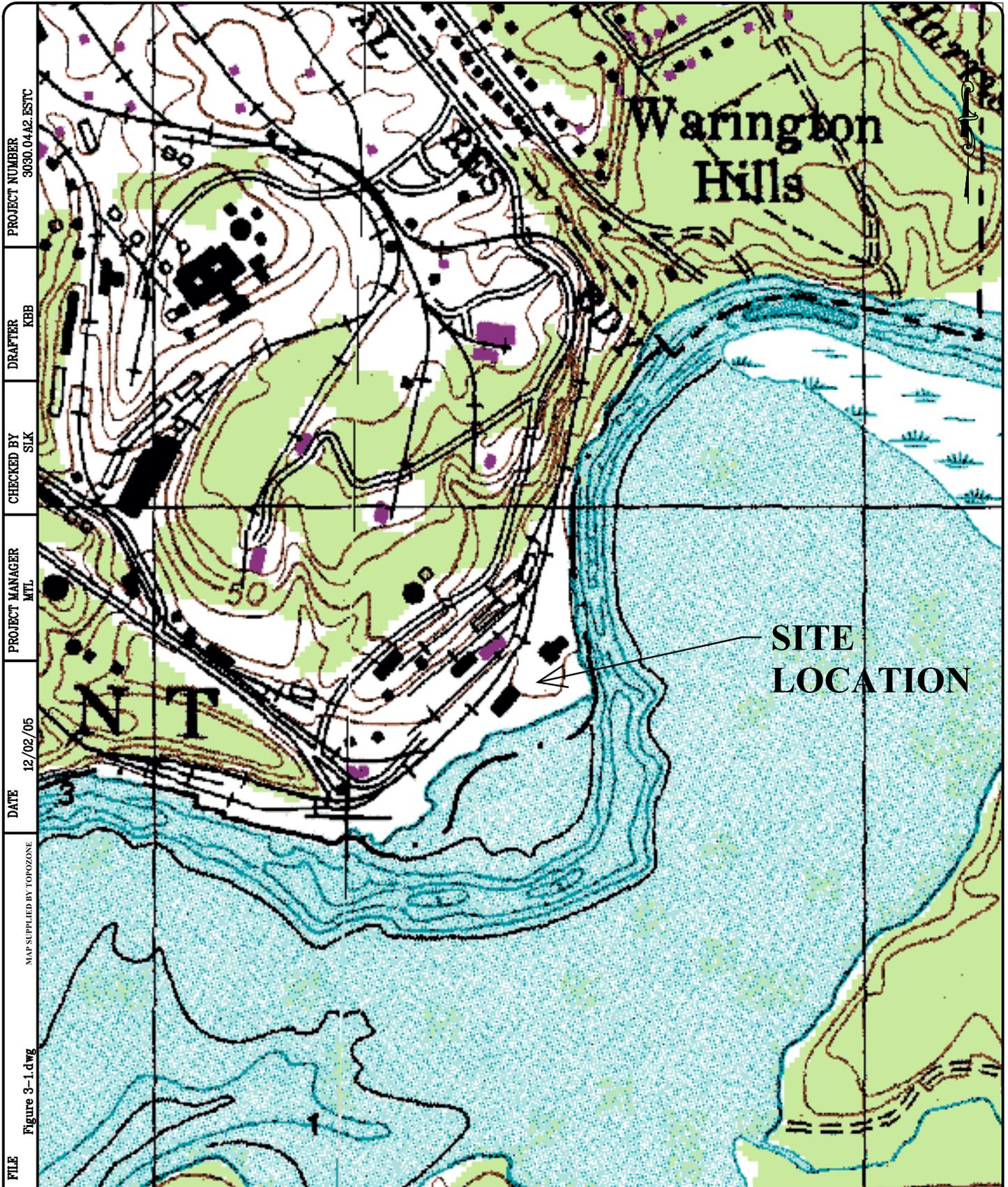
### 3.3 Test Site History/Characteristics

During preliminary work at Indian Head, Mr. Randall Cramer was identified as the site contact for the Indian Head site. The following report prepared by Randall J. Cramer and Cary Yates, Indian Head Division (IHDIV) and Paul Hatzinger and Jay Diebold of Shaw Environmental, Inc. (Shaw) was used as the primary source of historical information about the site.

Randall J. Cramer and Cary Yates, Indian Head Division, Naval Surface Warfare Center and Paul Hatzinger and Jay Diebold of Shaw Environmental, Inc., *Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419*, January, 2004 (Cramer *et al.*, 2004).

#### 3.3.1 Test Site History and Description

The technical demonstration site is located at the Indian Head Division (IHDIV), Naval Surface Warfare Center, near Indian Head in Charles County, Maryland, and is located approximately 30 miles south of Washington, DC (**Figure 3-1**). The Indian Head site is also referred to as the Building 1419 site, and is located on the southeast side of the IHDIV facility. The Indian Head site consists of approximately 2 acres of grassy land containing a small drum storage building and numerous groundwater monitoring, injection, and extraction wells. The area is bordered to the southeast by Mattawoman Creek (**Figure 3-2**), which is a large tributary to the Potomac River. Building 1419 is used to clean out or “hog out” solid propellant containing ammonium perchlorate from various devices, including rockets and ejection seat



FILE Figure 3-1.dwg

MAP SUPPLIED BY TOPOZONE

DATE 12/02/05

PROJECT MANAGER MTL

CHECKED BY SLK

DRAFTER KBB

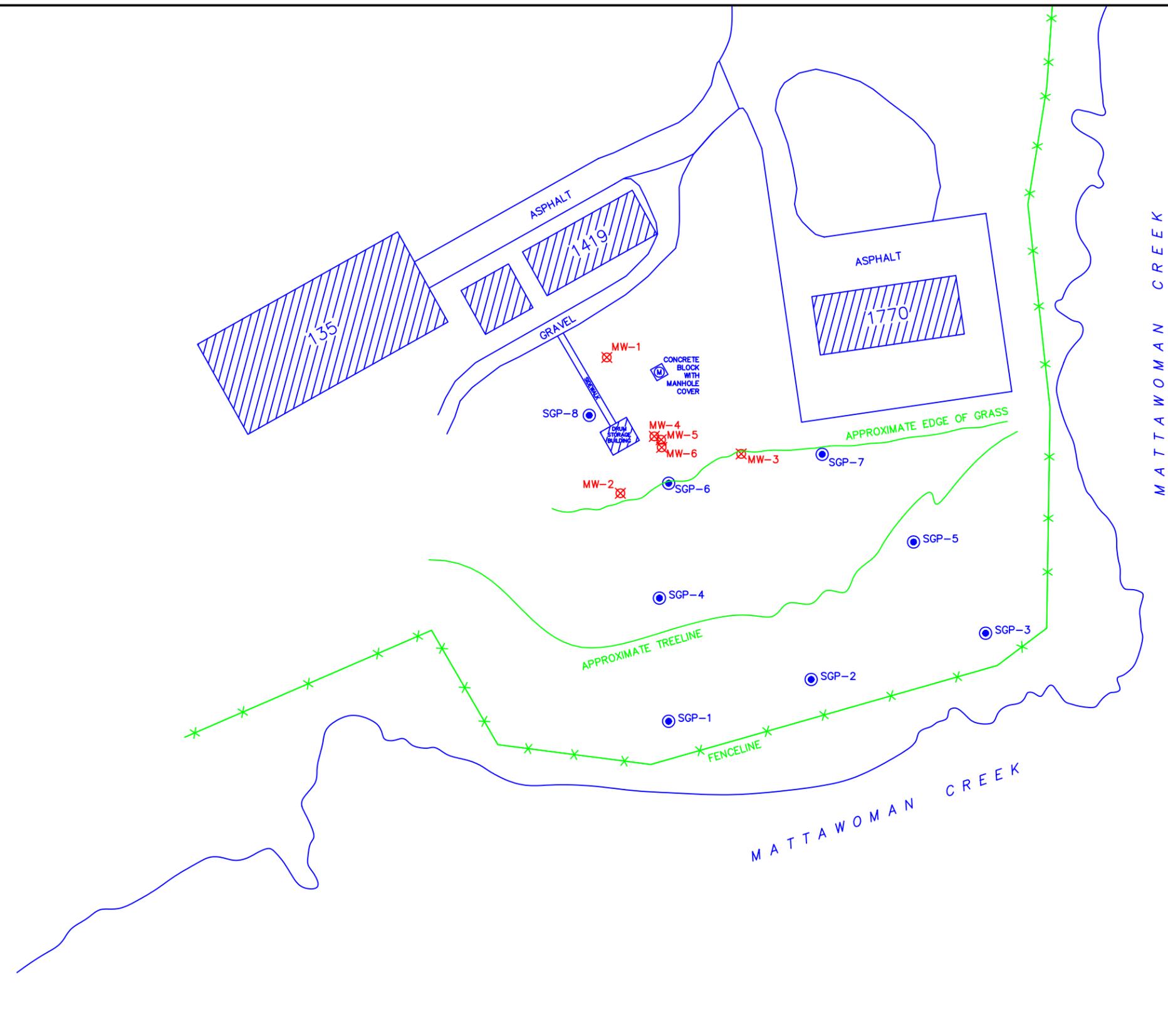
PROJECT NUMBER 3030.04.02. ESTC

**Solutions-IES**  
 Industrial & Environmental Services  
 1101 NOWELL ROAD  
 RALEIGH, NORTH CAROLINA 27607  
 TEL.: (919) 873-1060 FAX.: (919) 873-1074

TOPOGRAPHIC SITE MAP  
 INDIAN HEAD SITE  
 INDIAN HEAD NAVAL WARFARE CENTER  
 INDIAN HEAD, MARYLAND

FIGURE:  
 3-1

FILE Figure 3-2.dwg (Base Map) DATE 11/29/05 PROJECT MANAGER SLK CHECKED BY SLK DRAFTER KBB PROJECT NUMBER 3030.04A2.ESTC



**LEGEND**

- ⊗ MW-3 EXISTING MONITORING WELL (SHAW)
- SGP-3 BORING/TEMPORARY WELL PAIR SOLUTIONS-IES)

0 100 200  
SCALE IN FEET

motors, that have exceeded their useful life span. The hog out process and former waste handling methods have impacted the groundwater near Building 1419.

### 3.3.2 Historical Site Activities, Geology, and Hydrogeology

In 2002, Shaw performed an evaluation of enhanced *in situ* bioremediation by applying lactate substrate to impacted groundwater at the Indian Head site. A pilot system was created employing a recirculation cell design consisting of two field areas located in the immediate vicinity of monitoring wells MW-5 and MW-6. In the test area around MW-5, groundwater was extracted from the site, amended with a lactate substrate and a pH buffer, and then re-injected into the aquifer. Groundwater was extracted and re-injected without substrate or buffer amendment in the control area near MW-6. Each Shaw pilot test cell (test area and control area) covered an area measuring approximately 10 X 10 ft (100 sq. ft.) in the middle of the filled area south of the hog-out facility (**Appendix I**, Figure A).

The study area used by Shaw for their pilot test is located southeast of Building 1419 and approximately 350 feet northwest of Mattawoman Creek. The surficial geology of the area was derived from soil samples collected from 17 Geoprobe® borings and six test borings that ranged in depth from 16 to 20 feet bgs. The top 2 to 4 feet consisted of fill material including organic soils, gravel, and silty sand (Cramer *et al.*, 2004). The underlying 11 to 13 feet consisted of mottled light to olive brown clay to sandy silts. The clay and sand fractions of the silts varied horizontally and vertically. Fine-grained sand seams 1 to 2 inches in thickness were seen in many of the boring locations, but these seams were not continuous from boring to boring. At a depth of approximately 15 ft bgs, a 1 to 1.5 ft thick layer of sand and gravel was encountered. This layer was found to be continuous throughout the area. The sand and gravel layer is underlain by a gray clay layer, which extends to a depth of at least 20 feet bgs, the deepest extent of the Geoprobe® and test borings (**Appendix I**, Figures B, C, D). This is likely the clays of the Potomac Group.

Groundwater elevations measured in the six monitoring wells in the field indicate a groundwater flow direction to the southeast toward the Mattawoman Creek (**Appendix I**, Figure E). The flow direction basically follows the surface topography. Depth to groundwater ranged from approximately 6.5 to 10.3 ft bgs. The average hydraulic gradient, as measured between wells MW-1 and MW-3, was 0.023 ft/ft, indicating a relatively flat gradient. **Appendix I**, Figure F shows an interpretation of the 100 mg/L perchlorate isoconcentration contour from the January 2004 report. Based on historical information, the plume extends from Building 1419 to the southeast, but neither the distal end nor the lateral extent of the perchlorate migration is estimated. Pre-demonstration work was performed to update the information concerning the perchlorate concentrations downgradient at this test area. That work is discussed in greater detail in Section 3.5.

To obtain additional information for the site-selection process, Solutions-IES traveled to the site on February 14, 2005 to collect soil and groundwater samples. Monitoring well MW-1 is located about 80 feet upgradient from the Shaw pilot test cells, MW-2 is located approximately 50 ft southwest of the test cells, and MW-4 is located at the north edge of the control treatment cell (**Figure 3-2**). Groundwater samples were collected from these existing monitoring wells using a peristaltic pump and polyethylene tubing. Field parameters were collected during low flow sampling at each monitoring well. **Table 3-2** summarizes field parameters collected during the groundwater sampling activities at each monitoring well. The table also summarizes the perchlorate concentration detected in each groundwater sample.

Table 3-2 Groundwater Characterization in Selected Monitoring Wells, February 14, 2005 Indian Head Site, Naval Surface Warfare Center				
Monitoring Well Identification	pH (Standard Unit)	Oxidation/Reduction Potential (mV)	Dissolved Oxygen (ppm)	Perchlorate ( $\mu\text{g/L}$ )
MW-1	4.9	105.	~1.0	92,820
MW-2	6.9	< -1000	~3.5	3
MW-4	5.4	5.6	~8	36,263

Note: Laboratory analysis of perchlorate performed at NCSU Civil and Environmental Engineering Laboratory, Raleigh, NC

Solutions-IES returned to the site on September 28, 2005 and collected groundwater samples from existing monitoring wells MW-4D and MW-5, located within the lactate injection treatment cell of Shaw's pilot test, to measure perchlorate and TOC concentrations within the former test area (Appendix I, Figure A). The objective was to determine whether there was any long-term impact of the lactate injection treatment that was completed in 2002 that could complicate the current planned evaluation of the potential for MNA in this area. **Table 3-3** summarizes the current field parameters, the current TOC concentrations and the perchlorate concentrations reported measured during this event and those reported in 2002 for comparison.

Table 3-3 Groundwater Characterization in Selected Monitoring Wells, September 28, 2005 Indian Head Site, Naval Surface Warfare Center						
Monitoring Well Identification	pH (Standard Unit)	Oxidation/Reduction Potential (mV)	Dissolved Oxygen (ppm)	Perchlorate 2002 ( $\mu\text{g/L}$ )	Perchlorate 9/28/05 ( $\mu\text{g/L}$ )	TOC (mg/L)
MW-4D	5.5	117	4.5	181,000	38,500	2.2
MW-5	5.9	53	2.3	82,800	36,200	3.2

Note: Laboratory analysis of perchlorate on 9/28/05 samples performed at NCSU Civil and Environmental Engineering Laboratory, Raleigh, NC

Based on information gathered during the site visit and summarized in Table 3-3, perchlorate concentrations measured in September 2005 were much lower in the test area that had been treated with lactate than the concentrations reported in 2002. However, there was little indication of residual organic carbon in this area of the site and the perchlorate concentrations remain sufficiently elevated. Therefore, Solutions-IES concluded that the long-term impact from the lactate injection would not likely complicate the technical demonstration of MNA at the Indian Head site.

### 3.4 Present Operations

Operations at Indian Head Site 1419 remain essentially the same as described in Section 3.3.1. In summary, propellant is removed from rocket motors by water jet extraction. All wash water is contained, analyzed, and treated as hazardous waste based on the analytical results and disposed off-site under a contract. Operations at Building 1419 can also include some ordnance handling and storage.

### 3.5 Pre-Demonstration Testing and Analysis

#### 3.5.1 Pre-Demonstration Testing - Probable Source Area

During a conference call with the ESTCP project review team on October 12, 2005, the Indian Head site was approved as the first of two locations for technical demonstration of the potential for the MNA of perchlorate in groundwater. As previously discussed, a portion of this same site was used for a separate ESTCP-funded demonstration of lactate injection technology. However, according to previous reporting, a complete delineation of the perchlorate plume at this site was not performed. The last full round of sampling of the wells installed as part of the earlier demonstration was performed in winter 2002. Because the perchlorate contaminant plume had not been fully assessed, particularly in the southeast direction closer to Mattawoman Creek, pre-demonstration work was performed to accomplish this task prior to completing the Technology Demonstration Plan.

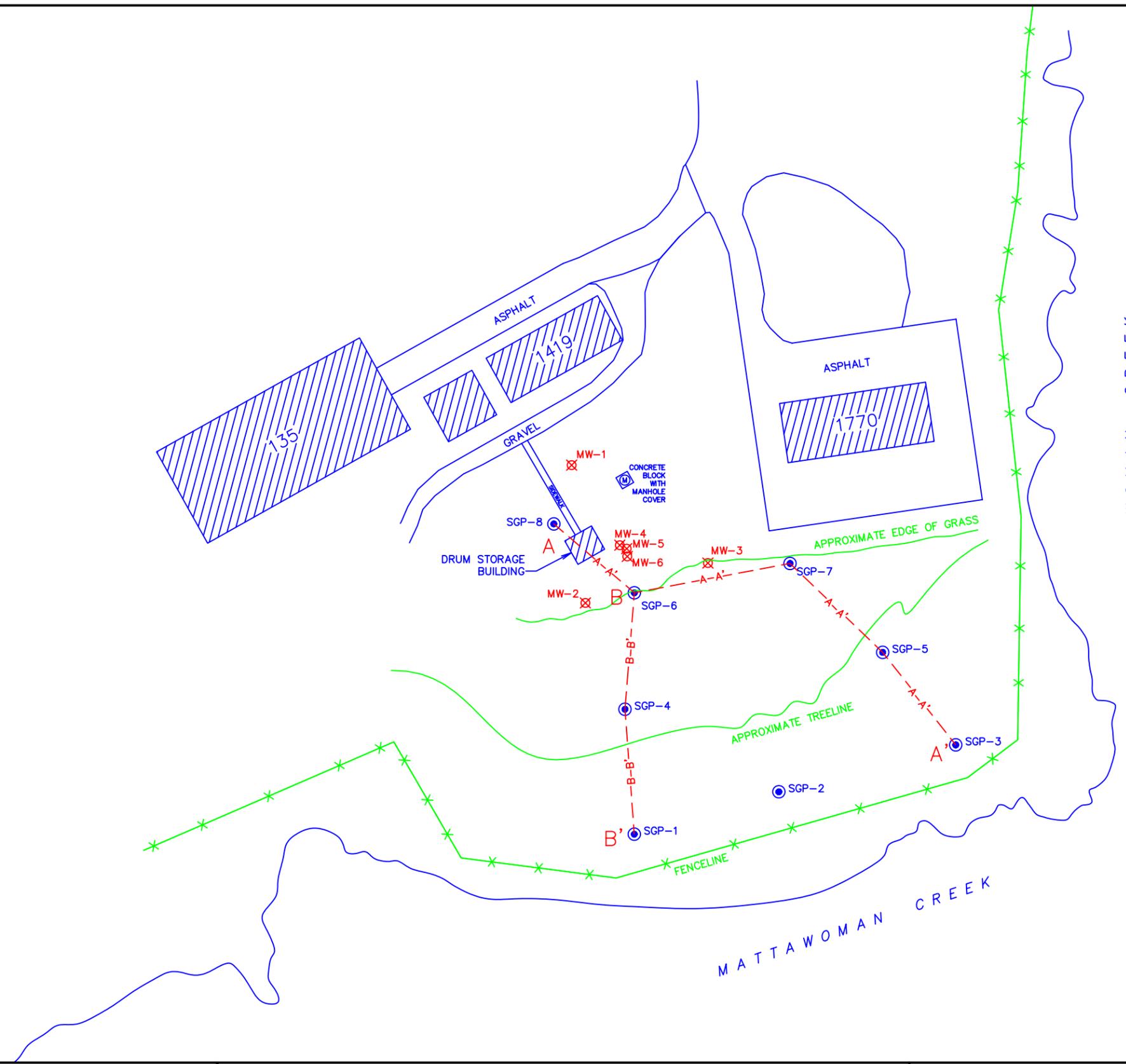
The pre-demonstration assessment work was performed during the second week of November 2005. Borings were advanced upgradient, cross-gradient, and downgradient of the probable source area (**Figure 3-2**). The Site-Specific Workplan that was implemented is included in **Appendix II**. The borings were advanced in pairs. The initial boring at each location was terminated approximately 1 to 2 inches within the clay layer (Potomac Group) located approximately 16 ft bgs. The second boring of each pair was placed approximately 2 feet from the initial boring and advanced to a total depth of 13 ft bgs. The soil profile from the initial deeper boring was continuously logged. Boring logs are provided in **Appendix III**. Each boring was then converted to 1-inch diameter PVC temporary well with a fine-filter sand packing surrounding the screen, a bentonite seal to the surface, and a PVC slip cap.

Based on the latest soil sampling activities, the geology in the study area is composed of a gray clay overlain by sandy silt to clayey silt with discontinuous fine sand seams, sand and gravel lenses with fines (**Figures 3-3, 3-4 and 3-5**). This is indicative of an urbanized fluvial depositional environment. The current riverbed runs north-south to the east of the study area. The predominant sediment type is a 10 to 15 foot thick section of sandy silt to clayey silt resting upon a gray, clay confining unit. This information is similar to the lithology described in the Shaw report (Cramer *et al.*, 2004). Historical cross-sections are provided in Appendix I for comparison.

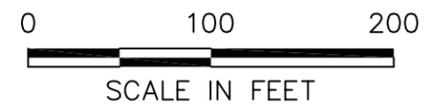
The total well depths ranged from 13 to 16 ft bgs. The well in the initial boring was installed to a total depth of approximately 16 ft bgs with a 2-ft length of screen (14 to 16 ft bgs). The depth of this screen interval was designed to transect the gravel/sand layer, if present. The second well in the boring pair was installed to a total depth of approximately 13 ft bgs with a 5-foot length of screen (~8 to 13 ft bgs), which was designed to transect sandy silt/clayey silt layer expected to be present at depths less than 13 ft bgs. The bottom of the screened interval in the second, shallower well was positioned at least one foot above the top of the screen interval in the deeper, first well of each pair. The 5-ft screen interval in the shallower well was intended to screen across suspected sand stringers that may be present in the upper zone. For detailed information regarding the advancement of borings using the Geoprobe<sup>®</sup>, or well installation, see **Appendix IV**.

Groundwater samples were also collected from each of the temporary wells and the existing monitoring wells (MW-1, MW-2, MW-3, MW-4, MW-5, MW-6). In addition, specific capacity tests were performed on control plot monitoring well (CPMW)-2S and CPMW-2D (Appendix I) installed by Shaw, and Solutions-IES Geoprobe<sup>®</sup> (SGP)-6S and SGP-6D installed by Solutions-IES (**Figure 3-2**). Based on groundwater elevations measured in old and new wells during the recent mobilization, the groundwater flow direction is to the southeast toward the Mattawoman Creek (**Figure 3-6**). The flow direction

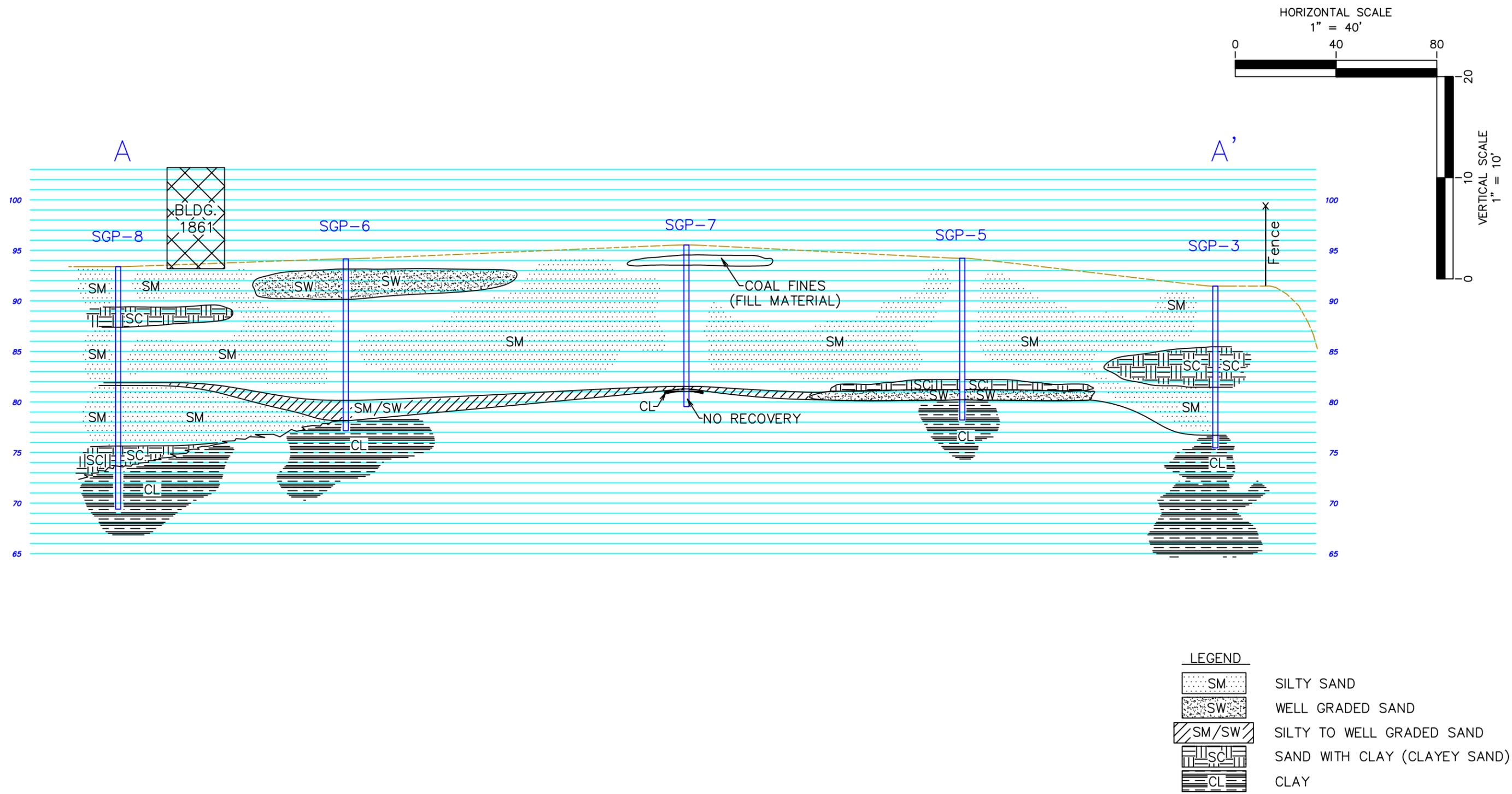
FILE Figure 3-3.dwg DATE 11/29/05 PROJECT MANAGER SLK CHECKED BY SLK DRAFTER KBB PROJECT NUMBER 3030.04A2.ESTC



**LEGEND**  
 X MW-3 EXISTING MONITORING WELL (SHAW)  
 ● SGP-3 BORING/TEMPORARY WELL PAIR (SOLUTIONS-IES)  
 -A-A'- CROSS-SECTION BASELINE



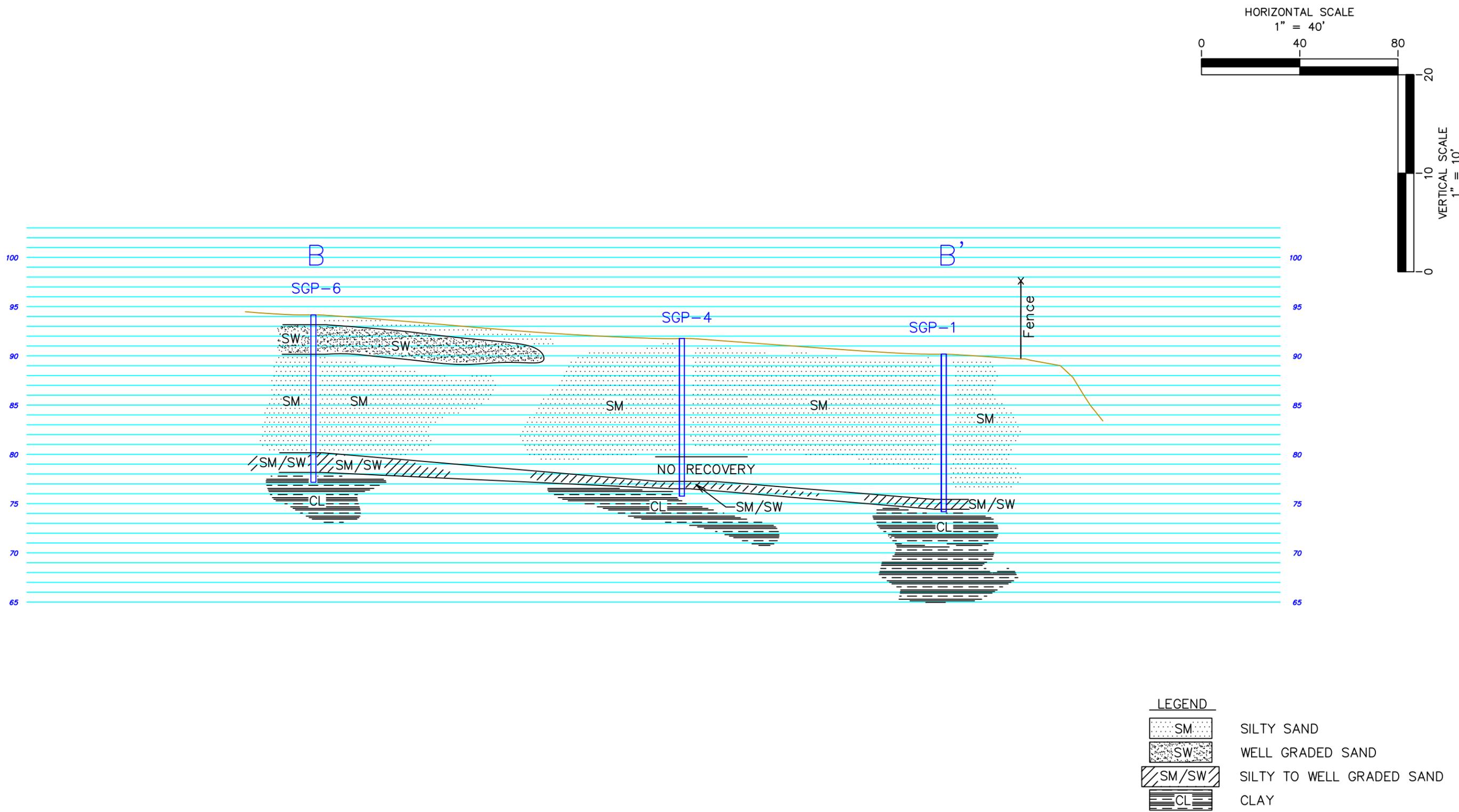
FILE Figure 3-4.dwg DATE 11/29/05 PROJECT MANAGER SLK CHECKED BY BW DRAFTER KBB PROJECT NUMBER 3030.04A2.ESTC



GEOLOGIC CROSS-SECTION A - A'  
INDIAN HEAD SITE  
INDIAN HEAD NAVAL WARFARE CENTER  
INDIAN HEAD, MARYLAND

FIGURE:  
3-4

FILE Figure 3-5.dwg DATE 12/15/05 PROJECT MANAGER SLK CHECKED BY BW DRAFTER KBB PROJECT NUMBER 3030.04A2.ESTC



FILE Indian Head Base.dwg DATE 11/29/05 PROJECT MANAGER SLK CHECKED BY SLK DRAFTER KBB PROJECT NUMBER 3030.04A2.ESTC



**LEGEND**

- ⊗ MW-3 EXISTING MONITORING WELL (SHAW)
- ⊙ SGP-3 BORING/TEMPORARY WELL PAIR (SOLUTIONS-IES)
- 86.49 GROUNDWATER ELEVATION\*
- ~86.0~ POTENTIOMETRIC CONTOUR

0 100 200  
SCALE IN FEET

\* GROUNDWATER ELEVATION CALCULATED FROM TOP-OF-CASING ELEVATIONS  
BASED ON PREVIOUS SURVEY USING ASSUMED BENCHMARK.

basically follows the surface topography. Depth to groundwater ranged from approximately 6 to 10 ft bgs.

### 3.5.2 Test Site Characterization

Groundwater samples were obtained using standard collection equipment such as pumps/tubing. **Appendix IV** identifies the collection protocol specific to the Indian Head site and details for groundwater sampling. The groundwater samples were collected from the existing and new monitoring wells and analyzed according to the methods described in the following table:

<b>Table 3-4</b> <b>Sample Collection and Analysis Details</b> <b>Indian Head Site, Naval Surface Warfare Center</b>					
<b>Target Constituent</b>	<b>Dissolved Oxygen (DO)</b>	<b>Methane<sup>a</sup></b>	<b>Perchlorate<sup>b</sup></b>	<b>Chloride, Nitrate, Nitrite, Sulfate, Phosphate<sup>c</sup></b>	<b>Total Organic - Carbon<sup>a</sup></b>
<b>Method</b>	Chemetrics	Method 8015M	Method 314.0	Method 9056	Method 9060

a. Methane and Total Organic Carbon analyses performed by Environmental Science Corp., Mt. Juliet, TN.

b. Perchlorate laboratory analysis (Method 314.0) performed by Columbia Analytical Services, Kelso, WA

c. Laboratory analysis performed at NCSU Civil and Environmental Engineering Laboratory, Raleigh, NC

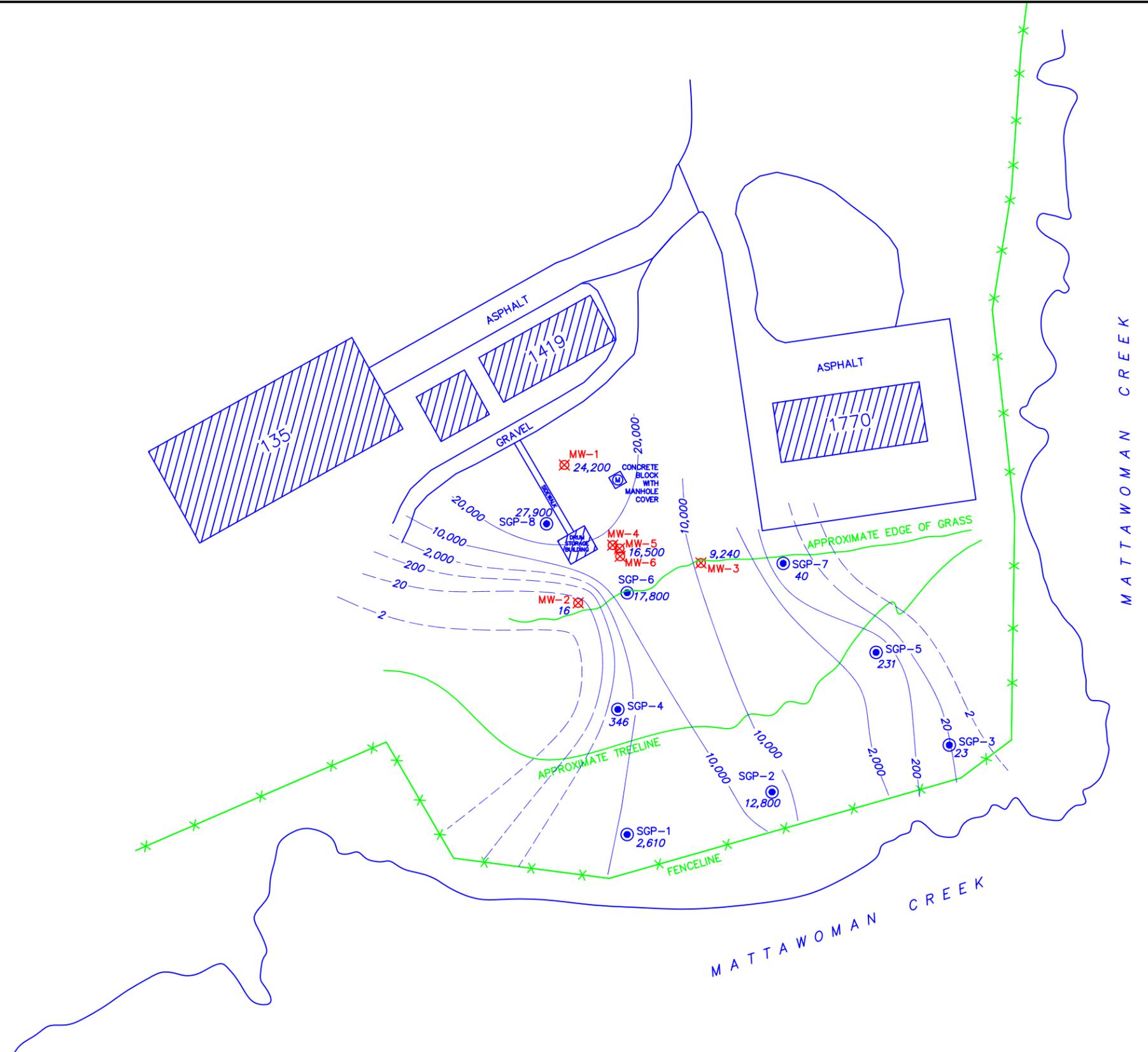
All water samples planned for laboratory analysis were labeled, packed on ice and shipped to the appropriate laboratory for overnight delivery. Laboratory results from field sampling activities are summarized below.

**Table 3-5**  
**Groundwater Characterization, November 15 and 16, 2005**  
**Indian Head Site, Naval Surface Warfare Center**

Monitoring Well Identification		Target Constituent					
		DO (ppm)	pH (Standard Unit)	Methane (mg/L)	Perchlorate (µg/L)	Nitrate (mg/L)	TOC (mg/L)
MW-1		0.2	5.46	<0.01	24,200	136	2.2
MW-2		0.5	7.14	<0.01	16.4	3	5.2
MW-3		2 to 3	3.81	<0.01	9,240	1	2.4
MW-4		0.1	4.96	0.042	26,400	2	2.8
MW-5		0.1	3.79	0.027	16,500	2	3.5
SGP-1	Shallow	2.5	4.92	<0.01	2,610	<0.5	1.6
	Deep	4	5.39	<0.01	2,660	1	1.8
SGP-2	Shallow	1	4.65	0.059	12,800	1	1.2
	Deep	NR	4.81	0.23	12,300	<0.5	8
SGP-3	Shallow	5 to 6	5.46	<0.01	22.8	<0.5	1.3
	Deep	5 to 6	4.30	<0.01	80	1	<1.0
SGP-4	Shallow	7	10.75	<0.01	346	6	15
	Deep	8 to 10	7.78	<0.01	5,730	1.4	2.2
SGP-5	Shallow	7	5.43	<0.01	231	1	2.6
	Deep	2	3.71	<0.01	316	2	1.5
SGP-6	Shallow	5	6.62	0.083	17,800	3	3.1
	Deep	2 to 3	6.35	1.1	16,900	<0.5	29
SGP-7	Shallow	4 to 5	5.49	<0.01	40	3	3.5
	Deep	3 to 4	3.96	<0.01	41	<0.5	9.2
SGP-8	Shallow	2 to 3	4.69	0.011	27,900	8	2.1
	Deep	2	6.28	<0.01	26,800	5	3.4

The analytical results from the pre-demonstration characterization are summarized on **Table 3-5**. The laboratory analytical reports are provided in **Appendix VII**. Based on these results, the geometry of the shallow perchlorate plume (**Figure 3-7**) and deep perchlorate plume (**Figure 3-8**) appears to follow the generalized groundwater flow direction, but is still not fully delineated. In addition, the plume does not clearly indicate a source area for the release although it is commonly acknowledged that hog-out activities at Building 1419 were the primary source. Perchlorate appears to discharge into the Mattawoman Creek at a concentration of at least 10,000 µg/L along the central axis (i.e., northwest to southeast) of the plume.

In all of the sampled locations, except SGP-4, there was no appreciable difference in perchlorate concentrations between the shallow and deep monitor well intakes. Specific capacity test results from

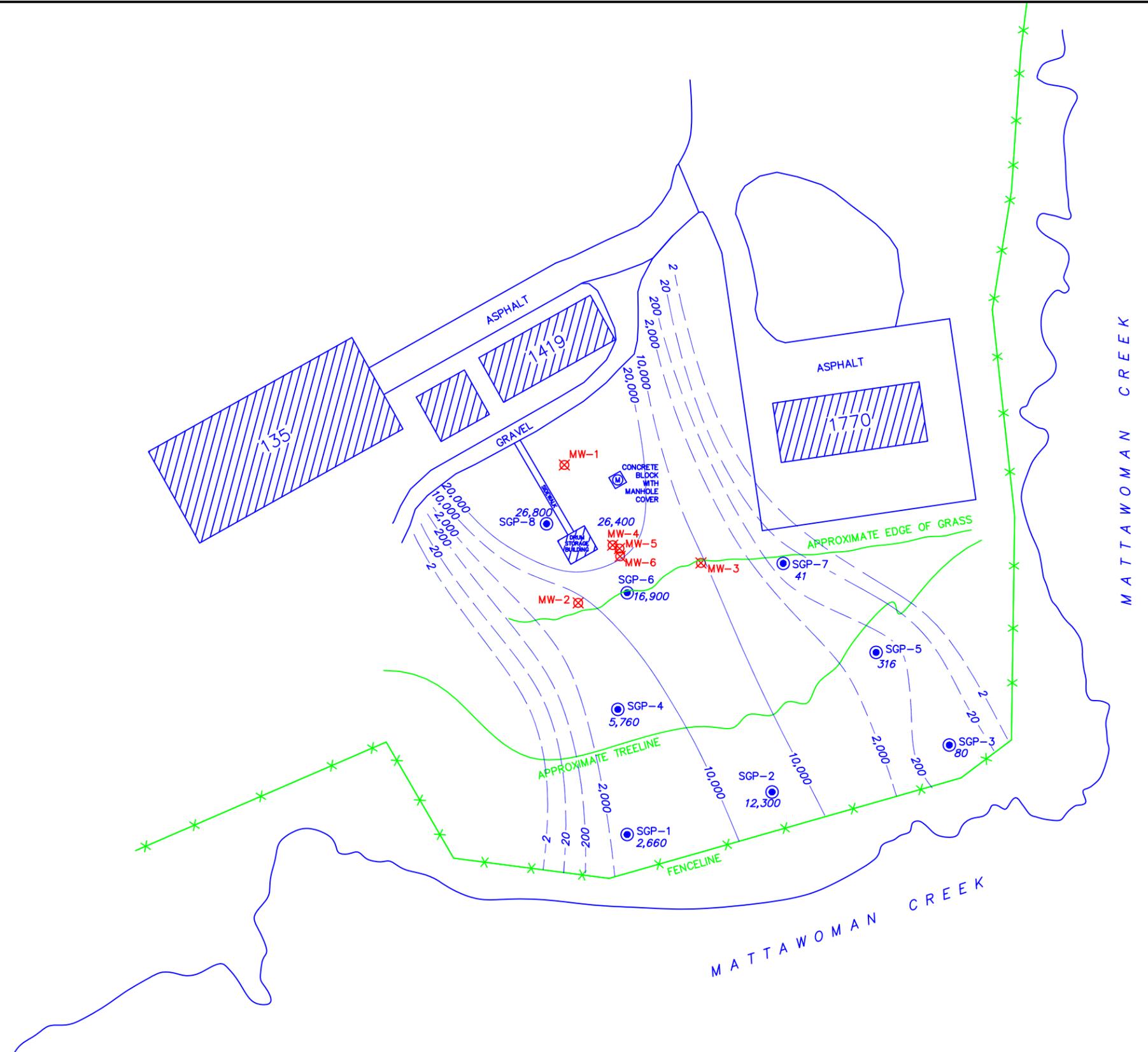


**LEGEND**

- ⊗ MW-3 EXISTING MONITORING WELL (SHAW)
- ⊙ SGP-3 BORING/TEMPORARY WELL PAIR (SOLUTIONS-IES)
- 250 PERCHLORATE CONCENTRATION (ug/L)
- ~200~ ISOCONCENTRATION CONTOUR



FILE Figure 3-8.dwg DATE 12/08/05 PROJECT MANAGER SLK CHECKED BY SLK DRAFTER KBB PROJECT NUMBER 3030.0442.ESTC



**LEGEND**

- ⊗ MW-3 EXISTING MONITORING WELL (SHAW)
- ⊙ SGP-3 BORING/TEMPORARY WELL PAIR (SOLUTIONS-IES)
- 250 PERCHLORATE CONCENTRATION (ug/L)
- ~200~ ISOCONCENTRATION CONTOUR

0 100 200  
SCALE IN FEET

SGP-6 also indicate there is no appreciable difference in the hydraulic conductivity of the shallow zone ( $K = 0.49$  ft/d in screened interval from 8 to 13 ft bgs) and deeper zone ( $K = 0.13$  ft/d in screened interval from 14 to 16 ft bgs). These results indicate that a single screened interval for new monitoring wells should be sufficient to monitor contaminant concentrations and estimate the total mass flux of contaminants during the technical demonstration.

### 3.5.3 Pre-Demonstration Testing – Mudflats

Monitoring results from the pre-demonstration characterization suggest the perchlorate plume is discharging towards a large wetland / mudflat adjoining Mattawoman Creek. **Figure 3-9** shows the area surrounding the site and Mattawoman Creek with the extensive mudflats clearly visible extending over 400 ft from the shoreline; the mudflats study area is shaded on the figure. In this general location, the Mattawoman Creek experiences approximately a 2-foot tidal fluctuation. At high tide, the mudflats are submerged while at low tide much of the mudflat surface is exposed. We anticipate that groundwater will discharge from the underlying aquifer to the surface at low tide and surface water will enter the aquifer at high tide. The surficial sediments in the mudflats are expected to contain significant amounts of organic material which are expected to enhance perchlorate biodegradation. However, the varying groundwater flow direction in the mudflats (due to tidal fluctuations) may make it more difficult to interpret the field monitoring results.

During this portion of pre-demonstration testing, we will evaluate several conditions within the mudflats some of which include contaminant distribution, natural organic carbon distribution, effects on permeability caused by plant and animal life in the mudflats, groundwater discharge to surface water, and tidal effects. The following field activities will be performed prior to the demonstration set-up to help understand the perchlorate distribution considering these conditions and the potential for anaerobic biodegradation within the mudflat sediments:

- Collect groundwater samples via Geoprobe® Screen Point Sampler or temporary/permanent monitor wells. If necessary, use a Maryland-licensed well contractor to obtain the permits necessary from MDE and to perform this work
- Obtain a “dig permit” from IHDIV prior to collecting groundwater samples from borings advanced within the mudflat area.
- Observe conditions (tidal, biota, etc.) within the mudflats study area for up to one day prior to contractor mobilization to better identify boring locations.
- Advance up to 12 soil borings in the mudflats study area (**Figure 3-9a**) to a depth of approximately 11 ft bgs using a mechanical pile driver. Each boring should terminate two feet above the clay layer identified in previous work at the site; the depth of each boring could vary based on the depth to the clay layer encountered at each specific location. Although these samples will not be collected by a “Geoprobe”, for consistency with the prior pre-demonstration activities, each boring will be identified as SGP-9 through SGP-20. The pile driver will also be used to push a split-spoon sampler or Geoprobe® Large Bore sampler to collect a soil/sediment sample in the upper and lower half of each boring for a total of two samples. Each sample will be designated according to the location and depth from which it was collected (i.e., SGP-9 2-3’ or SGP-9 10-11’, etc.). Depth will be measured from the sediment surface, not the surface water elevation. Each of these samples will be analyzed for TOC. Sampling procedures and analytical parameters are discussed in Section 3.6.
- A groundwater sample will be collected from each boring via a Geoprobe® Screen Point Sampler® or 1-inch temporary well. To collect the groundwater sample, the sampler or well screen will be installed to approximately 2 ft above the estimated clay interface.



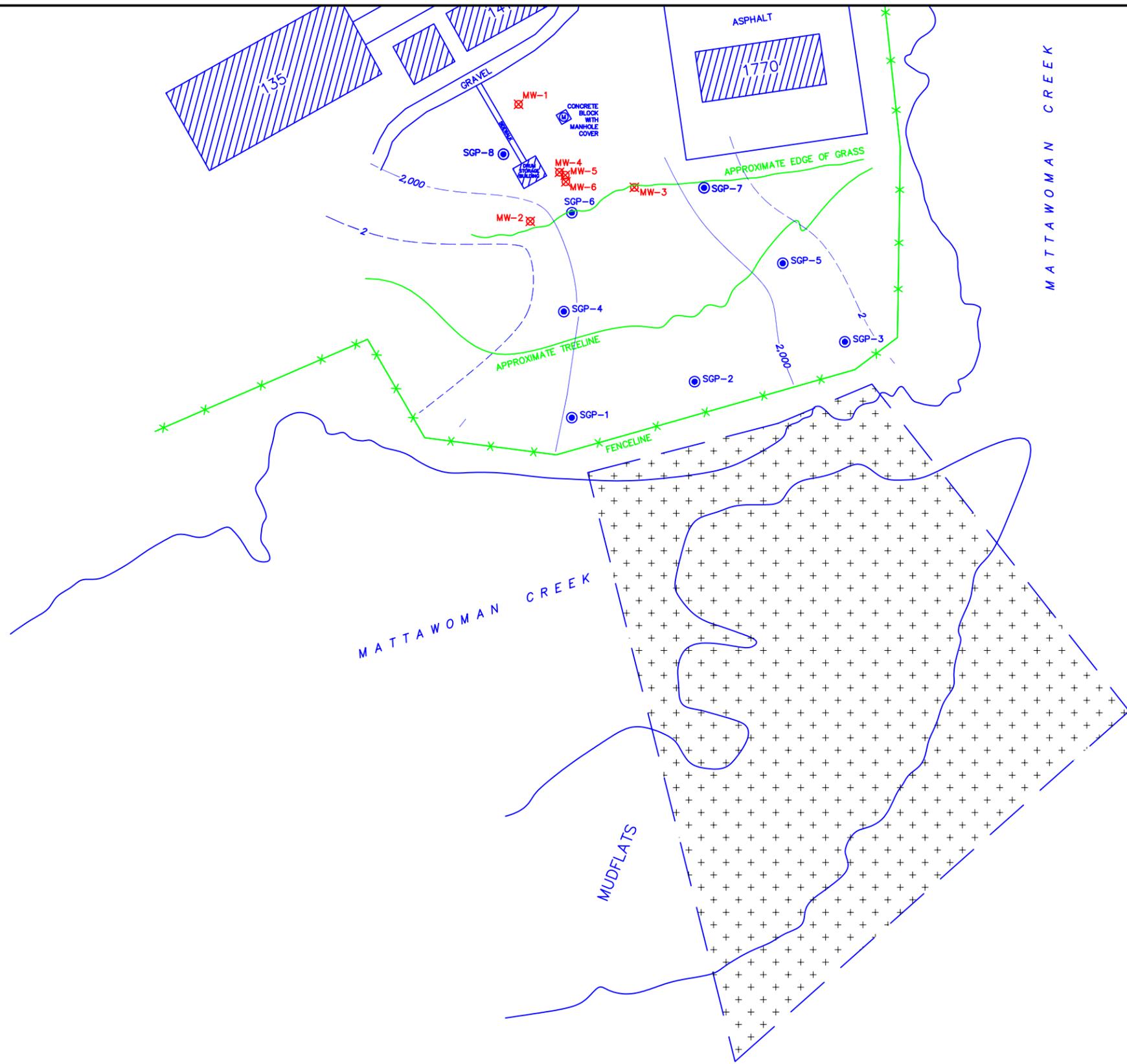
Approximate Scale: 1" = 275'

AERIAL VIEW OF MUDFLATS AND  
 PROPOSED MUDFLATS STUDY AREA  
 INDIAN HEAD SITE  
 INDIAN HEAD NAVAL WARFARE CENTER  
 INDIAN HEAD, MARYLAND



1101 Nowell Road, Raleigh, NC 27609 Phone (919) 873-1060, Fax (919) 873-1074	
Created by: KBB	Project: 3030.04A2.ESTC
Checked by: SLK	Date: 02/13/06
File: FIG1.mxd	
Software: ESRI ArcMap 9.0	<b>FIGURE</b> <b>3-9</b>

FILE Figure 3-9A 2006.dwg DATE 02/08/06 PROJECT MANAGER SLK CHECKED BY SLK DRAFTER KBB PROJECT NUMBER 3030.04A2.ESTC



**LEGEND**

- X MW-3 EXISTING MONITORING WELL (SHAW)
- SGP-3 EXISTING BORING/TEMPORARY WELL PAIR (NOVEMBER 2005)
- + + + MUDFLATS STUDY AREA

NOTE: BORING LOCATIONS IN MUDFLATS ARE FOR PLANNING PURPOSES. ACTUAL LOCATIONS MAY CHANGE BASED ON FIELD CONDITIONS.



Groundwater entering the screen will be extracted using a peristaltic pump with disposable tubing. Each groundwater sample will be designated by the location from which it was collected (i.e., SGP-9, SGP-10, etc.). Groundwater samples will be analyzed for TOC, perchlorate, chloride, nitrate, sulfate, and methane. See Section 3.6 for sampling details.

Solutions-IES will use the analytical results from pre-demonstration activities to further refine permanent monitoring well locations near the shore southeast of the probable source area and in the mudflats. If necessary, some of the temporary wells will be converted to permanent wells.

### **3.6 Testing and Evaluation Plan**

#### **3.6.1 Demonstration Set-Up and Start-Up**

After reviewing the information from the pre-demonstration assessment near the probable source area, it appears that the residual elevated perchlorate concentrations in many of the wells may be obscuring clear evidence of natural attenuation. However, the pre-demonstration assessment activities yet to be performed in the mudflats have strong potential to illustrate that natural attenuation of perchlorate is occurring in the mudflats beyond the property line, in addition to the more contaminated portions of the plume where it may be more difficult to document.

The demonstration set-up will consist of two parts: 1) installation of a permanent monitoring well network both southeast of the probable source area and in the mudflats; and 2) installation of *in situ* biodegradation columns in the mudflats. In part one, based on field observations and contaminant concentrations, selected pre-demonstration groundwater sampling locations/temporary monitoring wells will be converted to permanent monitoring wells (Section 3.5.3). The permanent monitoring wells will be spaced to estimate the mass flux along the perchlorate plume shown on **Figures 3-7 and 3-8**. In part two, *in situ* biodegradation columns will be placed in the mudflats to assist in estimating perchlorate biodegradation rates. Additional details are provided below:

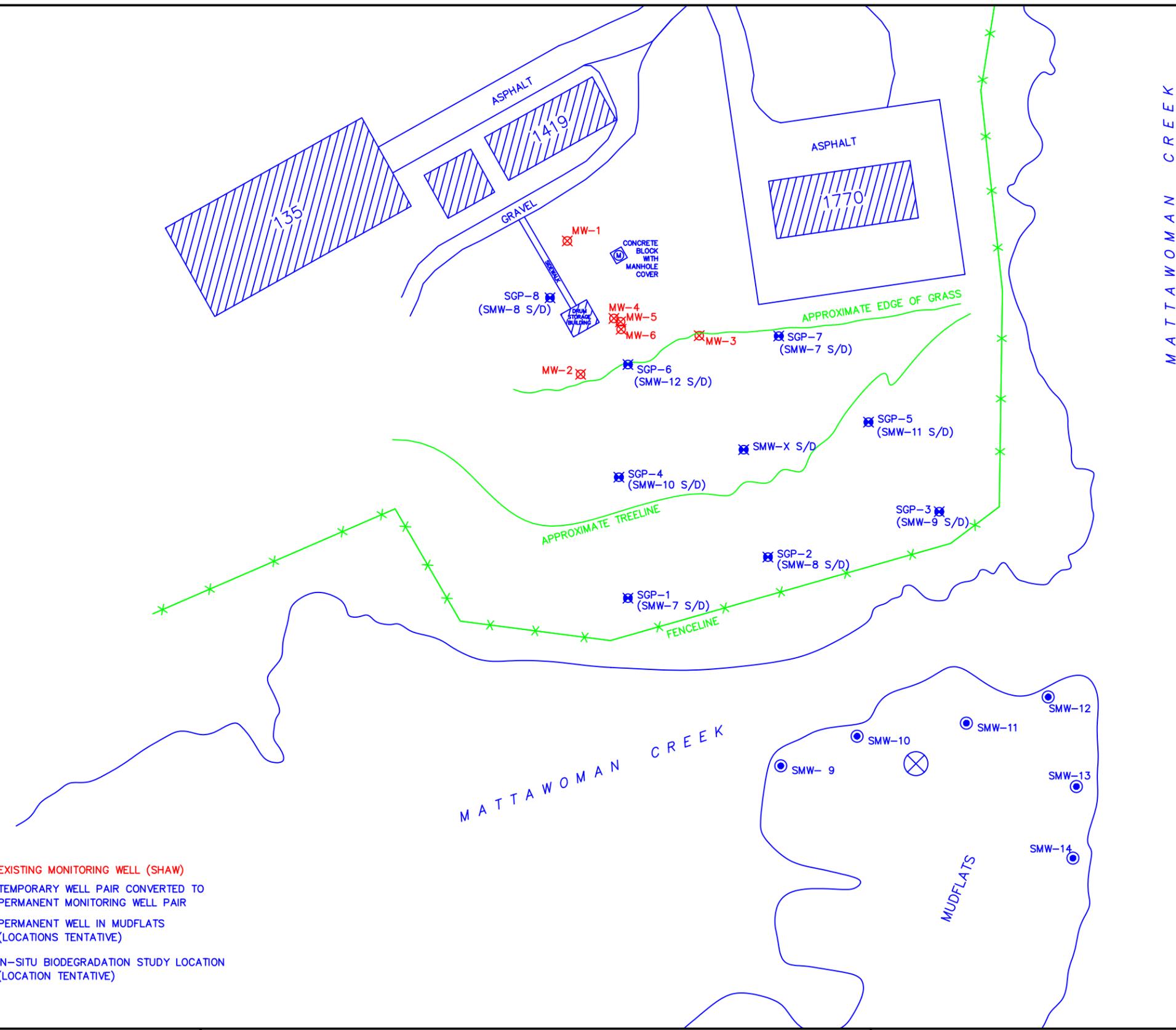
##### **3.6.1.1 Monitoring Well Installation for Mass Flux Study**

- Convert the temporary monitoring wells SGP-1 through SGP-8 located in the grassy area southeast of probable source area near the tree line and along the fence line to permanent monitoring wells as shown in **Figure 3-10**. These temporary wells will be re-named as Solutions-IES monitoring wells (SMW) starting with number SMW-1 to avoid confusion with the pilot test wells installed by Shaw. The shallow well will be designated “S” and the deeper of the pair designated “D”. The designations are illustrated on **Table 3-6**.
- Obtain a “dig permit” from IHDIV prior to installation of the new mass flux wells. Upon approval, a Maryland-licensed well contractor will be used to obtain monitoring well permits from MDE in order to install one additional new well pair near the probable source area and approximately six to twelve new monitoring wells in the mudflats. The new permanent shallow/deep well pair in the probable source area will be located between SGP-4 and SGP-5 (**Figure 3-10**). This well will be named after it is determined how many permanent wells are installed in the mudflats study area. The well pair construction will be the same as those well pairs installed during pre-demonstration testing performed in November 2005, and described in the Site-Specific Workplan found in **Appendix II**. According to IHDIV, special permitting is not required for installation of wells on the mudflats.

FILE Figure 3-10 2006.dwg DATE 02/08/06 PROJECT MANAGER SLK CHECKED BY SLK DRAFTER KBB PROJECT NUMBER 3030.04A2.ESTC

**LEGEND**

- ⊗ MW-3 EXISTING MONITORING WELL (SHAW)
- (SMW-10 S/D) ⊗ TEMPORARY WELL PAIR CONVERTED TO PERMANENT MONITORING WELL PAIR
- (SMW-15) ● PERMANENT WELL IN MUDFLATS (LOCATIONS TENTATIVE)
- ⊗ IN-SITU BIODEGRADATION STUDY LOCATION (LOCATION TENTATIVE)



PROPOSED PERMANENT MONITORING WELL LOCATIONS  
 FEBRUARY 2006  
 INDIAN HEAD SITE  
 INDIAN HEAD NAVAL WARFARE CENTER  
 INDIAN HEAD, MARYLAND

FIGURE:  
 3-10

- Finish each monitoring well with a permanent stick-up well cover and a locking cap. The newly finished monitoring wells (SMW-1 S/D through SMW-8 S/D and SMW X S/D) located in the grassy area downgradient of the probable source, the new monitoring wells installed in the mudflats, and the four of the six wells installed by Shaw (MW-1 through MW-4), will comprise the monitoring well network for the technology demonstration. These wells will be used to measure changes in contaminant mass flux with distance. **Figure 3-10** shows six permanent monitoring well locations in the mudflats. These locations are tentative and are for illustration purposes only.
- Perform specific capacity tests on all new wells. The specific capacity test, as described by Wilson *et al.* (1997), will be performed by inserting a ¼ inch polyethylene tube to a known depth beneath the water surface. The depth of the intake tube is determined by attaching a water level gauge to the side of the tube. When the exact known depth is reached below the static water table, a peristaltic pump will be switched-on at full flow. When the drawdown is stabilized, as witnessed by the occurrence of bubbles in the tubing, a graduated cylinder will be filled. The time to fill the cylinder, volume of the cylinder, and depth of the intake is entered into a spreadsheet formula to estimate the hydraulic conductivity. A minimum of three tests will be performed at each location so that an average can be determined.
- Collect groundwater elevation data from the monitoring well located closest to edge of mudflats of Mattawoman Creek to measure the fluctuation in groundwater elevation between sampling events. The creek is tidally influenced with daily fluctuations between 1 and 2 ft and the influence on groundwater flow direction will be important to evaluate.
- Install a stream channel gauge to provide a constant measuring point for subsequent monitoring events.

Table 3-6 Sample Locations and Designations Indian Head Site, Naval Surface Warfare Center				
Pre-Demonstration Soil/Sediment Samples	Pre-Demonstration Groundwater Samples	Installed by	Year	Technical Demonstration Groundwater Samples
<b>Sample Locations in Probable Source and Downgradient Areas</b>				
	MW-1	Shaw	2000	MW-1
	MW-2	Shaw	2000	MW-2
	MW-3	Shaw	2000	MW-3
	MW-4	Shaw	2000	MW-4
	SGP-1 S/D	Solutions-IES	2005	SMW-1 S/D
	SGP-2 S/D	Solutions-IES	2005	SMW-2 S/D
	SGP-3 S/D	Solutions-IES	2005	SMW-3 S/D
	SGP-4 S/D	Solutions-IES	2005	SMW-4 S/D
	SGP-5 S/D	Solutions-IES	2005	SMW-5 S/D
	SGP-6 S/D	Solutions-IES	2005	SMW-6 S/D
	SGP-7 S/D	Solutions-IES	2005	SMW-7 S/D
	SGP-8 S/D	Solutions-IES	2005	SMW-8 S/D
		Solutions-IES	2006	SMW-X S/D
<b>Proposed Sample Locations in Mudflats Beyond Property Line</b>				
SGP-9 S/D*	SGP-9	Solutions-IES	2006	SMW-9 To SMW-20, as needed.
SGP-10 S/D*	SGP-10	Solutions-IES	2006	
SGP-11 S/D*	SGP-11	Solutions-IES	2006	
SGP-12 S/D*	SGP-12	Solutions-IES	2006	
SGP-13 S/D*	SGP-13	Solutions-IES	2006	
SGP-14 S/D*	SGP-14	Solutions-IES	2006	
SGP-15 S/D*	SGP-15	Solutions-IES	2006	
SGP-16 S/D*	SGP-16	Solutions-IES	2006	
SGP-17 S/D*	SGP-17	Solutions-IES	2006	
SGP-18 S/D*	SGP-18	Solutions-IES	2006	
SGP-19 S/D*	SGP-19	Solutions-IES	2006	
SGP-20 S/D*	SGP-20	Solutions-IES	2006	

\* Actual depth of shallow (S) and deep (D) samples below the surface of the mud flats will be shown for soil/sediment samples (e.g., SGP-9 2-3' and SGP-9 10-11').

### 3.6.1.2 *In Situ* Biodegradation Study in the Mud Flats

An *in situ* biodegradation study will be conducted in the mudflats in an area where it is likely that perchlorate is degrading or where it is likely that perchlorate would degrade if it were present. A tentative location for this study is shown in **Figure 3-10**, but the actual location is subject to pre-demonstration results from the mudflats. The objective of this work is to estimate biodegradation rates as perchlorate migrates upward through the surficial mudflat sediments that are expected to contain elevated levels of organic carbon. The exact details of the *in situ* biodegradation test have not been finalized and will depend on the vertical distribution of organic carbon in the mudflat sediments, groundwater flow rates through this system, and physical access considerations.

One approach for measuring *in situ* biodegradation rates would be to install *in situ* (close-ended) columns within the mudflats using a design similar to the columns used by Gillham *et al.* (1990) and Borden *et al.* (1997a). Each column would consist of a 1-m long chamber that is pushed into the sediment surface allowing sediment and groundwater to be isolated from the surrounding aquifer for controlled observation. Groundwater would be extracted from the column (or an adjoining well), amended with a non-reactive bromide tracer and perchlorate (if required), and injected back into the column. Water samples will then be collected from the column over time and monitored for perchlorate and bromide. By comparing perchlorate concentrations with the non-reactive tracer, we can estimate *in situ* biodegradation rates. This *in situ* measurement approach is expected to be most appropriate when groundwater flow rates are low.

An alternative approach for measuring *in situ* biodegradation rates would be to install open-ended columns into the sediment surface extending from approximately 3 ft bgs to above the maximum high tide level. A check valve would be installed in the side of the column at the average water level in the Mattawoman Creek. When the tide is low, ambient groundwater flow will cause water to flow upward through the sediment within the column, and discharge out through the check valve. By monitoring perchlorate concentrations at the bottom (intake) of the column and at the top (discharge) of the column, we can evaluate the extent of perchlorate biodegradation under ambient conditions. This *in situ* measurement approach is expected to be most appropriate when groundwater flow rates are high, allowing collection of sufficient water for the required chemical analyses.

Once additional information is obtained on groundwater flow conditions, sediment TOC levels, and perchlorate concentrations in the mudflats, a brief memo will be submitted to ESTCP providing a detailed description of the proposed monitoring protocols.

### **3.6.1.3 Surveying and Initial Groundwater Sampling**

This demonstration plan assumes that new monitoring well installation and *in situ* biodegradation column installation can be implemented in a relatively close time frame. If, for some reason, there is a large time period between activities, the surveying and sampling activities described below can be adjusted.

- The top-of-casing elevations for each of the new wells and *in situ* biodegradation columns will be surveyed relative to existing monitoring wells. Groundwater elevation measurements will be collected from the new wells and nearby existing wells. Surface water measurements will also be measured accordingly using the stream gage. The groundwater flow direction in the vicinity of the well network will be compared to historical information. Horizontal and vertical gradients will be calculated.
- A full round of sampling, including the monitoring wells installed by Shaw, will be performed subsequent to installation of the monitoring well network. Sampling procedures and analytical parameters are discussed in greater detail in Section 3.6.7.

### **3.6.2 Period of Operation**

Installation of the monitoring well field for mass flux calculations, and groundwater sampling and analysis, should be completed in approximately 3 months. After those tasks are complete, four

performance monitoring events remain and will require approximately 12 months to complete. A more detailed schedule is provided in Section 3.10.

### **3.6.3 Amount/Treatment Rate of Materials to be Treated**

Based on the site characterization and hydrogeology, the amount of perchlorate attenuated within the demonstration area will be estimated based on the change in the perchlorate concentration near Building 1419, the drum storage building (**Figure 3-2**), the last line of monitoring wells located in the mudflats, and the volume of water passing through the demonstration area. The rate of anaerobic biodegradation will be estimated during the demonstration through *in situ* biodegradation studies, mass flux calculations, and stable isotope studies.

### **3.6.4 Residuals Handling**

Because the groundwater is being treated by natural attenuation, it will not be removed from the subsurface for treatment, and will not require disposal. However, it is anticipated that several types of investigation-derived waste (IDW) will be generated on this site, including:

- Personnel protective equipment (PPE).
- Disposable equipment, such as plastic ground and equipment covers, aluminum foil, tubing, bailers, discarded or unused sample containers, boxes, etc.
- Soil cuttings/drilling muds/cores from well installation.
- Groundwater obtained through well development or well purging.
- Cleaning fluids such as detergents, spent solvents and wash water.
- Packing and shipping materials.

Based on generator knowledge, IDW anticipated at the site will be classified as non-hazardous. At the time of generation, soil cuttings/cores will be spread on site in the grassy area south of the drum storage building.

Contaminated groundwater and decontamination fluids derived from well sampling, and equipment decontamination will also be disposed of in the grassy area south of the drum storage building. Solid IDW waste, such as PPE, bailers, tubing, in-line filters, etc., will be double-bagged and deposited in a dumpster for transport to a municipal landfill.

### **3.6.5 Operating Parameters for the Technology**

The purpose of the technical demonstration is to evaluate the potential for monitored natural attenuation of perchlorate in groundwater. Because we are demonstrating a process that is occurring without engineered intervention, there is no aboveground equipment to operate or maintain. Consequently, there are no mechanical operating parameters for the technology.

Groundwater monitoring and hydraulic conductivity testing will be used to monitor the performance of natural attenuation and estimate mass flux. Groundwater monitoring will be conducted as described in Section 3.6.7. Hydraulic conductivity will be estimated using specific capacity tests (Section 3.6.1.1). However, alternate methods may be utilized to measure the hydraulic conductivity (slug testing) should specific capacity testing prove insufficient. Specific capacity testing will be performed on all of the monitoring wells installed during the demonstration. A data logger will be installed in the monitoring well located closest to edge of the mudflats of Mattawoman Creek to measure the fluctuation in groundwater elevation between sampling events.

### 3.6.6 Experimental Design

The analytical results obtained from the pre-demonstration work performed in November of 2005 (Section 3.4) and pre-demonstration work in the mudflats will be used to optimize the location of permanent monitoring wells used in the perchlorate mass flux study and the *in situ* biodegradation studies.

When all of the monitoring wells that will be used to estimate mass flux are installed, the change in downgradient mass flux will be monitored over several sampling events. Using this technique, we hope to show a consistent, reproducible decline in total contaminant mass flux during the downgradient migration of perchlorate. By collecting data on multiple dates over several years, we intend to generate statistically valid estimates of the first order degradation rate for perchlorate within 95% confidence limits. If appropriate, contaminant transport and attenuation will be simulated using a simple first order decay model similar to BIOCHLOR, an instantaneous reaction model similar to BIOPLUME (Borden and Bedient, 1986), or a three-dimension model similar to RT3D. The modeling approach selected will depend on the site-specific monitoring results.

We will likely analyze the results from the perchlorate *in situ* biodegradation study following the same general procedures employed by Borden *et al.* (1997a). The statistical significance of the slopes and 95% confidence limits will be determined following standard statistical procedures.

### 3.6.7 Groundwater Sampling Plan

Groundwater sampling activities will be performed to evaluate the natural conditions of the aquifer, and how those conditions affect the potential for the biodegradation of perchlorate. In general, the procedures that Solutions-IES will use for groundwater sampling are provided in *Environmental Investigations Standard Operating Procedures and Quality Assurance Manual* (EISOPQAM; US EPA, 1996), with site-specific requirements in the QAPP in **Appendix VI**, and outlined in the following paragraphs.

Prior to the collection of groundwater samples, water levels will be measured. Each well to be sampled will then be purged to remove stagnant water from the well and to allow its replacement by groundwater from the adjacent formation, which is more representative of actual aquifer conditions. Because of the anticipated shallow depth to water, the wells will be sampled using either a peristaltic pump/tubing, or disposable polyethylene bailers. When the monitoring wells are sampled using a low-flow purge and sampling method, an adequate purge is achieved when the pH, specific conductance, and temperature of the groundwater have stabilized. The number of parameters measured in wells located in the mudflats may be altered in order to collect the volume of sample required for perchlorate analysis. The goals for stabilization are as follows:

- pH- Measurements remain constant within 0.1 Standard Unit (SU).
- Specific Conductance – Measurements vary by no more than 10 percent.
- Temperature – Measurements remain constant for at least three successive readings.

After an adequate purge has been achieved, field measurements will be collected and groundwater samples will be collected for analysis. The samples will be collected in laboratory prepared sample containers appropriate for the analytical method being used. The sample containers will be immediately sealed, labeled, and placed on ice in an insulated cooler for subsequent delivery to the analytical laboratory. Chain-of-custody forms will accompany all samples sent to the laboratory. The field parameters that will be measured at each location

include: dissolved oxygen (DO); oxidation-reduction potential (ORP – Eh); pH, temperature, and specific conductance.

Assuming that most of the monitoring wells will be sampled using a peristaltic pump, a groundwater sample will be collected for DO analysis as water is flowing out of the sampling tubing by inserting a Chemetrics 0 - 1 mg/L self-filling DO ampoule into the end of the tube. The ampoule tip will be broken off inside the tube below the flowing water surface, pulling water into the ampoule while being careful to exclude any oxygen. The DO concentration will be determined by a visual comparison to color standards. If the DO exceeds 1 mg/L, the process will be repeated using the 1 – 12 mg/L DO ampoules.

After the field parameters are measured for the specific monitoring well, a groundwater sample will be collected. For pre-demonstration groundwater sampling, groundwater samples will only be collected from sampling points in the mudflats. For performance monitoring (four events), groundwater samples will be collected from the newly finished permanent monitoring well pairs (SMW-1 S/D through SMW-8 S/D and SMW-X), monitoring wells installed in the mudflats, and the existing wells MW-1 through MW-4. The first, second and third sampling events will be separated by a three month interval while the third and fourth sampling event will be separated by a six month interval.

#### **3.6.7.1 Laboratory Analysis**

Approximately 24 soil samples will be collected from borings advanced in the mudflats during pre-demonstration testing discussed in Section 3.5.2. From each boring, one soil sample will be collected from the upper half of the boring and one soil sample will be collected from the lower half of the boring prior to boring termination at approximately 11 feet bgs. Each of these soil samples will be analyzed for TOC.

Groundwater samples collected for pre-demonstration testing will be analyzed for perchlorate, TOC, chloride, nitrate-N, sulfate, and methane. Groundwater samples collected from monitoring wells during performance monitoring will be analyzed for perchlorate, TOC, chloride, nitrate-N, sulfate, and methane as well as dissolved iron and manganese, ammonia-N, and alkalinity.

**Table 3-7  
Sample Collection and Analysis Details  
Indian Head Site, Naval Surface Warfare Center**

<b>Number of Sample Bottles per Sample Location</b>	<b>Containers</b>	<b>Target Constituent/Method</b>	<b>Field/Laboratory</b>
1	250-ml plastic bottle	Conductivity, temperature, pH, oxidation-reduction potential/Field Meters	Field
0	From tubing	Dissolved oxygen/Chemetrics	Field
1	0.45 µm filtered sample	Dissolved manganese and iron/Chemetrics	Field
2	40-mL VOA vial (no preservative)	Methane/gas chromatography	NCSU CCEE Lab
1	250 ml plastic bottle minimum of 120 ml sample while retaining headspace (no preservative) coupled 1.0µm and 0.45µm filtering setup	Perchlorate/ion chromatography	NCSU CCEE Lab
1	A minimum of 120 ml (no preservative) coupled 1.0µm and 0.45µm filtering setup confirmation samples (10%)	Perchlorate/Method 330	Columbia Analytical Services, Inc.
1	250-mL plastic bottle (preservative)	Chloride, nitrate, sulfate/ ion chromatography	NCSU CCEE Lab
1	500 ml plastic bottle (no preservative)	Alkalinity/Method 310.2	Environmental Science Corp.
1	250 ml plastic bottle (preservative)	Ammonia/Method 350.1	Environmental Science Corp.
1	4-oz jar	Total organic carbon (soil)/Loss on ignition	Environmental Science Corp.
1	250-mL amber bottle preserved with HCL)	Total organic carbon (groundwater)/Method 9060	Environmental Science Corp.
1	1-liter bottle (no preservative)	Chlorite Dismutase Assay/ mRNA	Microbial Insights, Inc.
1	Flow-through glass column containing ion-exchange resin	Stable Isotope Studies	Paul Hatzinger, Shaw Environmental

**Table 3-7** provides the details for collecting groundwater samples for the planned analyses and shows the laboratories that will perform each analysis. Most of the analyses that are planned will be performed using standard field or laboratory methodologies. However, this demonstration relies on several relatively new approaches for collecting and processing samples. These special methods are described in the following sections:

#### **3.6.7.1.1 Groundwater Collection for Perchlorate Analysis.**

After the groundwater is withdrawn from the monitoring well, solids within the sample will be allowed to settle in a plastic container while the other groundwater samples are collected. After the other groundwater samples are collected, a 60-ml syringe will be used to withdraw the sample from the top to avoid solids. Then, the syringe will be used to push the groundwater through sequentially stacked 1.0  $\mu\text{m}$  and 0.45  $\mu\text{m}$  filters. The filtered groundwater will be placed into a clean plastic bottle with no preservative. Headspace will be retained within the sample bottle. Approximately 10% of groundwater samples will be sent to a certified laboratory for confirmatory analysis of perchlorate by Method 330.

#### **3.6.7.1.2 *In Situ* Biodegradation Studies**

Groundwater samples will be collected from *in situ* biodegradation columns during each of the four performance monitoring sampling events. Each of the samples will be analyzed for perchlorate, chloride, sulfate, TOC, and DO. If *in situ* closed ended columns are used in the *in situ* biodegradation study, bromine will be added to the laboratory analysis.

We will likely analyze the results from the perchlorate *in situ* biodegradation columns following the same general procedures employed by Borden *et al.* (1997a). The statistical significance of the slopes and 95% confidence limits will be determined following standard statistical procedures

#### **3.6.7.1.3 Chlorite Dismutase Enzyme Assays**

Approximately 10 groundwater samples will be collected for CD enzyme assay during one of the five sampling events. Sampling locations will be selected to include locations where groundwater conditions suggest that perchlorate may be biodegrading, and locations where concentrations of perchlorate are low or not detected. Available information indicates that the CD enzyme is only present in organisms that are actively reducing perchlorate or chlorate. As a consequence, detection of the CD enzyme should provide a direct indication that perchlorate is being degraded under *in situ* conditions, and therefore, use of the enzyme assay would provide another tool to evaluate the potential for MNA of perchlorate.

#### **3.6.7.1.4 Stable Isotope Studies**

Microorganisms often preferentially use lighter isotopes in their metabolic processes (Mariotti *et al.*, 1981; Heaton, 1986) and, as a contaminant is degraded, the isotopic composition of the remaining material becomes progressively heavier. This isotopic shift can be described by the Raleigh Distillation formula  $R/R_0 = f^{(\alpha-1)}$ , where  $R_0$  is the isotopic ratio of the original material,  $R$  is the isotopic ratio of the remaining material,  $\alpha$  is the

fractionation factor and  $f$  is the fraction of material degraded. If the ratio  $R/R_0$  can be accurately measured and  $\alpha$  is known, the fraction of material degraded can be calculated.

A variety of different investigators have successfully used stable isotope ratios to evaluate the MNA of petroleum hydrocarbons (Ahad *et al.*, 2000), methyl-*tert*-butyl ether (MTBE; Kolhatkar *et al.*, 2002), chlorinated solvents (Lollar *et al.*, 2001), and nitrate (Karr *et al.*, 2001). However, there are some important limitations to this approach: (1) a sensitive, reproducible method is needed to monitor the isotopic shifts; (2) variations in the isotopic composition of the different sources can mask isotopic shifts caused by microbial fractionation; and (3) the isotopic fractionation factor  $\alpha$  may vary between different microorganisms and environmental conditions (Slater *et al.*, 2001).

Currently available information suggests that monitoring isotopic ratios may be a very useful tool for evaluating the extent of perchlorate attenuation. Ader *et al.* (2001) developed a highly reproducible and accurate method for stable isotopic analysis of chlorine ratios  $Cl^{34}:Cl^{37}$  ( $\delta^{37}Cl$ ) in perchlorate. Recently, Coleman *et al.* (in press) observed that perchlorate reduction by *D. suillum* resulted in significant fractionation ( $\sim -15\%$ ) of the chlorine stable isotopic composition. The resulting shifts in  $\delta^{37}Cl$  associated with perchlorate reduction were much larger than the isotopic variations between different sources ( $+0.2\%$  to  $+2.3\%$ ) observed by Ader *et al.* (2001). These results suggest that isotopic ratios could be used to assess perchlorate attenuation in the field.

Approximately 8 to 10 groundwater samples will be monitored for measurement of stable isotopes during one of the five sampling events. Groundwater samples will be collected from 8 to 10 wells during one of the five sampling events and assayed for  $\delta^{37}Cl$  of perchlorate. Sampling locations will be selected to include locations where groundwater conditions suggest that perchlorate may be biodegrading. Because of the perchlorate concentrations present in groundwater at the Indian Head Site, several liters of groundwater will be pumped through glass columns containing ion exchange resin at a low flow rate until the column contains an estimated mass of perchlorate of approximately 10 mg (Bohlke *et al.*, 2005). Each cartridge will then be shipped to a laboratory for perchlorate extraction and  $\delta^{37}Cl$  analysis. Spatial variations in  $\delta^{37}Cl$  will be examined to determine if there is significant isotopic fractionation during downgradient transport. If there is clear evidence of isotopic shifts, the extent of perchlorate degradation will be estimated using the fractionation factor.

### **3.6.8 Demobilization**

MNA does not include the installation of aboveground equipment or structures that will require removal at the end of the demonstration. At the completion of the monitoring phase of the project, the monitoring wells may be abandoned. Personnel at the Indian Head site may want some of the monitoring wells to remain in working order, so we will coordinate the abandonment activities with Indian Head personnel prior to abandoning monitoring wells installed by Solutions-IES. Each of the selected monitoring wells will be abandoned by inserting a tremie pipe to the bottom and pumping the well full of a neat cement grout mixture until filled to the surface. For the monitoring wells, each riser will be cut off below the surface and the plugged wells/columns will be covered with soil.

### **3.6.9 Health and Safety Plan**

The Health and Safety Plan for this project is provided in **Appendix V**.

### 3.7 Selection of Analytical/Testing Methods and Laboratory

Table 3-7 summarizes the analytical methods and laboratories that will be used for the performance monitoring activities.

### 3.8 Selection of Analytical/Testing Methods

**Microbial Insights has completed development of the RNA-based assay to identify the expression of a CD gene (Section 3.6.7.1.3) and maintains the expertise necessary to produce reliable and reproducible results for this assay which is not widely available.**

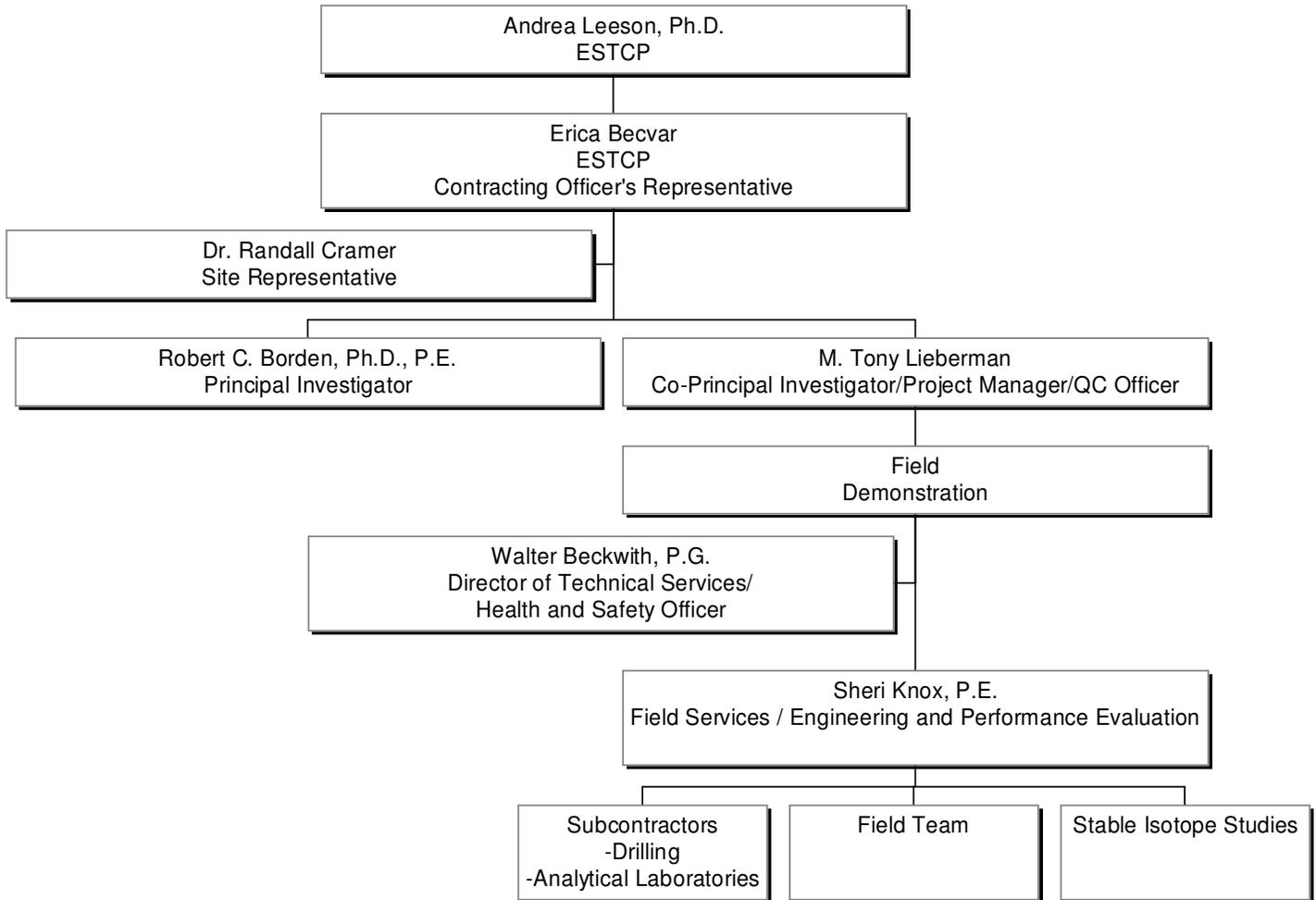
Dr. Paul Hatzinger of Shaw Environmental will perform the stable isotope studies. This approach is not widely available and will specifically require his expertise. The addresses are listed in the Table 3-8 below:

<b>Table 3-8 Specialized Laboratory Expertise Indian Head Site, Naval Surface Warfare Center</b>		
<b>Laboratory/Person</b>	<b>Address</b>	<b>Expertise</b>
Microbial Insights, Inc.	2340 Stock Creek Boulevard, Rockford, TN 37853	<b>mRNA chlorite dismutase assay</b>
Dr. Paul Hatzinger	Shaw Environmental, Inc. 17 Princess Road Lawrenceville, NJ 08648	<b>stable isotope assays</b>

### 3.9 Management and Staffing

Figure 3-11 provides the organizational chart for the technology demonstration project. The roles and responsibilities of relevant project personnel are summarized below.

**Figure 3-11  
Organizational Chart**



**Principal Investigator:** Responsible for providing overall project direction, coordination with ESTCP, site representatives, and regulatory agencies, and final review and approval of reports.

**Project Manager/Co-PI:** Responsible for project coordination, scheduling, budget management, technical oversight, and report preparation.

**3.10 Demonstration Schedule**

The milestones for the implementation of the proposed technology are summarized in **Table 3-9**, and **Figure 3-12** is a Gantt chart showing the project schedule through 2008.

**Table 3-9**  
**Demonstration Schedule**  
**Indian Head Site, Naval Surface Warfare Center**

Activity		Estimated Completion Date
1	Contract award	06/2/2004
2	Site Selection Memorandum	9/20/2005
3a	Pre-demonstration testing and analysis	11/16/2005
4	Submittal of draft Tech. Demonstration Plan, HASP, etc.	2/20/2006
4a	Complete Tech. Demonstration Plan review	3/20/2006
4b	Approval of revisions to Tech. Demo Plan, if needed.	4/20/2006
3b	Completion of pre-demonstration testing and analysis	5/15/2006
5	Demonstration Setup (Mass flux well installation and <i>in situ</i> closed and/or open column installation)	6/30/2006
6	Submit draft MNA Protocol	5/30/2006
7	Performance monitoring, <i>in situ</i> biodegradation studies, and CD analysis	7/31/2006
8	Performance monitoring, <i>in situ</i> biodegradation studies, & stable isotope studies	10/30/2006
9	Performance monitoring & <i>in situ</i> biodegradation studies	1/31/2007
10	Performance monitoring & <i>in situ</i> biodegradation studies	7/31/2007
11	Submit draft Technical Report	3/31/2008
12	Submit draft Cost and Performance Analysis	5/30/2008
13	Submit final Protocol (including 2 <sup>nd</sup> demonstration site)	6/30/2008

Figure 3-12

Project Schedule

TASK	2004			2005			2006			2007			2008													
	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7
Contract Award	█																									
Site Selection		█	█	█	█	█	█	█	█																	
Pre-Demonstration Field Work								█	█																	
Demonstration Plan Preparation										█	█	█	█													
Demonstration Plan Review & Revisions																										
Demonstration Set-up																										
Draft MNA Protocol																										
<i>In-Situ</i> Column Studies																										
CD Assay																										
Stable Isotope Studies																										
Performance Monitoring																										
Draft Technical Report																										
Cost/Performance Analysis																										
Application Protocol																										

## 4.0 Performance Assessment

### 4.1 Performance Criteria

The performance criteria for this technology demonstration project are presented in **Table 4-1**.

<b>Table 4-1 Performance Criteria Indian Head Site, Naval Surface Warfare Center</b>		
<b>Performance Criteria</b>	<b>Description</b>	<b>Primary or Secondary</b>
Reduce perchlorate concentration	Reduce average perchlorate concentrations by 90% in the most downgradient monitor wells.	Primary
Reduce contaminant mass flux	Reduce total mass flux of perchlorate by over 75% between the source area and the most downgradient line of wells.	Primary
Biodegrade perchlorate	Stable isotope monitoring results show a statistically significant change in isotopic ratio at downgradient locations indicating biodegradation of perchlorate. <i>In situ</i> biodegradation studies indicate a measurable biodegradation rate.	Secondary
Meet regulatory standards	Maryland has a health advisory level of 1.0 µg/L for perchlorate. EPA has adopted 24.5 µg/L to be considered (TBC) as a preliminary remediation goal. Concentrations should be below the TBC goal at compliance point.	Secondary
Contaminant Mobility	The hydrogeology should not be altered by the MNA approach. However, if aquifer conditions change outside of a range that is supportive of MNA, changes will be noted and the impact identified in the protocol.	Secondary
Hazardous Materials	MNA does not produce or use hazardous materials as part of the treatment technology.	Not Applicable
Process Waste	MNA is a passive remedial strategy; therefore, waste will be limited to soil cuttings from well installation and groundwater from well development and purging. IDW could potentially contain elevated concentrations of perchlorate.	Secondary
Factors Affecting Performance	Aquifer conditions (pH, DO, ORP, etc.) that are favorable to anaerobic biodegradation support MNA performance. If the aquifer conditions are outside of a range that is supportive of anaerobic biodegradation, then the success of MNA may be affected.	Primary
Reliability	1) There should be no equipment failure since there are no aboveground appurtenances. If monitoring wells are damaged by traffic etc., replacement wells may be necessary. 2) If aquifer conditions remain amenable to MNA, the remedial approach is reliable.	Secondary
Ease of Use	1) The installation of mass flux monitoring wells/columns requires a drilling team and one geologist. 2) OSHA's health & safety training is required because the groundwater at the site may contain concentrations of unknown substances given the past use of the facility.	Primary
Versatility	The MNA remedial approach has been used for a variety of contaminants including petroleum hydrocarbons and chlorinated solvents. The MNA approach will potentially be evaluated for use with other geologic environments (sedimentary and fractured rock, deep water tables, etc.)	Secondary
Maintenance	No operation and maintenance will be required during ESTCP demonstration. General maintenance of monitoring wells may be required.	Primary

<b>Table 4-1</b> <b>Performance Criteria</b> <b>Indian Head Site, Naval Surface Warfare Center</b>		
<b>Performance Criteria</b>	<b>Description</b>	<b>Primary or Secondary</b>
Scale-Up Constraints	There are no scale-up restraints. The successful demonstration of MNA requires a monitoring well network designed to illustrate attenuation downstream from the source and prior to intercepting sensitive receptors.	Secondary

## 4.2 Performance Confirmation Methods

The objective of the field demonstration is to evaluate the rate and extent of perchlorate biodegradation and natural attenuation at the Indian Head site. The effectiveness of the demonstration will be accomplished by generating multiple lines of evidence for perchlorate degradation/attenuation including:

- (a) detailed field characterization results showing a decline in contaminant mass flux with distance;
- (b) microbiological evidence for the *in situ* activity of perchlorate-degrading organisms (CD enzyme assays and *in situ* biodegradation studies); and
- (c) changes in isotopic composition of perchlorate indicative of biodegradation.

**Table 4-2** summarizes the expected performance and performance confirmation methods.

**Table 4-2  
Expected Performance and Performance Confirmation Methods**

Performance Criteria	Expected Performance Metric (pre-demo)	Performance Confirmation Method	Actual Performance Metric (post-demo)
<b>Primary Criteria (Qualitative Performance Objectives)</b>			
Remediation	Reduced contaminant concentrations	Monitoring well data.	
Maintenance	General and limited maintenance to monitoring wells, if necessary	Experience from <i>in situ</i> demonstration	
Ease of Use	Contaminant reduction is part of the natural aquifer system, and is monitored by a network of wells	Experience from demonstration <i>in situ</i>	
<b>Primary Performance Criteria (Quantitative Performance Objectives)</b>			
Target Contaminant -- % Reduction -- Regulatory Standard	Expect concentrations of perchlorate in a portion of the source area to be around 27,000 µg/L; expect up to 90% reduction of the average perchlorate concentration in wells near downgradient receptor, resulting in concentrations <2,700 µg/L; the target concentration will be the EPA “to be considered” (TBC) preliminary remediation goal of 24.5 µg/L (99.9% reduction). Achieving 24.5 µg/L is a secondary performance criterion.	Groundwater samples collected from several locations at different distances upgradient, downgradient, and within the plume extent will be analyzed for perchlorate. Changes in concentration will be calculated both on a concentration and molar basis for comparison.	
Hazardous Materials -- Generated	Natural attenuation of perchlorate is not expected to result in production of hazardous by-products.	Analysis of groundwater samples for degradation products.	
Process Waste -- Generated	Minimal IDW from collecting soil samples and sampling monitoring wells.	Observation	
<b>Factors Affecting Performance</b> -- Biodegradation of perchlorate  -- Microbial population -- Changes in area of plume -- Favorable aquifer conditions	-- Biodegradation expected. A high percent reduction of perchlorate was observed during microcosm studies performed during the site screening process.  -- Microbial population capable of biodegrading perchlorate is expected based on positive results for DNA based CD enzyme analysis. -- Based on historical information, plume is expected to remain stable. -- Based on historical information, and pre-demonstration testing, aquifer conditions are expected to be favorable to MNA along the fringes of the perchlorate plume and in the mud flats.	-- Actual biodegradation rates will be estimated from the mass flux and <i>in situ</i> biodegradation studies. When biodegradation is significant, observe statistically significant change in isotopic ratio of perchlorate during downgradient migration. -- Secondary evidence of biodegradation observed in field parameters and laboratory analysis of groundwater samples.  -mRNA based CD enzyme analysis will be performed during monitoring to verify CD enzyme activity. -- Plume stability or shrinkage will be verified through statistical tests. -- Groundwater samples from wells upgradient, within, and downgradient of the plume will be analyzed for DO, ORP, nitrate, sulfate, dissolved iron, and methane as secondary indicators of performance.	
<b>Secondary Performance Criteria (Qualitative Performance Objectives)</b>			
Plume size	Stable or smaller	Same or decreasing concentration identified during monitoring	
Safety -- Hazards -- Protective Clothing	Perchlorate is the single contaminant that has been identified at the site. Given the industrial nature of activities near the site and unknown contaminants that may be present, Level D PPE should be worn during well installation activities.	Experience	
Versatility -- Other Applications	Yes – MNA is also effective for other contaminants, such as chlorinated solvents and petroleum hydrocarbons.	Experience.	
<b>Scale-up Constraints</b> -- Contaminant Concentration  -- Aquifer conditions -- Timing	-- Toxicity levels of solvents to bacteria can be a concern, but perchlorate is an anion of a salt. It has not been demonstrated to be toxic to bacteria. It is not expected to be applicable to this demonstration.  --Varying aquifer conditions will affect performance. MNA is a natural process and may not be applicable to sites that require an accelerated clean-up.	--Review of site information and information gathered during the screening process suggest concentrations downgradient of the probable source area should not be toxic to bacteria.  -Aquifer conditions will be monitored throughout the demonstration.	

The rate and extent of perchlorate biodegradation will be evaluated by measuring changes in concentrations of perchlorate over time in wells within, and downgradient of the contaminant plume. In the field, it can be difficult to distinguish between reduced contaminant concentrations due to dissolution versus biodegradation. To assist with the interpretation of the data, in addition to the measurement of perchlorate, other typical bio-geochemical parameters will also be utilized as secondary indicators to monitor aquifer conditions. These parameters include:

- Dissolved Oxygen (DO) – DO concentrations <1 mg/L are favorable to MNA.
- Oxidation-reduction potential (ORP) – ORP measurements less than less than -50 mV are favorable to MNA.
- Electron Acceptors – Lower concentrations of nitrate (< 5 mg/L) are favorable to MNA. .
- Dissolved iron (Fe<sup>+2</sup>) – If the aquifer conditions support anaerobic biodegradation of perchlorate, higher concentrations of dissolved iron (> 0.5 mg/L) may be observed during groundwater monitoring
- Methane – The presence of methane indicates microbial degradation (methanogenesis) is occurring and conditions are favorable for anaerobic biodegradation.

### 4.3 Data Analysis, Interpretation and Evaluation

Data will be tabulated and graphed as it is obtained during the course of the performance monitoring period. Combinations of line graphs and bar graphs will be used to illustrate MNA.

The effectiveness of MNA for perchlorate will be determined by evaluating changes in contaminant concentrations and indicator parameters over time. Changes in the indicator parameters discussed in Section 4.2 will be evaluated throughout the course of the demonstration project to evaluate whether aquifer conditions are favorable for biodegradation. Changes in perchlorate will be evaluated on a concentration and molar basis and percent reductions will be calculated.

In addition, results from the mass flux, *in situ* biodegradation, and stable isotope studies will be combined to provide an overall summary of the rate and extent of perchlorate biodegradation. Effective 1<sup>st</sup> order decay rates with associated 95% confidence limits will be calculated from the mass flux data using the statistical procedures employed by Borden *et al.* (1997b). If appropriate, contaminant transport and attenuation will be simulated using a simple first order decay model similar to BIOCHLOR, an instantaneous reaction model similar to BIOPLUME (Borden and Bedient, 1986), or a three-dimension model similar to RT3D. The modeling approach selected will depend on the site-specific monitoring results.

## 5.0 COST ASSESSMENT

### 5.1 Cost Reporting

Throughout the demonstration project, costs will be tracked and recorded to allow estimation of the costs associated with implementation of the MNA. The primary costs will be associated with mobilization, the installation of permanent mass flux wells downgradient of the probable source area and in the mudflats, *in situ* biodegradation columns, CD enzyme analysis, and stable isotope studies. After this part of the project has been completed, subsequent costs will be associated with monitoring and evaluating the performance of MNA. **Table 5-1** summarizes the anticipated categories of costs that will be tracked.

<b>Table 5-1 Cost Tracking Indian Head Site, Naval Surface Warfare Center</b>		
<b>Cost Category</b>	<b>Sub-Category</b>	<b>Details</b>
START-UP COSTS	Mobilization	Includes (but not limited to) planning, contracting, personnel mobilization, transportation, site preparation.
CAPITAL COSTS	Equipment Purchase/Rental	Monitoring well supplies, Sampling Equipment
	Installation	Includes costs of installing mass flux wells.
	Design	Includes costs for designing the well field.
OPERATING COSTS Direct Environmental Activity Costs	Sampling and Analysis	Labor and analytical costs for monitoring performance of MNA including <i>in situ</i> biodegradation studies, CD enzyme analysis and stable isotope analysis. Additional costs incurred by sending 10% of samples for perchlorate confirmation using Method 330.
	Long-term Monitoring	Anticipated long-term monitoring costs.
Indirect Environmental Activity Costs	Environmental and Safety Training	Indirect costs required on most environmental projects. However, the cost of training may change based on the selected approach or technology.

<b>Table 5-1            Cost Tracking            Indian Head Site, Naval Surface Warfare Center</b>		
<b>Cost Category</b>	<b>Sub-Category</b>	<b>Details</b>
	OSHA Ambient Environment Sampling	Indirect costs required on most environmental projects. However, the cost of training may change based on the selected approach or technology.
	Waste Manifesting (if any)	The cost of waste manifesting is important to consider when comparing cost of remedial alternatives.
Demobilization		Includes (but not limited to) removal of equipment and structures, site restoration, decontamination, and personnel demobilization.

## 5.2 Cost Analysis

### -- *Cost Comparison*

In the ESTCP final technical report and the ESTCP cost and performance report, costs for the innovative technology will be compared with two alternative technologies: (1) pump-and-treat with ion exchange; and (2) emulsified oil barriers.

### -- *Cost Basis*

Costs will be assessed on a basis of the cost per gallon of groundwater managed and cost per monitoring well.

### -- *Cost Drivers*

The primary cost drivers associated with the MNA approach for perchlorate are related to the installation of mass flux wells, *in situ* biodegradation studies, CD enzyme analysis, and stable isotope studies. These costs are primarily influenced by the subsurface lithology and contaminant mass (time associated with monitoring). A sensitivity analysis will be performed to evaluate how different factors impact costs. Factors that will be considered include contaminant concentrations, presence of co-contaminants, impacted depth, lithology, and groundwater velocity.

### -- *Life Cycle Costs*

An analysis of the total cost of completion for the technology and the two alternatives listed above (pump-and-treat and emulsified oil barrier) will be performed. The total net present value (NPV) for implementation of the technology will also be calculated over a 30-year period using the current discount rate established by the Office of Management and Budget. The major cost factors for the technology are expected to be: initial set-up costs including well field installation and monitoring costs. To the extent possible, we will separate out costs for regulatory compliance monitoring which would likely include fewer analytical parameters and a lower monitoring frequency and MNA performance monitoring.

## **6.0 Implementation Issues**

### **6.1 Environmental Checklist**

Monitor well permits will be obtained from the MDE by the Maryland-certified driller prior to installation of the new mass flux wells and in situ biodegradation columns. Solutions-IES does not anticipate that any other permits will be required from MDE to complete the technical demonstration at the Indian Head site. However, environmental “dig” permits will be required from the IHDIIV to complete well installations at the site.

An on-site incinerator is operated in the vicinity of the Indian Head site. The fieldwork will be coordinated with Indian Head personnel to address safety concerns while working in the vicinity of the incinerator located in a building nearby. According to Indian Head personnel, permits are not necessary for work performed in the mudflats.

### **6.2 Other Regulatory Issues**

The Navy regulatory contact for the site is Mr. Shawn Jorgenson of the Naval Support Facility- East Potomac.

### **6.3 End-User Issues**

Potential end users of the technology include a variety of agencies within the federal government (Dept. of Defense, Dept. of Energy, and Environmental Protection Agency), state and local governments and private industry.

## 7.0 References

- Ader M., M.L. Coleman, S.P. Doyle, M. Stroud and D. Wakelin, 2001. Methods for the Stable Isotopic Analysis of Chlorine in Chlorate and Perchlorate Compounds. *Anal. Chem.* 73 (20): 4946-4950.
- AFCEE, 2004. Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents, Air Force Center for Environmental Excellence, Brooks City-Base, Texas.
- Ahad, J.M.E., B.S. Lollar, E.A. Edwards, G.F. Slater and B.E. Sleep, 2000. Carbon Isotope Fractionation during Anaerobic Biodegradation of Toluene: Implications for Intrinsic Bioremediation. *Environ. Sci. Tech.* 34(5): 892-896.
- Bender, K.S., S.M. O'Connor, R. Chakraborty, J.D. Coates and L.A. Achenbach, 2002. Sequencing and Transcriptional Analysis of the Chlorite Dismutase Gene of *Dechloromonas agitata* and Its Use as a Metabolic Probe. *Appl. Environ. Microbiol.* 68(10): 4820-4826.
- Böhlke, J.K., N.C. Sturchio, B. Gu, J. Horita, G.M. Brown, W.A. Jackson, J. Batista and P. Hatzinger, 2005. Perchlorate Isotope Forensics. *Anal. Chem.* 77: 7838-7842.
- Borden, R.C. and P.B. Bedient, 1986. Transport of Dissolved Hydrocarbons Influenced by Re-aeration and Oxygen Limited Biodegradation: 1. Theoretical Development. *Water Resources Res.* 22(13): 1973-1982.
- Borden, R.C., M.J. Hunt, M.B. Shafer, M.A. Barlaz, 1997a. Environmental Research Brief – Anaerobic Biodegradation of BTEX in Aquifer Material. EPA/600/S-97/003, US EPA, Washington, DC, pp. 9.
- Borden, R.C., R.A. Daniel, L.E. LeBrun IV, and C.W. Davis, 1997b. Intrinsic Biodegradation of MTBE and BTEX in a Gasoline-Contaminated Aquifer, *Water Resources Research*, 33(5): 1105-1115.
- Chaudhuri, S.K., S.M. O'Connor, R.L. Gustavson, L.A. Achenbach and J.D. Coates, 2002. Environmental Factors that Control Microbial Perchlorate Reduction. *Appl. Environ. Microbiol.* 68(9): 4425-4430.
- Coates, J.D., U. Michaelidou, R.A. Bruce, S.M. O'Connor, J.N. Crespi, and L.A. Achenbach, 1999. Ubiquity and Diversity of Dissimilatory (Per)chlorate-Reducing Bacteria. *Appl. Environ. Microbiol.* 65 (12): 5234-5241.
- Coates, J.D. and J. Pollock, 2003. Potential for *In Situ* Bioremediation of Perchlorate in Contaminated Environments. Presented at: *In Situ* and On-Site Bioremediation, the Seventh International Symposium, Orlando, FL, June 2003.
- Coleman, M., S. Chaudhuri, M. Ader and J.D. Coates (in press). Microbial Isotopic Fractionation of Perchlorate Chlorine.
- Cramer, R.J., C. Yates, P. Hatzinger and J. Diebold, 2004. Field Demonstration of *In Situ* Perchlorate Bioremediation at Building 1419, Shaw Environmental, Inc.
- Gillham, R.W., R.C. Starr and D.J. Miller, 1990. A Device for *In situ* Determination of Geochemical Transport Parameters; 2 Biochemical Reactions. *Ground water* 82: 858-862.

- Heaton, T.H.E., 1986. Isotopic Studies of Nitrogen Pollution in the Hydrosphere and Atmosphere: A Review. *Chemical Geology* 59: 87-102.
- Herman, D.C. and W.T. Frankenberger, Jr., 1998. Microbial-Mediated Reduction of Perchlorate in Groundwater. *J. Environ. Qual.* 27: 750-754.
- Interstate Technology and Regulatory Council (ITRC) Work Group, 2005. Perchlorate: Overview of Issues, Status, and Remedial Options. September 2005. (<http://www.itrcweb.org>).
- Karr, J.D., W.J. Showers, J.W. Gilliam, A.S. Andres, 2001. Tracing Nitrate Transport and Environmental Impact from Intensive Swine Farming using Delta Nitrogen-15. *J. Environ. Qual.* 30(4): 1163-1175.
- Kolhatkar, R., T. Kuder, P. Allen, and J.T. Wilson, 2002. Use of Compound-Specific Stable Carbon Isotope Analyses to Demonstrate Anaerobic Biodegradation of MTBE in Groundwater at a Gasoline Release Site. *Environ. Sci. Tech.* 36(23): 5139-5146.
- Logan, B.E. Assessing the Outlook for Perchlorate Remediation. *Environ. Sci. Tech* 35 (23): 482A-487A, December 1, 2001.
- Lollar, B.S., G.F. Slater, M. Witt, G.M. Klecka, M. Harkness and J. Spivack, 2001. Stable Carbon Isotope Evidence for Intrinsic Bioremediation of Tetrachloroethene and Trichloroethene at Area 6, Dover Air Force Base. *Environ. Sci. Tech.* 35(2): 261269.
- Mariotti, A., J.C. Germon, P. Hubert, P. Kaiser, R. Letolle, A. Tardieux and P. Tardieux, 1981. Experimental Determination of Nitrogen Kinetic Isotope Fractionation: Some Principles: Illustration for the Denitrification and Nitrification Processes. *Plant and Soil* 62: 413-430.
- Rikken, G.B., A.G.M. Kroon and C.G. van Ginkel. 1996. Transformation of (Per)chlorate into Chloride by a Newly Isolated Bacterium: Reduction and Dismutation. *Appl. Microbiol. Biotechnol.* 45: 420-426.
- Slater, G.F., B. S. Lollar, B.E. Sleep and E.A. Edwards, 2001. Variability in Carbon Isotopic Fractionation during Biodegradation of Chlorinated Ethenes: Implications for Field Applications. *Environ. Sci. Tech.* 35(5): 901-907.
- U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM). Perchlorate in Drinking Water. (<http://chppm-www.apgea.army.mil/documents/FACT/31-003-0502.pdf>).
- US EPA. 1996. Environmental Investigations Standard Operating Procedures and Quality Assurance Manual. (<http://www.epa.gov/region04/sesd/eisopqam/eisopqam.html>.) Region 4, Science and Ecosystem Support Division. Athens, GA.
- US EPA, 1997. Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. OSWER Directive 9200.4-17, Interim Final, November 1997.
- US EPA, 2005. Perchlorate Treatment Technology Update: Federal Facilities Forum Issue Paper. EPA No. 542-R05-015. InfoNational Service Center for Environmental Protection, Cincinnati, OH. (<http://yosemite.epa.gov/ncepihom/nsCatalog.nsf/fe334be39822543485256fbf005fe5ec/84308272e16c68dc852570dd0056d0d5!openDocument>)
- US EPA, 2006. Assessment Guidance for Perchlorate. Memorandum from S.P. Bodine, Asst. Administrator, to Regional Administrators. January 26, 2006.

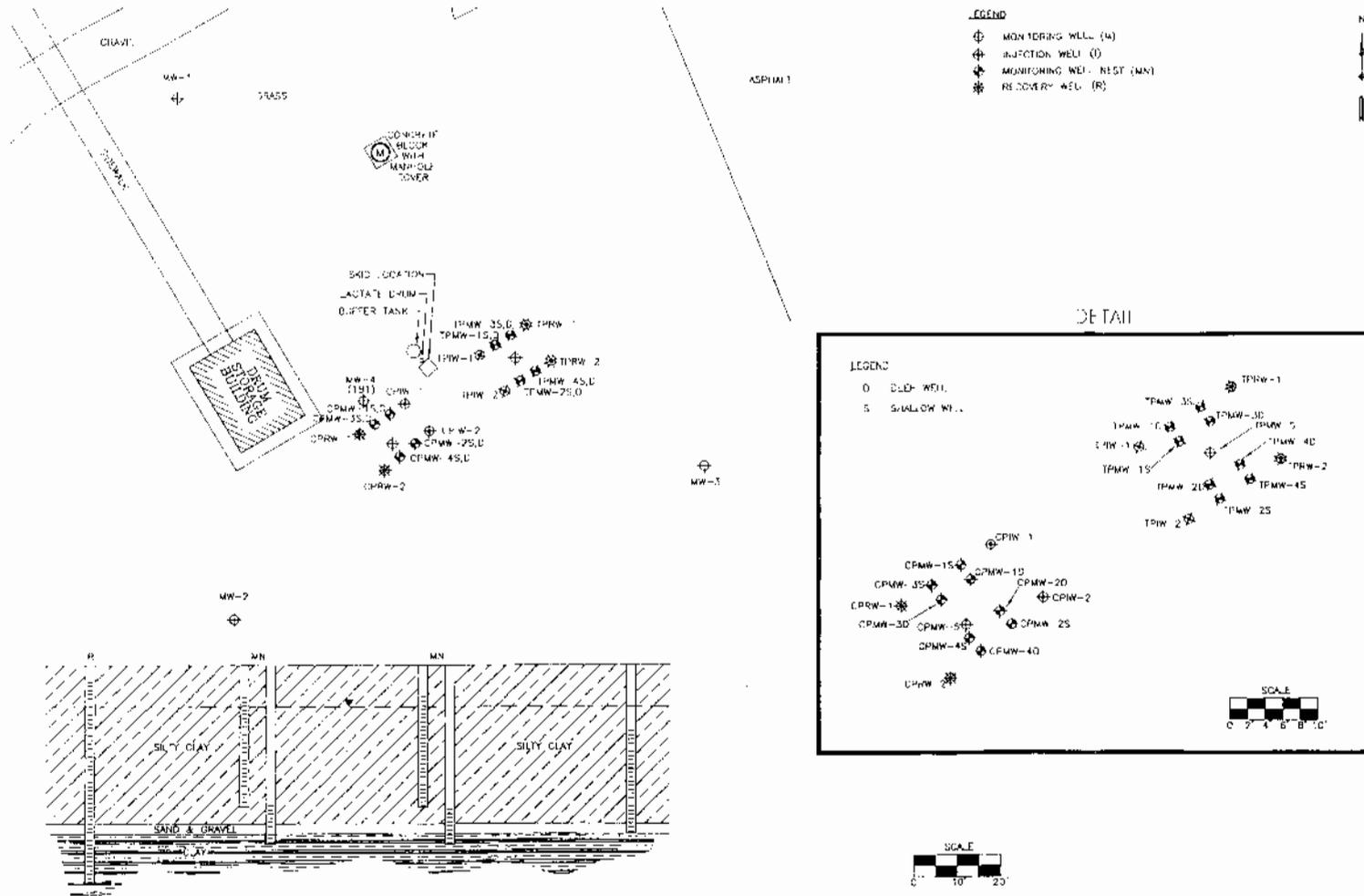
Wiedemeier, T.H., M.A. Swanson, D.E. Moutoux, E.K. Gordon, J.T. Wilson, B.H. Wilson, D.H. Kampbell, P.E. Haas, R.N. Miller, J.E. Hansen and F.H. Chapelle, 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water. EPA/600/R-98/128 (<ftp://ftp.epa.gov/pub/ada/reports/protocol.pdf>)

Wilson, J.T., H.S. Cho and F.P. Beck, 1997. Field Estimation of Hydraulic Conductivity for Assessments of Natural Attenuation. *In Situ* and On-Site Bioremediation, Volume 2. Columbus: Battelle Press: pp 309-314.

## 8.0 Points of Contact

<b>Table 8-1 Points of Contact Indian Head Site, Naval Surface Warfare Center</b>			
<b>POINT OF CONTACT NAME</b>	<b>ORGANIZATION NAME ADDRESS</b>	<b>PHONE/FAX/EMAIL</b>	<b>ROLE IN PROJECT</b>
M. Tony Lieberman, R.S.M.	Solutions-IES, Inc. 1101 Nowell Road Raleigh, NC 27607	919-873-1060 919-873-1074 (fax) tlieberman@solutions-ies.com	Co-Principal Investigator; Project Manager
Dr. Robert C. Borden, P.E.	North Carolina State University Civil, Construction & Environmental Engineering Mann Hall Raleigh, NC 27695	919-515-1625 919-515-7908 (fax) rcborden@eos.ncsu.edu	Principal Investigator
Erica Becvar	AFCEE 3300 Sidney Brooks Brooks City-Base, TX 78235-5112	210-536-4314 210-536-5989 (Fax)	Contracting Officer Representative (COR)
Dr. Randall Cramer	IHDIV Naval Surface Warfare Center Indian Head, MD 20640	301-744-2878 301-744-4843 (Fax) 703-568-0560 (Cell)	Site Representative
Shawn Jorgenson	Naval Support Facility-East Potomac	301-744-2263	Navy Environmental

**APPENDIX I**  
**HISTORICAL INFORMATION**



**FIGURE A** *Recirculation Cell Layouts and Schematic Cross-Section View*

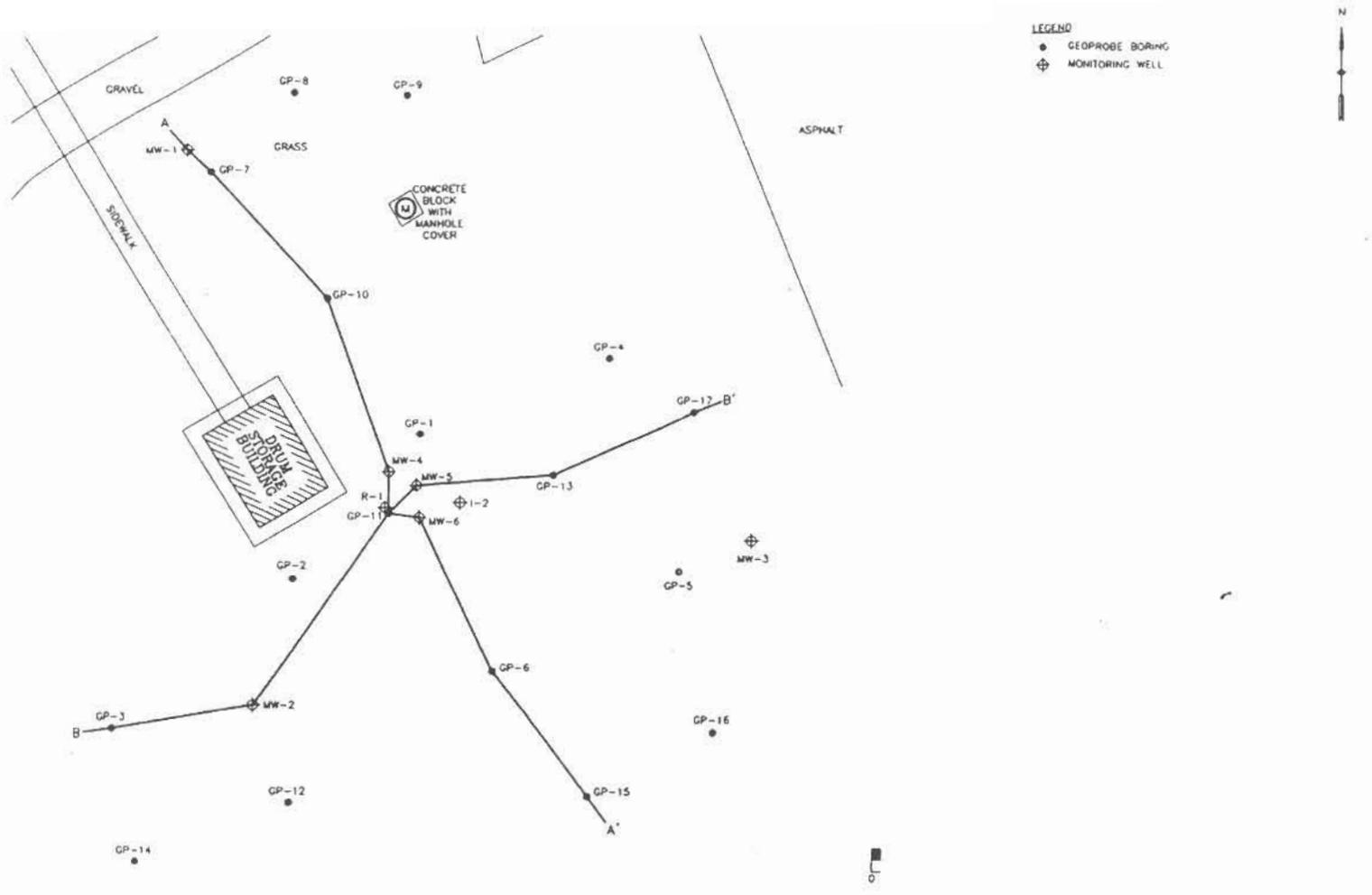


FIGURE B Boring Location and Cross-Section Plan View

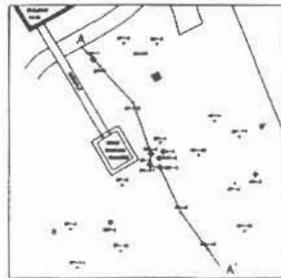
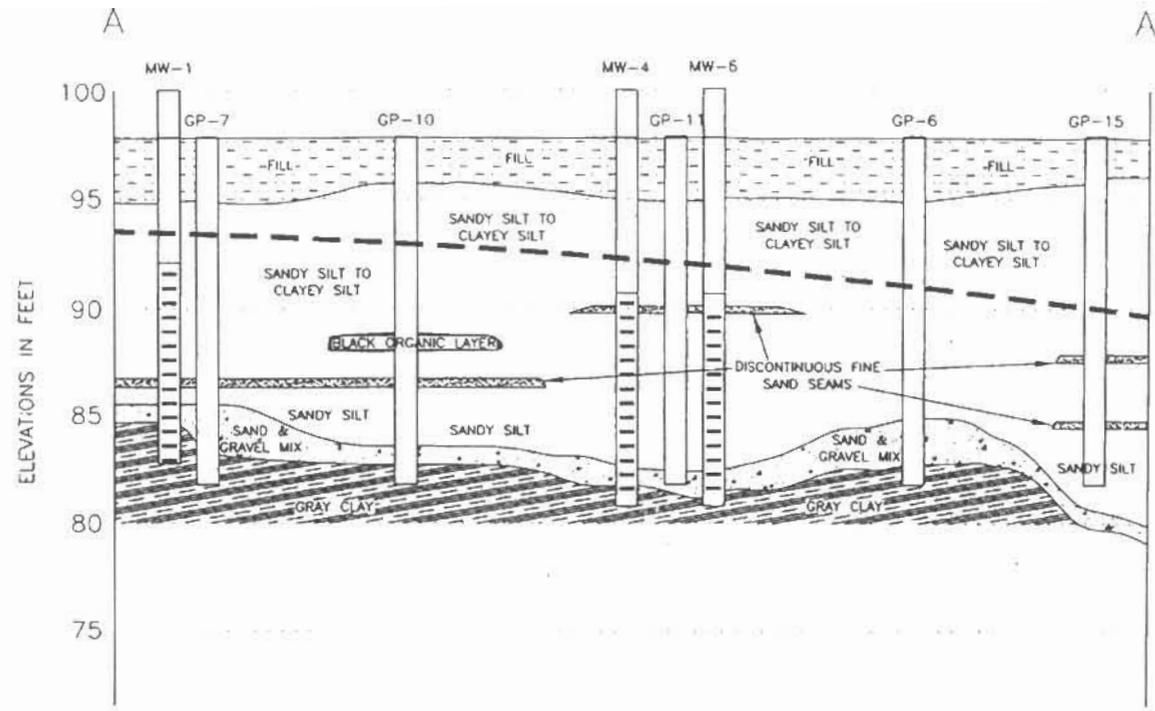


FIGURE C *Geologic Cross-Section A-A'*

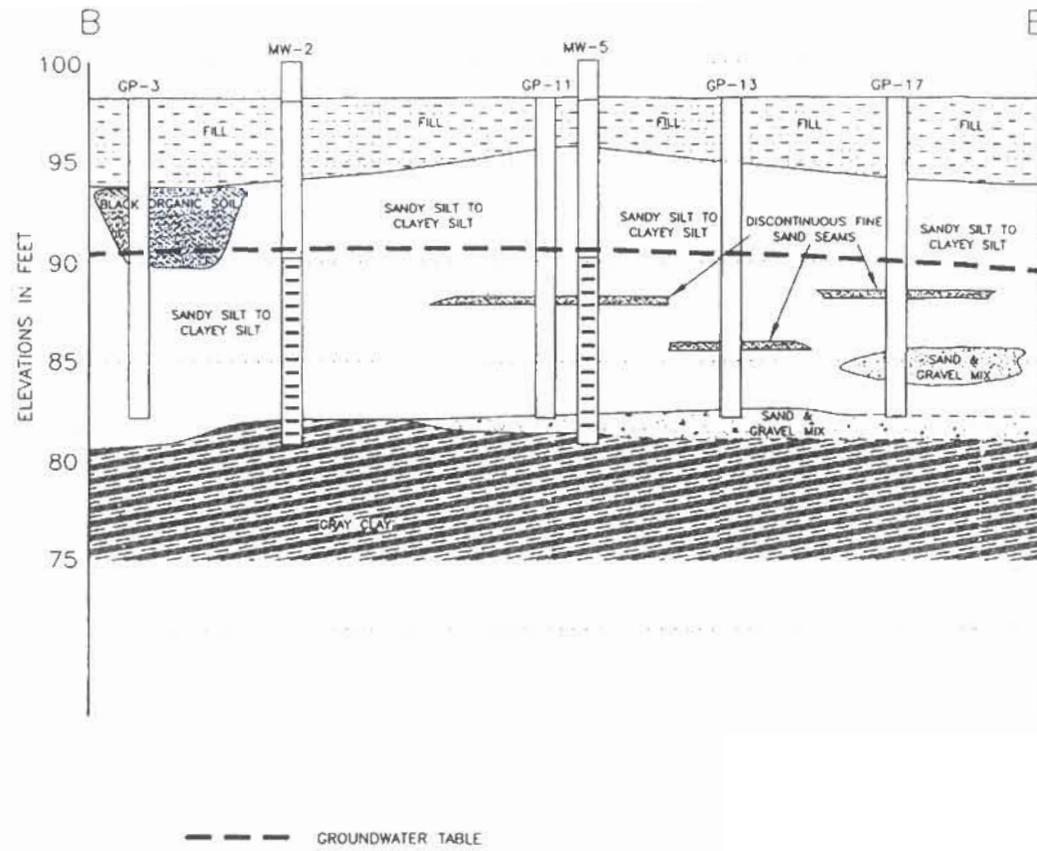
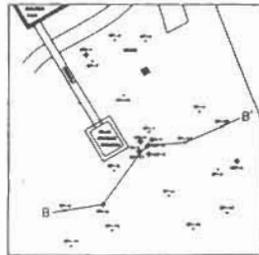
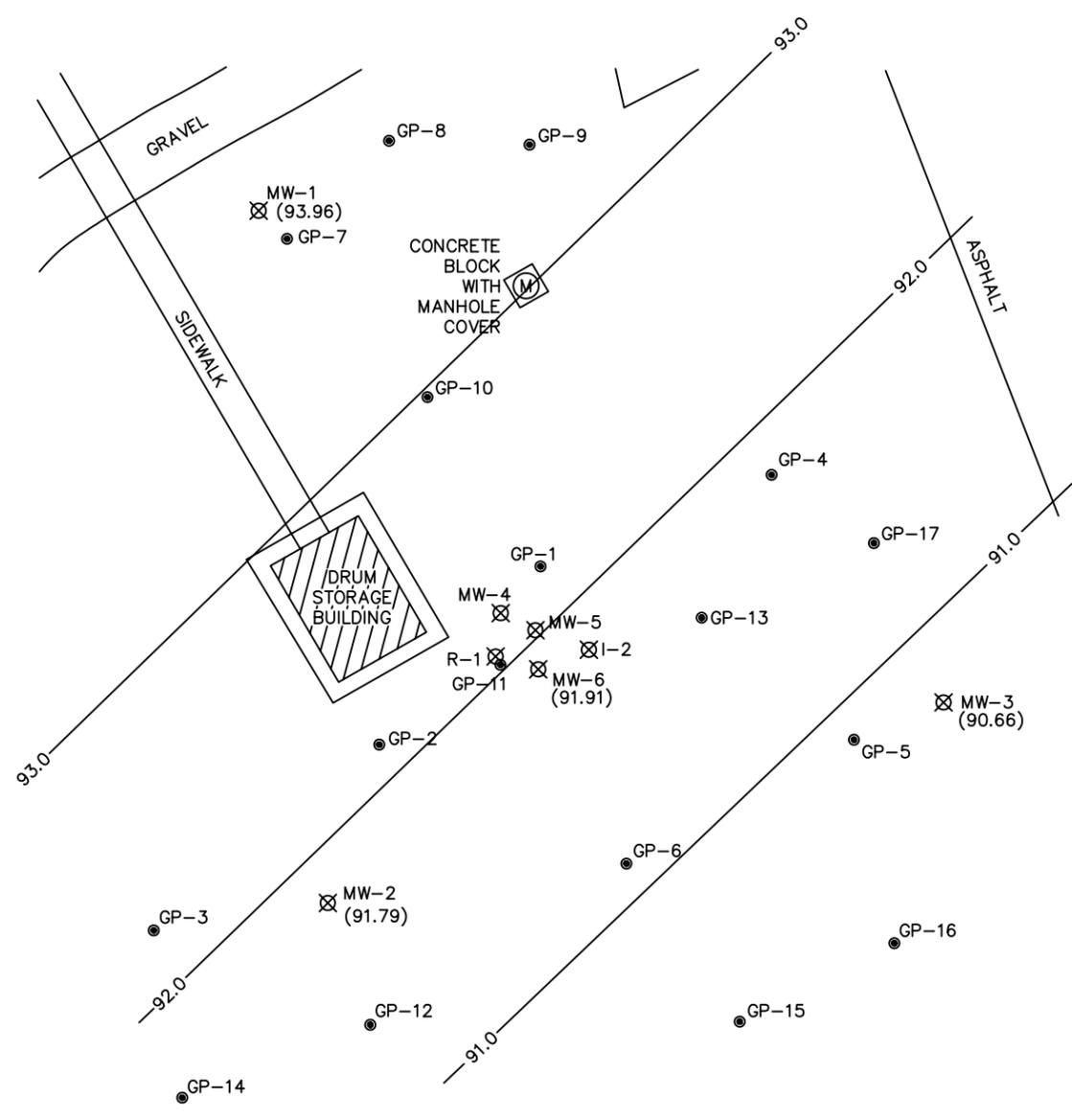
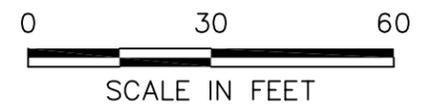


FIGURE D Geologic Cross-Section B-B'

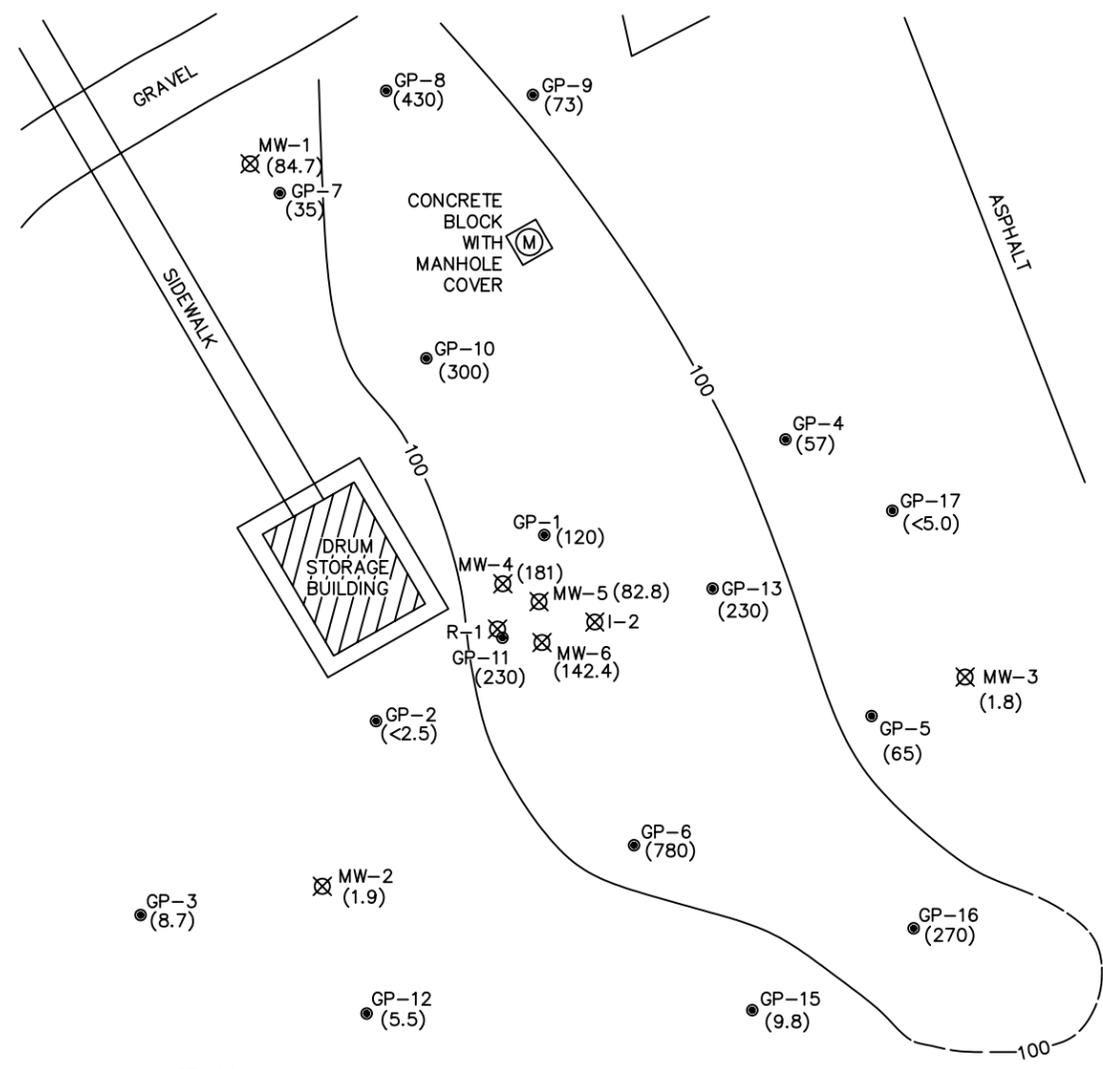
FILE Figure 2.dwg DATE 11/04/05 PROJECT MANAGER MTL CHECKED BY SLK DRAFTER KBB PROJECT NUMBER 3030.04A2.ESTC



**LEGEND**  
 ● GP-17 GEOPROBE BORING  
 ⊗ MW-3 MONITORING WELL  
 (91.57) GROUNDWATER ELEVATION  
 92.0 POTENTIOMETRIC CONTOUR

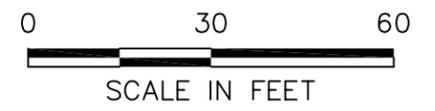


FILE Figure 3.dwg DATE 11/04/05 PROJECT NUMBER 3030.04A2.ESTC PROJECT MANAGER MTL CHECKED BY SLK DRAFTER KBB



**LEGEND**  
 ● GP-17 GEOPROBE BORING  
 ☒ MW-3 MONITORING WELL  
 ( ) PERCHLORATE CONCENTRATION IN PPM  
 -100- PERCHLORATE ISOCONTOUR

**NOTE**  
 GEOPROBE RESULTS ARE FROM WATER SAMPLES COLLECTED BETWEEN JAN. 22 & JAN. 24, 2002.  
 MONITORING WELL RESULTS ARE FROM SAMPLES COLLECTED ON FEB. 5-6, 2002.



**APPENDIX II**

**SITE-SPECIFIC WORKPLAN FOR PRE-DEMONSTRATION SAMPLING  
(NOVEMBER 2005)**

**SITE-SPECIFIC WORK PLAN  
INDIAN HEAD DIVISION  
NAVAL SURFACE WARFARE CENTER  
INDIAN HEAD SITE  
INDIAN HEAD, CHARLES COUNTY, MARYLAND**

Prepared by:

**Solutions-IES, Inc.**  
1101 Nowell Road  
Raleigh, North Carolina 27607  
[www.solutions-ies.com](http://www.solutions-ies.com)

**Solutions-IES Project No. 3030.04A2.ESTC**

**November 3, 2005**

---

M. Tony Lieberman  
Principal Investigator

---

Sheri L. Knox, P.E.  
Senior Engineer



## TABLE OF CONTENTS

1.0	Introduction.....	1
2.0	Site Background and Description .....	1
2.1	Location and Background.....	2
2.2	Site Geology, Hydrogeology and Plume Geometry.....	2
3.0	Site Characterization and sample collection .....	4
3.1	Overall Project Objectives .....	4
3.3	Scope of Work .....	4
3.3.1	Soil Boring and Monitor Well Installation .....	4
3.3.2	Groundwater Sampling Procedures .....	5
4.0	QA/QC Samples .....	7
5.0	Investigation-Derived Waste (IDW).....	7
6.0	Results Evaluation and Reporting.....	8
7.0	Project Schedule .....	9

### FIGURES

- Figure 1 – Site Layout Map
- Figure 2 – Groundwater Potentiometric Surface Map
- Figure 3 – Perchlorate Isoconcentration Map
- Figure 4 – Proposed Boring/Monitoring Well Pair Locations

### TABLES

- Table 1 – Groundwater Characterization in Selected Monitor Wells, February 28, 2005
- Table 2 – Groundwater Characterization in Selected Monitor Wells, September 28, 2005
- Table 3 – Sample Collection and Analysis Details

### APPENDIX A

- Appendix A – Site-Specific Health & Safety Plan
- Appendix B – Boring Advancement and Sample Collection Procedures

## 1.0 INTRODUCTION

Groundwater and surface water contaminated with perchlorate ( $\text{ClO}_4^-$ ) has become a major environmental issue for the US Department of Defense (DoD) due to the use, release and/or disposal of solid rocket fuel and munitions containing ammonium perchlorate. Perchlorate is a highly mobile, soluble salt that sorbs poorly to most aquifer material, and can persist for decades under aerobic conditions. As a consequence, discharge of perchlorate to the environment can impact ground and surface water with the potential for human consumption through direct (drinking water) and indirect (crop uptake from irrigation water) pathways. Currently, there is no federal cleanup standard for perchlorate in groundwater or soil. However, several states have identified health-based goals, cleanup goals and action levels for groundwater, surface water and drinking water that range in concentration from 1  $\mu\text{g/L}$  to 18  $\mu\text{g/L}$ . Specifically, the State of Maryland has identified a health-based goal of 1  $\mu\text{g/L}$ <sup>2</sup>.

As an emerging technology, the promise of using monitored natural attenuation (MNA) as a groundwater remediation strategy for perchlorate is significant. Recent laboratory research has shown that a diverse array of bacteria can anaerobically degrade perchlorate to chloride and oxygen. These organisms appear to be widespread in the environment and can use a variety of different organic substrates as electron donors for perchlorate reduction. This suggests that perchlorate may naturally degrade at some sites without active human intervention. However, field demonstrations are essential to show that perchlorate does naturally attenuate, and the conditions where attenuation is most likely to occur.

The current project is being conducted under funding provided by the Environmental Security Technology Certification Program (ESTCP Project: ER-0428). During a conference call with the ESTCP project review team on October 12, 2005, the site at Building 1419 at the Naval Surface Warfare Center, Indian Head Division (IHDIV), Indian Head, Maryland was approved as the first of two locations for technical demonstration of the potential for the MNA of perchlorate in groundwater. A portion of this same site was used previously for a separate ESTCP-funded demonstration of an enhanced *in situ* bioremediation technology (see Section 2.1). However, according to previous reporting, a complete delineation of the perchlorate plume at this site has not been conducted. The last full round of sampling of the wells installed as part of the earlier demonstration was performed in winter 2002. As part of the forthcoming technical demonstration of the potential for MNA at the site, the installation of a number of monitoring wells will be required to assist us in determining mass flux and perchlorate degradation rates. However, because the perchlorate contaminant plume has not been fully assessed, particularly in the southeast direction closer to Mattawoman Creek, this Site-Specific Work Plan (SSWP) has been prepared to describe steps to accomplish this task prior to completing the Technology Demonstration Plan for this site.

This SSWP describes the methods and procedures to perform preliminary groundwater assessment field work at the Indian Head site. The following sections provide details regarding monitoring well installation, sample collection, and field and laboratory testing from of the area identified as the Building 1419 site at Indian Head. A site-specific Health and Safety Plan (HASP) is provided in Appendix A.

## 2.0 SITE BACKGROUND AND DESCRIPTION

In December 2004, Solutions-IES initially contacted personnel at Indian Head familiar with the Building 1419 site about the potential for including the site in the MNA investigation. Mr. Cary Yates completed a questionnaire prepared by Solutions-IES and provided invaluable information about the history and site

---

<sup>2</sup> Interstate Technology & Regulatory Council, 2005. *Perchlorate: Overview of Issues, Status, and Remedial Options*, September 2005.

conditions. Recently, Mr. Randall Cramer was identified as the site contact for this area. A report entitled *Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419* prepared in January 2004 (“the January 2004 report”) was used as the primary source of historical information about the site<sup>3</sup>.

Based on the information in the January 2004 report, Solutions-IES conducted a sampling event on February 14, 2005 to obtain information about groundwater conditions for use in the site selection process for the current project. Subsequently, additional samples were collected on September 28, 2005 in anticipation of the selection of the Building 1419 site at Indian Head for a field demonstration of the technology. The background information from the January 2004 report and the groundwater results from Solutions-IES’ testing in 2005 are described in the following section.

## 2.1 Location and Background

The IHDIV is located near Indian Head in Charles County, Maryland, and is approximately 30 miles south of Washington, DC. The Building 1419 site, also referred to as the Hog-out Facility, is located on the southeast side of the IHDIV. The perchlorate-impacted groundwater is located southeast of Building 1419 in a 2-acre grassy area containing a small drum storage building, and numerous groundwater monitoring, injection, and extraction wells. The area is bordered to the southeast by Mattawoman Creek which is a large tributary to the Potomac River (Figure 1). Building 1419 was used to clean out or “hog out” solid propellant containing ammonium perchlorate from various devices, including rockets and ejection seat motors, that had exceeded their useful life span. According to Randall Cramer, historically the hog-out liquid was simply washed out of Building 1419 into a marshy area between the building and Mattawoman Creek. When this process was stopped, the marshy area was filled in and seeded with grass cover. The hog-out process and former waste handling methods have impacted the groundwater near Building 1419.

To evaluate remedial alternatives for impacted groundwater at Building 1419, an investigation to determine the effectiveness of injecting lactate substrate into the subsurface was performed by Shaw Environmental, Inc. A pilot system was created employing a recirculation cell design consisting of two field areas: a test area and a control area. In the test area, groundwater was extracted from the site, amended with a lactate substrate and a pH buffer, and then re-injected into the aquifer. Groundwater was extracted and re-injected without substrate or buffer amendment in the control area. Each Shaw pilot test cell covered an area measuring approximately 10 X 10 ft (100 sq. ft) in the middle of the filled area south of the hog-out facility.

## 2.2 Site Geology, Hydrogeology and Plume Geometry

The study area used by Shaw Environmental for their pilot test is located southeast of Building 1419 and is approximately 220 to 300 feet north of Mattawoman Creek. The surficial geology of the area was derived from soil samples collected from 17 Geoprobe borings and six test borings that ranged in depth from 16 to 20 feet below ground surface (bgs). The top 2 to 4 feet consisted of fill material including organic soils, gravel, and silty sand. The underlying 11 to 13 feet consisted of mottled light to olive brown clay to sandy silts. The clay and sand fractions of the silts varied horizontally and vertically. Fine-grained sand seams 1 to 2 inches in thickness were seen in many of the boring locations, but these seams were not continuous from boring to boring. At a depth of approximately 15 ft bgs, a 1 to 1.5 ft thick layer of sand and gravel was encountered. This layer was found to be continuous throughout the area. The sand and gravel layer is underlain by a gray clay layer, which extends to a depth of at least 20 feet bgs, the deepest extent of the Geoprobe<sup>®</sup> and test borings. This is likely the clays of the Potomac Group.

---

<sup>3</sup> Randall J. Cramer and Cary Yates, Indian Head Division, Naval Surface Warfare Center and Paul Hatzinger and Jay Diebold of Shaw Environmental, Inc., *Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419* (Appendix E), January, 2004.

Groundwater elevations measured in the six monitoring wells in the field indicate a groundwater flow direction to the southeast toward the Mattawoman Creek (Figure 2). The flow direction basically follows the surface topography. Depth to groundwater ranged from approximately 6.5 to 10.25 ft bgs. The average hydraulic gradient, as measured between wells MW-1 and MW-3, was 0.023 ft/ft, indicating a relatively flat gradient. Figure 3 shows an interpretation of the 100 mg/L perchlorate isoconcentration contour from the January 2004 report. The plume extends from Building 1419 to the southeast, but neither the distal end or lateral extent of the migration is estimated.

In order to obtain additional information for the site-selection process, Solutions-IES traveled to the site on February 14, 2005 to collect soil and groundwater samples. Monitoring well MW-1 is located about 80 feet upgradient from the Shaw pilot test cells, MW-2 is located approximately 50 ft southwest of the test cells and MW-4 was located at the north edge of the control treatment cell. Groundwater samples were collected from these monitoring wells using a peristaltic pump polyethylene tubing. Field parameters were collected during low flow sampling at each monitoring well. Table 1 summarizes field parameters collected during the groundwater sampling activities at each monitoring well. The table also summarizes the perchlorate concentration detected in each groundwater sample.

<b>Table 1</b> <b>Groundwater Characterization in Selected Monitoring Wells, February 14, 2005</b> <b>Building 1419 Site, Naval Surface Warfare Center</b> <b>Solutions-IES Project No. 3030.04A2.ESTC</b>				
Monitoring Well Identification	pH (Standard Unit)	Oxidation/Reduction Potential (mV)	Dissolved Oxygen (ppm)	Perchlorate (µg/L)
MW-1	4.9	105.	~1.0	92,820
MW-2	6.9	< -1000	~3.5	3
MW-4	5.4	5.6	~8	36,263

Solutions-IES returned to the site on September 28, 2005 and collected groundwater samples from monitoring wells MW-4D and MW-5, located within the lactate injection treatment cell of Shaw's pilot test, to measure perchlorate and total organic carbon (TOC) concentrations within the test area. The objective was to determine whether there was any long-term impact of the lactate injection treatment that was ended in 2002 that could complicate the planned evaluation of the potential for MNA in this area. Table 2 summarizes the field parameters, the current TOC concentrations and the perchlorate concentrations reported in 2002 and measured during this event.

<b>Table 2</b> <b>Groundwater Characterization in Selected Monitoring Wells, September 28, 2005</b> <b>Building 1419 Site, Naval Surface Warfare Center</b> <b>Solutions-IES Project No. 3030.04A2.ESTC</b>						
Monitoring Well Identification	pH (Standard Unit)	Oxidation/Reduction Potential (mV)	Dissolved Oxygen (ppm)	Perchlorate (µg/L) 2002	Perchlorate (µg/L) 9/28/05	TOC (mg/L)
MW-4D	5.5	117	4.5	181,000	38,500	2.2
MW-5	5.9	53	2.3	82,800	36,200	3.2

Although it appears that perchlorate concentrations are currently much lower in the test area that had been treated with lactate than the concentrations reported in 2002, there is no indication of residual organic carbon in this area of the site and the perchlorate concentrations remain sufficiently elevated to perform the technical demonstration proposed for the current project.

### **3.0 Site Characterization and Sample Collection**

#### **3.1 Overall Project Objectives**

The overall objective of this project is to provide DoD managers with the tools needed to: (1) identify sites where MNA may be appropriate for management of perchlorate releases; and (2) demonstrate to regulatory agencies that perchlorate MNA is effective for controlling adverse impacts to the environment at some sites. Overall objectives to be accomplished in this project are listed below.

Evaluate the rate and extent of perchlorate biodegradation in aquifer material and groundwater from a variety of sites that received perchlorate.

Evaluate the use of enzyme assays and isotopic ratios as indicators of perchlorate biodegradation in laboratory incubations and field trials.

Develop multiple lines of evidence to evaluate the monitored natural attenuation of perchlorate at two field sites.

Develop a protocol for monitoring the natural attenuation of perchlorate.

Transfer the knowledge gained about perchlorate MNA to the regulatory community.

#### **3.2 Site-Specific Sampling Objective**

The site-specific objective is to better define the existing perchlorate contaminant plume, obtain updated information on the hydrogeology, and collect monitoring data which will aid Solutions-IES in locating monitoring wells associated with the technical demonstration. Field work will include installing additional temporary/permanent monitoring wells, collecting groundwater samples from new and existing monitoring wells, and performing specific capacity tests to confirm and extend the information previously obtained at Indian Head.

This SSWP outlines the methods for temporary/permanent well installation, and groundwater sampling which will be performed at the Building 1419 site. The results of the activities described in this SSWP will provide a more complete characterization of the groundwater perchlorate plume and help optimize the selection of well locations for use in the technical demonstration.

#### **3.3 Scope of Work**

The scope of work for this portion of the project includes updating the perchlorate plume delineation, hydrogeology, and groundwater data previously obtained for Indian Head.

##### **3.3.1 Soil Boring and Monitor Well Installation**

Based on a review of the January 2004 report and Solutions-IES' field observations and testing during the site selection process, approximately two days of Geoprobe<sup>®</sup> work (10 to 20 borings) will be performed to advance soil borings in the vicinity of the existing perchlorate plume at the Building 1419 site. Figure 4 shows the proposed locations of new pairs of borings across the site in relation to the site features and the previously drawn 100 mg/L perchlorate isoconcentration contour. The proposed layout covers areas upgradient, cross-gradient, and downgradient of the existing plume. At each location, a pair of borings will be advanced, and the soil profile from the deeper boring will be continuously logged. Each boring will then be converted to 1-inch diameter PVC temporary well with a bentonite seal and locking or PVC slip cap.

Total well depths ranged from 13 to 16 ft bgs where the clay layer identified as the Potomac Group is encountered. Although actual depths may vary slightly, for purposes of this SSWP, we have assumed that the initial boring at each location will be advanced to the clay layer approximately 16 ft bgs, taking care to terminate the boring an inch or two within the clay layer. The well in this boring will be installed to a total depth of approximately 16 ft bgs with a 2-ft length of screen (14 to 16 ft bgs). ***The depth of this screen interval is targeted to transect the gravel/sand layer, if present. Based on field observations, the well depth will be adjusted to screen the gravel layer.*** The second boring of each pair will then be placed approximately 2 feet from the initial boring and advanced to a total depth of 13 ft bgs. The second well in the pair will be installed to a total depth of approximately 13 ft bgs with a 5-foot length of screen (~8 to 13 ft bgs) which is designed to transect sandy silt/clayey silt layer predominately present a depths less than 13 ft bgs. ***The actual depths may vary depending on the final depth of the deeper well. However, the bottom of the screened interval in the second, shallower well should be at least one foot higher than the top of the screen interval in the deeper, first well of each pair. The 5-ft screen interval in the shallower well is intended to screen across suspected any sand stringers that may be present in the upper zone.*** Figure 4 also shows a cross-section depicting general location of screened intervals for well pairs installed at the site. For detailed information regarding the advancement of borings using the Geoprobe® or well installation see Appendix B.

For this scope of work, the location of the temporary wells will be established by measuring from existing site features. A licensed survey will not be performed at this time. The locations will be recorded with sufficient accuracy to place them on a scaled map suitable for selecting well locations for the technology demonstration. Solutions-IES personnel will survey the elevation of the top-of-casing of each well based on an assumed benchmark of 100 ft established on site or tied into an existing well elevation, if available.

Groundwater samples will be collected from each of the new temporary wells, and the existing monitoring wells (MW-1, MW-2, MW-3, MW-4, MW-5, MW-6). Prior to sample collection, each of the wells will be developed with a peristaltic pump. In addition, specific capacity tests will be performed on one new well and one well installed during previous work (old well) screened over the deeper gravel/sand layer and two wells (one old and one new) screened in the shallower sandy silt/clayey silt zone. The results will be compared to permeability information previously identified at Building 1419.

After the groundwater results are analyzed, some of the temporary wells may be converted to permanent monitoring wells for possible use in the technical demonstration. To convert temporary wells to permanent, the well will be finished with a flush-mount manhole cover. All other temporary wells will be abandoned in place by pulling downhole materials from the borehole and filling the borehole from the bottom with a bentonite-grout mix. A licensed well contractor will abandon the wells.

### 3.3.2 Groundwater Sampling Procedures

Groundwater samples will be obtained using standard collection equipment such as pumps/tubing. Appendix B identifies the collection protocol specific to the Building 1419 site. The procedure for collecting samples at each of the new and existing monitoring wells will be as follows.

- (a) Water level: Measure the depth to water from the top-of-casing elevation using electronic water level meter and record measurement in the field book. Elevations will be measured to the nearest 0.01 ft.
- (b) Groundwater collection: Pump groundwater at a low flow rate to minimize the disturbance to oxygen concentration in the sampled wells. Use a peristaltic pump with new disposable tubing for each well.

- (c) Field parameters: Periodically collect groundwater quality parameters until conditions stabilize (i.e., less than 10% change over 5 minutes of pumping) by collecting a 100-mL water sample in a 250-mL plastic jar and measure pH, temperature, conductivity and oxidation-reduction potential (ORP) using standard field meters.
- (d) Dissolved oxygen: As water is flowing out of the sampling tubing, insert a Chemetrics 0 - 1 mg/L self-filling dissolved oxygen (DO) ampoule into the end of the tube. Break off the ampoule tip below the water surface, pulling water into the ampoule while being careful to exclude any oxygen. Read the DO concentration by visual comparison to color standards or using a field photometer. If the DO exceeds 1 mg/L, repeat this process with the 1 – 12 mg/L DO ampoules.
- (e) Total organic carbon: Collect one 250-ml amber bottle preserved with hydrochloric acid for TOC analysis.
- (f) Methane and permanent gases: Collect two 40-ml VOA vial with no preservative and no headspace for analysis of permanent gases.
- (g) Perchlorate: Fill a 200-ml plastic bottle with groundwater. Insert a 50-ml plastic disposable syringe into the sample and withdraw the groundwater sample into the syringe. Prepare a sequential filtering stack by affixing a disposable 0.45  $\mu\text{m}$  pore size filter to a 0.20  $\mu\text{m}$  pore size filter. Place the coupled syringe filter stack onto the end of the syringe and filter the volume into a clean 200 ml plastic bottle with no preservative. Repeat until approximately 125 ml of sample have been filtered into the bottle. Close the bottle while retaining the headspace.
- (i) Collect one 250-ml plastic bottle with no preservative and no headspace for anion analysis ( $\text{Cl}^-$ ,  $\text{NO}_2^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{PO}_4^{3-}$ ).

All water samples planned for laboratory analysis will be labeled, packed on ice and shipped to the appropriate laboratory for overnight delivery. Chemical analyses and required glassware are summarized in Table 3.

<b>Table 3</b> <b>Sample Collection and Analysis Details</b> <b>Building 1419 Site, Naval Surface Warfare Center</b> <b>Solutions-IES Project No. 3030.04A2.ESTC</b>			
<b>Number of Sample Bottles</b>	<b>Containers</b>	<b>Target Constituent/Method</b>	<b>Field/Laboratory</b>
1	250-mL plastic bottle	Conductivity, temperature, pH, oxidation-reduction potential/Field Meters	Field
0	From tubing	Dissolved oxygen/Chemetrics	Field
2	40-mL VOA vial (no preservative)	Methane/Method 8015M	Environmental Science Corp.
1	A minimum of 100 ml (no preservative) coupled 0.45µm and 0.20 µm filtering setup	Perchlorate/Method 314	Columbia Analytical Services
1	250-mL plastic bottle (preservative)	Chloride, nitrate, nitrite, sulfate, phosphate/Method 9056	NCSU CCEE Lab
1	250-mL amber bottle preserved with HCL)	Total organic carbon/Method 9060	Environmental Science Corp.

#### 4.0 QA/QC Samples

Selected QA/QC samples will be prepared. New disposable polyethylene tubing will be used to purge and sample each well. Therefore, no rinse blank will be collected. One duplicate groundwater sample will be collected from one well. One duplicate sample from one well will be subjected to analysis for perchlorate and TOC, only. All sample containers will be new and will be supplied directly from the laboratory. They will be labeled immediately upon filling, stored on ice and submitted to the laboratory under chain-of-custody control.

#### 5.0 Investigation-Derived Waste (IDW)

Minimization of IDW is an important aspect of the sampling and sample collection activities. All disposal of IDW will be coordinated with the IHDIIV personnel. Personnel will segregate all clean wastes from impacted materials. Clean waste would include plastic sheeting, boxes, and packaging materials. These materials will be contained in plastic bags and disposed of as directed by IHDIIV personnel. Soiled or impacted disposable personal protective equipment such as Tyveks<sup>®</sup> and gloves will be cleaned to the extent possible, double bagged and also disposed as directed in coordination with IHDIIV.

Purge water and soil cores will be handled as directed by IHDIV personnel. IHDIV personnel are aware of the amount and kind of waste that may be generated and are prepared to dispose of it accordingly.

## **6.0 Results Evaluation and Reporting**

The results of the site characterization activities described in this SSWP will be incorporated in the Technical Demonstration Plan. If requested, a table summarizing the data will be made available to IHDIV.

## **7.0 Project Schedule**

Implementation of the SSWP includes the following activities:

1. Coordinate access, digging permits or boring permits.
2. Mobilization, boring advancement, groundwater sample collection, permeability tests and demobilization.
3. Conversion of selected temporary wells to permanent wells. Abandonment of other temporary wells not needed for the technology demonstration.

Laboratory analyses will be requested using a standard turnaround of two weeks from sample submittal except for perchlorate analyses which may be requested using a one week turnaround.

## **FIGURES**

**APPENDIX A**  
**(UPDATED HEALTH AND SAFETY PLAN PROVIDED IN APPENDIX V**  
**OF TECHNOLOGY DEMONSTRATION PLAN)**

**SITE-SPECIFIC HEALTH AND SAFETY PLAN: BUILDING 1419, IHDIV**

**ESTCP PROJECT NO. ER-0428  
SOLUTIONS-IES PROJECT NO. 3030.04A2.ESTC**

**A. General Information**

**Site Name:** Building 1419, Indian Head Division, Naval Surface Warfare Center (IHDIV)

**Site Contact:** Mr. Randall Cramer

**Contact Address:** Indian Head Division, Naval Surface Warfare Center  
101 Strauss Avenue, Indian Head, Maryland, 20640

**Contract Office Phone No.:** (301) 744-2578

**Site Location:** The site is on the southeast side of IHDIV near Indian Head, MD.

**Date(s) of Reconnaissance/Assessment:** SSWP activities are planned for November 2005.

**Nature of Visit** (check all that apply):

On-Site Reconnaissance	_____
<b>Boring Advancement</b>	<u>  X  </u>
<b>Temporary Well Installation</b>	<u>  X  </u>
Groundwater Sampling	<u>  X  </u>
Remediation Overview	_____

**Site Investigation Team:** All site personnel have read the site-specific Health and Safety Plan and are familiar with its provisions.

<u>Personnel</u>	<u>Responsibilities</u>	<u>Signature</u>
_____	<b>Well Installation, Groundwater Sampling, and Permeability Tests</b>	_____
_____	<b>Groundwater Sampling, and Permeability Tests</b>	_____

**Site Health and Safety Officer:** \_\_\_\_\_

**Plan Prepared by:** Sheri L. Knox, P.E. \_\_\_\_\_

**Plan Reviewed by:** Walt Beckwith, P.G. \_\_\_\_\_

**APPENDIX III**  
**BORING LOGS**

# Log of Soil Boring SGP-1S

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Water Level From TOC: 7.89 feet

Boring Date: 11/15/05

State: Maryland

Water Level BGS: 4.74 feet

Installed By: Vironex

Logged By: DH

Checked By: DH

Depth of Well: 12.71 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen ● ppm ● 250 500 750	OVA Field Screen ■ ppm ■ 250 500 750	Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery				
0	m	Ground Surface							
1		Boring Not logged. Refer to adjacent boring SGP-1D							
2									
3	1								
4									
5									
6									
7	2								
8									
9									
10	3								
11									
12									
13	4								
14									
15									
16	5								
17									
18									
19									
20	6								

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-1D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Water Level From TOC: 5.38 feet

Boring Date: 11/15/05

State: Maryland

Water Level BGS: 4.52 feet

Installed By: Vironex

Logged By: DH

Checked By: DH

Depth of Well: 16.01 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						•	•	•		
						■	■	■		
						250	500	750		
						250	500	750		
0		Ground Surface								
0	<b>SM</b>	Brown, silty fine sand with organic matter								
1	<b>SM</b>	Tan, silty fine sand		MC	100					
2	<b>SM</b>	Tan and grey, silty fine sand								
3	<b>SM</b>	Grey, silty fine sand								
4	<b>SM</b>	Wet, tan and grey, silty fine sand		MC	100					
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15	<b>GM</b>	Tan, silty fine sand, grading to a medium sand at the bottom 4 inches (quartz grained >1 inch)		MC	100					
16	<b>CL</b>	Light grey, dense plastic clay								
17		Boring terminated at 16 feet bgs								
18										
19										
20										

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-2S

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Boring Date: 11/15/05

State: Maryland

Installed By: Vironex

Logged By: DH

Checked By: DH

Water Level From TOC: 8.49 feet

Water Level BGS: 7.14 feet

Depth of Well: 13.56 feet bgs

SUBSURFACE PROFILE			SAMPLE						Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	PID Field Screen ● ppm ● 250 500 750				
						OVA Field Screen ■ ppm ■ 250 500 750				
0	0	Ground Surface								
		Boring not logged. Refer to adjacent boring SGP-2D								
1										
2										
3	1									
4										
5										
6										
7	2									
8										
9										
10	3									
11										
12										
13	4									
14										
15										
16	5									
17										
18										
19										
20	6									

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-2D

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Sampler Type: **Macro-Core**

County: **Charles**

Boring Date: **11/15/05**

State:

Water Level From TOC: **7.64 feet**

Installed By:

Water Level BGS: **7.16 feet**

Logged By: **DH**

Checked By: **DH**

Depth of Well:

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	• ppm •	• ppm •	• ppm •		
						250	500	750		
						■ ppm ■	■ ppm ■	■ ppm ■		
						250	500	750		
0		Ground Surface								
1	<b>SW</b>	Brown, silty fine sand with organic material								
2	<b>SW</b>	Brown, silty fine sand with gravel fill material		MC	100					
3	<b>SW</b>	Tan, silty fine sand								
4	<b>SC</b>	Wet, tan, clayey fine- sand								
5	<b>SW</b>	Tan, silty fine sand		MC	100					
6	<b>SW</b>	Tan, silty fine sand								
7	<b>SW</b>	Tan, silty fine sand								
8	<b>SW</b>	Tan, silty fine sand								
9	<b>SW</b>	Tan, silty fine sand								
10	<b>SW</b>	Tan, silty fine sand		MC	100					
11	<b>SW</b>	Tan, silty fine sand								
12	<b>SW</b>	Tan, silty fine sand with <1/2 inch dia. gravel								
13	<b>CL</b>	Tan, plastic and dense clay								
14	<b>SW</b>	Tan, silty fine sand.		MC	100					
15	<b>SW</b>	Tan, silty fine sand.								
16	<b>SW</b>	Tan, silty fine sand with slightly more clay.								
17	<b>SW</b>	Tan, silty fine sand with slightly more clay.								
18	<b>SW</b>	Tan, silty fine sand with slightly more clay.		MC	100					
19	<b>GC</b>	Tan, clayey fine- sand								
20	<b>GC</b>	Tan, clayey fine- sand								

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-2D

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Initial Water Level: **6 feet**

Sampler Type: **Macro-Core**

County: **Charles**

Stabalized Water Level: **N/A**

Boring Date: **11/15/05**

Cave In Depth: **N/A**

Logged By: **DH**

Checked By: **DH**

Total Depth of Boring: **16.62 feet**

SUBSURFACE PROFILE			SAMPLE						Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	PID Field Screen ● ppm ● 250 500 750				
						OVA Field Screen ■ ppm ■ 250 500 750				
<div style="display: flex; flex-direction: column; align-items: center;"> <div style="margin-bottom: 10px;">21</div> <div style="margin-bottom: 10px;">22</div> <div style="margin-bottom: 10px;">23</div> <div style="margin-bottom: 10px;">24</div> <div style="margin-bottom: 10px;">25</div> <div style="margin-bottom: 10px;">26</div> <div style="margin-bottom: 10px;">27</div> <div style="margin-bottom: 10px;">28</div> <div style="margin-bottom: 10px;">29</div> <div style="margin-bottom: 10px;">30</div> <div style="margin-bottom: 10px;">31</div> <div style="margin-bottom: 10px;">32</div> <div style="margin-bottom: 10px;">33</div> <div style="margin-bottom: 10px;">34</div> <div style="margin-bottom: 10px;">35</div> <div style="margin-bottom: 10px;">36</div> <div style="margin-bottom: 10px;">37</div> <div style="margin-bottom: 10px;">38</div> <div style="margin-bottom: 10px;">39</div> <div style="margin-bottom: 10px;">40</div> </div>	<div style="background-color: #cccccc; width: 100%; height: 100%; border: 1px solid black;"></div>	<p><b>CL</b> Bluish, grey sandy clay</p>	<div style="border-left: 3px solid black; border-right: 3px solid black; width: 100%; height: 100%;"></div>	<p>MC</p>	<p>100</p>					
<p>Boring terminated at 24 feet bgs</p>										

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-3S

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Sampler Type: **Macro-Core**

County: **Charles**

Water Level From TOC: **8.46 feet**

Boring Date: **11/15/05**

State: **Maryland**

Water Level BGS: **5.53 feet**

Installed By: **Vironex**

Logged By: **DH**

Checked By: **DH**

Depth of Well: **12.04 feet bgs**

SUBSURFACE PROFILE			SAMPLE			PID Field Screen ● ppm ● 250 500 750	OVA Field Screen ■ ppm ■ 250 500 750	Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery				
0	m	Ground Surface							
1		Boring not logged. Refer to adjacent boring SGP-3D							
2									
3	1								
4									
5									
6	2								
7									
8									
9									
10	3								
11									
12									
13	4								
14									
15									
16	5								
17									
18									
19									
20	6								

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-3D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Boring Date: 11/15/05

State: Maryland

Installed By: Vironex

Logged By: DH

Checked By: DH

Water Level From TOC: 7.55 feet

Water Level BGS: 5.82 feet

Depth of Well: 15.52 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						•	•	•		
						250	500	750		
						■	■	■		
						250	500	750		
0		Ground Surface								
0	<b>SM</b>	Brown silty fine sand with organic matter								
1	<b>SM</b>	Tan, brown, orange, silty fine sand (dense and dry)		MC	100					
2	<b>SC</b>	Wet, tan, grey, clayey fine sand.		MC	100					
3	<b>SC</b>	Grey, green, clayey fine sand								
4	<b>SM</b>	Wet, tan, orange, silty fine sand (no gravel at bottom, and white in color from 14.5 to 14.75 feet bgs)		MC	100					
5	<b>CL</b>	Light grey, plastic and dense clay		MC	100					
6		Boring terminated at 16 feet bgs								

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-4S

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Sampler Type: **Macro-Core**

County: **Charles**

Water Level From TOC: **8.67 feet**

Boring Date: **11/15/05**

State: **Maryland**

Water Level BGS: **5.43 feet**

Installed By: **Vironex**

Logged By: **DH**

Checked By: **DH**

Depth of Well: **11.31 feet bgs**

SUBSURFACE PROFILE			SAMPLE						Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	PID Field Screen • ppm • 250 500 750				
						OVA Field Screen ■ ppm ■ 250 500 750				
0	0	Ground Surface								
1		Boring not logged. Refer to adjacent boring SGP-4D								
2										
3	1									
4										
5										
6										
7	2									
8										
9										
10	3									
11										
12										
13	4									
14										
15										
16	5									
17										
18										
19										
20	6									

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-4D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Water Level From TOC: 7.08 feet

Boring Date: 11/15/05

State: Maryland

Water Level BGS: 5.86 feet

Installed By: Vironex

Logged By: DH

Checked By: DH

Depth of Well: 15.83 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen • ppm • 250 500 750	OVA Field Screen ■ ppm ■ 250 500 750	Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery				
0		Ground Surface							
0	SM	Brown silty fine sand with organic matter							
1	SM	Tan, orange, silty fine sand with approx. 3% asphalt (fill material)		MC	100				
2	SM	Tan, orange, silty fine sand							
3									
4	SM	Tan, orange, silty fine sand							
5									
6	SM	Tan, silty fine sand		MC	100				
7									
8									
9									
10				MC	100				
11									
12									
13		No recovery			0				
14									
15	GM	Orange, silty coarse sand with gravel (< 1/4 inch)		MC	37				
16	CL	Light grey, plastic and dense clay							
17		Boring terminated at 16 feet bgs							
18									
19									
20									

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-5S

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Sampler Type: **Macro-Core**

County: **Charles**

Water Level From TOC: **14.32 feet**

Boring Date: **11/15/05**

State: **Maryland**

Water Level BGS: **10.7 feet**

Installed By: **Vironex**

Logged By: **DH**

Checked By: **DH**

Depth of Well: **11.38 feet bgs**

SUBSURFACE PROFILE			SAMPLE						Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	PID Field Screen ● ppm ● 250 500 750				
						OVA Field Screen ■ ppm ■ 250 500 750				
0	0	Ground Surface								
1		Boring not logged. Refer to adjacent boring SGP-5D								
2										
3	1									
4										
5										
6										
7	2									
8										
9										
10	3									
11										
12										
13	4									
14										
15										
16	5									
17										
18										
19										
20	6									

**Solutions-IES, Inc.**  
**1101 Nowell Road**  
**Raleigh, NC 27607**  
**(919) 873-1060**

# Log of Soil Boring SGP-5D

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Sampler Type: **Macro-Core**

County: **Charles**

Water Level From TOC: **10.98 feet**

Boring Date: **11/15/05**

State: **Maryland**

Water Level BGS: **8.41 feet**

Installed By: **Vironex**

Logged By: **DH**

Checked By: **DH**

Depth of Well: **14.43 feet bgs**

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm • 250 500 750 •				
						OVA Field Screen ■ ppm ■ 250 500 750				
0		Ground Surface								
1	<b>SM</b>	Tan, brown, silty fine sand with approx. 3% asphalt (dense)								
2	<b>SM</b>	Tan, silty fine sand (dry and dense)		MC	100					
3										
4										
5										
6				MC	100					
7										
8	<b>SM</b>	Tan, silty fine sand (wet)								
9										
10										
11	<b>SM / SC</b>	Tan, silty fine sand transitioning to tan, clayey fine sand (wet)								
12										
13	<b>GW</b>	White, medium sand with < 1/2 inch dia. quartz gravel in bottom 3 inches		MC	50					
14										
15		No recovery			0					
16										
17		Boring terminated at 14.43 feet bgs								
18										
19										
20										

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-6S

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Boring Date: 11/15/05

State: Maryland

Installed By: Vironex

Logged By: DH

Checked By: DH

Water Level From TOC: 8.11 feet

Water Level BGS: 5.85 feet

Depth of Well: 13.72 feet bgs

SUBSURFACE PROFILE			SAMPLE						Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	PID Field Screen • ppm • 250 500 750				
						OVA Field Screen ■ ppm ■ 250 500 750				
0	0	Ground Surface								
1		Boring not logged. Refer to adjacent boring SGP-6D								
2										
3	1									
4										
5										
6	2									
7										
8										
9										
10	3									
11										
12										
13	4									
14										
15										
16	5									
17										
18										
19										
20	6									

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-6D

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Sampler Type: **Macro-Core**

County: **Charles**

Water Level From TOC: **7.04 feet**

Boring Date: **11/15/05**

State: **Maryland**

Water Level BGS: **5.99 feet**

Installed By: **Vironex**

Logged By: **DH**

Checked By: **DH**

Depth of Well: **16.04 feet bgs**

SUBSURFACE PROFILE			SAMPLE			PID Field Screen • ppm • 250 500 750  OVA Field Screen ■ ppm ■ 250 500 750			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery					
0		Ground Surface								
0 to 1	<b>SM</b>	Brown, silty fine sand with organic material and gravel		MC	100					
1 to 3	<b>SW</b>	Red, fine sand with gravel								
3 to 4	<b>SM</b>	Tan, orange, silty fine sand (dry)								
4 to 7	<b>SM</b>	Tan, silty fine sand (wet). Low strength zone from 14 to 16 feet. 50% recovery from 12 to 16 feet due to 1 inch sized gravel blocking Geoprobe sleeve		MC	100				▼	
7 to 10										
10 to 13				MC	100					
13 to 14										
14 to 15	<b>GM</b>	Silty gravel, inferred.		MC	50					
15 to 16										
16 to 17	<b>CL</b>	Light tan, plastic and dense clay		MC	100					
17 to 18		Boring terminated at 17 feet bgs								
18 to 19										
19 to 20										

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP7-S

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Water Level From TOC: 12.07 feet

Boring Date: 11/15/05

State: Maryland

Water Level BGS: 8.79 feet

Installed By: Vironex

Logged By: DH

Checked By: DH

Depth of Well: 11.65 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						OVA Field Screen				
						ppm				
0	0	Ground Surface				●	●	●		
1		Boring not logged. Refer to adjacent boring SGP-7D				■	■	■		
2										
3	1									
4										
5										
6										
7	2									
8										
9										
10	3									
11										
12										
13	4									
14										
15										
16	5									
17										
18										
19										
20	6									

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-7D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Boring Date: 11/15/05

State: Maryland

Installed By: Vironex

Logged By: DH

Checked By: DH

Water Level From TOC: 11.25 feet

Water Level BGS: 8.79 feet

Depth of Well: 14.67 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	• ppm •	• ppm •	• ppm •		
						250	500	750		
						■ ppm ■	■ ppm ■	■ ppm ■		
						250	500	750		
0		Ground Surface								
0	<b>SM</b>	Brown, orange, silty fine sand (fill material)								
1	<b>PT</b>	Black coal fines (fill material)		MC	100					
2	<b>SM</b>	Tan, orange, silty fine sand (dry)								
3										
4										
5										
6	<b>SM</b>	Tan, orange, silty fine sand (wet)		MC	100					
7										
8										
9	<b>SM</b>	Tan, silty fine sand (dry)								
10										
11										
12										
13										
14										
15	<b>GM</b>	Tan, silty fine sand mixed with gravel <1.5 inches dia.			0					
16	<b>CL</b>	Light tan, plastic and dense clay								
17		No recovery.								
18		Boring terminated at 16 feet bgs.								
19										
20										

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-8S

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Sampler Type: **Macro-Core**

County: **Charles**

Water Level From TOC: **7.33 feet**

Boring Date: **11/15/05**

State: **Maryland**

Water Level BGS: **4.27 feet**

Installed By: **Vironex**

Logged By: **DH**

Checked By: **DH**

Depth of Well: **11.91 feet bgs**

SUBSURFACE PROFILE			SAMPLE			PID Field Screen ● ppm ● 250 500 750	OVA Field Screen ■ ppm ■ 250 500 750	Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery				
0	m	Ground Surface							
1		Boring not logged. Refer to adjacent boring SGP-8D							
2									
3	1								
4									
5									
6	2								
7									
8									
9									
10	3								
11									
12									
13	4								
14									
15									
16	5								
17									
18									
19									
20	6								
21									
22									
23	7								
24									
25									

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-8D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Boring Date: 11/15/05

State: Maryland

Installed By: Vironex

Logged By: DH

Checked By: DH

Water Level From TOC: 19.48 feet

Water Level BGS: 17.21 feet

Depth of Well: 22.81 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						OVA Field Screen				
						ppm				
0		Ground Surface								
1	SM	Brown, silty fine sand with organic material								
2	SM	Brown, silty fine sand with gravel fill material		MC	100					
3										
4	SM	Tan, silty fine sand								
5	SC	Tan, clayey fine sand (wet)		MC	100					
6										
7	SM	Tan, silty fine sand								
8										
9	SM	Tan, silty fine sand								
10				MC	100					
11										
12	GM	Tan, silty fine sand with <1/2 inch dia. gravel								
13										
14	CL	Tan, plastic and dense clay		MC	100					
15										
16	SM	Tan, silty fine sand								
17	SM	Tan, silty fine sand with slightly more clay								
18				MC	100					
19	SC	Tan, clayey fine sand								
20										
21	CL	Bluish grey sandy clay								
22				MC	100					
23										
24		Boring terminated at 24 feet bgs.								
25										

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

**APPENDIX IV**

**BORING ADVANCEMENT AND GROUNDWATER SAMPLING**

**SAMPLE COLLECTION DETAILS BUILDING 1419  
INDIAN HEAD  
ESTCP PROJECT NO. CU-0248  
SOLUTIONS-IES PROJECT NO. 3030.04A2.ESTC**

**Soil Sampling and Monitoring Well Installation** – Solutions-IES personnel or a subcontracted Geoprobe® drilling contractor will provide soil collection services. During the pre-demonstration work, a mechanical pile driver will be used to install borings in the mudflats. One of the objectives of this work is to gain a knowledge of the hydrogeology, and geochemistry in the mudflats at Indian Head. The mechanical pile driver will be used to drive a Geoprobe® Large Bore Sampler or split-spoon sampler into the mudflats located southeast of the source area. The borings will likely be advanced to a depth of approximately 11 ft bgs approximately 2 feet above the clay layer that has been previously identified at the site. Soil samples will be collected from the upper and lower portion of the boring. If possible, a number of the borings will be converted to a temporary monitoring well by inserting a 1-inch diameter PVC slotted well screen and casing into a shorter outer casing that will be used to keep the boring open while the well screen is inserted into the boring. A bentonite seal will be placed within the borehole around the well screen. A 2-foot well screen will be used in the well construction. During the demonstration set-up, a number of the temporary wells may be converted to permanent monitoring wells for use in the technical demonstration. Selected temporary wells will be abandoned with a bentonite-grout mix by a licensed well contractor.

**Groundwater Sampling**- Groundwater samples will be collected via a temporary monitoring well or a Geoprobe®.Screen Point Sampler. If a groundwater sample is collected from a temporary monitoring well, plastic tubing will be placed in the temporary well and pumped with a peristaltic pump at a low flow rate collecting groundwater sample while minimizing disturbance to the dissolved oxygen concentration. Hand bailers will be available, if necessary.

If a groundwater sample is collected via a Geoprobe®.Screen Point Sampler, the sampler will be driven to the appropriate depth. The sleeve of the sampler will be retracted to expose the screen, and the groundwater sample will be collected using a peristaltic pump as described above.

During the pre-demonstration work, and performance monitoring, groundwater samples will be analyzed for those parameters outlined in Section 3.5.3 and Section 3.6.7 of the Technical Demonstration Plan.

**Specific Capacity Tests** - Specific capacity tests will be performed on several new shallow and deep wells. The specific capacity test, as described by Wilson *et al.* (1997), will be performed by inserting a ¼

inch polyethylene tube to a known depth beneath the water surface. The depth of the intake tube is determined by attaching a water level gauge to the side of the tube. When the exact known depth is reached below the static water table, a peristaltic pump will be switched-on at full flow. When the drawdown is stabilized, as witnessed by the occurrence of bubbles in the tubing, a graduated cylinder will be filled. The time to fill the cylinder, volume of the cylinder, and depth of the intake is entered into a spreadsheet formula to estimate the hydraulic conductivity. A minimum of three tests will be performed in at each location so that an average can be determined.

**APPENDIX V**

**UPDATED SITE-SPECIFIC HEALTH AND SAFETY PLAN**

**SITE-SPECIFIC HEALTH AND SAFETY PLAN: BUILDING 1419, IHDIV  
ESTCP PROJECT NO. ER-0428  
SOLUTIONS-IES PROJECT NO. 3030.04A2.ESTC**

**A. General Information**

**Site Name:** Building 1419, Indian Head Division, Naval Surface Warfare Center (IHDIV)

**Site Contact:** Mr. Randall Cramer

**Contact Address:** Indian Head Division, Naval Surface Warfare Center  
101 Strauss Avenue, Indian Head, Maryland, 20640

**Contract Office Phone #** (301) 744-2578

**Site Location:** The site is on the southeast side of IHDIV near Indian Head, MD.

**Date(s) of Reconnaissance/Assessment:** SSWP activities are planned for "DATE"..

**Nature of Visit** (check all that apply):

On-Site Reconnaissance	_____
<b>Boring Advancement</b>	<b>X</b>
<b>Monitoring Well Installation</b>	<b>X</b>
<b>Groundwater Sampling</b>	<b>X</b>
Remediation Overview	_____

**Site Investigation Team:** All site personnel have read the site-specific Health and Safety Plan and are familiar with its provisions.

<u>Personnel</u>	<u>Responsibilities</u>	<u>Signature</u>
_____	Well Installation, Groundwater Sampling, and Permeability Tests	_____
_____	Groundwater Sampling, and Permeability Tests	_____

**Site Health and Safety Officer:** \_\_\_\_\_

**Plan Prepared by:** Sheri L. Knox, P.E. \_\_\_\_\_

**Plan Reviewed by:** Walt Beckwith, P.G. \_\_\_\_\_

## **B. Site Characterization**

**Site Description:** The Building 1419 Site is located approximately 30 miles south of Washington, DC. Building 1419 is also referred to as the Hog-out Building. The study area includes approximately 2 acres of grassy area containing a drum storage building, a concrete block with a manhole cover, and numerous groundwater monitoring, injection, and extraction wells. The area is bordered to the southeast by Mattawoman Creek, a large tributary to the Potomac River.

**History of the Site:** Building 1419 is used to clean out or “hog out” solid propellant containing ammonium perchlorate from various devices, including rockets and ejection seat motors, that have exceeded their useful life span. The hog-out process and former waste handling methods have impacted the groundwater near Building 1419.

**Unusual Conditions or Features on Site (ponds, chemical lines, terrain, etc.)** The land surface in the immediate site vicinity of the perchlorate plume appears to be relatively flat and open. The south edge of the site is bordered by a wooded area just prior to the shore of Mattawoman Creek, which is a tributary to the Potomac River. Small saplings or low lying branches may require clearing in the wooded area. Mudflats lie to the southeast of the shore. Slippery conditions as well as standing water may exist in the mudflats.

**Prevailing Weather Conditions:** Local forecasts should be reviewed prior to mobilization to help identify the weather conditions prior to site work.

## **C. Work Plan Instruction**

### **Work Schedule / Visit Objectives:**

The site-specific objective is to better define the perchlorate contaminant plume, obtain additional information concerning the hydrogeology, and obtain updated monitoring data which will aid Solutions-IES in locating permanent monitoring wells associated with the technology demonstration. Field work may include any of the following: collecting groundwater samples using a peristaltic pump or bailer and/or soil samples using a split spoon sampler or MacroCore<sup>®</sup> sampler, and installing permanent/temporary monitoring wells using standard well drilling techniques, direct push technology or pile driver, installing *insitu* columns, collecting groundwater samples from new and existing monitoring wells, and performing permeability tests in selected wells. The work will be performed in the spring of 2006.

Groundwater will be recovered from wells for sample analysis. Investigative derived waste will be containerized in drums and disposed of in coordination with IHDIV. See Section 3.6.4 of the Technical Demonstration Plan for details concerning investigative derived waste. IHDIV personnel are aware of the amount and kind of waste that may be generated. IHDIV will dispose of all IDW.

**Map:** Maps are attached to the Site-Specific Work Plan (Attached Figures).

**D. Site Waste Characterization:** The primary contaminants of concern are

Waste Type(s):

  X   Liquid        X   Solid      \_\_\_\_\_ Sludge      \_\_\_\_\_ Gas

**Characteristics:** Perchlorate is the only contaminant identified in groundwater in the vicinity of Building 1419. It is a highly soluble, inorganic anion that results from the disassociation of the ammonium perchlorate. It possesses none of the characteristics listed below.

\_\_\_\_\_ Corrosive      \_\_\_\_\_ Ignitable      \_\_\_\_\_ Radioactive      \_\_\_\_\_ Volatile

\_\_\_\_\_ Toxic      \_\_\_\_\_ Reactive      \_\_\_\_\_ Other

**Personal Protection Equipment (PPE):**

The level of protection at the site is Level D PPE. Level D PPE will consist of standard work clothes (including tyvek overalls, as needed), steel-toed work boots, safety glasses, and nitrile gloves. A hard hat and hearing protection must be worn during drilling or Geoprobe activities. To avoid overexposure to the weather, appropriate winter gear will be worn when necessary.

**Decontamination Procedures**

X      Level D      If Level D personal protection contacts contaminated soil or groundwater, boot soles and safety glasses will be washed and rinsed, nitrile gloves will be removed. When necessary, standard work clothes will be removed and replaced with dry items.

**Emergency Precautions:** The greatest hazard is anticipated to be skin contact with contaminated soil or groundwater from contaminants that may be present in the groundwater.

**Possible Exposure Route/First Aid:** Perchlorate is the only contaminant of concern known to be in soil and groundwater at this site. However, because it is an industrial site, there is some potential that other undocumented contaminants are present, as well. The following information summarizes the first aid that will be implemented as a result of minor exposure via the listed exposure routes. The exposure method identified is based on the possibility of encountering unknown contaminants in the vicinity of Building 1419 since it is located in industrialized portion of the Indian Head Site.

Exposure Route	Exposure Method	First Aid
Eyes	Yes, Splash	Flush with clean water for at least 15 minutes.
Skin	Yes, Splash, Contact with Soil	Wash with copious amounts of water.
Inhalation	Yes, Possibility of unknown volatiles present in the Groundwater.	Move upwind from the area of concern.
Ingestion	Yes, Splash, Contact with Soil	Flush the mouth with copious amount of clean water

Note: With any exposure route, inform the site contact if prolonged or unusual symptoms occur.

#### **E. Hazard Evaluation**

Previous investigations showed that perchlorate has been handled in the vicinity of Building 1419 (Table within Attachment A of the Health & Safety Plan). Contaminants are expected to be dilute in groundwater. However, the area in the vicinity of Building 1419 is highly industrialized, so there is a possibility that other unknown contaminants are present at that location.

Other hazards include slips, trips and falls, hypothermia, and operation of vehicles on wet and muddy surfaces. To address these concerns, the “buddy system” will be employed in muddy areas, the work area will be kept in order, and rain gear will be available on-site. Depending on work area, sampling activities may occur from a floating vessel or platform. When working in these conditions the “buddy system” will be used, and a life preserver, life saving ring, and/or life pole may be necessary, and will be positioned in close proximity to the work area as conditions warrant.

In addition, biting insects and ticks may be present during site work, so insect repellent will be available if needed. Snakes may also be present in the vicinity of the work area. Care will be taken to avoid snakes and their habitats.

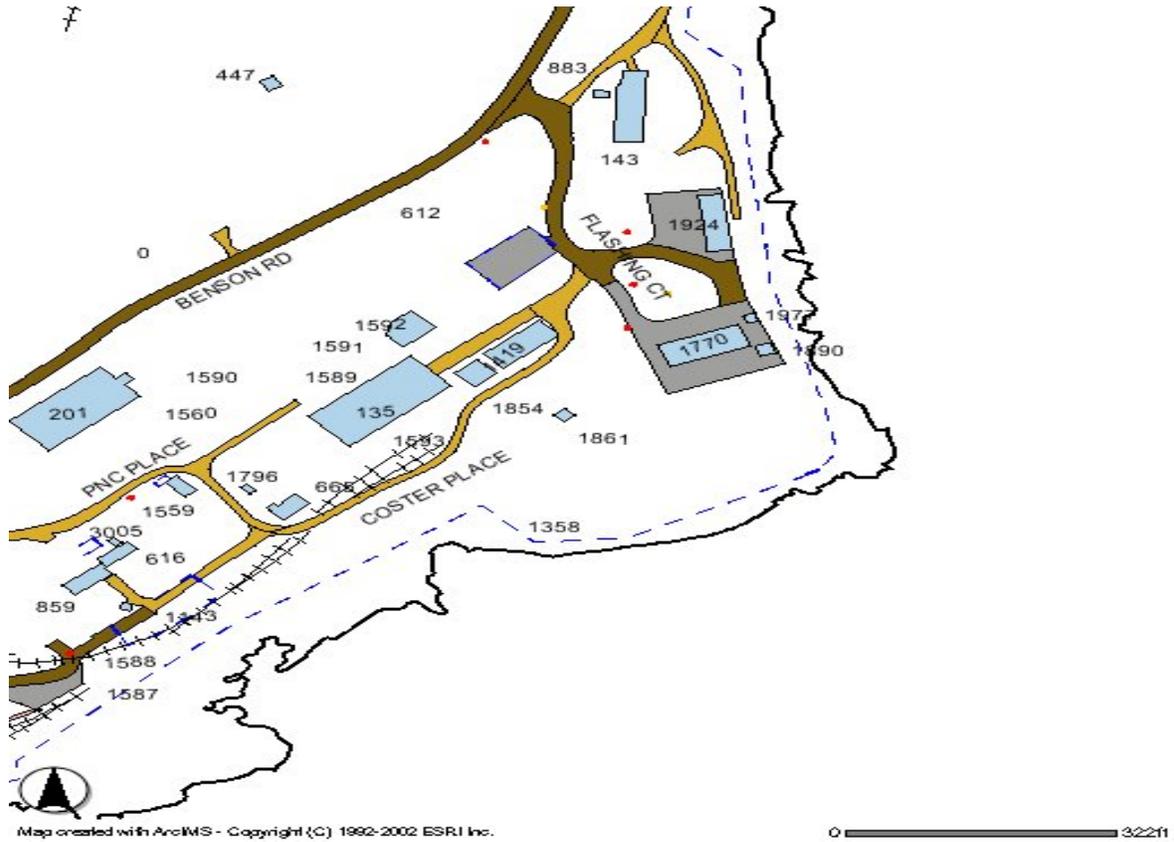
### **Air Monitoring:**

Although there is a minimal chance of airborne contamination, air monitoring will be conducted during boring advancement by Solutions-IES personnel. During soil sampling activities, a Photoionization Detector (PID) or Organic Vapor Analyzer (OVA) will be used to monitor the air. Periodic air monitoring will be performed in the worker's breathing zone and at point sources (at the top of casing, soil piles etc.). The breathing zone is defined as the area within a 2-foot sphere around the worker's head. Background readings will be taken before work starts. If concentrations greater than 5 ppm above background concentrations are detected in the worker's breathing zone, work will stop, and air monitoring will be performed 5, 15 and 30 minutes after stopping to evaluate the conditions. If air concentrations in the breathing zone do not return to background levels in 30 minutes, reevaluate the situation with the Health and Safety Coordinator. Engineering controls may be required to continue work.

Unless there is evidence of airborne contamination during boring advancement and soil sampling, air monitoring will not be required during the groundwater sampling event, but will be available on site during groundwater sampling

### **F. Emergency Contacts**

**Location of Nearest Phone:** Cell phones cannot be used on site. Phones are located at the fire box stations marked in red shown in following illustration. The closest firebox is located near Building 1770. At the fire box location, **dial 4333 to reach assistance.**



**Hospital Address:** Civista Medical Center, 701 Charles St, La Plata, MD

**Hospital Phone Number:** 301-609-4000

**Emergency Transportation Systems (Phone Numbers):** At Fire Box location **dial 4333** and the call will be routed to IHDIV Security.

**Cell Phones:** Dial IHDIV Security Direct: **(228) 688-3636**

Verify emergency response procedures required by the facility before starting work.

## Emergency Route to Hospital:

### Maneuvers

Distance Maps

[Reverse Route](#) | [Avoid Highways](#) | [Revise Route](#)

Total Est. Time: 24 minutes Total Est. Distance: 13.44 miles

**START** 1: Start out going EAST on INDIAN HEAD HWY/MD-210 N toward N PROSPECT AVE. 1.5 miles [Map](#)



2: Turn RIGHT onto MD-225/HAWTHORNE RD.

10.5 miles [Map](#)



3: Turn RIGHT onto CRAIN HWY/US-301 S/BLUE STAR MEMORIAL HWY.

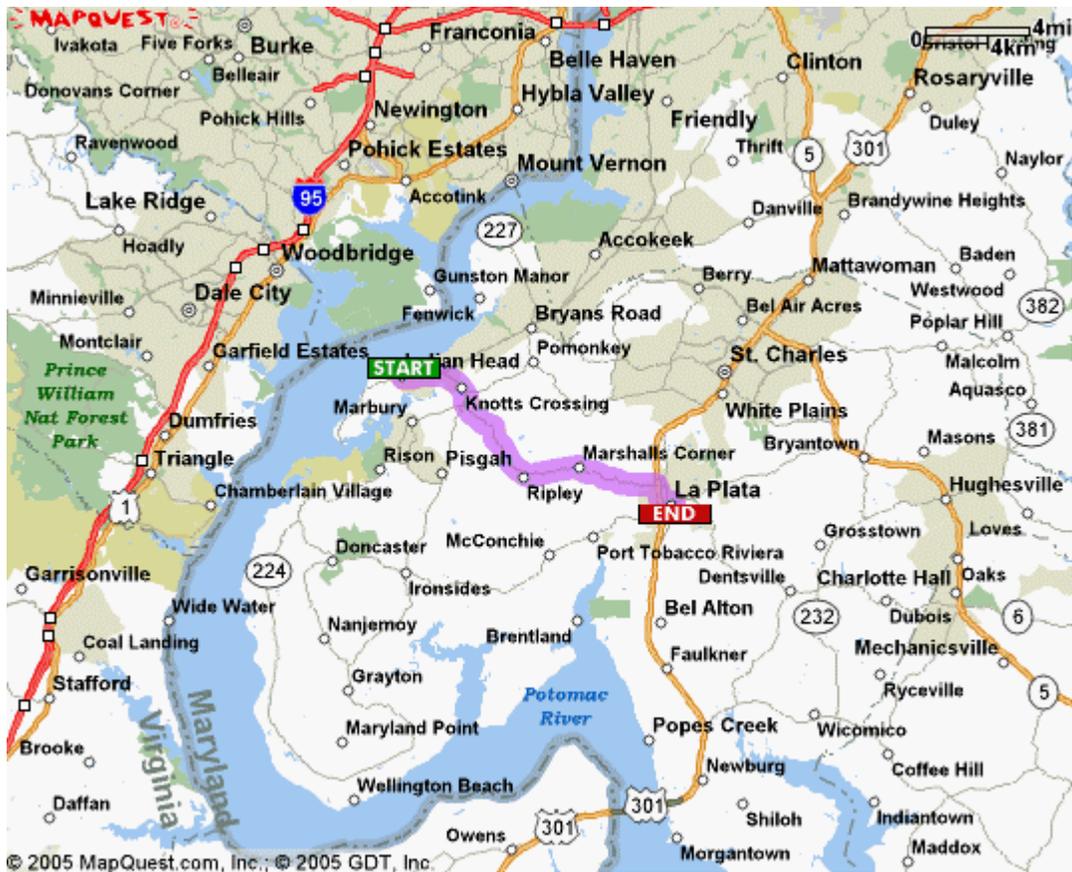
0.7 miles [Map](#)



4: Turn LEFT onto MD-6.

0.5 miles [Map](#)

**END** 5: End at **Civista Medical Ctr** 301-609-4000  
701 Charles St, La Plata, MD 20646 US



## **TABLE**

**Table-Attachment A**  
**Toxicological Characteristics of Chemical Constituent**

<b>CHEMICAL (CAS NO.)</b>	<b>OSHA PEL ACGIH TLV ACGIH STEL NIOSH IDLH</b>	<b>CHARACTERISTICS</b>	<b>ROUTE OF EXPOSURE</b>	<b>SYMPTOMS OF EXPOSURE</b>
Perchlorate	NA	Appearance and properties vary with specific compound	ING	Evidence of long term exposure may include interference with iodine uptake in the production of hormones in the human thyroid.

NA = Not available

ING = Ingestion

**APPENDIX VI**  
**QUALITY ASSURANCE PROJECT PLAN**

## **Quality Assurance Project Plan**

Evaluation of Potential for Monitored Natural Attenuation of Perchlorate in  
Groundwater

Technology Demonstration Plan  
for  
Building 1419 Site, Naval Surface Warfare Center,  
Indian Head, MD  
ESTCP Project No. ER-0428

Prepared by:

**Solutions IES, Inc.**  
1101 Nowell Road  
Raleigh, NC 27607

**February 2006**

# Table of Contents

<u>Section</u>	<u>Page</u>
<b>QUALITY ASSURANCE PROJECT PLAN.....</b>	<b>1</b>
<b>1.0 PURPOSE AND SCOPE .....</b>	<b>4</b>
<b>2.0 QUALITY ASSURANCE RESPONSIBILITIES .....</b>	<b>4</b>
<b>3.0 DATA QUALITY OBJECTIVES.....</b>	<b>5</b>
3.1 Objectives for Water-Level Measurements .....	5
3.2 Objectives for Field Measurements in Aqueous Media.....	5
3.3 Objectives for Ambient Air and Volatile Gas Monitoring.....	6
3.4 Objectives for Media Sample Analyses .....	6
<b>4.0 CALIBRATION, QC CHECKS, AND CORRECTIVE ACTION.....</b>	<b>6</b>
4.1 Instrument Calibration Procedures and Frequency .....	6
4.2 Field Quality Assurance and Quality Control Checks .....	6
4.3 Laboratory Quality Assurance and Quality Control Checks.....	7
4.4 Performance and System Audits .....	8
4.4.1 Field System Audit.....	8
4.4.2 Performance Evaluation Audits .....	8
4.5 Instrument Preventive Maintenance.....	9
4.5.1 Field Equipment.....	9
4.5.2 Laboratory Equipment .....	9
4.6 Assessment of Data Precision, Accuracy, and Completeness.....	9
4.6.1 Precision.....	9
4.6.2 Accuracy .....	9
4.6.3 Completeness .....	9
4.7 Data Reduction and Validation .....	10
4.7.1 Validation of Field Data Package .....	10
4.7.2 Validation of the Analytical Data Package .....	10
4.8 Corrective Action.....	11
4.8.1 Field Conditions.....	11
4.8.2 Laboratory Corrective Action .....	11
4.8.3 Reporting of Corrective Actions .....	12
<b>5.0 DEMONSTRATION PROCEDURES .....</b>	<b>12</b>
<b>6.0 EQUIPMENT DECONTAMINATION PROCEDURES .....</b>	<b>12</b>
<b>7.0 SAMPLE CUSTODY, HANDLING, AND SHIPMENT.....</b>	<b>13</b>
7.1 Field Records .....	13
7.2 Sample Labeling .....	13

7.3	Sample Container Custody.....	13
7.4	Sample Custody, Shipment, and Laboratory Receipt .....	13
<b>8.0</b>	<b>SAMPLE COLLECTION AND PRESERVATION.....</b>	<b>14</b>
8.1	Groundwater Samples .....	14
<b>9.0</b>	<b>HANDLING AND DISPOSAL OF INVESTIGATION-DERIVED WASTE .....</b>	<b>14</b>
<b>10.0</b>	<b>REFERENCES .....</b>	<b>15</b>

**Figure**

Figure 1      Organizational Chart

# QAPP Preparation

**Prepared by: Sheri L. Knox, P.E.**

2/15/06

---

Solutions-IES Senior Engineer

---

Date

**Reviewed and Approved by: M. Tony Lieberman**

2/15/06

---

Solutions-IES Project Manager and Co-Principal Investigator

---

Date

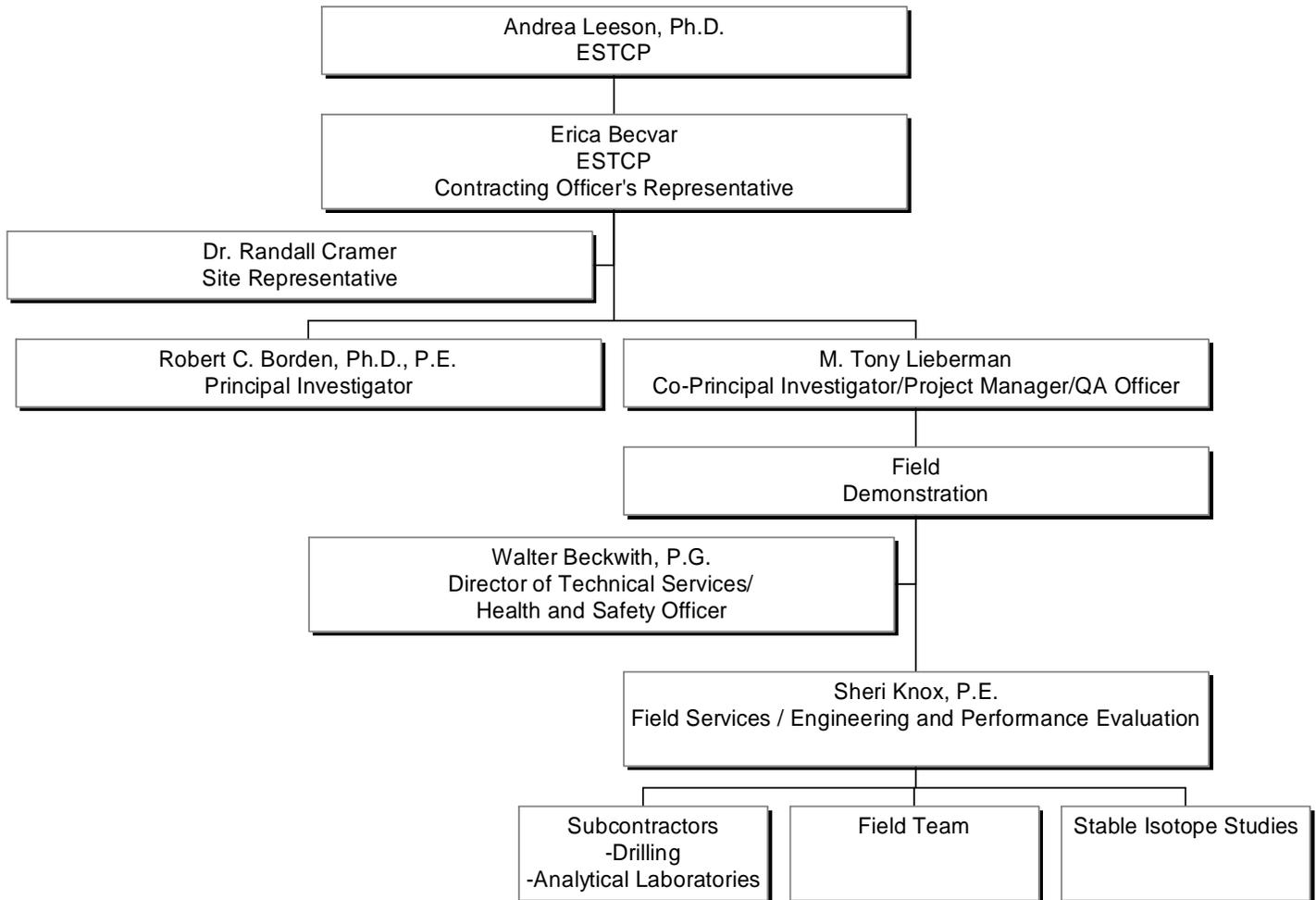
## 1.0 Purpose and Scope

The purpose of this Quality Assurance Project Plan (QAPP) is to provide guidelines that, when followed, will optimize the potential to obtain high quality field and laboratory data during the technology demonstration project. This QAPP describes methodologies for sampling and analysis of environmental media, proper record keeping protocols, data quality objectives, and procedures for data review. The overall objective of the QA program is to obtain and evaluate project-specific data that are accurate, precise, complete, adequately documented, and representative of actual field conditions to allow verification of the performance of monitored natural attenuation of perchlorate in groundwater.

## 2.0 Quality Assurance Responsibilities

Figure 1 provides the organizational chart for the technology demonstration project. The roles and responsibilities of relevant project personnel are summarized below.

**Figure 1**  
**Organizational Chart**



Principal Investigator:	Responsible for providing overall project direction, coordination with ESTCP, site representatives, and regulatory agencies, and final review and approval of reports.
Project Manager:	Responsible for project coordination, scheduling, budget management, technical oversight, and report preparation.
QA Officer:	Responsible for ongoing review, monitoring, auditing, and evaluation of the field and laboratory QA/QC program.
Field Services/Eng:	Responsible for implementation of field QA/QC procedures, oversight of field team, and coordination with subcontractors.

### **3.0 Data Quality Objectives**

The overall quality assurance objective is to ensure that data of known and acceptable quality are produced during the demonstration. Proper execution of each task will yield reliable data that are representative of media and conditions measured and are useful for meeting the intended project objectives. Data Quality Objectives (DQOs) are statements of the level of uncertainty that a decision maker is willing to accept in results derived from environmental data. These are developed for specific projects.

#### **3.1 Objectives for Water-Level Measurements**

Water-level measurement is a critical aspect of any groundwater evaluation. Water-level measurements are required during the course of the demonstration project to evaluate the groundwater flow direction. Water levels will be measured by sampling team personnel during all sampling events. Water levels will be measured with an electronic measuring device. Water-level measurements will be recorded to the nearest one-hundredth (0.01) of a foot, and the data will be referenced to surveyed top-of-casing data to determine groundwater elevations.

#### **3.2 Objectives for Field Measurements in Aqueous Media**

Field analyses will be performed on aqueous samples collected from monitoring wells in accordance with the Technology Demonstration Plan. Measurements of pH, temperature, and specific conductance will be collected to assure that an adequate purge has been achieved prior to actual sample collection and to evaluate changes in aquifer conditions during the course of the project. Quality assurance objectives for these parameters are presented as follows:

- pH – Measurements remain constant within 0.1 standard units.
- Specific Conductance - Measurements vary by no more than 10 percent.
- Temperature - Measurements remain constant for at least three successive readings.

Descriptions of the calibration and measuring procedures for these field instruments are provided in Section 4.1.

### **3.3 Objectives for Ambient Air and Volatile Gas Monitoring**

Field analyses of ambient air quality will be performed as part of the site-specific health and safety program. It should be noted that perchlorate is the only contaminant identified in groundwater at this site and perchlorate is not detected by headspace monitoring. Nonetheless, monitoring for volatile organic compounds (VOCs) in the headspace of soil samples may be performed on samples as a screening step during boring and well installation activities. Field measurements will be performed either with a Photoionization Detector (PID) or an Organic Vapor Analyzer (OVA) with a Flame Ionization Detector (FID). The calibration and measurement procedures for these instruments are described in Section 4.1.

As a general rule, the PID should not be used to monitor for low molecular weight hydrocarbon compounds whose structures contain only single bonds (methane, ethane, pentane, hexane, heptane, carbon tetrachloride, and hydrogen sulfide). The PID should be used to detect: aromatics such as benzene, toluene and styrene; aliphatic amines such as dimethylamine; and chlorinated unsaturated compounds such as vinyl chloride and trichloroethene.

The OVA uses a hydrogen FID as its detection principle. This detector allows the monitor to respond to a wide variety of organic compounds, but limits its sensitivity to around 10 ppm under ideal circumstances. The OVA's best response is to single -bonded hydrocarbons such as methane and dichloroethane.

### **3.4 Objectives for Media Sample Analyses**

The analytical level is appropriate for the following data uses that are applicable to this project:

- Site characterization;
- Engineering design;
- Monitoring during implementation.

The QA objectives for precision and accuracy established by contract laboratories are available upon request.

## **4.0 Calibration, QC Checks, and Corrective Action**

### **4.1 Instrument Calibration Procedures and Frequency**

Calibration of field equipment, such as pH meters, DO meters, ORP meters, specific conductance meters, PIDs and OVAs will be performed according to the procedures outlined in the equipment instruction manuals. Calibration of field equipment will be conducted each day the equipment is used in the field prior to use. The calibration procedures and calibration frequency employed by the contracted laboratories are described in their QA/QC Plans.

### **4.2 Field Quality Assurance and Quality Control Checks**

Solutions-IES will collect field quality control (QC) samples during implementation of field activities to assess the quality of field procedures, preservation reagents, and sample bottles and the reliability of sample shipping and storage procedures.

As part of the overall project QA program, field replicate samples, method confirmation samples, and equipment rinsate blank samples will be collected for selected constituents. These field QC samples will be collected at the same time as the field samples and in the same type of containers. The QC samples will be handled in an identical manner as the field samples and shipped to the laboratory for analysis of the same constituents by the same analytical procedures as the field samples.

Field QC samples will include one of more of the following:

- Field Replicates – Sample aliquots taken from the same sampling device (bailer, hand auger, etc.) and sent to the same analytical laboratory for identical analyses. Field Replicates will be prepared at a frequency of one per 20 samples per media-type sampled.
- Method Confirmation Samples –Approximately 10% of the total samples collected during performance monitoring for perchlorate analysis by Method 314 will be sent to a certified laboratory for confirmatory analysis of perchlorate by Method 330.
- Equipment Rinsate Blanks – Organic-free, deionized water prepared in the laboratory that is placed in contact with cleaned sampling devices. The water is collected in appropriately labeled and preserved containers and sent for analysis. These samples will verify that field sampling equipment was properly cleaned. Rinsate blanks will be prepared at a frequency of one per 20 samples per media type sampled.
- Field QC samples will be labeled accordingly:
  - Field Replicates – REP- (1,2,3...)
  - Equipment Rinsate Blanks – RB –(1,2,3...)

#### **4.3 Laboratory Quality Assurance and Quality Control Checks**

The contract laboratories will demonstrate the ability to produce acceptable results using the procedures recommended by the analytical method. The data will be evaluated by the laboratory based on the following criteria (as appropriate for organic and inorganic chemical analyses):

- Method performance is evaluated using the following QC checks:
  - Calibration curve linearity
  - Blank contamination
  - Initial and continuing calibration standards
  - Spike recoveries (matrix and surrogate)
  - Relative Percent Differences (RPDs) between matrix spikes and matrix spike duplicates, samples and laboratory duplicates
  - Recoveries of laboratory control samples and independent QC check samples
  
- Percent recovery of internal standards
- Percent recovery of surrogate compounds
- Adequacy of detection limits obtained
- Precision of replicate analyses

Specific QA/QC procedures are included in the laboratory's QA/QC Plan, which is available upon request.

#### **4.4 Performance and System Audits**

Performance audits monitor the accuracy and precision of the analytical systems through the submission and analysis of control samples. System audits assess how closely the QAPP is adhered to during all phases of field data collection, sample collection, sample shipping, sample analyses, and data reduction and reporting. Performance and system audits for sampling and analysis operations consist of on-site review of field and laboratory procedures and QA systems and on-site review of equipment for sampling, calibration, and measurement.

##### **4.4.1 Field System Audit**

Solutions-IES field team leader may evaluate the performance of field personnel and general field operations in progress. The auditor will compare the performance of the field team during field activities (such as water-level measurements and sample collection) with the procedures specified in the QAPP.

##### **4.4.2 Performance Evaluation Audits**

A performance evaluation (PE) audit evaluates a laboratory's ability to obtain an accurate and precise answer in the analysis of a known check sample by a specific analytical method. Following the analytical data validation, a PE audit of the laboratory may be requested and conducted by Solutions-IES. This audit may be conducted if it is determined that the QA data provided in the analytical data package is outside acceptance criteria control limits. These PE audits may include a review of all raw data developed by the laboratory and not reported (laboratory non-reportables) and the submission of blind spike check samples for the analysis of the parameters in question. These check samples may be submitted disguised as field samples, in which case the laboratory will not know the purpose of the samples, or the samples may be obvious (known) check samples (USEPA or NIST traceable).

PE audits also may be conducted by reviewing the laboratory's results from "round-robin" certification testing and/or USEPA CLP evaluation samples. An additional component of PE audits includes the review and evaluation of raw data generated from the analysis of PE samples and actual field samples that may be in question.

## **4.5 Instrument Preventive Maintenance**

### **4.5.1 Field Equipment**

Records of calibration and preventive maintenance performed while collecting samples will be documented in field notebook during sampling.

### **4.5.2 Laboratory Equipment**

Each contract laboratory will ensure that instruments are operating properly, and that rigorous maintenance and trouble-shooting procedures are followed. Specific preventative maintenance procedures followed by each contract laboratory is included in their respective QA/QC Plans.

## **4.6 Assessment of Data Precision, Accuracy, and Completeness**

Brief descriptions of protocols that will be used to assess the precision, accuracy and completeness of the analytical data are provided below. Detailed methods used to assess precision and accuracy of data by the analytical laboratories are provided in their QA/QC Plans.

### **4.6.1 Precision**

Precision is an estimate of the reproducibility of a method, and it may be estimated by several statistical tests, including the coefficient of variation and the relative percent difference (RPD) between replicate (or duplicate) samples. For the field sampling activities, precision will be evaluated by calculating the RPD for laboratory duplicate and field replicate samples. The calculated RPD then will be compared to the precision criteria established by the laboratory for analysis of laboratory duplicates.

### **4.6.2 Accuracy**

The accuracy of a method is an estimate of the difference between the true value and the determined mean value. Certain QC samples, such as laboratory control samples, reagent water spike samples, QC check samples, matrix spike samples, and surrogate spike samples, have known concentrations prior to analysis. By comparing the percent recovery of the analysis of these samples to the known true value, it is possible to measure the accuracy of the analysis.

The laboratory collects recovery data for each of these parameters from approximately 30 analytical batches during routine analysis. The percent recovery data are averaged and the standard deviation of the percent recoveries is calculated. Ranges are established as practical control limits based on the desired level of confidence. Control charts are constructed, and the calculated range becomes the practical control limits used by the laboratory until another set of data is developed and new control limits are calculated.

### **4.6.3 Completeness**

Data completeness will be expressed both as the percentage of total tests conducted that are deemed valid and as the percentage of the total tests required in the scope of work that are

deemed valid. Completeness will be calculated by Solutions-IES as part of the data validation process.

#### **4.7 Data Reduction and Validation**

The contract laboratories will utilize USEPA precision and accuracy criteria as guidance for data validation. Specific objectives for accuracy (percent recovery) and precision (relative percent difference) of the analytical measurements are presented in the laboratories QA/QC Plans. Additional documentation of analytical QA data will be available upon request to the laboratory to support validation conclusions and data usability determinations if increased defensibility of laboratory report data is required.

##### **4.7.1 Validation of Field Data Package**

The field data package will be reviewed by Solutions-IES for completeness and accuracy. The field data package includes all of the field records and measurements developed by the sampling team personnel. Failure in any of these areas may result in data being invalidated. The field data package validation procedures will consist of:

- A review of field data contained in the sampling logs for accuracy and completeness.
- A verification that samples, field replicates, field splits, and equipment blanks were properly prepared, preserved, and identified.
- A check of field analyses for equipment calibration and instrument condition.
- A review of the chain-of-custody forms for proper completion, signatures of field personnel, and the laboratory sample custodian and dates.

##### **4.7.2 Validation of the Analytical Data Package**

Validation of the analytical data package will be performed after completing the validation of the field data package. The validation steps will be performed by applying, where appropriate, the most current USEPA Laboratory Data Validation Functional Guidelines For Evaluating Inorganics Analyses (USEPA 2/94) and Organic Analyses (USEPA 12/94), and the precision and accuracy statements specified in the laboratory QA/QC Plan.

The analytical data package validation procedure will include:

- A comparison of the data package to the reporting level requirement to ensure completeness in the analytical data package.
- A comparison of sampling dates, sample extraction dates, and analysis dates to check that samples were extracted and/or analyzed within proper holding times.
- A review of the field and laboratory blanks to evaluate possible contamination sources.

- A review of QC check sample spike results and expected values (initial and continuing calibration verification standards) for inorganics analysis, to ensure that the recoveries are within the established control limits specified in the Laboratory QA/QC Plan.
- A review of the field replicate sample data, to check the precision of the chemical analyses and field sample collection techniques. Laboratory duplicates for solid and water matrices, if available, will also be reviewed.
- A review of the surrogate spike results and expected values for organic analyses to ensure that recoveries are within the control limits specified in the Laboratory QA/QC Plan.

## **4.8 Corrective Action**

### **4.8.1 Field Conditions**

Field personnel are responsible for ensuring that field instruments are functioning properly, that work progresses satisfactorily, and that work is performed in compliance with this QAPP. If a problem is detected by the field personnel, the Solutions-IES Project Manager shall be notified immediately by the Field Services Manager, at which time the problem will be investigated further and corrective action will begin.

### **4.8.2 Laboratory Corrective Action**

Data evaluations necessary to verify proper analytical function must be performed by the contracting lab as early as possible in the analysis program within the time constraints imposed by individual analysis procedures.

A preliminary check of standard curve linearity, precision, and sensitivity should be performed when practical either before the analysis of the samples is begun (manual procedures) or while the first samples are being analyzed (automated procedures). The results are compared to QA/QC limits established by the contracting laboratory and the USEPA. Any analysis not conforming to control limits for precision, accuracy, detection limit, or linearity will be halted until the problem is identified and corrected. Laboratory batch sheets and control charts will document data evaluations and will contain all information necessary for assessment of the data quality, including: (1) information regarding indices of sensitivity, (2) precision, (3) detection limit, and (4) accuracy achieved during that run or batch.

Out-of-control incidents shall be documented concerning the nature of the incident and the corrective action taken to set the system back in control. A corrective action report (CAR), to be signed by the laboratory director and the laboratory QA officer, will be prepared and reported in the narrative summary of the laboratory report. Specific situations requiring the preparation of a CAR are described in the laboratory QA/QC Plan.

### **4.8.3 Reporting of Corrective Actions**

A written report describing the nature of a corrective action case with an evaluation of the cause, if known, and the action taken, will be prepared by the Solutions-IES Field Services or Project Manager. The report will be distributed to the Solutions-IES Project Manager (if not preparing the report) and Principal Investigator.

All corrective actions taken by the contracted laboratories will be reported to the Solutions-IES Project Manager. The laboratory will include in each data package a discussion of the problems encountered and corrective actions taken. In addition, the laboratories will maintain a file for Solutions-IES' review that documents all corrective actions taken regardless of whether the actions performed were pertinent to the analysis of sample from Solutions-IES' project.

## **5.0 Demonstration Procedures**

The Technology Demonstration Plan outlines the procedures for setting up and starting the demonstration. Materials such as monitoring well supplies will be routinely inspected to ensure proper function, and faulty materials will be discarded. Equipment used in the *in situ* columns will be inspected prior to installation. Equipment malfunctions will be recorded in the field logbook.

## **6.0 Equipment Decontamination Procedures**

The cleaning procedures specified in this section are to be used by sampling personnel to decontaminate sampling and other field equipment prior to field use. Downhole drilling equipment (augers, tag lines, etc.) will be steam cleaned prior to and between each location to minimize the potential for cross-contamination. Split-spoon, hand-auger and other soil sampling devices and non-dedicated groundwater purging and sampling equipment will be scrubbed with laboratory-grade detergent, rinsed with tap water, and double rinsed with organic-free, deionized water prior to and between each use.

All liquids resulting from equipment decontamination will be containerized and properly disposed.

## **7.0 Sample Custody, Handling, and Shipment**

### **7.1 Field Records**

The key aspect of documenting sample custody is thorough record keeping. Daily records will be completed in the field logbook during field activities to document the collection of samples. All documents will be completed in ink, dated, and signed by the field person conducting the work.

### **7.2 Sample Labeling**

Samples collected for chemical analysis will be fully labeled at the time of collection. At a minimum, the sample label information will include the sample identification, the date and time of collection, the analyses requested, the preservatives used, and the initials of the personnel collecting the sample. The sample collection data and the information contained on the label will be recorded in the field logbook as the samples are collected.

### **7.3 Sample Container Custody**

All sample containers to be provided by the subcontract laboratories for this project will be new, pre-cleaned, and pre-baked according to the procedures specified in the analytical methods. All containers will be shipped from the laboratories to the designated location by common carrier in sealed coolers.

### **7.4 Sample Custody, Shipment, and Laboratory Receipt**

All samples will be maintained in the custody of the sampling personnel. At the end of each sampling day prior to the transfer of the samples off-site, chain-of-custody entries will be made for all samples using the standard chain-of-custody form. All information on the chain-of-custody form and the sample container labels will be checked against the sample field log entries and samples will be recounted before leaving the sampling site. Upon transfer of custody, the chain-of-custody form will be signed and dated by the sample team leader. Because common carriers (Federal Express, Airborne Express, etc.) will not sign chain-of-custody forms, the forms will be sealed in the cooler prior to shipping. The tracking number of the express shipping label will be included in the comments section of the chain-of-custody form. All chain-of-custody forms sent to the laboratory must be signed and dated by the sample team member shipping the samples.

Upon receipt of the samples at the laboratory, the laboratory sample custodian will note the condition of each sample received as well as any questions or observations concerning sample integrity. The laboratory custodian will also measure the temperature of the samples. The temperature will be recorded on the chain-of-custody form. The laboratory sample custodian also will maintain a sample-tracking record that will follow each sample through all stages of laboratory processing. The sample tracking records will document sample removal from storage as well as the date of sample extraction or preparation and sample analysis. These records will be used to determine compliance with handling and holding time requirements. Samples will be stored by the laboratory in their original containers in walk-in refrigerators designated by the contracted laboratories..

## **8.0 Sample Collection and Preservation**

### **8.1 Groundwater Samples**

Groundwater sample collection will be accomplished in three steps: (1) measurement of the water level in the well, (2) evacuation of standing water; and (3) collection of samples for analysis. Evacuation of water will be performed with a peristaltic pump, an electric submersible groundwater pump, or a bailer. The well will be purged until three well volumes have been removed or until field measurements of pH, temperature, and conductivity have stabilized. Field measurements will be recorded in the logbook. After an adequate purge is achieved, the groundwater samples will be collected in the appropriate laboratory-prepared sample containers. Certain samples must be preserved at the time of sampling. The sample bottles will have the appropriate preservative added to the bottle by the laboratory prior to shipment to the site. Care will be taken to prevent water to fill bottles and overflow to minimize potential dilution of preservatives. Immediately after collection, the sample containers will be placed on ice in an insulated cooler at 4 °C for shipment to the laboratory.

## **9.0 Handling and Disposal of Investigation-Derived Waste**

Because the groundwater is being treated by natural attenuation, it will not be removed from the subsurface for treatment, and will not require disposal. However, it is anticipated that several types of investigation-derived waste (IDW) will be generated on this site, including:

- Personnel protective equipment (PPE).
- Disposable equipment, such as plastic ground and equipment covers, aluminum foil, tubing, bailers, discarded or unused sample containers, boxes, etc.
- Soil cuttings/drilling muds/cores from well installation.
- Groundwater obtained through well development or well purging.
- Cleaning fluids such as detergents, spent solvents and wash water.
- Packing and shipping materials.

Based on generator knowledge, IDW anticipated at the site will be classified as non-hazardous. At the time of generation, soil cuttings/cores will be spread on site in the grassy area south of the drum storage building.

Contaminated groundwater and decontamination fluids derived from well sampling, and equipment decontamination will also be disposed of in the grassy area south of the drum storage building. Solid IDW waste, such as PPE, bailers, tubing, in-line filters, etc., will be double-bagged and deposited in a dumpster for transport to a municipal landfill.

## 10.0 References

- American Public Health Association (APHA), 1989. *Standard Methods for the Examination of Water and Wastewater*. Seventeenth Edition. Washington, DC.
- U.S. Environmental Protection Agency (USEPA), 1996. *Environmental Compliance Branch Standard Operating Procedures and Quality Assurance Manual*. Region IV, Environmental Services Division, Athens, GA. May 1996.
- U.S. Environmental Protection Agency (USEPA), 1994. *National Functional Guidelines for Organic Data Review*. USEPA Contract Laboratory Program. December.
- U.S. Environmental Protection Agency (USEPA), 1990. *Draft National Functional Guidelines for Organic Data Review*. USEPA Contract Laboratory Program. December. Revised June 1991.
- U.S. Environmental Protection Agency (USEPA), 1994. *National Functional Guidelines for Inorganic Data Review*. USEPA Contract Laboratory Program. February.
- U.S. Environmental Protection Agency (USEPA), 1988. *Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses*. USEPA Hazardous Site Evaluation Division. July.
- U.S. Environmental Protection Agency (USEPA), 1986. *Test Methods for Evaluating Solid Waste*. Third Edition with Revisions and Updates – SW-846. Office of Solid Waste and Emergency Response, Washington, DC. November.
- U.S. Environmental Protection Agency (USEPA), 1983. *Methods for Chemical Analysis of Water and Wastes*. Office of Research and Development, Cincinnati, OH. USEPA 600/4-79-020. March.
- U.S. Environmental Protection Agency/Corps of Engineers (USEPA/COE), 1981. *Procedures for Handling and Chemical Analysis of Sediment and Water Samples*. Technical Committee on Criteria for Dredged and Fill Material – Technical Report. EPA/CE-81-1.

**APPENDIX VII**

**LABORATORY ANALYTICAL RESULTS FROM  
PRE-DEMONSTRATION SAMPLING  
(NOVEMBER 2005)**

**COLUMBIA ANALYTICAL SERVICES, INC.**

Analytical Report

**Client :** Environmental Solutions Inc.  
**Project Name :** ESTCP-NSWC Indian Head, MD  
**Project Number :** 3030.04A2.ESTC  
**Sample Matrix :** WATER

**Service Request :** K0505983  
**Date Collected :** 11/15-17/05  
**Date Received :** 11/18/05

Perchlorate

Analysis Method 314.0  
 Test Notes :

Units : ug/L (ppb)  
 Basis : NA

Sample Name	Lab Code	MRL	Dilution Factor	Date Analyzed	Result	Result Notes
MW-1	K0505983-001	4000	2000	12/04/05	24200	
MW-2	K0505983-002	2.0	1	12/04/05	16.4	
MW-3	K0505983-003	2000	1000	12/04/05	9240	
MW-4	K0505983-004	4000	2000	12/04/05	26400	
MW-5	K0505983-005	2000	1000	12/04/05	16500	
SGP-1D	K0505983-006	400	200	12/04/05	2660	
SGP-1S	K0505983-007	400	200	12/04/05	2610	
SGP-2S	K0505983-008	2000	1000	12/04/05	12800	
SGP-2D	K0505983-009	2000	1000	12/04/05	12300	
SGP-5D	K0505983-010	40	20	12/04/05	316	
SGP-3D	K0505983-011	10	5	12/04/05	80	
SGP-3S	K0505983-012	4.0	2	12/04/05	22.8	
SGP-7S	K0505983-013	10	5	12/04/05	40	
SGP-7D	K0505983-014	10	5	12/04/05	41	
SGP-5S	K0505983-015	40	20	12/05/05	231	
SGP-4S	K0505983-016	40	20	12/05/05	346	
SGP-4D	K0505983-017	1000	500	12/04/05	5730	
SGP-6S	K0505983-018	2000	1000	12/05/05	17800	
SGP-6D	K0505983-019	2000	1000	12/04/05	16900	
SGP-8D	K0505983-020	4000	2000	12/04/05	26800	
SGP-8S	K0505983-021	4000	2000	12/04/05	27900	
DUP-1-Filtered	K0505983-022	4000	2000	12/04/05	16600	
DUP-1-Unfiltered	K0505983-023	2000	1000	12/04/05	10900	
Method Blank	K0505983-MB	2.0	1	12/04/05	ND	
Method Blank	K0505983-MB	2.0	1	12/04/05	ND	

COLUMBIA ANALYTICAL SERVICES, INC.

QA/QC Report

**Client :** Environmental Solutions Inc.  
**Project Name :** ESTCP-NSWC Indian Head, MD  
**Project Number :** 3030.04A2.ESTC  
**Sample Matrix :** WATER

**Service Request :** K0505983  
**Date Collected :** 11/16/05  
**Date Received :** 11/18/05  
**Date Prepared :** NA  
**Date Analyzed :** 12/04/05

Duplicate Summary  
Inorganic Parameters

Sample Name : SGP-5D  
Lab Code : K0505983-010DUP  
Test Notes :

Units : ug/L (ppb)  
Basis : NA

<b>Analyte</b>	<b>Analysis Method</b>	<b>MRL</b>	<b>Sample Result</b>	<b>Duplicate Sample Result</b>	<b>Average</b>	<b>Relative Percent Difference</b>	<b>Result Notes</b>
Perchlorate	314.0	40	316	325	321	3	

**COLUMBIA ANALYTICAL SERVICES, INC.**

QA/QC Report

**Client :** Environmental Solutions Inc.  
**Project Name :** ESTCP-NSWC Indian Head, MD  
**Project Number :** 3030.04A2.ESTC  
**Sample Matrix :** WATER

**Service Request :** K0505983  
**Date Collected :** 11/16/05  
**Date Received :** 11/18/05  
**Date Prepared :** NA  
**Date Analyzed :** 12/04/05

Matrix Spike Summary  
 Inorganic Parameters

Sample Name : SGP-5D  
 Lab Code : K0505983-010MS  
 Test Notes :

Units : ug/L (ppb)  
 Basis : NA

Analyte	Prep Method	Analysis Method	MRL	Spike Level	Sample Result	Spiked Sample Result	Percent Recovery	CAS	Result Notes
								Percent Recovery	
Perchlorate	None	314.0	100	500	316	807	98	80-120	

COLUMBIA ANALYTICAL SERVICES, INC.

QA/QC Report

**Client :** Environmental Solutions Inc.  
**Project Name :** ESTCP-NSWC Indian Head, MD  
**Project Number :** 3030.04A2.ESTC  
**Sample Matrix :** WATER

**Service Request :** K0505983  
**Date Collected :** 11/16/05  
**Date Received :** 11/18/05  
**Date Prepared :** NA  
**Date Analyzed :** 12/04/05

Duplicate Summary  
Inorganic Parameters

Sample Name : SGP-3D  
Lab Code : K0505983-011DUP  
Test Notes :

Units : ug/L (ppb)  
Basis : NA

Analyte	Analysis Method	MRL	Sample Result	Duplicate Sample Result	Average	Relative Percent Difference	Result Notes
Perchlorate	314.0	10	80	81	81	1	

COLUMBIA ANALYTICAL SERVICES, INC.

QA/QC Report

**Client :** Environmental Solutions Inc.  
**Project Name :** ESTCP-NSWC Indian Head, MD  
**Project Number :** 3030.04A2.ESTC  
**Sample Matrix :** WATER

**Service Request :** K0505983  
**Date Collected :** 11/16/05  
**Date Received :** 11/18/05  
**Date Prepared :** NA  
**Date Analyzed :** 12/04/05

Matrix Spike Summary  
Inorganic Parameters

Sample Name : SGP-3D  
Lab Code : K0505983-011MS  
Test Notes :

Units : ug/L (ppb)  
Basis : NA

Analyte	Prep Method	Analysis Method	MRL	Spike Level	Sample Result	Spiked Sample Result	Percent Recovery	CAS Percent Recovery Acceptance Limits	Result Notes
Perchlorate	None	314.0	20	100	80	173	93	80-120	

COLUMBIA ANALYTICAL SERVICES, INC.

QA/QC Report

**Client :** Environmental Solutions Inc.  
**Project Name :** ESTCP-NSWC Indian Head, MD  
**Project Number :** 3030.04A2.ESTC  
**Sample Matrix :** WATER

**Service Request :** K0505983  
**Date Collected :** NA  
**Date Received :** NA  
**Date Prepared :** NA  
**Date Analyzed :** 12/04/05

Laboratory Control Sample Summary  
Inorganic Parameters

**Sample Name :** Laboratory Control Sample  
**Lab Code :** K0505983-LCS1  
**Test Notes :**

**Units :** ug/L (ppb)  
**Basis :** NA

<b>Analyte</b>	<b>Prep Method</b>	<b>Analysis Method</b>	<b>True Value</b>	<b>Result</b>	<b>Percent Recovery</b>	<b>CAS Percent Recovery Acceptance Limits</b>	<b>Result Notes</b>
Perchlorate	None	314.0	17.6	17.1	97	85-115	

**COLUMBIA ANALYTICAL SERVICES, INC.**

QA/QC Report

**Client :** Environmental Solutions Inc.  
**Project Name :** ESTCP-NSWC Indian Head, MD  
**Project Number :** 3030.04A2.ESTC  
**Sample Matrix :** WATER

**Service Request :** K0505983  
**Date Collected :** NA  
**Date Received :** NA  
**Date Prepared :** NA  
**Date Analyzed :** 12/04/05

Laboratory Control Sample Summary  
 Inorganic Parameters

**Sample Name :** Laboratory Control Sample  
**Lab Code :** K0505983-LCS2  
**Test Notes :**

**Units :** ug/L (ppb)  
**Basis :** NA

Analyte	Prep Method	Analysis Method	True Value	Result	Percent Recovery	CAS		Result Notes
						Acceptance Limits	Percent Recovery	
Perchlorate	None	314.0	17.6	16.4	93	85-115		



**ENVIRONMENTAL  
SCIENCE CORP.**

12065 Lebanon Rd.  
Mt. Juliet, TN 37122  
(615) 758-5858  
1-800-767-5859  
Fax (615) 758-5859

Tax I.D. 62-0814289

Est. 1970

REPORT OF ANALYSIS

Ms. Sheri Knox  
Solutions-IES  
1101 Nowell Road  
Raleigh, NC 27607

November 28, 2005

Date Received : November 18, 2005  
Description : ESTCP - Indian Head, MD  
Sample ID : SGP-5S  
Collected By : Kevin Buchanan  
Collection Date : 11/17/05 08:15

ESC Sample # : L223086-01  
Site ID : Indian Head Division,  
Project # : 3030.04A2.ESTC

Parameter	Result	Det. Limit	Units	Method	Date	Dil.
Methane	BDL	0.010	ppm	8015M	11/22/05	1
TOC (Total Organic Carbon)	2.6	1.0	mg/l	9060	11/23/05	1

  
Jimmy Hunt, ESC Representative

BDL - Below Detection Limit

Det. Limit - Practical Quantitation Limit(PQL)

Laboratory Certification Numbers:

AIHA - 100789, AL - 40660, CA - I-2327, CT- PH-0197, FL - E87487, GA - 923, IN - C-TN-01  
KY - 90010, KYUST - 0016, NC - ENV375,DW21704, ND - R-140, SC - 84004, TN - 2006, VA - 00109, WV - 233  
AZ -0612, MN - 047-999-395, NY - 11742, NJ - 81002, WI - 998093910

Note:

The reported analytical results relate only to the sample submitted.

This report shall not be reproduced, except in full, without the written approval from ESC.

Reported: 11/28/05 13:46 Printed: 11/28/05 13:46



**ENVIRONMENTAL  
SCIENCE CORP.**

12065 Lebanon Rd.  
Mt. Juliet, TN 37122  
(615) 758-5858  
1-800-767-5859  
Fax (615) 758-5859

Tax I.D. 62-0814289

Est. 1970

REPORT OF ANALYSIS

Ms. Sheri Knox  
Solutions-IES  
1101 Nowell Road  
Raleigh, NC 27607

November 28, 2005

Date Received : November 18, 2005  
Description : ESTCP - Indian Head, MD  
Sample ID : SGP-4S  
Collected By : Kevin Buchanan  
Collection Date : 11/17/05 08:55

ESC Sample # : L223086-02  
Site ID : Indian Head Division,  
Project # : 3030.04A2.ESTC

Parameter	Result	Det. Limit	Units	Method	Date	Dil.
Methane	BDL	0.010	ppm	8015M	11/22/05	1
TOC (Total Organic Carbon)	15.	1.0	mg/l	9060	11/23/05	1

  
Jimmy Hunt, ESC Representative

BDL - Below Detection Limit

Det. Limit - Practical Quantitation Limit(PQL)

Laboratory Certification Numbers:

AIHA - 100789, AL - 40660, CA - I-2327, CT- PH-0197, FL - E87487, GA - 923, IN - C-TN-01  
KY - 90010, KYUST - 0016, NC - ENV375,DW21704, ND - R-140, SC - 84004, TN - 2006, VA - 00109, WV - 233  
AZ -0612, MN - 047-999-395, NY - 11742, NJ - 81002, WI - 998093910

Note:

The reported analytical results relate only to the sample submitted.

This report shall not be reproduced, except in full, without the written approval from ESC.

Reported: 11/28/05 13:46 Printed: 11/28/05 13:46



**ENVIRONMENTAL  
SCIENCE CORP.**

12065 Lebanon Rd.  
Mt. Juliet, TN 37122  
(615) 758-5858  
1-800-767-5859  
Fax (615) 758-5859

Tax I.D. 62-0814289

Est. 1970

REPORT OF ANALYSIS

November 28, 2005

Ms. Sheri Knox  
Solutions-IES  
1101 Nowell Road  
Raleigh, NC 27607

Date Received : November 18, 2005  
Description : ESTCP - Indian Head, MD  
Sample ID : SGP-4D  
Collected By : Kevin Buchanan  
Collection Date : 11/17/05 09:35

ESC Sample # : L223086-03  
Site ID : Indian Head Division,  
Project # : 3030.04A2.ESTC

Parameter	Result	Det. Limit	Units	Method	Date	Dil.
Methane	BDL	0.010	ppm	8015M	11/22/05	1
TOC (Total Organic Carbon)	2.2	1.0	mg/l	9060	11/23/05	1

  
Jimmy Hunt, ESC Representative

BDL - Below Detection Limit

Det. Limit - Practical Quantitation Limit(PQL)

Laboratory Certification Numbers:

AIHA - 100789, AL - 40660, CA - I-2327, CT- PH-0197, FL - E87487, GA - 923, IN - C-TN-01  
KY - 90010, KYUST - 0016, NC - ENV375,DW21704, ND - R-140, SC - 84004, TN - 2006, VA - 00109, WV - 233  
AZ -0612, MN - 047-999-395, NY - 11742, NJ - 81002, WI - 998093910

Note:

The reported analytical results relate only to the sample submitted.

This report shall not be reproduced, except in full, without the written approval from ESC.

Reported: 11/28/05 13:46 Printed: 11/28/05 13:46



**ENVIRONMENTAL  
SCIENCE CORP.**

12065 Lebanon Rd.  
Mt. Juliet, TN 37122  
(615) 758-5858  
1-800-767-5859  
Fax (615) 758-5859

Tax I.D. 62-0814289

Est. 1970

REPORT OF ANALYSIS

Ms. Sheri Knox  
Solutions-IES  
1101 Nowell Road  
Raleigh, NC 27607

November 28, 2005

Date Received : November 18, 2005  
Description : ESTCP - Indian Head, MD  
Sample ID : SGP-6S  
Collected By : Kevin Buchanan  
Collection Date : 11/17/05 10:50

ESC Sample # : L223086-04  
Site ID : Indian Head Division,  
Project # : 3030.04A2.ESTC

Parameter	Result	Det. Limit	Units	Method	Date	Dil.
Methane	0.083	0.010	ppm	8015M	11/22/05	1
TOC (Total Organic Carbon)	3.1	1.0	mg/l	9060	11/26/05	1

  
Jimmy Hunt, ESC Representative

BDL - Below Detection Limit

Det. Limit - Practical Quantitation Limit (PQL)

Laboratory Certification Numbers:

AIHA - 100789, AL - 40660, CA - I-2327, CT- PH-0197, FL - E87487, GA - 923, IN - C-TN-01  
KY - 90010, KYUST - 0016, NC - ENV375, DW21704, ND - R-140, SC - 84004, TN - 2006, VA - 00109, WV - 233  
AZ -0612, MN - 047-999-395, NY - 11742, NJ - 81002, WI - 998093910

Note:

The reported analytical results relate only to the sample submitted.

This report shall not be reproduced, except in full, without the written approval from ESC.

Reported: 11/28/05 13:46 Printed: 11/28/05 13:46



**ENVIRONMENTAL  
SCIENCE CORP.**

12065 Lebanon Rd.  
Mt. Juliet, TN 37122  
(615) 758-5858  
1-800-767-5859  
Fax (615) 758-5859

Tax I.D. 62-0814289

Est. 1970

REPORT OF ANALYSIS

Ms. Sheri Knox  
Solutions-IES  
1101 Nowell Road  
Raleigh, NC 27607

November 28, 2005

Date Received : November 18, 2005  
Description : ESTCP - Indian Head, MD  
Sample ID : SGP-6D  
Collected By : Kevin Buchanan  
Collection Date : 11/17/05 11:25

ESC Sample # : L223086-05  
Site ID : Indian Head Division,  
Project # : 3030.04A2.ESTC

Parameter	Result	Det. Limit	Units	Method	Date	Dil.
Methane	1.1	0.010	ppm	8015M	11/22/05	10
TOC (Total Organic Carbon)	29.	1.0	mg/l	9060	11/26/05	1

  
Jimmy Hunt, ESC Representative

BDL - Below Detection Limit

Det. Limit - Practical Quantitation Limit(PQL)

Laboratory Certification Numbers:

AIHA - 100789, AL - 40660, CA - I-2327, CT- PH-0197, FL - E87487, GA - 923, IN - C-TN-01  
KY - 90010, KYUST - 0016, NC - ENV375,DW21704, ND - R-140, SC - 84004, TN - 2006, VA - 00109, WV - 233  
AZ -0612, MN - 047-999-395, NY - 11742, NJ - 81002, WI - 998093910

Note:

The reported analytical results relate only to the sample submitted.

This report shall not be reproduced, except in full, without the written approval from ESC.

Reported: 11/28/05 13:46 Printed: 11/28/05 13:46



**ENVIRONMENTAL  
SCIENCE CORP.**

12065 Lebanon Rd.  
Mt. Juliet, TN 37122  
(615) 758-5858  
1-800-767-5859  
Fax (615) 758-5859

Tax I.D. 62-0814289

Est. 1970

REPORT OF ANALYSIS

Ms. Sheri Knox  
Solutions-IES  
1101 Nowell Road  
Raleigh, NC 27607

November 28, 2005

Date Received : November 18, 2005  
Description : ESTCP - Indian Head, MD  
Sample ID : SGP-8D  
Collected By : Kevin Buchanan  
Collection Date : 11/17/05 12:00

ESC Sample # : L223086-06  
Site ID : Indian Head Division,  
Project # : 3030.04A2.ESTC

Parameter	Result	Det. Limit	Units	Method	Date	Dil.
Methane	BDL	0.010	ppm	8015M	11/22/05	1
TOC (Total Organic Carbon)	3.4	1.0	mg/l	9060	11/26/05	1

  
Jimmy Hunt, ESC Representative

BDL - Below Detection Limit

Det. Limit - Practical Quantitation Limit(PQL)

Laboratory Certification Numbers:

AIHA - 100789, AL - 40660, CA - I-2327, CT- PH-0197, FL - E87487, GA - 923, IN - C-TN-01  
KY - 90010, KYUST - 0016, NC - ENV375,DW21704, ND - R-140, SC - 84004, TN - 2006, VA - 00109, WV - 233  
AZ -0612, MN - 047-999-395, NY - 11742, NJ - 81002, WI - 998093910

Note:

The reported analytical results relate only to the sample submitted.

This report shall not be reproduced, except in full, without the written approval from ESC.

Reported: 11/28/05 13:46 Printed: 11/28/05 13:46



**ENVIRONMENTAL  
SCIENCE CORP.**

12065 Lebanon Rd.  
Mt. Juliet, TN 37122  
(615) 758-5858  
1-800-767-5859  
Fax (615) 758-5859

Tax I.D. 62-0814289

Est. 1970

REPORT OF ANALYSIS

Ms. Sheri Knox  
Solutions-IES  
1101 Nowell Road  
Raleigh, NC 27607

November 28, 2005

Date Received : November 18, 2005  
Description : ESTCP - Indian Head, MD  
Sample ID : SGP-8S  
Collected By : Kevin Buchanan  
Collection Date : 11/17/05 12:30

ESC Sample # : L223086-07  
Site ID : Indian Head Division,  
Project # : 3030.04A2.ESTC

Parameter	Result	Det. Limit	Units	Method	Date	Dil.
Methane	0.011	0.010	ppm	8015M	11/22/05	1
TOC (Total Organic Carbon)	2.1	1.0	mg/l	9060	11/26/05	1

  
Jimmy Hunt, ESC Representative

BDL - Below Detection Limit

Det. Limit - Practical Quantitation Limit(PQL)

Laboratory Certification Numbers:

AIHA - 100789, AL - 40660, CA - I-2327, CT- PH-0197, FL - E87487, GA - 923, IN - C-TN-01  
KY - 90010, KYUST - 0016, NC - ENV375,DW21704, ND - R-140, SC - 84004, TN - 2006, VA - 00109, WV - 233  
AZ -0612, MN - 047-999-395, NY - 11742, NJ - 81002, WI - 998093910

Note:

The reported analytical results relate only to the sample submitted.

This report shall not be reproduced, except in full, without the written approval from ESC.

Reported: 11/28/05 13:46 Printed: 11/28/05 13:46



**ENVIRONMENTAL  
SCIENCE CORP.**

12065 Lebanon Rd.  
Mt. Juliet, TN 37122  
(615) 758-5858  
1-800-767-5859  
Fax (615) 758-5859

Tax I.D. 62-0814289

Est. 1970

REPORT OF ANALYSIS

Ms. Sheri Knox  
Solutions-IES  
1101 Nowell Road  
Raleigh, NC 27607

November 28, 2005

Date Received : November 18, 2005  
Description : ESTCP - Indian Head, MD  
Sample ID : DUP-1  
Collected By : Kevin Buchanan  
Collection Date : 11/17/05 10:50

ESC Sample # : L223086-08  
Site ID : Indian Head Division,  
Project # : 3030.04A2.ESTC

Parameter	Result	Det. Limit	Units	Method	Date	Dil.
TOC (Total Organic Carbon)	3.3	1.0	mg/l	9060	11/26/05	1

  
Jimmy Hunt, ESC Representative

BDL - Below Detection Limit

Det. Limit - Practical Quantitation Limit(PQL)

Laboratory Certification Numbers:

AIHA - 100789, AL - 40660, CA - I-2327, CT- PH-0197, FL - E87487, GA - 923, IN - C-TN-01  
KY - 90010, KYUST - 0016, NC - ENV375,DW21704, ND - R-140, SC - 84004, TN - 2006, VA - 00109, WV - 233  
AZ -0612, MN - 047-999-395, NY - 11742, NJ - 81002, WI - 998093910

Note:

The reported analytical results relate only to the sample submitted.

This report shall not be reproduced, except in full, without the written approval from ESC.

Reported: 11/28/05 13:46 Printed: 11/28/05 13:47

Attachment A  
List of Analytes with QC Qualifiers

Sample #	Analyte	Qualifier
L223086-04	TOC (Total Organic Carbon)	K
L223086-05	TOC (Total Organic Carbon)	K
L223086-06	TOC (Total Organic Carbon)	K
L223086-07	TOC (Total Organic Carbon)	K
L223086-08	TOC (Total Organic Carbon)	K

Attachment B  
Explanation of QC Qualifier Codes

Qualifier	Meaning
K	REX(EPA)- Re-prepared: The indicated analytical results were generated from a re-extraction or preparation of the sample.

Qualifier Report Information

ESC utilizes sample and result qualifiers as set forth by the EPA Contract Laboratory Program and as required by most certifying bodies including NELAC. In addition to the EPA qualifiers adopted by ESC, we have implemented ESC qualifiers to provide more information pertaining to our analytical results. Each qualifier is designated in the qualifier explanation as either EPA or ESC. Data qualifiers are intended to provide the ESC client with more detailed information concerning the potential bias of reported data. Because of the wide range of constituents and variety of matrices incorporated by most EPA methods, it is common for some compounds to fall outside of established ranges. These exceptions are evaluated and all reported data is valid and useable unless qualified as 'R' (Rejected).

Definitions

**Accuracy** - The relationship of the observed value of a known sample to the true value of a known sample. Represented by percent recovery and relevant to samples such as: control samples, matrix spike recoveries, surrogate recoveries, etc.

**Precision** - The agreement between a set of samples or between duplicate samples. Relates to how close together the results are and is represented by Relative Percent Difference.

**Surrogate** - Organic compounds that are similar in chemical composition, extraction, and chromatography to analytes of interest. The surrogates are used to determine the probable response of the group of analytes that are chemically related to the surrogate compound. Surrogates are added to the sample and carried through all stages of preparation and analyses.

		Control Limits				(AQ)	(SS)
2-Fluorophenol	31-119	Nitrobenzene-d5	43-118	Dibromfluoromethane	68-128	64-125	
Phenol-d5	12-134	2-Fluorobiphenyl	45-128	Toluene-d8	76-115	69-118	
2,4,6-Tribromophenol	51-141	Terphenyl-d14	43-137	4-Bromofluorobenzene	79-127	61-134	

**TIC** - Tentatively Identified Compound: Compounds detected in samples that are not target compounds, internal standards, system monitoring compounds, or surrogates.

Summary of Remarks For Samples Printed  
11/28/05 at 13:47:02

TSR Signing Reports: 350  
R5 - Desired TAT

Sample: L223086-01 Account: SOLINDRNC Received: 11/18/05 11:00 Due Date: 11/28/05 00:00 RPT Date: 11/28/05 13:46  
Added QC2 - jeh 11/22/05  
Sample: L223086-02 Account: SOLINDRNC Received: 11/18/05 11:00 Due Date: 11/28/05 00:00 RPT Date: 11/28/05 13:46  
Added QC2 - jeh 11/22/05  
Sample: L223086-03 Account: SOLINDRNC Received: 11/18/05 11:00 Due Date: 11/28/05 00:00 RPT Date: 11/28/05 13:46  
Added QC2 - jeh 11/22/05  
Sample: L223086-04 Account: SOLINDRNC Received: 11/18/05 11:00 Due Date: 11/28/05 00:00 RPT Date: 11/28/05 13:46  
Added QC2 - jeh 11/22/05  
Sample: L223086-05 Account: SOLINDRNC Received: 11/18/05 11:00 Due Date: 11/28/05 00:00 RPT Date: 11/28/05 13:46  
Added QC2 - jeh 11/22/05  
Sample: L223086-06 Account: SOLINDRNC Received: 11/18/05 11:00 Due Date: 11/28/05 00:00 RPT Date: 11/28/05 13:46  
Added QC2 - jeh 11/22/05  
Sample: L223086-07 Account: SOLINDRNC Received: 11/18/05 11:00 Due Date: 11/28/05 00:00 RPT Date: 11/28/05 13:46  
Added QC2 - jeh 11/22/05  
Sample: L223086-08 Account: SOLINDRNC Received: 11/18/05 11:00 Due Date: 11/28/05 00:00 RPT Date: 11/28/05 13:46  
Added QC2 - jeh 11/22/05

# Solutions-IES

1101 Nowell Road  
Raleigh, NC 27607

Report to: **Ms. Sheri Knox**

Project Description: **ESTCP - Indian Head, MD**

Phone: (919) 873-1060  
FAX: (919) 873-1074

Collected by (print): *Kevin Buchanan*  
Collected by (signature): *[Signature]*

Packed on Ice:  N  Y

Email: **sknox@solutions-ies.com**

City/State Collected

Lab Project #

**SOLINDRNC-3030.04A2.**

P.O.#:

Site/Facility ID#: **Indian Head Division, BI**  
 Rush? (Lab MUST Be Notified)  
 Same Day .....200%  
 Next Day .....100%  
 Two Day .....50%

Date Results Needed  
 Email?  No  Yes  
 FAX?  No  Yes  
 No. of Cntrs: **3**

Analysis/Container/Preservative	METHANE 40ml Amb-NoPres	TOC 250ml Amb-Septa-HCl	Remarks/Contaminant	Sample # (lab only)
	X	X		L222930-01
	X	X		02
	X	X		03
	X	X		04
	X	X		05
	X	X		06
	X	X		07
	X	X		08
	X	X		09

Accnum: **SOLINDRNC** (lab use only)  
 Template/Prelogin: **T33685/P160153**  
 Cooler #: *11/17/05*  
 Shipped Via: **FedEX Ground**

Chain of Custody  
 Page **1** of **2**

Prepared by:  
**ENVIRONMENTAL SCIENCE CORP.**  
 12065 Lebanon Road  
 Mt. Juliet, TN 37122  
 Phone (800) 767-5859  
 FAX (615) 758-5859

Alternate billing information:	Alternate billing information:

\*Matrix: **SS** - Soil **GW** - Groundwater **WW** - WasteWater **DW** - Drinking Water **OT** - Other

Remarks: **FedEx AieBill # 845411483573**

pH \_\_\_\_\_ Temp \_\_\_\_\_  
 Flow \_\_\_\_\_ Other \_\_\_\_\_

Relinquished by (Signature)	Date:	Time:	Received by (Signature)	Date:	Time:	Condition:	Temp	Bottles Received	Date:	pH Checked	NGF
<i>[Signature]</i>			<i>[Signature]</i>				2.4°C	424TS	11-17-05	12	
<i>[Signature]</i>			<i>[Signature]</i>								
<i>[Signature]</i>			<i>[Signature]</i>								

Samples returned via:  UPS  FedEx  Courier  
 Condition: (lab use only)

# Solutions-IES

1101 Nowell Road  
Raleigh, NC 27607

Report to: **Ms. Sheri Knox**

Email: **sknox@solutions-ies.com**

Project Description: **ESTCP - Indian Head, MD**

City/State Collected

Phone: (919) 873-1060  
FAX: (919) 873-1074

Client Project #: **3030.04A2. ESTC**  
Lab Project #: **SOLINDRNC-3030.04A2.**

Collected by (print): *Kevin Buchanan*

P.O.#:

Collected by (signature): *[Signature]*

Site/Facility ID#:

**Indian Head Division, BI**  
[Rush?] (Lab MUST Be Notified)  
\_\_\_ Same Day ..... 200%  
\_\_\_ Next Day ..... 100%  
\_\_\_ Two Day ..... 50%

Date Results Needed  
Email? \_\_\_ No \_\_\_ Yes  
FAX? \_\_\_ No \_\_\_ Yes

Packed on Ice: **N**

No. of Cntrs

Sample ID	Comp/Grab	Matrix*	Depth	Date	Time	METHANE 40ml Amb-Nopres	TOC 250ml Amb-Septa-HCl	Remarks/Contaminant	Sample # (lab only)
<del>SGP-3</del>	G	GW		11/16/05	1330	X	X		L222930 -10
<del>SGP-4</del>	G	GW		11/16/05	1405	X	X		-11
<del>SGP-5</del>	G	GW		11/16/05	1430	X	X		-12
<del>SGP-6</del>	G	GW		11/16/05	1505	X	X		-13
<del>SGP-7</del>	G	GW		11/16/05	1535	X	X		-14
<del>SGP-8</del>		<del>GW</del>				X	X		
<del>SGP-9</del>		<del>GW</del>				X	X		
<del>SGP-10</del>		<del>GW</del>				X	X		
<del>SGP-11</del>		<del>GW</del>				X	X		

\*Matrix: SS - Soil GW - Groundwater WW - WasteWater DW - Drinking Water OT - Other

pH \_\_\_\_\_ Temp \_\_\_\_\_  
Flow \_\_\_\_\_ Other \_\_\_\_\_

*Fedex A.R.BILL # 8454 11483573*

Relinquished by (Signature): <i>[Signature]</i>	Date:	Time:	Received by (Signature): <i>[Signature]</i>	Date:	Time:	Samples returned via: <input checked="" type="checkbox"/> UPS <input type="checkbox"/> FedEx <input type="checkbox"/> Courier	Condition: (lab use only)
Relinquished by (Signature): <i>[Signature]</i>	Date:	Time:	Received by (Signature): <i>[Signature]</i>	Date:	Time:	Temp: <b>2.4°C</b> Bottles Received: <b>42FB</b>	
Relinquished by (Signature): <i>[Signature]</i>	Date:	Time:	Received for lab by (Signature): <i>[Signature]</i>	Date:	Time:	Date: <b>11-17-05</b> Time: <b>11:00</b>	pH Checked: <b>C2</b> NCF: <input checked="" type="checkbox"/>

Analysis/Container/Preservative

Chain of Custody  
Page **2** of **2**

Prepared by: **ENVIRONMENTAL SCIENCE CORP.**  
12065 Lebanon Road  
Mt. Juliet, TN 37122  
Phone (800) 767-5859  
FAX (615) 758-5859

Account: **SOLINDRNC** (lab use only)  
Template/Prelog in: **T33685/PI60153**  
Cooler #: **1190584**  
Shipped Via: **FedEX Ground**



**IC Analysis-Solutions IES  
NSWC-Indian Head, MD**

**N. C. State University  
Environmental Engineering  
Laboratory**

Date Sampled: 11/15-17/05

Date Received: 11/28/05

Date Analyzed: 12/15/05

David C. Black

**Quality Control Information**

Certified Standard from AccuStandard Inc.

Sample ID	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate
Certified Standard	19.9	18.1	19.6	18.7	20.3	19.6
% Recovery	99.5%	90.5%	98.0%	93.5%	101.5%	98.0%

Blank	<0.5	<0.5	<1	<0.5	<1	<0.5
-------	------	------	----	------	----	------

**Sample Information:** (Samples labeled a and b are lab replicates)

All units are mg/L

Sample ID	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate
MW-1	16.2	<0.5	<1	136.2	<1	40.5
MW-2	1.8	<0.5	<1	3.4	<1	62.9
MW-3	4.7	<0.5	<1	0.8	<1	57.1
MW-4a	2.0	<0.5	<1	1.6	<1	56.2
MW-4b	2.1	<0.5	<1	1.6	<1	57.3
MW-5	2.3	<0.5	<1	2.4	<1	96.1
SGP-1D	5.2	<0.5	<1	0.9	<1	80.0
SGP-2D	9.7	<0.5	<1	<0.5	<1	77.5
SGP-3D	2.3	<0.5	<1	<0.5	<1	59.8
SGP-4Da	2.4	<0.5	<1	1.4	<1	43.4
SGP-4Db	2.6	<0.5	<1	1.4	<1	46.5
SGP-5D	10.7	<0.5	<1	2.0	<1	168.2
SGP-6D	10.9	<0.5	<1	<0.5	<1	76.7
SGP-7D	4.4	<0.5	<1	<0.5	<1	79.8
SGP-8D	10.4	<0.5	<1	4.9	<1	62.7
SGP-1Sa	2.5	<0.5	<1	<0.5	<1	57.4
SGP-1Sb	2.6	<0.5	<1	<0.5	<1	57.4
SGP-2S	11.3	<0.5	<1	0.8	<1	127.4
SGP-3S	4.8	<0.5	<1	<0.5	<1	54.6
SGP-4S	6.4	<0.5	<1	6.0	<1	16.4
SGP-5S	5.3	<0.5	<1	1.1	<1	100.2
SGP-6Sa	9.9	<0.5	<1	2.5	<1	92.8
SGP-6Sb	11.3	<0.5	<1	2.8	<1	109.2
SGP-7S	3.8	<0.5	<1	2.6	<1	62.1
SGP-8S	15.0	<0.5	<1	7.7	<1	78.1



# **Natural Attenuation of Perchlorate In Groundwater:**

---

## **Processes, Tools and Monitoring Techniques**

**ESTCP PROJECT NO. ER-0428**

Prepared by:

**Solutions-IES, Inc.**  
1101 Nowell Rd.  
Raleigh, NC 27607  
[www.solutions-ies.com](http://www.solutions-ies.com)

**August 2008**

**Approved for Public Release; Distribution is Unlimited**

**Natural Attenuation of Perchlorate in Groundwater: Processes, Tools and  
Monitoring Techniques**

# Table of Contents

ACKNOWLEDGEMENTS .....	i
LIST OF ACRONYMS AND ABBREVIATIONS .....	ii
EXECUTIVE SUMMARY .....	iv
1.0 INTRODUCTION .....	1
1.1 Purpose of this Document.....	1
1.2 Background.....	1
1.3 Monitored Natural Attenuation .....	2
1.4 EPA Policy on Monitored Natural Attenuation.....	3
2.0 FATE AND TRANSPORT OF PERCHLORATE IN GROUNDWATER .....	6
2.1 Purpose of this Section .....	6
2.2 Sources of perchlorate .....	7
2.2.1 Anthropogenic Sources.....	7
2.2.2 Natural Sources.....	8
2.3 Physical and Chemical Properties of Perchlorate.....	9
2.4 Attenuation Processes.....	10
2.4.1 Advection and Dispersion.....	11
2.4.2 Sorption to Aquifer Material.....	12
2.4.3 Biodegradation Processes .....	13
2.4.4 Abiotic Degradation Processes .....	14
2.4.5 Phytoremediation .....	14
3.0 TOOLS AND TECHNIQUES FOR EVALUATING PERCHLORATE ATTENUATION .....	17
3.1 Purpose .....	17
3.2 Geochemical Indicators of Perchlorate Attenuation.....	17
3.2.1 Dissolved Oxygen (DO) .....	17
3.2.2 Nitrate .....	18
3.2.3 Iron.....	18
3.2.4 Sulfate .....	19
3.2.5 Methane .....	19
3.2.6 Oxidation-Reduction Potential (ORP).....	19
3.2.7 pH and Temperature .....	22
3.2.8 Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC) .....	22
3.2.9 Trace Metals: Molybdenum.....	23
3.3 Field Methods for Perchlorate Analysis .....	23
3.3.1 Sample collection and preservation .....	23
3.3.2 Ion-selective Electrodes .....	25
3.3.3 Colorimetry.....	25
3.3.4 Chemical Sensors.....	25
3.4 Laboratory Methods for Perchlorate Analysis.....	26
3.4.1 Analytical methods .....	26
3.5 Microbial Indicators of Perchlorate Attenuation .....	28
3.5.1 Degradation Daughter Products.....	28
3.5.2 Microbial Enumeration Methods .....	29
3.5.3 qPCR and Chlorite Dismutase Enzyme Assays.....	29
3.5.4 Stable Isotope Methods.....	30
3.6 Laboratory Microcosms and Bench-Scale Column Tests .....	32
3.6.1 Laboratory Microcosm Studies.....	32

3.6.2	Bench-Scale Column Studies.....	34
3.7	Field Evaluation Tools and Techniques .....	34
3.7.1	In Situ Columns .....	34
3.7.2	Plume Stability, Statistical Evaluations and Mass Flux.....	36
4.0	ASSESSING THE NATURAL ATTENUATION OF PERCHLORATE: A TIERED APPROACH.....	38
4.1	Purpose of this section.....	38
4.2	Tier 1 – Spatial and Temporal Distribution of Perchlorate .....	38
4.3	Tier 2 – Bio-geochemical Conditions for Perchlorate Biodegradation .....	39
4.4	Tier 3 – Microbiological Indicators of Perchlorate Biodegradation.....	41
4.4.1	qPCR and CD Enzyme Analysis.....	41
4.4.2	Laboratory Evaluations.....	42
4.4.3	Confirmational Field Evaluations.....	43
5.0	SUMMARY.....	44
6.0	REFERENCES .....	45
7.0	Points of Contact.....	54

## LIST OF FIGURES

Figure 2-1	Perchlorate Anion .....	7
Figure 2-2	Plug Flow Resulting from Advection Only and Advection and Dispersion.....	12
Figure 2-3	Perchlorate Biodegradation Pathway .....	13
Figure 2-4	Phytoremediation Processes.....	15
Figure 2-5	Relative Rate of Perchlorate Degradation by Phytoaccumulation Followed by Rhizodegradation .....	16
Figure 3-1	ORP of Common Chemical Species .....	20
Figure 3-2	Redox Potential for Degradation Processes .....	21
Figure 3-3	Photograph Illustrating Field Preservation of the Aqueous Sample by Filtration through a Filter Stack.....	25
Figure 3-4	Anaerobic Benzene Loss in <i>In Situ</i> Columns .....	35
Figure 3-5	<i>In Situ</i> Column Set-Up.....	36

## LIST OF TABLES

Table 1-1	Summary of the EPA MNA Policy.....	4
Table 1-2	Uses of Perchlorate .....	8
Table 2-1	Properties of Perchlorate Compounds .....	9
Table 2-2	Summary of Important Subsurface Processes Acting on Perchlorate .....	10

## APPENDIX

### CASE HISTORIES

1. ALLIANT TECHSYSTEMS, INC., ELKTON, MD
2. NAVAL SURFACE WARFARE CENTER, INDIAN HEAD, MD

## **ACKNOWLEDGEMENTS**

Solutions-IES gratefully acknowledges the financial and technical support provided by the Environmental Security Technology Certification Program (ESTCP). We greatly appreciate the contributions of Dr. Andrea Leeson, Ms. Erica Becvar (the Contracting Officer's Representative), and Dr. Hans Stroo for their comments and input during the performance of the project. Solutions-IES, Inc. employees contributing to the preparation of this document included Mr. M. Tony Lieberman and Ms. Sheri L. Knox, P.E. In addition, Dr. Robert C. Borden, P.E. of North Carolina State University provided valuable direction, technical assistance, review and feedback on all facets of this project. Dr. Todd Weidemeier also provided a review of the document.

This report was prepared for ESTCP by Solutions-IES, Inc. In no event shall either the United States Government or Solutions-IES have any responsibility or liability for any consequences of any use, misuse, inability to use, or reliance upon the information contained herein, nor does either warrant or otherwise represent in any way the accuracy, adequacy, efficacy, or applicability of the contents hereof.

## LIST OF ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
µg/L	micrograms per liter
µm	micromoles
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence (now: Air Force Center for Engineering and the Environment)
ASTM	American Society for Testing and Materials
CD	chlorite dismutase
Cl <sup>-</sup>	chloride ion
<i>cld</i>	chlorite dismutase gene
cm <sup>3</sup>	cubic centimeters
CO <sub>2</sub>	carbon dioxide
DNA	Deoxyribonucleic acid
DNAPL	dense nonaqueous-phase liquid
DO	dissolved oxygen
DOC	dissolved organic carbon
DoD	Department of Defense
Eh	measure of oxidation-reduction potential
EOS <sup>®</sup>	Emulsified (edible) Oil Substrate
ESTCP	Environmental Security Technology Certification Program
Fe(II)	ferrous iron
Fe(III)	ferric iron
H <sub>2</sub> O	water
IC	ion chromatography
ITRC	Interstate Technology & Regulatory Council
LC	liquid chromatography
MCL	maximum contaminant level
MBT	molecular biological tool
ml	milliliters
mM	milliMolar
<i>mRNA</i>	messenger RNA
MTBE	methyl- <i>tert</i> -butyl ether
mV	millivolts
MNA	monitored natural attenuation
MPN	most probable number

MS	mass spectroscopy
OD	outside-diameter
ORP	oxidation-reduction potential
PCE	perchloroethene or tetrachloroethene
<i>pcr</i>	perchlorate reductase gene
ppb	parts per billion
ppm	parts per million
PRB	permeable reactive barrier
PVC	polyvinyl chloride
qPCR	quantitative polymerase chain reaction
RNA	ribonucleic acid
SERDP	Strategic Environmental Research and Development Program
TCE	trichloroethene
TDS	total dissolved solids
TOC	total organic carbon
USEPA	United States Environmental Protection Agency
VOA	volatile organic analysis
VOCs	volatile organic compounds

## EXECUTIVE SUMMARY

Sources of perchlorate can be both natural and anthropogenic and the extent of perchlorate in the environment is becoming more widely acknowledged. The fate and transport of this inorganic contaminant are still being studied. Because of the potential health risks associated with its consumption, there is regulatory pressure to establish meaningful and realistic goals for cleanup. Depending on the state, regulatory limits for perchlorate in groundwater range from 1 to 24.5 µg/L. Monitored natural attenuation (MNA) is one of several new technologies being evaluated for effectiveness in remediating perchlorate in groundwater.

Acceptance of MNA typically requires multiple lines of evidence. For perchlorate, biodegradation is especially important because it is not readily sorbed, volatilized, or abiotically degraded. Analytical methods are available to monitor the concentration of perchlorate in the environment with high sensitivity and selectivity, geochemical tests can indicate whether ambient conditions are conducive to perchlorate biodegradation, and molecular biological tools are being developed to monitor the activity and sustainability of perchlorate-reducing bacterial populations. When properly applied, MNA of perchlorate can be protective of human and environmental health.

This guidance document presents a systematic tiered approach to determine the potential for natural attenuation of perchlorate in groundwater. The three tiers of evidence include: 1) plume stability; 2) geochemical indicators; and 3) biological indicators (US EPA, 1999).

*Tier 1: Plume Stability and Geometry.* Historical data can be used to delineate the extent of the contamination and determine the fate of contaminants of concern. With a properly designed monitor well network, trends in the data can successfully illustrate plume geometry and stability. Ideally, one should show that the contaminant plume is stable or retreating. A stable or shrinking perchlorate plume would indicate that attenuation processes are removing perchlorate from the groundwater at least as fast as perchlorate is released from the source area. The simplest tools available include visual isopleths maps and concentration trend analysis versus time. Relatively simple statistical techniques can also be used to evaluate plume stability including regression analyses, the Mann-Whitney U Test, the Mann-Kendall Test, and center of mass calculations. The challenge at all sites is to understand the inherent temporal and spatial variability so the data obtained are meaningful and can be correctly interpreted. This can require extensive monitoring with data acquisition over long time periods. Tier 1 monitoring to evaluate changes in the spatial and temporal distribution of perchlorate can offer the first line of evidence that perchlorate is naturally attenuating.

*Tier 2: Bio-geochemical Conditions.* The collection of site-specific bio-geochemical information is the best understood and most widely employed step to evaluate the potential for MNA of perchlorate. Research has shown that many microorganisms have the genetic capability to degrade perchlorate and perchlorate-reducing bacteria are present in numerous and disparate environments. Many of the same parameters important for natural attenuation of chlorinated solvents are equally important for assessing the potential for perchlorate to biodegrade. Optimal conditions for MNA of perchlorate include low dissolved oxygen (i.e., anaerobic or microaerophilic conditions), a reducing environment with a negative oxidation-reduction

potential, pH between 5 and 8, nitrate concentrations less than 5 mg/L, and total organic carbon concentrations greater than 2 mg/L. Elevated methane and reduced iron are also indirect indicators of a favorable environment. The practitioner must keep in mind that these groundwater parameters serve as indicators of favorable conditions for natural attenuation of perchlorate.

*Tier 3: Microbiological Indicators.* For situations where additional lines of evidence are required, Tier 3 offers laboratory and field tests that provide both indirect and direct evidence of perchlorate biodegradation. The perchlorate reductase gene (*pcr*) catalyzes the conversion of perchlorate to chlorate and chlorite. The chlorite dismutase gene (*cld*) reduces chlorite to chloride and oxygen. Qualitative polymerase chain reaction (PCR) and quantitative PCR (qPCR), performed on microbial DNA extracted from site matrices, can provide a sensitive, rapid approach to evaluate the molecular potential for perchlorate biodegradation to occur. When performed on RNA from the same population, these methods are useful as direct measures of on-going bioactivity.

Microcosms and bench-scale column studies can be used to demonstrate that natural attenuation is occurring and to estimate the rate and extent of perchlorate biodegradation. However, these studies are time consuming and expensive to implement and should not be employed until a good understanding of site conditions has been achieved through site investigation activities (i.e., Tier 1 and Tier 2). If laboratory studies are conducted, laboratory biodegradation rate derived from these studies should be used with care since differences between field and laboratory conditions can lead to non-representative results.

Newer field methods including installation of *in situ* columns and stable isotope monitoring can be used where there is expectation that anaerobic biodegradation of perchlorate is occurring. *In situ* columns isolate an intact column of soil and groundwater from the rest of the aquifer and can be used to monitor the rate of perchlorate biodegradation over time within a controlled but natural environment. Isotopic ratios of chlorine and oxygen atoms in perchlorate ( $^{35}\text{Cl}/^{37}\text{Cl}$  and  $^{16}\text{O}/^{18}\text{O}$ ) provide another tool to measure the extent of perchlorate degradation. Stable isotope analysis provides a method for distinguishing biotic from abiotic attenuation since microorganisms often preferentially use lighter isotopes in their metabolic processes. As a contaminant is degraded, the isotopic composition of the remaining material becomes progressively heavier. If there is clear evidence of isotopic shifts, the extent of perchlorate degradation can be estimated using the fractionation factor.

The guidance provided in this document is meant to assist in monitoring the fate of perchlorate in the environment and provide a systematic approach to evaluate the potential for perchlorate MNA. The weight of evidence obtained through this tiered process can be used to identify sites where MNA is a safe and effective approach for managing perchlorate impacted groundwater.

## **1.0 INTRODUCTION**

### **1.1 Purpose of this Document**

The purpose of this document is to provide users with information on: (a) fate, transport and transformation of perchlorate in different geochemical environments; (b) emerging and/or specialized technologies for evaluating perchlorate attenuation in groundwater; and (c) a tiered approach for evaluating the monitored natural attenuation (MNA) of perchlorate. This protocol does not provide a step-by-step guide to MNA of perchlorate. Instead, it presents several procedures to aid the user in determining if natural attenuation processes are sufficient to meet remedial objectives in a reasonable timeframe while protecting human health and the environment. Before implementing a study to assess MNA of perchlorate, users should be generally familiar with previously developed protocols for assessing the MNA of petroleum hydrocarbons and chlorinated solvents. Depending on site-specific conditions and regulatory factors, the user can implement some or all of these procedures to develop a weight-of-evidence case for MNA as a viable remedial strategy for perchlorate-impacted groundwater.

### **1.2 Background**

The acceptance of natural attenuation as a groundwater remedy has grown rapidly over the last decade. In the mid- to late-1980s and into the 1990s, numerous researchers and practitioners in the field of environmental engineering noticed that solute plumes were not migrating nearly as far as predicted based on commonly-held tenants of solute behavior in the subsurface. In fact, many solute plumes were stable or receding. Concurrently, research studies were conducted at several universities to elucidate the causes for the greater-than-predicted solute degradation. These studies determined that biodegradation, both aerobic and anaerobic, was significantly more important than originally thought. In the early- to mid-1990s, several groups, most notably the Air Force Center for Environmental Excellence (AFCEE)<sup>1</sup>, began to take the knowledge gained in the laboratory and apply it at the field-scale. Large amounts of solute and biogeochemical data were collected and used to evaluate plume behavior. It was found that many, if not most, of the solute plumes were stable or receding and that biological mechanisms were largely responsible for keeping the solutes from migrating downgradient with the advective flow of groundwater. Based on the information gained from these studies, several technical protocols for evaluating the natural attenuation of common contaminants were published. Although these documents are still valid as a framework for evaluating the natural attenuation of many common contaminants in the subsurface, perchlorate does not fall neatly into the groups of contaminants discussed in the commonly cited protocols. The approach presented in this document references framework protocols for the reader's use, but details the mechanisms specific to the natural attenuation of perchlorate.

---

<sup>1</sup> Name changed to Air Force Center for Engineering and the Environment in 2007.

### 1.3 Monitored Natural Attenuation

The U.S. Environmental Protection Agency (EPA) defines MNA as a "knowledge-based" remedy that relies upon natural processes of contaminant attenuation to achieve site-specific remediation requirements within a reasonable time frame as compared to other more active methods (USEPA, 1997). These natural processes include a variety of physical, chemical, and biological methods, such as biodegradation, dilution, sorption and volatilization that under favorable conditions reduce the mass, toxicity, mobility, volume, or concentration of contaminants without human intervention (USEPA, 1997). Like enhanced bioremediation, MNA requires an in-depth understanding of the microbiology, chemistry, and hydrogeology of the environment under consideration (ITRC, 2002). Unlike enhanced bioremediation, MNA does not involve the active anthropogenic manipulation of *in situ* conditions. Instead, an evaluation of natural attenuation typically involves an assessment of: 1) site geology and hydrogeology, 2) the nature and disposition of the contaminants, and 3) the efficacy of degradation mechanisms (typically biological) in removing contaminant mass from the system. Taken together, the assessment of these parameters allows the investigator to determine if naturally occurring processes are capable of achieving remediation goals in a reasonable period of time (ITRC, 2002). In addition, an evaluation of natural attenuation typically takes into account the biodegradation rates and the suitability of the natural biogeochemical conditions to support or sustain attenuation.

MNA has evolved as an accepted remedial approach for petroleum hydrocarbons (ASTM, 2004) and chlorinated solvent groundwater plumes (Wiedemeier et al., 1998). Although less widely accepted, MNA has also been applied for other contaminants, such as methyl-*tert*-butyl ether (Wilson et al., 2005), wood preservatives (Stroo et al., 1997), and nitroaromatic explosives (Pennington et al., 1999). Numerous guidance documents and technical protocols are available to assist users with evaluating and implementing MNA for various contaminants. These documents include:

- ASTM, 2004. *Standard Guide for Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites*. Standard E 1943-98 (Reapproved 2004), American Society for Testing and Materials, West Conshohocken, PA.
- Wiedemeier, T.H., 1995. *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater*. Air Force Center for Environmental Excellence.
- Wiedemeier, T.H. et al., 1998. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*. USEPA., EPA/600/R-98/128.
- Wiedemeier, T.H. et al., 2006. *Designing Monitoring Programs to Effectively Evaluate the Performance of Natural Attenuation*. Air Force Center for Environmental Excellence.
- Kennedy, L. et al., 2000. *Aqueous and Mineral Intrinsic Bioremediation Assessment (AMIBA) Protocol*. Air Force Center for Environmental Excellence.
- AFCEE, 1999. *Methyl tert-Butyl Ether (MTBE) – Its Movement and Fate in the Environment and Potential for Natural Attenuation*. Air Force Center for Environmental Excellence.

- Wilson, J.T., 2000. *Natural Attenuation of MTBE in the Subsurface under Methanogenic Conditions*. USEPA, EPA/600/R-00/006.
- Pennington, J.C. et al., 1999. *Draft Protocol for Evaluating, Selecting, and Implementing Monitored Natural Attenuation at Explosives-Contaminated Sites*. Technical Report EL-99-10, U.S. Army Engineer Research Center. September 1999.
- American Petroleum Institute, 2007. *Protocol for Evaluating the Natural Attenuation of MTBE in Groundwater*.

Although MNA has become a widely accepted approach for remediation of all of these contaminants, MNA of perchlorate is still in a relatively immature stage of development.

#### **1.4 EPA Policy on Monitored Natural Attenuation**

Office of Solid Waste and Emergency Response (OSWER) Directive 9200.4-17 (USEPA, 1997) establishes EPA's expectations for application of MNA. In general, the appropriateness of MNA should be supported by site-specific data and analysis used in conjunction with a conceptual site model of contaminant fate and transport. Additionally, once those data have been collected and the model developed, the potential successfulness of MNA as a remediation strategy should be evaluated by collecting more detailed site-specific information about:

- 1) Historical data on groundwater and/or soil chemistry to demonstrate a decrease in contaminant mass and/or concentration;
- 2) Hydrogeologic and geochemical data to demonstrate indirectly the types of natural attenuation (specifically degradation) occurring at the site; and
- 3) Data from field or microcosm studies which directly demonstrate the occurrence of specific natural attenuation processes at the site.

Generally, the historical data (number 1 above) are accompanied by data identifying the natural attenuation processes (number 2 above) unless the EPA or other overseeing regulatory agency deems otherwise. Data from microcosm studies (number 3 above) are required when information provided by items 1 and/or 2 are not conclusive enough to be self-supporting. As with other remediation methods, long-term monitoring and documentation are required to ensure that the risk is being reduced to acceptable levels (USEPA, 1997). Table 1-1 summarizes the EPA's policy on MNA.

**Table 1-1: Summary of the EPA MNA Policy (Pennington et al., 1999)**

<b>General Elements in the Evaluation of Monitored Natural Attenuation</b>	<b>Related Factors, Issues, and Actions</b>
Role of monitored natural attenuation in the remedy selection process	<ul style="list-style-type: none"> <li>• May be an appropriate alternative under a limited set of circumstances</li> <li>• May be evaluated and compared with other viable remedies during the study phases leading to the selection of remedy</li> <li>• May be cautiously evaluated as a sole remedy</li> <li>• May be evaluated as a component of a total remedy that includes engineered remedial measures</li> <li>• May be evaluated as a follow-on to engineered remediation</li> <li>• Must not be considered a default or presumptive remedy</li> </ul>
General requirements for the selection of monitored natural attenuation as a remedy	<ul style="list-style-type: none"> <li>• Must meet all relevant remedy selection criteria</li> <li>• Must be fully protective of human health and the environment</li> <li>• Must meet site remediation objectives within a reasonable time frame compared with other methods</li> <li>• Must be supported by detailed site-specific information that demonstrates its efficacy</li> <li>• Must evaluate all contaminants that represent an actual or potential threat to human health or the environment</li> <li>• Must include opportunities for public involvement to both educate and gather feedback from interested parties</li> </ul>
Requirements for the demonstration of the effectiveness of monitored natural attenuation through site characterization	<ul style="list-style-type: none"> <li>• Site characterization will involve the collection and development of data and conduct of analyses to demonstrate that natural attenuation can meet the remedial action objectives. At a minimum, the following actions will be required:               <ul style="list-style-type: none"> <li>○ Collect data to define nature and distribution of contamination sources</li> <li>○ Collect data and conduct analyses to define the extent of the groundwater plume and potential impacts on receptors</li> </ul> </li> <li>• Other data and information required will be dependent upon site-specific characteristics, the nature of the contaminants, and the natural attenuation process(es) being evaluated</li> <li>• Data quality must be adequate, levels of confidence on attenuation rates documented, and sensitivity analyses performed to determine dependence of calculated remediation timeframes on uncertainties in rate constants and other factors</li> </ul>
Requirements for the evaluation of the efficacy of monitored natural attenuation through site-specific lines of evidence	<ul style="list-style-type: none"> <li>• The evaluation of efficacy may include the collection and evaluation of the following data and information:               <ul style="list-style-type: none"> <li>○ Historical groundwater and soil data that clearly demonstrate declining contaminant concentrations and/or masses</li> <li>○ Hydrogeologic or geochemical data that can indirectly demonstrate the mechanisms involved in natural attenuation at the site and the rate at which contaminant reductions occur</li> <li>○ Data from field or microcosm studies that demonstrate the occurrence of a natural attenuation process and its ability to effect contaminant reductions (particularly through degradation)</li> </ul> </li> </ul>
Requirements for the implementation of monitored natural attenuation	<ul style="list-style-type: none"> <li>• Source control and performance monitoring should be fundamental components of the remedy</li> <li>• Institutional controls may be necessary</li> <li>• Performance monitoring should continue as long as contamination remains above cleanup levels</li> <li>• Remedies employing natural attenuation should include evaluation of need for one or more contingency remedies</li> </ul>

Adapted from EPA, 1999.

The advantages and disadvantages of monitored natural attenuation compared to other remediation processes were identified in OSWER Directive 9200.4-17 (USEPA, 1997) as follows:

The **advantages** of MNA remedies include:

- As with any *in situ* process, generation of lesser volume of remediation wastes reduced potential for cross-media transfer of contaminants commonly associated with *ex situ* treatment, and reduced risk of human exposure to contaminated media;
- Less intrusion as few surface structures are required;
- Potential for application to all or part of a given site, depending on site conditions and cleanup objectives;
- Use in conjunction with, or as a follow-up to, other (active) remedial measures; and
- Lower overall remediation costs than those associated with active remediation.

The potential **disadvantages** of MNA include:

- Longer time frames may be required to achieve remediation objectives, compared to active remediation;
- Site characterization may be more complex and costly;
- Toxicity of transformation products may exceed that of the parent compound;
- Long-term monitoring will generally be necessary;
- Institutional controls may be necessary to ensure long-term protectiveness;
- Potential exists for continued contamination migration, and/or cross-media transfer of contaminants;
- Hydrologic and geochemical conditions amenable to natural attenuation are likely to changeover time and could result in renewed mobility of previously stabilized contaminants, adversely impacting remedial effectiveness; and
- More extensive education and outreach efforts may be required in order to gain public acceptance of monitored natural attenuation.

In general, each state has its own guidance on the use of MNA. Therefore, the appropriate state regulatory agency should be consulted to determine their current policy.

## **2.0 FATE AND TRANSPORT OF PERCHLORATE IN GROUNDWATER**

### **2.1 Purpose of this Section**

Groundwater and surface water contaminated with perchlorate have become a major environmental issue for the US Department of Defense (DoD) due to the use, release and/or disposal of solid rocket fuel and munitions containing ammonium perchlorate. Perchlorate is highly mobile and soluble and sorbs poorly to most aquifer material. It can persist for decades under aerobic conditions. As a consequence, discharge of perchlorate to the environment has resulted in extensive contamination of surface and groundwater supplies. In 1997, the California Department of Health Services (CaDHS) developed an analytical technique to detect perchlorate concentrations as low as 4 µg/L (Motzer, 2001). Since then, perchlorate concentrations at or above 4 µg/L have been found in the surface and groundwaters in over 35 states (USEPA, 2005b). In the western US, over 15 million people consume water with some level of perchlorate.

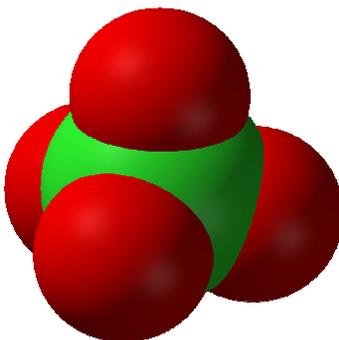
The human health concern from perchlorate is the inhibition of iodide uptake resulting from decreased thyroid hormone output which can disrupt metabolism (USEPA, 2005b). Additionally, environmental health concerns are associated with the uptake of perchlorate in food crops such as lettuce and milk (Kirk et al., 2003; USEPA, 2005b; Jackson et al., 2005, Renner, 2006). Currently, there is no federal cleanup standard for perchlorate in groundwater or soil (USEPA, 2005; ENS, 2006). In January 2006, the USEPA issued “Assessment Guidance for Perchlorate” identifying 24.5 µg/L as the recommended value “to be considered” (TBC) and preliminary remediation goal for perchlorate (USEPA, 2006). In 2006, California proposed a maximum contaminant level (MCL) for perchlorate in drinking water of 6 ppb (CaDHS, 2006). In July 2007, Massachusetts became the first state in the nation to promulgate drinking water and wastewater standards for perchlorate, adopting a standard of 2 ppb and requiring most public water systems to regularly test for perchlorate (ENS, 2006). Several states, but not all, have identified perchlorate advisory levels. These range in concentration from 1.0 to 52 µg/L. Remediation practitioners should consult with local regulatory authorities before adopting specific cleanup goals for their site.

In recent years, an extensive body of information has been developed demonstrating that a large and diverse population of microorganisms can degrade perchlorate to chloride and oxygen (Coates et al., 1999; Coates and Pollock, 2003). Perchlorate-reducing organisms are widespread in the environment (Coates et al., 1999; Logan, 2001) including pristine and hydrocarbon-contaminated soils, aquatic sediments, and industrial and agricultural waste sludges (Gingras and Batista, 2002). Perchlorate biodegradation can occur under strict anaerobic conditions as well as facultative anaerobic conditions, i.e., in mixed aerobic/anaerobic environments. This metabolic versatility suggests that environments exist that can support a variety of perchlorate-reducing microbial populations and that perchlorate may naturally degrade at some sites without active human intervention. Because there is a strong potential for MNA of perchlorate where site conditions are appropriate, identifying lines of evidence that suggest which sites are amenable to perchlorate MNA is highly important. The purpose of this section is to identify the sources and

characteristics of perchlorate so that appropriate lines of evidence can be selected to evaluate perchlorate MNA.

## 2.2 Sources of perchlorate

Perchlorate ( $\text{ClO}_4^-$ ) is composed of a chloride atom bonded to four oxygen atoms (Figure 2-1).



**Figure 2-1: Perchlorate Anion (ITRC, 2005)**

Perchlorate is usually found as the anion component of a salt and is released when the solid salts of ammonium, sodium, or potassium perchlorate and perchloric acid dissolve in water (Motzer, 2001).

### 2.2.1 Anthropogenic Sources

Perchlorate has been manufactured since the 1890s and is most commonly found as a manufactured compound (ITRC, 2005). The most common compounds<sup>2</sup> are ammonium perchlorate, sodium perchlorate, potassium perchlorate, and perchloric acid. Of these, in the United States, approximately 90% of the production is of ammonium perchlorate (Xu et al., 2003). Ammonium perchlorate is used as an oxidizing agent for solid propellant rockets and missiles. Other common uses for perchlorate are indicated in Table 1-2. Based on these uses, the presence of co-contaminants such as volatile organic compounds (VOCs), halogenated solvents, explosive compounds [e.g., trinitrotoluene (TNT); hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX); and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)], nitrate, and sulfate are also found with perchlorate (ITRC, 2002).

---

<sup>2</sup> See Appendix C of ITRC (2005) for a listing of additional, less-common manufactured perchlorate compounds.

**Table 1-2: Uses of Perchlorate (ITRC, 2005)**

Chemical and Electrical Uses	Explosive and Propellant Uses	Miscellaneous Uses
cathodic protection systems brine separation chlorate/chlorite manufacturing cloud seeding dielectric for transformers electroplating	military devices geoseismic devices chemical cutter ordnance tracer bullets solid rocket motor rocket motor airbags ejection seats fireworks	steel plate bonding Li-ion batteries enamel paints fertilizer laundry bleach pharmaceutical diagnosis/treatment pool sanitizer

### 2.2.2 Natural Sources

Perchlorate can be naturally occurring, but its exact origins are not known with certainty. A current theory suggests that in a process similar to nitrate formation in the atmosphere, chloride reacts with ozone to form perchlorate. Additionally, natural sources of perchlorate have been limited to arid regions and are often found as evaporite minerals in such natural materials as bromine, borates, gypsum, and nitrogen compounds (ITRC, 2005). In nature, the highest concentrations of perchlorate are found in Chilean caliche and potash ores (ITRC, 2005). Recent research has used isotopic fractionation methods to characterize perchlorate found in different locations worldwide to determine differences between naturally occurring and anthropogenic sources (Sturchio et al., 2006; Bohlke et al., 2005; Hatzinger et al., 2007).

There are other projects that are continuing to examine the natural occurrence of perchlorate. These include two ESTCP-funded projects: Evaluation of Alternative Causes of Widespread, Low Concentration Perchlorate Impacts to Groundwater (ER-1429) and Identification and Characterization of Natural Sources of Perchlorate (ER-1435). The reader is encouraged to review these documents for additional information on this topic.

## 2.3 Physical and Chemical Properties of Perchlorate

The properties of common perchlorate salts are shown in Table 2-1.

**Table 2-1: Properties of Perchlorate Compounds (ITRC, 2005)**

Properties	Ammonium perchlorate (NH <sub>4</sub> ClO <sub>4</sub> )	Potassium perchlorate (KClO <sub>4</sub> )	Sodium perchlorate (NaClO <sub>4</sub> )	Perchloric acid (HClO <sub>4</sub> )
CAS#	7790-98-9	7778-74-7	7601-89-0	7601-90-3
Molecular weight	117.49	138.55	122.44	100.47
Color/form	White orthorhombic crystal	Colorless orthorhombic crystal or white crystalline powder	White orthorhombic deliquescent crystal	Colorless oily liquid
Taste/odor	Odorless	Slightly salty	Odorless	Odorless
Density/specific gravity	1.95 g/cm <sup>3</sup>	2.53 g/cm <sup>3</sup>	2.52 g/cm <sup>3</sup>	1.67 g/cm <sup>3</sup>
Solubility	200 g/L water @25°C	15 g/L water @25°C	2096 g/L water @25°C	miscible in cold water
Sorption capacity	Very low	Very low	Very low	Very low
Volatility	Nonvolatile	Nonvolatile	Nonvolatile	Volatile
Octanol/H <sub>2</sub> O partition coefficient (log Kow)	-5.84	-7.18	-7.18	-4.63
Vapor density (air = 1)	No information	4.8	No information	3.5
pH	5.5 to 6.5	6.0 to 8.5	7.0	Highly acidic

Although dissolved perchlorate tends to be associated with groundwater, it important to recognize that other factors such as density and aquifer surface charge may also influence the fate and transport of perchlorate within the aquifer. For example, solid perchlorate salts like ammonium perchlorate and highly concentrated solutions of perchlorate, known as brine, can behave similarly to dense non-aqueous phase liquid (DNAPL) when released into an aquifer system. As such, the perchlorate tends to sink through the water column until the mass reaches a low permeability confining layer (Motzer, 2001) where it persists causing secondary or recurring perchlorate contamination (ITRC, 2002). Additionally, Motzer (2001) references studies showing that the ammonium cation derived from ammonium perchlorate brines will displace all other exchangeable cations in the soil matrix when it is retarded in soil. One study of silt and clay samples from the saturated zone and/or aquitard with high cation concentrations suggests that high concentrations of ammonium would remain in the soil and provide forensic clues regarding the source of perchlorate and plume history (Motzer, 2001).

## 2.4 Attenuation Processes

Several sources can be referenced for details and definitions of fate and transport mechanisms controlling environmental contaminants (Wiedemeier et al., 1995; Wiedemeier et al., 1998; Wiedemeier, 1999; ITRC, 2002). In general, these processes are controlled by both the contaminant's physical and chemical properties as well as the properties of the media through which the compound travels. The movement of perchlorate in soil is dependent on the amount of water present since perchlorate does not readily bond to soil particles (ITRC, 2005). Both abiotic and biologic processes affect the transformation of groundwater contaminants. However, abiotic reactions are much slower than biologic ones and are typically assumed to be negligible for perchlorate (ITRC, 2002). Table 2-2 summarizes the important attenuation processes.

**Table 2-2: Summary of Important Subsurface Processes Acting on Perchlorate**  
(Wiedemeier, 1999; ITRC, 2002)

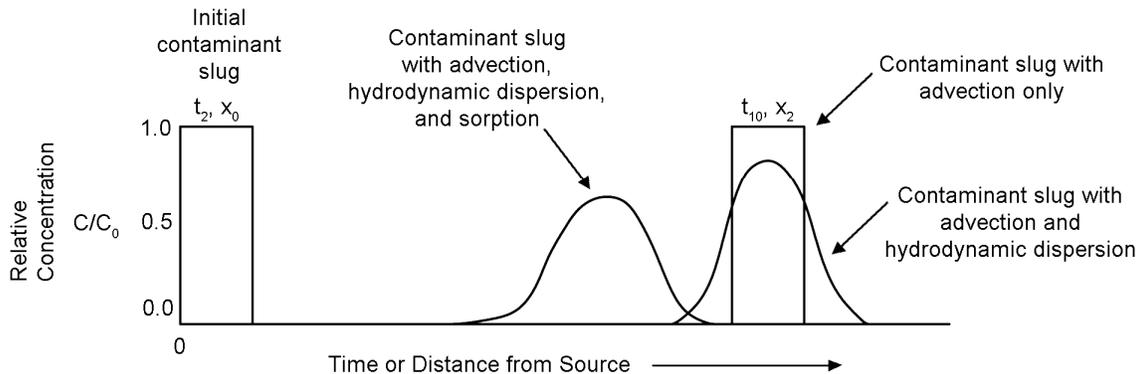
Process	Description	Dependencies	Effect
Advection	Movement of solute by bulk groundwater movement.	Dependent on aquifer properties such as hydraulic conductivity, effective porosity, and hydraulic gradient. Independent of contaminant properties.	Main mechanism driving contaminant movement in the subsurface.
Dispersion	Fluid mixing due to groundwater movement and aquifer heterogeneities.	Dependent on aquifer characteristics and scale of observation. Independent of contaminant properties.	Causes longitudinal, transverse, and vertical spreading of the plume. Reduces solute concentration.
Diffusion	Spreading and dilution of contaminant due to molecular diffusion.	Dependent on contaminant properties and concentration gradient. Described by Fick's Laws.	Diffusion of contaminant from areas of relatively high concentration to areas of relatively low concentration. Generally unimportant at most groundwater flow velocities.
Sorption	Reaction between aquifer matrix and solute.	Dependent upon aquifer matrix properties (organic carbon and clay mineral content, bulk density, specific surface area, and porosity) and contaminant properties (solubility, hydrophobicity, octanol-water partitioning coefficient).	Tends to reduce solute transport rate and remove solutes from the groundwater via sorption to the aquifer matrix.
Infiltration (Simple Dilution)	Infiltration of water from the surface to the subsurface.	Dependent upon the aquifer matrix properties, depth to groundwater, and climate.	Causes dilution of the contaminant plume and replenishes electron acceptor concentrations, especially dissolved oxygen.
Biodegradation	Microbially-mediated oxidation-reduction reactions that transform perchlorate to chloride and oxygen.	Dependent on groundwater geochemistry, microbial population, and contaminant properties. Perchlorate is biodegradable under anaerobic and facultative anaerobic conditions.	Results in complete mineralization of perchlorate to chloride and oxygen.

### **2.4.1 Advection and Dispersion**

Two mechanisms for contaminant movement in groundwater are advection and hydrodynamic dispersion. Advection is the movement of contaminants in the direction of and at the velocity of groundwater flow. Advection usually provides a greater contribution to mobility where the contaminant is highly soluble in water. Assuming that advection is the dominant mechanism, contaminant movement can be estimated using Darcy's Law.

Hydrodynamic dispersion is another mechanism for contaminant movement. Hydrodynamic dispersion is the sum of both molecular diffusion and mechanical mixing and results in the outward spread of or dilution of a dissolved contaminant apart from the flow of contaminants due to advection alone. Molecular diffusion is a result of the thermal-kinetic energy of the solute particles, and is typically important at low groundwater velocities while mechanical dispersion is the spreading of molecules as a result of interactions between the advective movement of the contaminant and the porous structure of the medium. For perchlorate, these processes are known as nondestructive mechanisms because they result in the reduction of concentration, but not the total mass. In general, as longitudinal dispersivity increases, the maximum concentration decreases and the time to reach steady state increases (Newell et al., 2002). Figure 2-2 illustrates a one-dimensional breakthrough curve showing plug flow resulting from advection and dispersion. This spreading occurs both in the direction of groundwater flow, longitudinal dispersion, as well as perpendicular to groundwater flow, transverse dispersion.

There are several forms of perchlorate salts that are manufactured in large amounts. In general, perchlorate salts are very soluble and once released to the environment will leach downward through the vadose zone into the groundwater with water infiltrating from the surface. In dilute concentrations, the leached perchlorate will travel with the average velocity of the groundwater. However, dispersion will often cause the leading edge of the contaminant to move somewhat faster than the average groundwater velocity (ITRC, 2005).



**Figure 2-2: Plug Flow Resulting from Advection Only and Advection and Dispersion**  
(Wiedemeier et al., 1999)

Dispersion can facilitate biodegradation by spreading the perchlorate beyond that anticipated by advection alone (ASTM, 2004).

## 2.4.2 Sorption to Aquifer Material

Sorption is the process where dissolved contaminants absorb onto soil surfaces (ASTM, 2004) and, therefore, play an important role in fate and transport. The chemical properties of the contaminant determine how strongly it will absorb onto soil surfaces. For example, the concentrations of a contaminant in groundwater will be reduced if a dissolved contaminant absorbs strongly to the soil, and becomes part of the aquifer matrix.

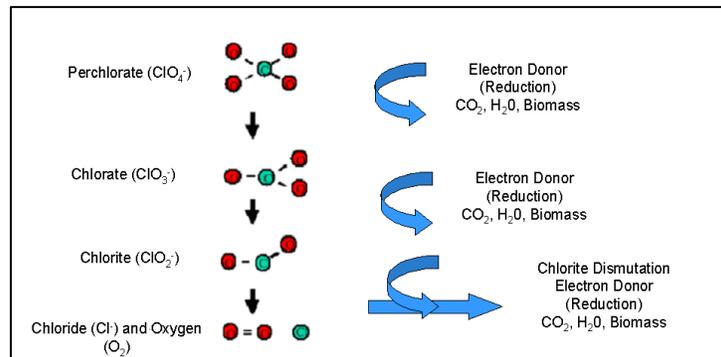
Sorption is considered a non-destructive mechanism because it only affects a contaminant's mobility and concentration and does not reduce the total mass present in the aquifer. It is generally assumed that anions such as bromide ( $\text{Br}^-$ ), chloride ( $\text{Cl}^-$ ), nitrate ( $\text{NO}_3^-$ ) and perchlorate ( $\text{ClO}_4^-$ ) do not sorb to aquifer materials because the most common clay minerals have a net negative charge. However, it is possible for the charge of aquifer materials to be altered. For example, some minerals and poorly crystalline iron oxides become more positively charged at low pH (Brooks et al., 1998) and do not bind as strongly to anions present in the aquifer. Under these conditions, movement of  $\text{Br}^-$ ,  $\text{Cl}^-$ , and  $\text{NO}_3^-$  can be somewhat retarded by anion exchange occurring on the positively charged surfaces (Brooks et al., 1998; Clay et al., 2004). This suggests that  $\text{ClO}_4^-$  might also sorb to sediment surfaces under certain conditions, and slow the movement of perchlorate within the aquifer system.

Perchlorate is generally assumed to sorb very weakly to soil surfaces and tends to migrate at essentially the same velocity as the groundwater (ITRC, 2002). Since many other groundwater contaminants (e.g., tetrachloroethene and trichloroethene) sorb to soil surfaces, perchlorate may appear to advance more rapidly than other contaminants (Motzer, 2001).

### 2.4.3 Biodegradation Processes

Biodegradation is usually the most important destructive process when gaining acceptance of MNA as a remedial strategy for a site. The reduction of perchlorate is a thermodynamically favorable reaction, but the reaction is impeded by high activation energy. This makes perchlorate very chemically stable under normal groundwater and surface water conditions (Urbansky, 1999; NASA, 2006). Perchlorate has been shown to biodegrade via a three-step reduction mechanism in which perchlorate is sequentially reduced to chlorate, chlorite, and finally the innocuous end products chloride and oxygen (Rikken et al., 1996). This pathway is illustrated in Figure 2-3. This enzyme-catalyzed reduction is very similar to biodenitrification. The perchlorate reducing microorganisms produce an enzyme that allows them to lower the activation energy for perchlorate reduction and to use perchlorate as an alternate electron acceptor for metabolism in place of oxygen or nitrate (NASA, 2006).

The first two steps in the breakdown of perchlorate are mediated by the same enzyme, perchlorate reductase. The rate-limiting step in the three-step degradation process is the initial conversion of perchlorate to chlorate. Once converted, the chlorate is readily catalyzed to chlorite by the same enzyme. Chlorite removal by the chlorite dismutase (CD) enzyme is the final step in perchlorate reduction (Xu and Logan, 2003). The specificity of the CD enzyme may be useful as an indicator of perchlorate biodegradation and, therefore, provide supporting evidence for MNA of perchlorate at certain sites. This is further discussed in Section 3.4.3.



**Figure 2-3: Perchlorate Biodegradation Pathway**

An extensive body of information has been developed demonstrating that a wide diversity of microorganisms can degrade perchlorate to chloride and oxygen (Coates et al., 1999; Coates and Pollock, 2003; Xu and Logan, 2003). Perchlorate-reducing bacteria are widespread in the environment (Coates et al., 1999; Logan, 2001). Perchlorate-reducing bacteria are phylogenetically diverse with members in the alpha, beta, gamma, and epsilon subclasses of the Proteobacteria phylum (Coates and Achenbach, 2004). Experiments conducted by Coates et al. (1999) showed that perchlorate-reducing bacteria are completely oxidizing, gram-negative, and non-fermenting facultative anaerobes and are readily found in both contaminated and pristine environments. Most of these bacteria can also utilize nitrate as an electron acceptor suggesting

that perchlorate reduction is distinct from nitrate reduction (Coates et al., 1999; Chaudhuri et al., 2002).

These organisms use either chlorate or perchlorate as a terminal electron acceptor and can use a variety of different organic substrates (e.g., acetate, propionate, lactate, soybean oil) as electron donors (Herman and Frankenberger, 1998; Coates et al., 1999; Borden et al., 2006; Schaefer et al., 2007). Perchlorate biodegradation can occur under strict anaerobic conditions as well as facultative anaerobic and microaerophilic conditions (Rikken et al., 1996; Chaudhuri et al., 2002; Coates and Achenbach, 2004). When biodegradable organic substrates are present, the available dissolved oxygen will be consumed and there is a very high probability that perchlorate will biodegrade. Recent work has suggested that biological perchlorate reduction also can be linked to insoluble inorganic substrates. Ju et al. (2007) demonstrated that a chemolithotrophic enrichment culture could effectively couple the oxidation of elemental sulfur to sulfate with the reduction of perchlorate to chloride. The energy gained from the process was used for cell growth.

For *in situ* biodegradation to occur, other favorable geochemical conditions must also be present. For perchlorate reduction, potentially favorable geochemistry includes a pH between 6.5 and 7.5, ORP between 0 and -100 mV, low oxygen concentrations, and low nitrate levels (ITRC, 2002). In addition, studies and observations indicate that the presence of molybdenum may be required by perchlorate-reducing bacteria (Chaudhuri et al., 2002). The bioavailability of molybdenum is often a limiting nutrient in soils, especially acidic soils where adsorption reduces the availability of these salts at lower pHs (Chaudhuri et al., 2002). The implication of molybdenum dependence on perchlorate bioremediation strategies is important and may explain the persistence of perchlorate even in the presence of perchlorate-reducing bacteria (Chaudhuri et al., 2002). However, these different trace mineral requirements may only be required by laboratory media (Xu et al., 2003).

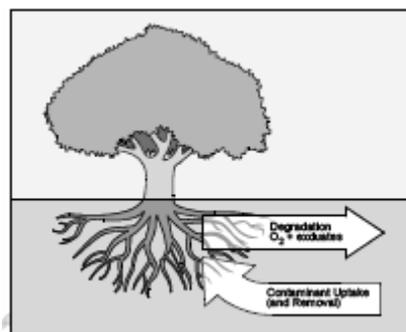
#### **2.4.4 Abiotic Degradation Processes**

By definition, abiotic processes are either chemical or physical. Typical abiotic mechanisms include the dilution, dispersion, and adsorption of chemical reactivity and result in the chemical reduction of perchlorate (Coleman et al., 2003; Sturchio et al., 2003). Since considerable energy (light, heat or another catalyst) is required to reduce the chlorine atom from a +7 oxidation state to a -1 state, chemical reduction of perchlorate is not seen in subsurface environments or in the laboratory even when the Eh of water is lowered to less than -200 mV (Motzer, 2001). It is presumed that dilution and precipitation have the most effect on the migration of perchlorate (Motzer, 2001; ITRC, 2002). Dilution causes the concentration of perchlorate to be significantly less the further away from the contamination source a sample is taken. While precipitation decreases the mobility of perchlorate, as a salt, perchlorate re-dissolves, is transported, and precipitates again in a continuous loop process.

#### **2.4.5 Phytoremediation**

Phytoremediation is a process, illustrated in Figure 2-4, that uses plants to remediate contaminated soil, surface water, and groundwater. Phytoremediation comprises different plants species and plant-mediated processes (Pilon-Smits, 2005). Many shrubs, trees, grasses, or

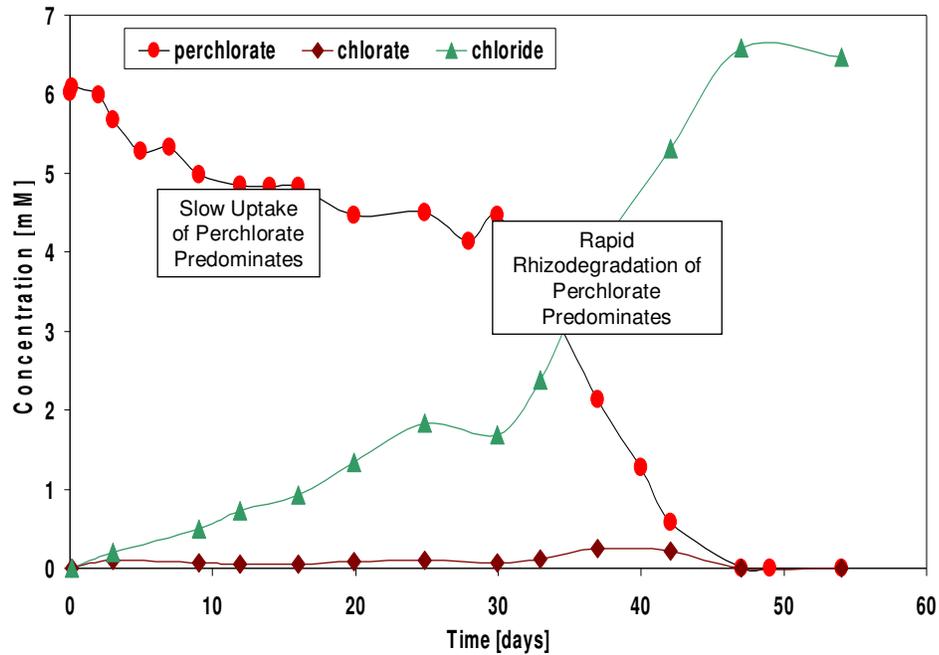
wetland plants (and/or their associated microorganisms) can extract, sequester, transform, degrade or transpire the contaminants (McCutcheon and Schnoor, 2003). Bench scale studies confirm that plants can be effective for reducing concentrations of perchlorate-contaminated surface water, groundwater and soils (Nzengung et al., 1999; Susarla et al., 1999, 2000; Nzengung et al., 2004; Nzengung and McCutcheon, 2003; Schnoor et al., 2002; Yifru and Nzengung, 2007b). Poplar trees and willow trees can degrade perchlorate completely to chloride (Xu et al., 2002).



**Figure 2-4: Phytoremediation Processes** (EPA, 2005)

Perchlorate concentrations can be reduced by plants by two mechanisms: 1) uptake and phytodegradation, and 2) rhizodegradation (Nzengung et al., 1999; Nzengung et al., 2004). The amount of perchlorate taken up and phytoaccumulated by terrestrial and aquatic plants is influenced by several factors, including: 1) the perchlorate concentration, 2) the type of plant species, and 3) the season. Rhizodegradation depends on the availability of dissolved organic carbon (DOC) or other electron donors and favorable biodegradation conditions in the rhizosphere. The concentration of available DOC is a limiting factor in the rhizodegradation of perchlorate (Mwegoha et al., 2007).

Rhizodegradation is more rapid and therefore a more desirable process for natural perchlorate biodegradation (Nzengung and McCutcheon, 2003; Yifru and Nzengung, 2007a, b). Figure 2-5 shows the initial removal of perchlorate from water by slow plant uptake followed by rapid removal of perchlorate by rhizodegradation. The much higher rate of chloride formation is observed during the rhizodegradation phase. Chlorate formed as an intermediate degradation product of perchlorate does not persist in the root zone.



**Figure 2-5: Relative Rate of Perchlorate Degradation by Phytoaccumulation followed by Rhizodegradation (Nzengung et al., 1999)**

Field studies have demonstrated that plant uptake and transformation can be important components of natural attenuation in wetlands impacted by perchlorate (Tan et al., 2004b, Krauter et al., 2005). Therefore, as perchlorate-contaminated groundwater migrates and comes in contact with plants, the opportunity for plant contribution to natural attenuation increases.

### **3.0 TOOLS AND TECHNIQUES FOR EVALUATING PERCHLORATE ATTENUATION**

#### **3.1 Purpose**

Section 2.0 provided a discussion of the sources, characteristics, fate and transport of perchlorate so that appropriate lines of evidence can be selected to evaluate perchlorate MNA. The purpose of this section is to inform the reader of various tools and techniques that can be used to evaluate perchlorate MNA.

The major portion of most perchlorate MNA investigations will include traditional tools to monitor spatial and temporal variations in contaminant concentration and geochemical indicators. The approach used for perchlorate will be very similar to that followed for chlorinated solvents and reader should be familiar with these standard protocols first. Titles of several useful existing protocols are provided earlier in Section 1.3.

#### **3.2 Geochemical Indicators of Perchlorate Attenuation**

Geochemical data can be used to provide supporting evidence of natural perchlorate biodegradation. Groundwater geochemical data from across the site should be reviewed to identify whether favorable conditions for natural attenuation of perchlorate are present. The following subsections describe the geochemical conditions that are preferable for perchlorate biodegradation.

##### **3.2.1 Dissolved Oxygen (DO)**

Dissolved oxygen (DO) is the most thermodynamically favored electron acceptor used by bacteria for the biodegradation of organic carbon, whether natural or anthropogenic (Weidemeier et al., 1998). Obligate anaerobic bacteria generally cannot function at DO concentrations greater than about 0.5 mg/L. In the presence of organic substrate, DO competes with perchlorate as an electron acceptor. Perchlorate-reducing bacteria can be strict anaerobes, microaerophiles or facultative anaerobes (Rikken et al., 1996; Chaudhuri et al., 2002) giving them the ability to grow either in the presence or absence of air, provided proper nutrients are available in the environment. The metabolic versatility of these organisms increases their sustainability in both contaminated and pristine environments.

Perchlorate degradation occurs when it is used as an electron acceptor in the presence of organic donor carbon. Although many perchlorate-reducing bacteria are versatile, DO concentrations greater than 2 mg/L are expected to inhibit perchlorate biodegradation, and DO concentrations less than 1 mg/L are expected to be more favorable for natural attenuation of perchlorate. The continued presence of DO will inhibit the potential for biodegradation of perchlorate. Conversely, in anaerobic environments, the opportunity for perchlorate to degrade in the role of electron acceptor improves.

### 3.2.2 Nitrate

Nitrate is a common co-contaminant in perchlorate contaminated waters. Most perchlorate-reducing bacteria are also denitrifiers and, as noted by Robertson et al. (2007), early work by Herman and Frankenberger (1999) suggested that nitrate-reduction (denitrification) and perchlorate reduction could occur under similar conditions and possibly using the same bacterial populations. Coates et al. (1999) suggested that most, but not all, perchlorate reducers can use nitrate as an electron acceptor and Logan et al. (2001) noted the reverse that some denitrifying bacteria are capable of perchlorate degradation (Logan et al., 2001).

There is evidence that perchlorate reduction can occur in the presence of alternate electron acceptors. Fixed-film bioreactor studies showed that simultaneous removal of DO, nitrate and perchlorate could occur, but oxygen and nitrate needed to be completely removed before complete degradation of perchlorate could be observed (Min et al., 2004; Choi and Silverstein, 2008). Other studies have shown that the presence of nitrate usually decreases the rate of perchlorate reduction (Xu et al., 2003, Choi and Silverstein, 2008), but does not necessarily eliminate it. Nitrate has been shown to negatively regulate the production of chlorite dismutase (CD) and inhibit perchlorate reduction by the perchlorate-reducing bacterium *Dechlorosoma suillum* (Chaudhuri et al., 2002) now known as *Azospira suillum* (Coates and Achenbach, 2006; Tan and Reinhold-Hurek, 2003). However, in some studies, inhibitory effects of nitrate were not observed (Xu et al., 2003).

Tan et al. (2004a) tested microcosms to evaluate degradation kinetics of perchlorate in sediment and soils. They showed that perchlorate degradation was affected by organic substrate availability, but not the concentration of nitrate. They concluded that more than one enzyme is involved and nitrate is not a competitive inhibitor of perchlorate enzyme activity. In further studies, Tan et al. (2004b) and Tan et al. (2005) found that lag time of perchlorate degradation in sediments increased with increased nitrate, but decreased in the presence of higher substrate availability. They concluded that organic substrate availability would become the limiting factor under high electron acceptor conditions.

Studies to date have shown that the impact of nitrate concentrations on potential for perchlorate biodegradation is not absolute. There is no one concentration of nitrate below which perchlorate reduction is optimal. Ideally, low nitrate concentrations provide less competition with perchlorate as an electron acceptor in the environment. However, in presence of excess organic carbon, this may not be as important. Practitioners should consider nitrate status in the environment in conjunction with organic carbon availability and dissolved oxygen status when considering nitrate's potential impact on MNA of perchlorate.

### 3.2.3 Iron

Iron reduction is an anaerobic process in which Fe(III) is reduced to Fe(II). The reduced form of iron is soluble in water. Thus, an increase in dissolved iron can be an indicator of conditions favorable for perchlorate biodegradation. When dissolved iron concentrations are greater than

0.5 mg/L, this indicates anaerobic conditions with a high potential for perchlorate biodegradation.

### **3.2.4 Sulfate**

Sulfate can also be used as an electron acceptor for anaerobic processes. But, sulfate reduction generally occurs after DO, nitrate, perchlorate (if present) and iron have been depleted in the microbiological treatment zone. Whereas sulfate concentration greater than 20 mg/L may cause competitive exclusion of anaerobic dehalorespiration of chlorinated solvents, the same is not true for perchlorate. In microcosms treated with 300 mg/L sulfate, there was no obvious effect on perchlorate biodegradation rates or lag time (Tan et al., 2004a).

### **3.2.5 Methane**

Methane concentrations can be observed in the aquifer when more strongly reducing conditions are achieved, i.e., after depletion of oxygen, nitrate, perchlorate and sulfate has occurred. During methanogenesis, acetate is split to form carbon dioxide and methane, or carbon dioxide is used as an electron acceptor, and is reduced to methane (Weidemeier et al., 1998). Since perchlorate reduction is an anaerobic process, elevated concentrations of methane indicate favorable conditions for the natural attenuation of perchlorate.

### **3.2.6 Oxidation-Reduction Potential (ORP)**

Many aquifers contain bacteria that biodegrade contaminants via electron transfers (ITRC, 2002). The type of biotic chemical contaminant transformations that have the best possibility of occurring are indicated by the oxidation-reduction potential (redox or ORP) of the saturated zone (ITRC, 2002). Redox processes involve a change in valence state of the elements such that some are oxidized and others are reduced (EPA, 2002). The ORP of common chemicals as well as the delineation between aerobic and anaerobic processes are shown in Figure 3-1. Analysis for these chemicals provides information relative to the potential for and the types of bioremediation processes in the groundwater sample. Generally, the ORP is expressed in relation to the standard hydrogen electrode as Eh. Figure 3-1 shows the redox potential for different degradation processes.

ORP is a measure of the electron activity of the groundwater and an indicator of the relative tendency of a solution to accept or transfer electrons. The ORP of a groundwater system depends upon and influences rates of biodegradation (Weidemeier et al., 1998). The ORP of groundwater generally ranges from -400 mV to +800 mV. As illustrated in Figure 3-2, some processes operate most effectively within a prescribed range of ORP conditions.

Figure 3-2 illustrates the sequence of utilization of various electron acceptors found in a perchlorate-contaminated environment, graphically demonstrating why depletion of oxygen and nitrate concentrations must be accomplished before perchlorate can be degraded. It also illustrates why achieving ORP levels necessary for sulfate reduction and methanogenesis are not necessary or preferred for stimulating anaerobic perchlorate reduction. Thus, potentially favorable geochemistry for perchlorate reduction includes an ORP between 0 and -100 mV (ITRC, 2002).

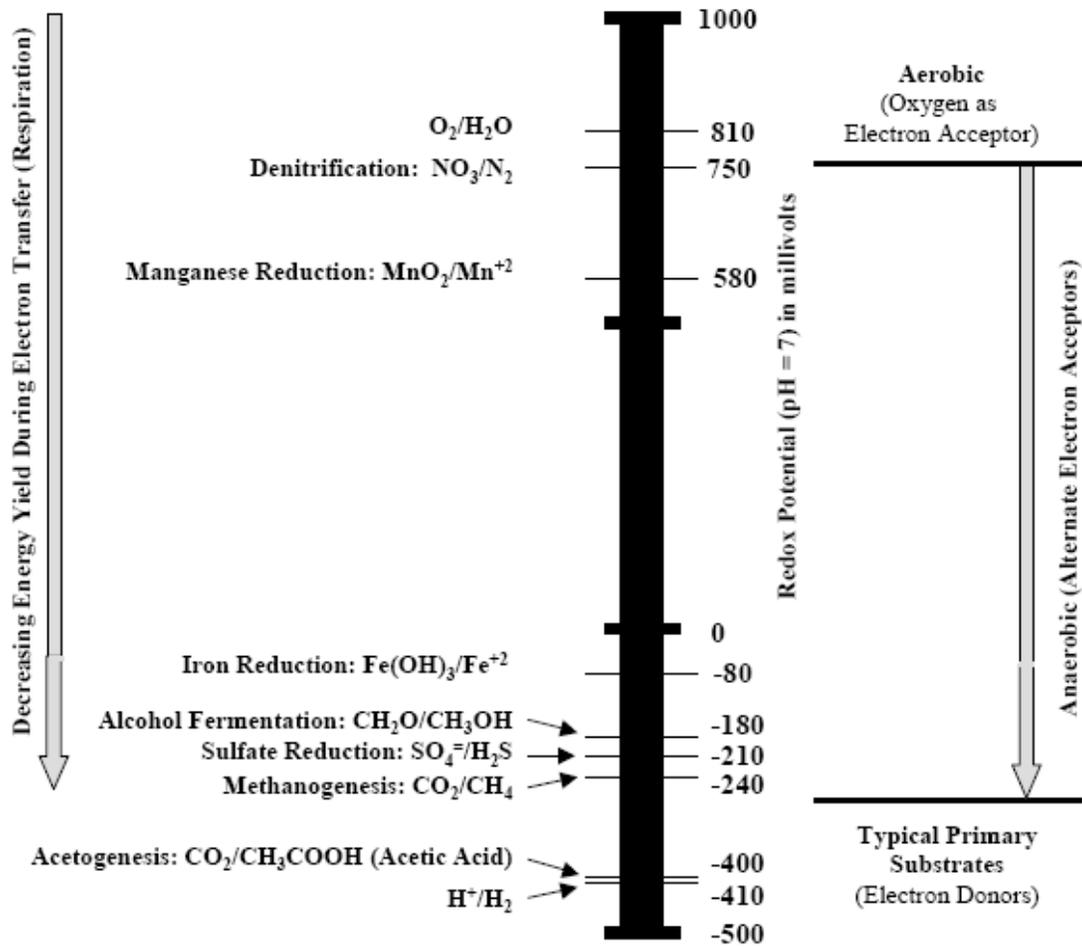
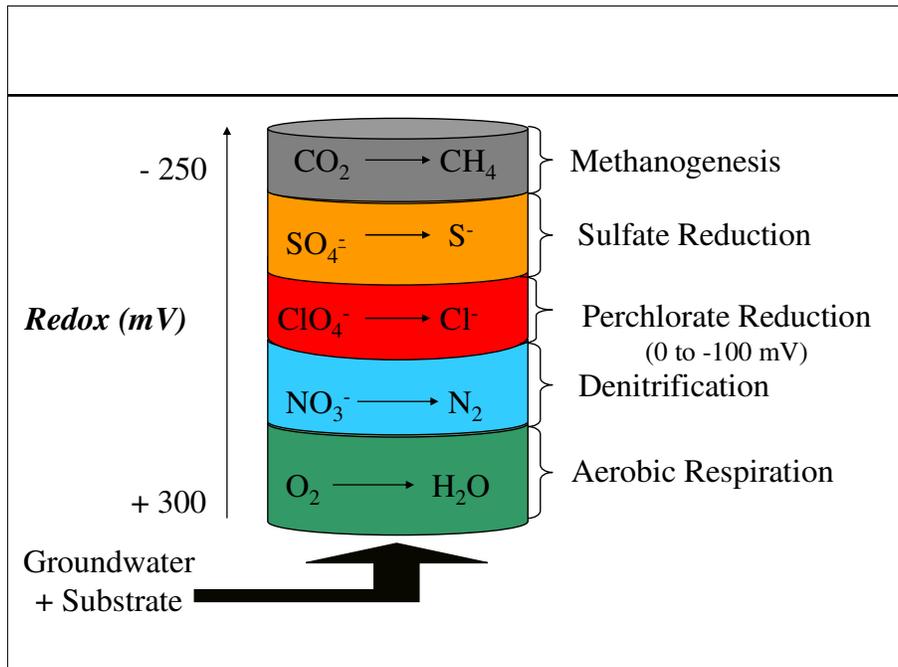


Figure 3-1: ORP of Common Chemical Species (ITRC, 2002)



**Figure 3-2: Redox Potential for Degradation Processes (ITRC, 2002)**

### 3.2.7 pH and Temperature

The presence and metabolic vitality of microorganism can be affected by pH. For example, dechlorinators are pH sensitive and dechlorination rates decline below a pH of 6. At many sites the pH is naturally low and can inhibit reductive dechlorination. However, the pH issue is further complicated by geochemical changes that occur during anaerobic bioremediation. Reduction of iron and manganese oxides and sulfate will consume H<sup>+</sup> causing an increase in pH, while CO<sub>2</sub> production and/or fatty acid accumulation during fermentation of complex substrates can cause a decline in pH.

The perchlorate-reducing bacteria generally grow optimally at pH values near neutrality. However, field studies have shown that some species are capable of growth and perchlorate respiration can occur at pH values as low as 5 (Coates and Achenbach, 2004). In evaluating the potential for MNA of perchlorate, pH values between 6 and 8 are preferable.

As stated by Weidemeier et al. (1995, 1998), “groundwater temperature directly affects the solubility of oxygen and other geochemical species...Groundwater temperature also affects the metabolic activity of bacteria. Rates of hydrocarbon biodegradation roughly double for every 10°C increase in temperature over the temperature range between 5 and 25°C.” This general rule is expected to apply to species capable of reducing perchlorate in the environment.

### 3.2.8 Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC)

For perchlorate degradation to occur, an electron donor must be present. TOC concentrations greater than 10 mg/L are preferable for perchlorate degradation, and TOC concentrations greater than 50 mg/L are believed to be more favorable for MNA.

Substrate demand can be described in terms of the electron acceptor demand exerted by the following three categories (ITRC, 2008):

- **Contaminant (Perchlorate) Electron Acceptor Demand.** Since perchlorate serves as an electron acceptor during biological reduction, there is a stoichiometric relationship for the electron donor (e.g., hydrogen) required to meet the electron acceptor requirements.
- **Native Electron Acceptor Supply.** The flux of groundwater and minerals on the solid aquifer matrix include electron acceptors that in many cases are preferentially used over perchlorate. Therefore, their presence exerts a demand on the electron donor required to satisfy the removal of more energetically favorable electron acceptors, which must occur before conditions conducive to anaerobic biological reduction are established.
- **Non-Specific Demand.** One must expect that a large percentage of indigenous organic materials will be used by opportunistic microbes for a myriad of life processes. In addition, numerous transformations of the solid mineral matrix may occur. Thus, there is a non-specific substrate demand that is not practical to calculate.

The substrate demand must be met until a contaminant source is depleted or until remedial goals have been met. The type of substrate/electron donor can play a role in how thoroughly a natural system is able to transform and perchlorate. In some aquifers, the electron donor demand due to the perchlorate flux alone can overwhelm the natural reducing capacity of the subsurface, so MNA may not be a sustainable long-term remedial option (Nzengung et al., 2008). Under MNA conditions, organic carbon may be available as a result of natural processes. For example, root exudates can promote rhizodegradation making it an effective process in shallow soil contamination situations. Perchlorate degradation half-lives of minutes to hours have been observed depending on the availability of dissolved organic carbon (DOC) or other electron donors.

Organic rich sediments found in wetlands, streams, mudflats and riparian buffers also offer potential conditions that would likely support natural attenuation of perchlorate (Borden et al., 2007). Continuous carbon supply may be provided by dead roots and stems, as well as exudates from the root zone (Tan et al., 2004b). However, Hines et al. (2002) examined perchlorate degradation in several depositional environments in the vicinity of missile launch operations including freshwater and marine sediments and peat and observed that perchlorate was not used as a terminal electron acceptor, at least within the one week duration of their evaluation. They did conclude that extended exposure to perchlorate in these environments would likely result in anaerobic biodegradation to occur. In a demonstration project performed at Indian Head, MD., Knox et al. (2007) showed >99 % decrease in perchlorate concentration as groundwater 8 to 10 feet below ground surface (ft bgs) contaminated with 10,100 µg/L moved vertically upward through a more organic intertidal mixing zone (See Indian Head, MD case study in the Appendix). Increased TOC (4 mg/L) and methane concentrations (450 µg/L) near the surface were measured and an increase in the number of perchlorate reductase gene copies correlated with the locations where perchlorate concentrations were reduced. Together these observations formed lines of evidence supporting the conclusions that MNA was occurring.

### **3.2.9 Trace Metals: Molybdenum**

Molecular studies have indicated the presence of a molybdenum-dependent chaperone gene associated with the genes encoding the CD and perchlorate reductase enzymes in certain strains of perchlorate-reducing bacteria (Chaudhuri et al., 2002). In addition, microbial growth and perchlorate reduction were completely inhibited when an active perchlorate-reducing bacterial culture was transferred into medium without molybdenum present (Chaudhuri et al., 2002). The results of these studies suggest molybdenum may be required for perchlorate reduction.

## **3.3 Field Methods for Perchlorate Analysis**

Field methods for detecting and measuring perchlorate are available. However, their use is not widespread. The ion-selective electrode (Section 3.3.2) and colorimetry (Section 3.3.3) methods are discussed below.

### **3.3.1 Sample collection and preservation**

The collection and preservation of perchlorate-contaminated matrices is an important step in obtaining representative and reliable site data. Soil samples can be collected by any number of

standard methods such as hand augers or split-spoon samplers and placed in small (4 or 8-oz) glass jars for transport to the laboratory. The presence of air in the soil sample jar is encouraged because it limits biodegradation of the perchlorate during transport. Because perchlorate is water soluble, decontamination of sampling tools should include tap water rinse, soapy wash, tap water rinse and final rinse with deionized water followed by air-drying. Final rinsing of the sampling equipment with isopropanol is not typically needed unless organic solvents are in the soil as co-contaminants. No additional preservation is required for soil samples beyond chilling the soil to approximately 4°C during transport. Further changes or degradation of perchlorate during shipping is limited by lowering the temperature to reduce metabolic activity of the perchlorate-reducing bacteria that may be in the sample.

Aqueous samples can be collected by any number of standard methods including bailers, submersible pumps and peristaltic pumps, as site conditions allow. Unless new bailers or tubing are being used for each location, submersible pumps or components should be decontaminated with a tap water rinse, soapy wash, tap water rinse and final rinse with deionized water followed by air-drying. Final rinsing of the sampling equipment with isopropanol is not typically needed unless organic solvents are in the aqueous matrix as co-contaminants. However, because perchlorate is subject to further degradation during transport in aqueous media, additional preservation steps are recommended to improve the stability of the sample.

A method has been developed that takes into account the biodegradability of perchlorate and minimizes potential for degradation of the perchlorate in the groundwater sample during transport and storage prior to analysis. ITRC (2005) describes a procedure that combines field filtration to reduce bacterial content in the sample, followed by packaging with an aerobic headspace to further limit anaerobic biodegradation. The field filtration step should not be confused with the filtration carried out by the laboratory just prior to ion chromatography (Method 314 discussed below); the former is for preservation of the sample while the latter is a preparation step for the method. To collect an aqueous perchlorate sample use traditional collection methods (i.e., bailers, pumps, etc.) to fill a plastic bottle (e.g., 200-mL volume) with groundwater. Allow solids within the sample to settle in the bottle for a brief period of time (approximately 5 to 10 minutes) and then use a 50 or 60-mL plastic disposable syringe to withdraw a sample from the top to avoid solids. Prepare a stack of disposable syringe filters comprised of a single 1.0 µm and 0.45 µm filter (Figure 3-3). Affix the filter stack to the syringe and push the groundwater through the stacked filters into a clean plastic or glass 40-ml VOA vial. Fill only 50 to 75% of the vial leaving the balance of the volume as headspace. Close the bottle while retaining the headspace and place the vial in a cooler on ice for transport.



**Figure 3-3: Photograph illustrating field preservation of the aqueous sample by filtration through a filter stack.**

### **3.3.2 Ion-selective Electrodes**

The Army Corps of Engineers developed an ion-specific electrode for monitoring perchlorate in groundwater monitoring wells and there is also a commercially available electrode for this purpose (ITRC, 2005). However, the detection limit is approximately 200  $\mu\text{g/L}$  and the electrode is subject to interference by thiocyanate, iodide, nitrate, chloride, phosphate and acetate, although there is some acceptable level of toleration of chloride and nitrate.

In 2004, the National Defense Center for Environmental Excellence (NDCEE) successfully demonstrated a prototype field instrument to measure down to 10  $\mu\text{g/L}$  perchlorate in water (NDCEE, 2004). The method was a more portable field adaptation of ion chromatography in conjunction with an ion selective electrode. At the time, NDCEE was seeking to improve and commercialize the technology, but few reports of perchlorate remediation have reported using this technology for data collection.

### **3.3.3 Colorimetry**

Thorn (2004) described a colorimetric method for perchlorate in water and soil extracts with detection limits reported to 1  $\mu\text{g/L}$  for water and 0.3  $\mu\text{g/g}$  for soil (ITRC, 2005). There are some interferences with the method, particularly in matrices with background coloration such as humic materials and chlorophyll containing materials.

### **3.3.4 Chemical Sensors**

Some efforts have been made to develop dipstick chemical sensors based on molecular recognition events to demonstrate a field, screening level chemical assay for perchlorate ions and nitroaromatic explosives including TNT and DNT (SERDP Project ER-1418). The commercialization and use of this method is unknown.

## **3.4 Laboratory Methods for Perchlorate Analysis**

### **3.4.1 Analytical methods**

Because of perchlorate's mobility in soil and groundwater, and its tendency to form long persistent contaminant plumes, much of the method development work has focused on analysis of perchlorate in aqueous media. Limited methodologies have addressed extraction of perchlorate from soil and other media, but where applicable these approaches will have importance in the overall identification and quantification process (Canas, 2005; Canas et al., 2006). The following sections discuss the methods available for the determination of perchlorate in aqueous media, principally drinking water. However, as more environmental projects are performed, remediation practitioners are using these methods for non-drinking water determinations. Practitioners are encouraged to consider splitting a portion (e.g., 10%) of samples collected early in the project and running the samples by at least two methods, typically a less selective method and a more selective method. By comparing methods, the user can gain confidence in the analyses, and select a preferred method to continue using throughout the project with greater assurance that the results are accurate and representative.

#### **3.4.1.1 Ion Chromatography (IC) Methods**

In November 1999, the USEPA promulgated an ion chromatographic method for the analysis of perchlorate in drinking water. Since that time several refinements of the basic have been made. The list of IC-based methods for perchlorate that are available includes:

- Method 314.0
- Method 9058
- Method 314.1

In Method 314.0 the perchlorate ion is separated from the introduced aqueous sample and measured using a system comprised of an ion chromatographic pump, sample injection valve, guard column, analytical column, suppressor device, and conductivity detector. The conductivity detector is non-specific; ions are differentiated based solely on retention times.

Sample matrices with high total dissolved solids (TDS) and high concentrations of common anions such as chloride, sulfate and carbonate can destabilize the baseline in the retention time window for perchlorate. These can be assessed indirectly by monitoring the conductivity of the matrix and the method requires determining the instrument-specific matrix conductivity threshold (MCT). The method is subject to false positives due to the unspecific nature of the conductivity detector (ITRC, 2005). Some pretreatment by the laboratory to attempt to reduce interferences has the potential to reduce the actual perchlorate content of the sample at low concentrations. The aqueous reporting limit using Method 314.0 is typically 4 µg/L.

Method SW 9058 is the USEPA's Office of Solid Waste (OSW) method for IC determination of perchlorate in aqueous media. The method is substantially the same as Method 314.0, although determining the instrument-specific MCT is not required. The method is stated to perform adequately on water samples with conductivities up to 1000 µS/cm and is potentially applicable

to surface water, mixed domestic water, and industrial wastewaters. The limitations for Method 314.0, including known interferences, false positives and false negatives, apply similarly to Method SW 9058.

Method 314.1 was adopted in May 2005 by EPA as an improved IC method for the analysis of perchlorate including samples with high TDS. It is a sample pre-concentration, matrix elimination IC method using suppressed conductivity detection for the determination of perchlorate in raw and finished drinking waters. This method is intended to add increased sensitivity, better tolerance of TDS, and better selectivity through use of a confirmation column and in-line concentration. The minimum reporting level (MRL) for the method is below 1 µg/L; the actual MRL depends on sample matrix, fortification concentration and instrument performance. Additional discussion of the applicability and analytical limitations of these IC methods is provided by ITRC (2005).

### 3.4.1.2 Mass Spectroscopy (MS) and Dual MS Methods

Coupling mass spectroscopy to basic ion or liquid chromatography increases the selectivity and lowers the detection threshold for the perchlorate molecule. A thorough discussion of the most common methods using mass spectroscopy is presented in ITRC (2005). The methods being developed include:

- EPA Method 6850 – Liquid Chromatography/ Mass Spectroscopy (LC/MS)
- EPA Method 331.0 – LC/MS or LC/MS/MS
- EPA Method 332.0 – IC/MS or IC/MS/MS
- FDA Method – IC/MS/MS

The LC/MS methods use a liquid chromatograph with a peptide-impregnated reverse phase column to perform the separation followed by a mass spectrometer for detection. Sample pretreatment is not required. This method has been evaluated with drinking water, soil, biota, synthetic ground water (Di Rienzo et al., 2004). The advantages of LC/MS are the increased sensitivity, increased specificity, the lack of sample pretreatment, and the lack of additional instrumentation. The quantitation limit in water is reported to be 0.1 µg/L.

LC/MS/MS uses a liquid chromatograph with an anion exchange column linked to a triple-stage quadrupole tandem MS with electrospray ionization in the negative mode. The advantage of the LC/MS/MS is the increased sensitivity and specificity based on the parent ions (m/z 99 and 101), the daughter ions (m/z 83 and 85) and the ion ratio of the naturally occurring abundance of Cl35 and Cl37 (3.08). The quantitation limit in water is reported to be 0.02 µg/L.

The IC/MS methods are essentially the same as the IC method, however a mass spectrometer with an electrospray interface is added. This method requires the use of a suppressor to avoid inorganic salt buildup and uses a conductivity meter to check its efficiency. It uses the mass-to-charge (m/z) 99 and 101 ions for peak identification of perchlorate, and monitors the ion ratio of the naturally occurring abundance of <sup>35</sup>Cl and <sup>37</sup>Cl, which should be 3.08.

The advantages of IC/MS are the increased sensitivity and increased specificity; however, high hydrogen sulfate ( $\text{HSO}_4^-$ ) content will elevate the baseline because it elutes prior to perchlorate. Even with high sulfate concentrations (~1000 ppm), 0.1  $\mu\text{g/L}$  perchlorate can still be detected. If the baseline is elevated, there is a mandatory clean-up step to remove the sulfate prior to sample injection. The quantitation limit in water is reported to be 0.1  $\mu\text{g/L}$ .

IC/MS/MS method uses an IC coupled with a conductivity detector and a tandem mass spectrometer, thereby increasing the sensitivity and specificity over that of IC/MS. The second MS allows further fragmentation of the perchlorate ions into the daughter ions ( $m/z$ ) 83 and 85, eliminating false positives or negatives that can be caused by interferences. The quantitation limit in water is reported to be 0.01  $\mu\text{g/L}$  (Penfold, 2004).

### **3.5 Microbial Indicators of Perchlorate Attenuation**

In many cases, contaminant and geochemical data may be sufficient to demonstrate natural attenuation of perchlorate. The disappearance of the parent perchlorate anion, combined with identification of and eventual disappearance of metabolic degradation intermediates can be used as supporting lines of evidence for natural attenuation. However, sites with marginal evidence of perchlorate biodegradation may benefit from the use of a variety of microbial screening methods. Microbial enumeration methods can be used to quantify the population density. Molecular biology tools (MBTs) can be used to characterize the structure, function, and activity of *in situ* microbial communities. Advances in molecular biology have had a profound effect on studies of chlorinated solvent bioremediation processes. Recently, MBTs have been developed to assess the potential for perchlorate biodegradation. While current use of these MBTs is limited, this technology is evolving very rapidly and there is tremendous potential for these tools to improve. The following sections describe methods for obtaining microbial-mediated data that can be used as lines of evidence for on-going natural attenuation.

#### **3.5.1 Degradation Daughter Products**

The biodegradation pathway for perchlorate was shown in Figure 2-2. As discussed in Section 2.4.3, perchlorate degradation proceeds through the sequential loss of oxygen from the anion from perchlorate to chlorate ( $\text{ClO}_3^-$ ), chlorite ( $\text{ClO}_2^-$ ), and finally chloride ( $\text{Cl}^-$ ) and oxygen ( $\text{O}_2$ ). The rate-limiting step in the three-step degradation process is the conversion of perchlorate to chlorate by a perchlorate reductase enzyme. Subsequent conversion of chlorate to chlorite is also catalyzed by a perchlorate reductase enzyme. Chlorite removal by the chlorite dismutase (CD) enzyme is the final step in perchlorate reduction.

Perchlorate can be detected at low concentrations by multiple laboratory methods such as IC, IC/MS, LC/MS, etc. discussed above. Method detection levels can routinely approach 4  $\mu\text{g/L}$  and below, depending on the method used. The disappearance of the parent molecule is presumptive evidence of degradation. The appearance and subsequent disappearance of metabolic breakdown intermediates can further support the claim that biodegradation is occurring. However, intermediates do not ordinarily accumulate in solution during perchlorate biodegradation (Logan, 2001) because the chlorite to chloride step proceeds rapidly, on the order of 1000 times that of the rate-limiting perchlorate reductase mediated conversion of perchlorate to chlorate (ITRC, 2002). Although chlorate, chlorite and chloride can all be detected by IC

Method 314.0 or 314.1, the detection limit for these anions is typically in the range of 500 µg/L which often precludes the detection of low levels of these intermediates. In the laboratory, stoichiometric conversion of perchlorate to chloride has been observed. However, changes in chloride due to perchlorate biodegradation may be difficult to measure on the field-scale depending on the background concentrations of chloride and the concentrations of perchlorate initially present.

### 3.5.2 Microbial Enumeration Methods

With the number and variety of microbial species capable of reducing perchlorate, traditional methods such as anaerobic plate counts are used in laboratory studies for enrichment and isolation, but not as frequently in field demonstrations for population enumerations. Coates et al. (1999) utilized laboratory salts media with either chlorate or perchlorate as the only electron acceptor to show that chlorate-reducing bacteria represented a significant population in diverse environments including pristine and hydrocarbon-contaminated soils, aquatic sediments, paper mill waste sludges and farm animal waste lagoons. Thirteen isolates were collected and shown capable of growth on acetate using perchlorate. The detailed nutritional requirements of the perchlorate reducing bacteria remains largely unknown and artificial media incorporating various buffers, vitamin solutions and trace mineral mixtures had all been tried (Xu et al., 2003).

Wu et al. (2001) developed a most probable number (MPN) method with anaerobic growth medium to enumerate perchlorate-reducing bacteria and chlorate-reducing bacteria. They concluded from their study of natural waters, soil and wastewater that bacteria capable of chlorate reduction appear to be more abundant than those able to degrade perchlorate. Kesterson et al. (2005) used MPN incubated under anoxic conditions and reported from <20 to 230 perchlorate-reducing bacteria/100 ml to <20 to >1.5 x 10<sup>5</sup>/g for Lake Mead water and Las Vegas Wash sediments, respectively. Choi and Silverstein (2008) used MPN to estimate perchlorate- and nitrate-reducing populations in bioreactor biofilms. Logan et al. (2001), Rikken et al. (1996) and others have used selective growth media to isolate bacteria capable of growth on perchlorate. Although some studies can be found that use these methods, relatively few remediations use these traditional methods to track changes in microbial populations of the perchlorate-reducing bacteria as part of the demonstration of effectiveness of the remedial strategy.

### 3.5.3 Perchlorate Reductase and Chlorite Dismutase Enzyme Assays

Newer, more specific real-time polymerase chain reaction (PCR) methods are commercially available that can provide a sensitive, rapid approach to qualitatively detect (i.e., the PCR assay) or quantify (i.e., the qPCR assay) specific microorganisms involved with bioremediation. These methods can be applied selectively to detect and/or enumerate the proportion of active perchlorate reducing bacteria in a total population of bacteria by targeting specific genes found in these organisms.

The MBTs that have been developed (and are under continuing refinement) for the perchlorate-reducing bacteria are based on the specificity of the perchlorate reductase and chlorite dismutase (CD) enzymes. Perchlorate reductase is the enzyme that mediates the initial breakdown of perchlorate to chlorate and chlorite; it is coded for by the perchlorate reductase gene operon which consists of subunits *pcrA* through *D*. CD is the single enzyme that mediates dismutation

of chlorite, the final step in reduction of perchlorate to chloride and oxygen; it is coded for by the chlorite dismutase (*cld*) gene (Gunawan, 2007). These genes and enzymes are common to all perchlorate-reducing bacteria.

In general, MBTs for perchlorate-reducing bacteria are based on the same general method applied to the different genetic material: DNA-based and RNA-based PCR. DNA-based approaches are used to determine if bacteria with the genetic potential to degrade perchlorate are present and, if so, at what concentration. This approach simply tells the user whether or not capable bacteria are present; however, it is not a measure of induced, stimulated or naturally occurring bioactivity. By contrast, RNA-based measurements are used to determine that the perchlorate-reducing bacteria are actively producing the enzymes, presumably for metabolizing perchlorate (Achenbach et al., 2006).

At this time, Microbial Insights, Inc. (Rockford, TN) offers DNA-based and RNA-based PCR assays for both genes. Either assay may be performed qualitatively or quantitatively. The DNA-based assay determines the presence of the functional *pcr* or *cld* genes in the sample matrix. Qualitative results from this approach determine if organisms with the genetic potential to degrade perchlorate are present or absent in the sample provided. If quantitation is desired, the method reports the number of gene copies per unit volume. However, the presence of the gene copies alone does not indicate that the bacteria are alive and metabolically active or expressing a particular function, i.e., whether or not perchlorate-reducing activity is actually occurring. Borden et al. (2007) reported the results of qualitative DNA-based CD assays on site matrices from seven DoD sites. The CD assay was useful in determining the potential presence of organisms capable of reducing perchlorate in the various environments included in the study.

RNA-based PCR measurements are a more direct indicator of enzymatic activity. They can also be applied to detection of either the perchlorate reductase or CD genes. However, in this method, RNA is extracted from the microbial population in the sample. The RNA is then analyzed using the PCR assay for the detection of the desired gene (i.e., *pcr* or *cld*). The RNA is used to determine the expression of the particular functional gene based upon the abundance of messenger RNA (*mRNA*). The perchlorate-reducing bacteria use the *mRNA* to assemble the enzyme, and the abundance of *mRNA* in the groundwater sample is an indirect indication of enzyme production and, therefore, active biodegradation of perchlorate.

Because of the simplicity, growing availability and accuracy of these methods, their use in monitoring the effectiveness of remediation will likely increase. At this time, the DNA-based qPCR assays are more stable and less subject to sample collection and matrix variability. The RNA is more difficult to perform and generally results in lower concentrations reported (personal communication, Microbial Insights, August 2008). Clearly however, evidence of even few RNA-based gene copies is direct evidence of perchlorate metabolism whereas DNA-based results should be considered along with all other lines of evidence.

### **3.5.4 Stable Isotope Methods**

One difficulty in demonstrating natural attenuation is distinguishing perchlorate removal due to biodegradation from other loss mechanisms, such as dilution, dispersion, chemical reactivity, etc. Stable isotope analysis provides a method for distinguishing biotic from abiotic attenuation since

microbial processes are known to make small but significant changes to isotopic compositions of many molecules (Coleman et al., 2003).

Microorganisms often preferentially use lighter isotopes in their metabolic processes (Mariotti et al. 1981; Heaton, 1986); and, as a contaminant is degraded, the isotopic composition of the remaining material becomes progressively heavier. This isotopic shift can be described by the Rayleigh Distillation formula,  $R/R_0 = f^{(\alpha-1)}$ , where  $R_0$  is the isotopic ratio of the original material,  $R$  is the isotopic ratio of the remaining material,  $\alpha$  is the fractionation factor and  $f$  is the fraction of material degraded. If the ratio  $R/R_0$  can be accurately measured and  $\alpha$  is known, the fraction of material degraded can be calculated.

A variety of different investigators have successfully used stable isotope ratios to evaluate the MNA of petroleum hydrocarbons (Ahad et al., 2000), MTBE (Kolhatkar et al., 2002), chlorinated solvents (Lollar et al., 2001), and nitrate (Karr et al., 2001). However, there are some important limitations to this approach: 1) a sensitive, reproducible method is needed to monitor the isotopic shifts; 2) variations in the isotopic composition of the different sources can mask isotopic shifts caused by microbial fractionation; and 3) the isotopic fractionation factor  $\alpha$  may vary between different microorganisms and environmental conditions (Slater et al., 2001).

Monitoring isotopic ratios may be a very useful tool for evaluating the extent of perchlorate attenuation. The isotopic signature of both the oxygen atoms ( $^{18}\text{O}/^{17}\text{O}/^{16}\text{O}$ ) and chloride atoms ( $^{37}\text{Cl}/^{35}\text{Cl}$ ) on perchlorate are useful for distinguishing sources of perchlorate as well as evidence of biodegradation-mediated changes (Sturchio et al., 2006; Bohlke et al., 2005). Bohlke et al. (2005) indicated that there was some evidence that microbial reduction of perchlorate caused the  $\delta^{18}\text{O}$  to increase about two times as fast as  $\delta^{37}\text{Cl}$ .

More studies have examined the isotopic shifts of the chlorine atoms in perchlorate. Ader et al. (2001) developed a highly reproducible and accurate method for stable isotopic analysis of chlorine ratios  $^{37}\text{Cl}/^{35}\text{Cl}$  ( $\delta^{37}\text{Cl}$ ) in perchlorate. Coleman et al. (2003) observed that perchlorate reduction by *D. suillum* resulted in significant fractionation ( $\sim -15\text{‰}$ ) of the chlorine stable isotopic composition. The resulting shifts in  $\delta^{37}\text{Cl}$  associated with perchlorate reduction were much larger than the isotopic variations between different sources ( $+0.2\text{‰}$  to  $+2.3\text{‰}$ ) observed by Ader et al. (2001). These results suggest that isotopic ratios could be used to assess biodegradation of perchlorate in the field and separate biodegradation from non-biological loss mechanisms.

To use stable isotope methods to evaluate perchlorate attenuation at a site, groundwater samples should be collected and assayed for  $\delta^{37}\text{Cl}$  or  $\delta^{18}\text{O}$  of perchlorate. The sampling locations should include locations where groundwater conditions suggest that perchlorate may be biodegrading as well as background locations. Depending on the concentrations of perchlorate present in the groundwater, large volumes of groundwater may be needed to perform the stable isotope analysis. Typically 10 mg of perchlorate are necessary for the analysis. For sites with low perchlorate concentration, a small portable ion exchange resin is used to trap the necessary sample mass as the groundwater is collected. Groundwater is pumped through columns containing the resin at a low flow rate until the column contains approximately 10 mg of perchlorate (Bohlke et al., 2005). Each cartridge is then shipped to a laboratory for perchlorate

extraction and isotope analysis. The data are used to assess spatial variations in  $\delta^{37}\text{Cl}$  or  $\delta^{18}\text{O}$  to determine if there is significant isotopic fractionation during downgradient transport. If there is clear evidence of isotopic shifts, the extent of perchlorate degradation can be estimated using the fractionation factor. Hatzinger et al. (2007) demonstrated that the isotopic shift in a permeable reactive barrier created by the injection of an emulsified oil substrate (EOS<sup>®</sup>) perpendicular to a perchlorate groundwater plume. Perchlorate-contaminated groundwater was extracted from an upgradient well, pumped into the barrier, extracted over time and analyzed. Perchlorate levels declined from 4300  $\mu\text{g/L}$  to 500  $\mu\text{g/L}$  during an 8-hr period, and the corresponding data measured significant fractionation of both isotopes:  $\delta^{37}\text{Cl}$  (-2.9‰) and  $\delta^{18}\text{O}$  (-7.9‰). These changes were clear indications that biodegradation of the perchlorate was being stimulated in the permeable reactive barrier.

### **3.6 Laboratory Microcosms and Bench-Scale Column Tests**

Laboratory microcosms and bench-scale column studies can be used to demonstrate that natural attenuation is occurring and to estimate the rate and extent of perchlorate biodegradation. Microcosms and bench-scale column studies can be time consuming and expensive and should not be employed until a considerable understanding of site conditions has been achieved through site investigation activities. The studies should be conducted using matrices that are representative of the prevailing geochemical conditions at the site. Careful planning should also be used in developing a sampling strategy and determining the duration of the study. These factors can greatly influence the results of the studies.

#### **3.6.1 Laboratory Microcosm Studies**

Microcosm studies typically consist of collecting representative aquifer material from the site and using this material to construct microcosms with different experimental treatments. At a minimum, treatments should include ambient site conditions and a killed control. Depending on the perchlorate levels found at the site, it might also be desirable to evaluate a treatment with a spiked, higher concentration of perchlorate. Whenever possible, for statistical purposes, each treatment should be run in triplicate. Typical sampling might include perchlorate, chlorate, chlorite, chloride, DO, ORP, pH, TOC and nitrate.

Previous studies have compared laboratory microcosm rates with field attenuation rates at multiple sites (Borden et al. 1995, 1997a, 1997b; Johnston et al. 1996; Hunt et al. 1998). This experience indicates that laboratory microcosms sometimes provide a very good prediction of field degradation rates. However, at other times, the microcosm rates do not match field rates. When microcosm and field rates do not match, the differences appear to be because: (a) levels of electron acceptor or donor in the microcosms do not match field conditions; and (b) the microbial distribution in the aquifer is very heterogeneous and blending of the aquifer material for the microcosm study enhances contact between the microbes, electron acceptors, and electron donors. As a consequence, great care must be taken when extrapolating laboratory rates directly to the field. However, whenever contaminant biodegradation is observed in the laboratory microcosms, field biodegradation is usually also observed. Conversely, when contaminants do not degrade in the laboratory, they do not usually degrade in the field. As a consequence, laboratory microcosms can provide a very useful indication of the potential for natural

attenuation. However, laboratory biodegradation rates should not be used to estimate field rates without accounting for differences in environmental conditions.

Microcosm studies assessing the natural attenuation of perchlorate have been performed previously, albeit infrequently. In many of these studies, the emphasis has been on the existence and enhancement of native microbial populations under various conditions, with little interest shown to the results of the “ambient control”, which reflects the potential for natural attenuation in the particular environment under study. For example, Borden et al. (2006) demonstrated the relatively quick biodegradation of 53,000  $\mu\text{g/L}$  perchlorate to less than 8  $\mu\text{g/L}$  in laboratory microcosms in less than 14 days when provided with excess electron donor. The ambient control did not change in the same period; because it was not the focus of the study, natural attenuation was not monitored any further.

Wu et al. (2001) studied persistence of perchlorate in waters, soil and wastewater while evaluating the population density of perchlorate reducing bacteria in these environments. Their findings supported the assertion that perchlorate- and chlorate-respiring bacteria were widely distributed in nature, and the initial population density likely reflected prior exposure to perchlorate contamination. Thus, intrinsic perchlorate remediation was more likely limited by a lack of suitable environmental conditions.

Hines et al. (2002) examined the impact of up to 1000 mg/L perchlorate on microbial respiration in freshwater and marine sediments and in bog peat. Their studies showed generally no inhibition of carbon dioxide production or methanogenesis as a result of increasing perchlorate concentrations. Their incubations lasted only one week and also showed no measurable degradation of the added perchlorate by indigenous microbes during this time. This was attributed lack of constitutive ability to utilize perchlorate by native microorganisms that had not previously been exposed to perchlorate.

Jackson et al. (2002) calculated a pseudo-first order degradation rate of  $0.185 \text{ day}^{-1}$  in an unamended control prepared from contaminated soil containing 10 mg/kg perchlorate. Tan et al. (2004a) performed a series of microcosm tests on perchlorate-contaminated sediments from Naval Weapons Industrial Reserve Plant (NWIRP) in McGregor, TX and soil from Longhorn Army Ammunition Plant (LHAAP) in Karnack, TX to investigate the potential of intrinsic perchlorate biodegradation in these matrices. Background organic substrate availability and the presence of nitrate were found to be crucial factors affecting microbial degradation rates and lag times. Intrinsic perchlorate degradation rates ranged from 0.13 to  $0.46 \text{ day}^{-1}$  corresponding to a half-life range of 1.4 to 5.0 days. The concentration of nitrate affected lag time, but not degradation rate, and in contrast to earlier findings, pre-exposure to perchlorate did not affect the biodegradation rate.

In a recent-ESTCP-funded evaluation, Borden et al. (2007) screened multiple DoD-related perchlorate-impacted sites located throughout the United States to identify sites where natural attenuation processes may be important. Groundwater and soil/sediment samples were collected from seven sites, characterized, and used in microcosms to evaluate the potential for natural attenuation of perchlorate to occur. Perchlorate concentration trends, biological activity indicators, electron acceptor and oxidation-reduction conditions, and organic carbon status were

evaluated. CD enzyme assays suggested that genetically capable microbes were ubiquitous, but the rates of degradation varied widely. Degradation rates were calculated for each site and fitted to one of two kinetic models. The degradation rates were zero-order at two of the seven sites (ATK Elkton and ATK Thiokol), 1st order at two sites (NSWC Indian Head and Redstone Arsenal) and could be fitted to both models at one site (Stennis Space Center). At two other sites (LMTA and Beale AFB), apparent zero-order biodegradation rates were less than 0.01 mg/L per year indicating no measureable perchlorate degradation. When measurable, zero order rates ranged from 0.13 mg/L/yr at Stennis Space Center to 33 mg/L/yr at ATK Thiokol. The first order rates ranged from 1.75 yr<sup>-1</sup> at Stennis Space Center to 5.1 yr<sup>-1</sup> at NSWC Indian Head.

All sites showed low nitrate (<10 mg/L); sites with lower redox potentials showed greater potential for natural attenuation. TOC in groundwater was less than 4.4 mg/L at all the sites, but there was sufficient carbon to support some degree of attenuation. Sites with neutral pH, low redox potential, low nitrate and elevated TOC would be expected to support perchlorate degrading bioactivity.

### **3.6.2 Bench-Scale Column Studies**

Bench-scale column studies can be used to evaluate biodegradation rates in simulated natural environments. Tipton et al. (2003) used 15-cm long by 7.5-cm i.d. columns to evaluate bromide and perchlorate transport through two California loam soils. The results demonstrated that biodegradation has the potential to affect the transport of perchlorate in native soils (unamended with nutrients or carbon) and that more biodegradation occurred in soils previously exposed to perchlorate. Further, lower hydraulic conductivity led to increased contact time yielding more biodegradation.

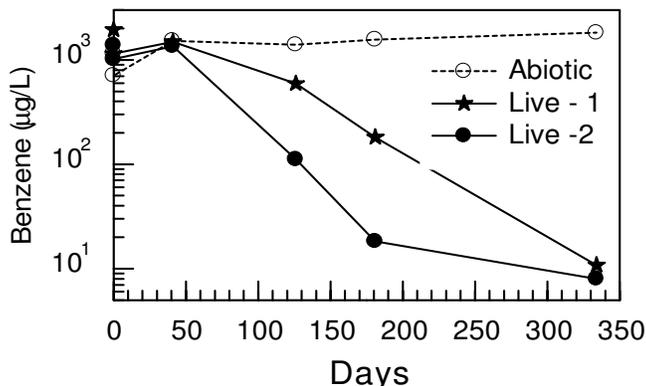
Tan et al. (2004b) examined the potential of natural wetland cores to treat perchlorate-contaminated water in vertical upflow wetland columns with and without native bullrushes. Intact cores were collected from a freshwater wetland in Madisonville, LA. In unplanted columns without nitrate, up to 32 mg/L perchlorate were removed effectively by the core sediments, but the rate of perchlorate biodegradation decreased from 6.49 to 0.42 day<sup>-1</sup> as the concentration of perchlorate and nitrate increased. Degradation was complete after a 9.6 day residence time in the 55-cm column. In planted columns, a mass balance indicated plant uptake accounted for transformation of 0 to 14.3% of initial perchlorate input. Microbial degradation played a more important role than plant uptake and transformation in the simulated wetland system.

## **3.7 Field Evaluation Tools and Techniques**

### **3.7.1 *In Situ* Columns**

The *in situ* column method was used by Borden et al. (1997a) to evaluate anaerobic biodegradation of benzene. Figure 3-4 shows the observed loss of benzene in the anaerobic *in situ* column experiments. The apparent first order decay rate can be calculated as the slope of the live columns minus the abiotic column. Using this procedure, Borden et al. (1997a) showed that

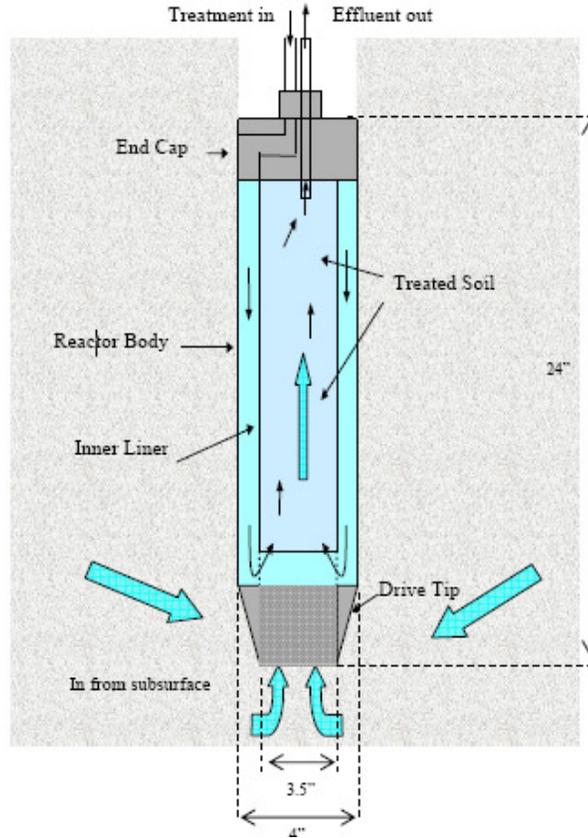
decay rates measured in the *in situ* columns provided a better match with plume-scale degradation rates than conventional laboratory microcosms.



**Figure 3-4: Anaerobic Benzene Loss in *In Situ* Columns.**

*In situ* columns can be installed at a location where there is evidence that perchlorate is degrading. During the *in situ* biodegradation studies, a column(s) of soil and groundwater, representative of the aquifer of concern, is isolated from the rest of the formation with a solid structure such as a PVC casing or pipe. The soil and groundwater within the column(s) is then treated with perchlorate so that a known concentration of perchlorate is present to start and potentially the rate of perchlorate biodegradation can be monitored over time within a controlled environment. Biodegradation rates obtained from the *in situ* biodegradation study may provide another line of evidence with which to evaluate perchlorate MNA.

Close-ended column(s) can be constructed in a manner that is similar to that reported by Radtke and Blackwelder (2005). The column design is also similar to that used by Gillham et al. (1990), Borden et al. (1997a), and Sandrin et al., (2004). Each column typically consists of a 1-m long chamber that is pushed into the sediment surface allowing sediment and groundwater to be isolated from the surrounding aquifer for controlled observation. To use, groundwater is extracted from the column (or an adjoining well), amended with a non-reactive bromide tracer and perchlorate (if required), and injected back into the column. In the up-flow mode, groundwater samples are then collected from each column immediately after injection and then on a prescribed performance monitoring schedule and analyzed for perchlorate, chlorate, chlorite, chloride, and bromide tracer, if used. Other parameters that could be monitored include DO, ORP, TOC, and nitrate. By comparing perchlorate concentrations over time, *in situ* biodegradation rates can be estimated. The non-reactive tracer (Br<sup>-</sup>) can be used to evaluate possible dilution effects that might occur during the incubation period. This *in situ* measurement approach is expected to be most appropriate when groundwater flow rates are low.



**Figure 3-5: *In Situ* Column Set-Up** (Radke and Blackwelder, 2005)

The case study at the ATK Elkton, MD project site provided in the Appendix illustrates the design and application of *in situ* columns for determining perchlorate degradation rates in the field. *In situ* columns were installed adjacent to groundwater monitoring wells with known concentrations of perchlorate. The wells were located toward the toe of the perchlorate plume near a stream considered to be a groundwater discharge feature. Three columns were installed below the groundwater table with tubing through the vadose zone to provide amendments and sampling access. Contaminated groundwater was mixed with bromide tracer and pumped into each column; one column was poisoned with nitric acid as a control. Perchlorate concentrations in replicate live columns decreased by 33% from 99.3 to 65.0  $\mu\text{g/L}$  in 43 days (0.80  $\mu\text{g/L/day}$ ) while only 10% from 101 to 109  $\mu\text{g/L}$  in the killed control (0.27  $\mu\text{g/L/day}$ ). Thus, monitoring changes in perchlorate concentrations in the columns further supported natural attenuation in this area of the plume.

### 3.7.2 Plume Stability, Statistical Evaluations and Mass Flux

Historical site groundwater data for perchlorate should demonstrate a clear trend of decreasing concentration and/or mass over time. There are several ways to evaluate historical perchlorate data to show changes in concentrations over time. The simplest method includes preparing isopleth maps of perchlorate over time and generating graphical plots of perchlorate versus time. Perchlorate is not sorbed to any large degree and therefore is expected to migrate at a rate that is

close to the average groundwater flow velocity. By comparing the overall plume size to the expected plume size, given an estimate of when perchlorate first impacted groundwater, one can evaluate whether the plume is stable. If the plume is somewhat shorter than expected, one might conclude that natural attenuation processes are at work.

Statistical techniques can also be used to evaluate plume stability. These techniques include regression analyses, the Mann-Whitney U Test, the Mann-Kendall Test, and center of mass calculations, as described in Principles and Practices of Enhanced Bioremediation of Chlorinated Solvents (AFCEE, 2004).

Reduction in perchlorate concentrations alone does not prove that the perchlorate is being biodegraded. The observed reductions could be due to non-biological process such as dispersion and dilution. However, changes in molar concentrations of perchlorate, chlorate, chlorite, and chloride can be used to evaluate biodegradation of perchlorate. Conventional concentration data can be converted into molar concentrations using the molecular weight of each compound (Table 2-2). The molar ratio of perchlorate to degradation products can be calculated over time and across the plume. Change in the molar ratio of perchlorate to degradation products can demonstrate perchlorate biodegradation. However, due to difficulties measuring perchlorate degradation products, this method may have limited usefulness on the field-scale.

While the classical methods of evaluating plume dynamics have been discussed briefly above, one additional line of evidence is increasingly being considered by those conducting or overseeing groundwater remediation efforts. This approach compares mass flux along the plume and can be used to produce estimates of the contaminant source strength, i.e. the total mass discharge rate to groundwater and surface water (Annable et al., 2005). By using mass fluxes instead of point concentrations, one can minimize the effects of vertical and transverse dispersion and suboptimal well placement (Borden et al., 1997b). One method to evaluate changes in the mass flux of perchlorate is to install monitor wells as transects across the contaminant plume. The mass flux across one transect can then be compared to downgradient transects to monitor the change in the downgradient mass flux of perchlorate (O'Toole et al., 2004). Adequate evaluation of mass flux changes using this method may require the installation of multiple monitor wells screened at varying depths with numerous samples collected over multiple years. The horizontal spacing of the wells should be sufficient to encompass the entire width of the perchlorate plume. To reduce costs, existing monitor wells and data can be used to the maximum extent possible. If done properly, the information gained can be used in groundwater models to help manage contaminated sites. When measured at locations downgradient from the source, mass flux measurements can be used to verify remediation technology performance, assess natural attenuation rates and evaluate environmental risks (Annable et al., 2005).

These approaches can suggest that perchlorate is naturally attenuating. When properly applied, they offer the first line of evidence that MNA may be influencing contaminant fate at the site. However, for MNA to be accepted, these tests should be included with the other evidence discussed in earlier sections of this document.

## **4.0 ASSESSING THE NATURAL ATTENUATION OF PERCHLORATE: A TIERED APPROACH**

### **4.1 Purpose of this section**

The evaluation of the potential for using MNA as a groundwater remedy for all contaminants requires consideration of multiple lines of evidence. In the case of perchlorate, biodegradation is especially important for MNA, because perchlorate is not readily sorbed, volatilized, or abiotically degraded (Nzengung et al., 2008). Analytical methods are available to monitor the concentration of perchlorate in the environment with high sensitivity and selectivity, and newer biological tools are under development to identify perchlorate-reducing bacterial population sustainability and activity. However, other than the disappearance of the parent anion, the demonstration of perchlorate degradation has often relied on circumstantial evidence involving the influence of bio-geochemical parameters such as pH, DO, redox potential, TOC, DOC, nitrate, sulfate and trace minerals.

As stated in Nzengung (2008), “The biodegradation pathways are well understood and the microorganisms involved in perchlorate biodegradation are known, they can use a variety of different organic substrates as electron donors, are relatively ubiquitous in soil and groundwater environments, and function as strict or facultative anaerobes. This suggests that natural attenuation of perchlorate should occur at many sites (Cooley et al., 2005), and that MNA can be effective in managing the risks posed by perchlorate contamination of groundwater under favorable conditions.” The frequency of sites with suitable conditions that would be expected to sustain natural attenuation of perchlorate is not easily quantified. To date, many site-specific evaluations have focused solely on changes to perchlorate concentrations over time and distance, but have not provided sufficient supporting evidence to justify regulatory acceptance of MNA. Therefore, more in-depth site-specific evaluations, including greater understanding of the conditions that influence perchlorate behavior and degradation, will be important to the application of MNA. Lines of evidence for MNA typically rely on three layers of testing (USEPA, 1999):

- Tier 1 - Spatial and temporal distribution of perchlorate;
- Tier 2 - Bio-geochemical conditions for perchlorate biodegradation; and
- Tier 3 - Microbiological indicators of perchlorate biodegradation.

This section shows how the processes, tools and monitoring techniques discussed in detail in earlier sections of this document can be applied in each tier specifically for the evaluation of the MNA of perchlorate. This section will summarize the findings and provide a framework for practitioners to systematically approach the problem.

### **4.2 Tier 1 – Spatial and Temporal Distribution of Perchlorate**

*Plume Stability and Geometry.* Historical data can be used effectively to delineate the extent of the contamination and determine the fate of contaminants of concern (and any toxic by-products). With a properly designed monitor well network, trends in the data can successfully

illustrate plume geometry and stability. Ideally, to support acceptance of MNA, one should show that the contaminant plume is stable or retreating. A stable or shrinking perchlorate plume would indicate that biodegradation is removing perchlorate from the groundwater at least as fast as the source is releasing it to the plume.

As discussed in Section 3.7.2, historical site groundwater data for perchlorate should demonstrate a clear trend of decreasing concentration and/or mass over time. The simplest tools that are available include visual isopleth maps and concentration trend analysis versus time. Relatively simple statistical techniques can also be used to evaluate plume stability. These techniques include regression analysis, the Mann-Whitney U Test, the Mann-Kendall Test, and center of mass calculations. A more recent and often more costly approach to evaluating contaminant changes is measuring and modeling mass flux across the plume. The practitioner is cautioned when using these methods to seek understanding and approval by the regulatory community before investing extra time and money in applying these to a particular site.

The challenge at all sites is to understand the inherent temporal and spatial variabilities so the data obtained are meaningful and can be applied correctly to the selected evaluation. This may require extensive monitoring and data acquisition over long periods of time before the chosen method can be used effectively and the results relied upon with confidence. These tools comprise Tier 1 and can offer the first line of evidence that perchlorate is naturally attenuating, or at a minimum, not changing. However, this alone is unlikely to be sufficient to make the case for MNA.

#### **4.3 Tier 2 – Bio-geochemical Conditions for Perchlorate Biodegradation**

Next to looking at trends in the data to demonstrate contaminant concentration or mass changes over time and distance, the collection of site-specific bio-geochemical information is the best understood and most widely employed step to provide evidence supporting the potential for MNA of contaminants. The data are evaluated for their affect on targeted biological activity on the contaminant of concern. For petroleum hydrocarbons, which are generally biodegradable under aerobic conditions, this typically includes the evaluation of DO, ORP, pH and possibly nutrient status (i.e.,  $\text{NH}_3\text{-N}$  and  $\text{PO}_4\text{-P}$ , which are needed for microbial growth). For chlorinated solvents, a list of over 20 parameters has been proposed as a scoresheet (Wiedemeier et al., 1998) that can be used to predict the potential for MNA of many chlorinated ethene and ethane solvents. Many of the same parameters important for natural attenuation of chlorinated solvents are equally important for assessing the potential for perchlorate to biodegrade. The practitioner must keep in mind that these groundwater parameters are not direct measures of ongoing degradation, but serve as indicators that identify whether favorable conditions for natural attenuation of perchlorate are present.

The individual bio-geochemical factors that can influence the biodegradation of perchlorate were discussed in Section 3.2 of this document. The optimal conditions for the process to occur are summarized below:

- **Dissolved Oxygen and Oxidation-Reduction Potential.** No or low DO and negative redox potentials are necessary for optimal biodegradation. Some perchlorate-reducing bacteria are facultative anaerobes and can tolerate low oxygen tension, but in general,

anaerobic processes are favored. The ORP in the range of 0 to -100 mV provides a favorable reducing environment.

- **Total (or Dissolved) Organic Carbon and Methane.** The presence of available organic carbon to serve as an electron donor (e.g., reduced organic compounds) is another key condition necessary for perchlorate biodegradation. TOC concentrations greater than 2 mg/L are preferable for perchlorate degradation, and TOC concentrations greater than 10 mg/L are believed to be more favorable for MNA. Naturally occurring sources of carbon can be found in wetlands, mudflats, riparian buffers. Where perchlorate plumes discharge into these features, the opportunity for MNA increases; in mineral soils with little TOC, this may be limited.

Methane can occur in groundwater as a result of biodegradation of organic matter. The source of the TOC may be naturally occurring or anthropogenic (e.g., a co-mingled fuel spill). Methane is not an indicator of the biodegradation of perchlorate, but can be used to support the conclusion that the aquifer is strongly reducing, a condition that favors perchlorate reduction.

- **Nitrate and Sulfate.** The impact of nitrate concentrations on potential for perchlorate biodegradation is not absolute and there is no one concentration of nitrate below which perchlorate reduction is considered optimal. In general, the same conditions that are required for denitrification (the conversion of nitrate to nitrogen gas) are favorable for perchlorate reduction. Many perchlorate-reducing bacteria can reduce nitrate as well as perchlorate (Herman and Frankenberger, 1998) and denitrifying bacteria have been shown to reduce perchlorate (Logan et al., 2001). Nzengung et al. (2008) suggested that a decrease in nitrate coupled with nitrite production, along with a decrease in perchlorate concentration along the flow path, may be good indicators of the natural attenuation of perchlorate. However, if the concentrations of nitrate and other electron acceptors such as oxygen are too high, they can inhibit perchlorate reduction (Chaudhuri et al., 2002; Krauter et al., 2005). This may be a problem in some situations because nitrate levels in groundwater can be orders of magnitude higher than the perchlorate levels. Ideally, low nitrate concentrations provide less competition with perchlorate as an electron acceptor in the environment. However, in presence of excess organic carbon, this may not be as important.

Sulfate is another electron acceptor often found in aqueous environments. Sulfate concentrations have not been shown to have a measurable impact on perchlorate reduction activity. Figure 3-2 in Section 3.2.6 illustrates that anaerobic perchlorate reduction can occur at redox potentials higher than those that are required for sulfate reduction. Therefore, the presence of sulfate is not a major detriment to perchlorate reduction.

- **Temperature and pH.** The presence and metabolic vitality of microorganisms can be affected by pH and temperature. The perchlorate-reducing bacteria generally grow optimally at pH values near neutrality. However, field studies have shown that some

species are capable of growth and perchlorate respiration can occur at pH values as low as 5 (Coates and Achenbach, 2004). In evaluating the potential for MNA of perchlorate, pH values between 5 and 8 are preferable. Warmer temperatures promote increased activity.

- **Chloride.** If starting concentrations of chloride are low and perchlorate is high, increased levels of chloride may also be directly indicative of perchlorate biodegradation. However, in many situations the chloride background is often relatively high and changes that could be attributable to perchlorate biodegradation are negligible. Perchlorate reducers can also be extremely salt-tolerant (Logan et al., 2001), but those considering the use of chloride as an indicator must be careful to separate naturally occurring concentrations from any additions as a result of biodegradation.
- **Iron.** An increase in dissolved iron Fe(II) can be an indicator of a reducing environment that is conducive to perchlorate degradation. When dissolved iron concentrations are greater than 0.5 mg/L, this indicates anaerobic conditions with a high potential for perchlorate biodegradation.

A consistent and explainable relationship between lines of evidence obtained in Tier 1 and Tier 2 testing may be sufficient to propose MNA as a viable groundwater remedy. If the groundwater conditions are optimal and the plume is stable or shrinking, the conclusion may be easily supported. Unfortunately, most sites are not as clear cut. In these situations, additional evidence may be needed.

#### **4.4 Tier 3 – Microbiological Indicators of Perchlorate Biodegradation**

In situations where additional lines of evidence are required, Tier 3 testing can be employed. Tier 3 offers several methods that provide direct evidence of biodegradation of perchlorate. The number of tests that are used and the sequence of the testing are not critical. Both laboratory and field tests are available and can be performed. These tests can be useful in determining rates of perchlorate degradation which can be factored into the overall acceptance of MNA as the groundwater remedy.

##### **4.4.1 Perchlorate Reductase and CD Enzyme Analysis**

Specific quantitative real-time polymerase chain reaction (qPCR) methods that are commercially available can provide a sensitive, rapid approach to detect and quantify specific microorganisms involved with bioremediation. The methods can enumerate the perchlorate-reducing bacteria in a total population of bacteria by quantifying the perchlorate reductase (*pcr*) or CD (*cld*) gene copies found in the site matrix. DNA-based qPCR assays provide evidence that perchlorate reducing capability is present in the environment. Used in conjunction with findings from *Tier 1* and *2*, this can be considered an important line of evidence for natural attenuation of perchlorate.

The RNA-based qPCR assays for the *pcr* and *cld* genes provide a direct indication of on-going perchlorate bioremediation activity. Where possible, this is a preferred analysis, but the test is not as well developed as the DNA-based qPCR assay. RNA-based assays have the potential to stand alone as definitive evidence that bioremediation is occurring. However, at this time,

results of this assay should also be considered in conjunction with additional lines of evidence from the preceding *Tiers*.

#### **4.4.2 Laboratory Evaluations**

Microcosms and bench-scale column studies can be time consuming and expensive and should not be employed until a considerable understanding of site conditions has been achieved through site investigation activities (Tier 1 and Tier 2). These studies can be used to demonstrate that natural attenuation is occurring and to estimate the rate and extent of perchlorate biodegradation. Under favorable bio-geochemical conditions, including the presence of excess electron donor, the biodegradation of perchlorate has been shown to be relatively quick which can substantially reduce the time needed to acquire data. In laboratory microcosms, Borden et al. (2006) showed a decrease from 53,000  $\mu\text{g/L}$  to less than 8  $\mu\text{g/L}$  in laboratory microcosms amended with an emulsified oil substrate in less than 14 days. However, evaluations of natural attenuation take longer.

The studies must be conducted using matrices that are representative of the prevailing geochemical conditions at the site. Careful planning should also be used in developing a sampling strategy and determining the duration of the study. These factors can greatly influence the results of the studies. The setup of typical microcosm studies was described in Section 3.6.1 along with advantages and precautions associated with the approach.

Laboratory microcosms can provide a very useful indication of the potential for natural attenuation. However, laboratory biodegradation rates should be used carefully to estimate field rates. Differences in actual field conditions compared with the microcosm setup can lead to non-representative results. In a series of microcosm studies conducted as part of this ESTCP-funded project, microcosm studies were prepared on matrices from seven perchlorate-impacted sites located throughout the United States (Borden et al., 2007). Degradation rates were calculated for each site and fitted to zero-order and/or 1st order kinetic models resulting in a wide range of rates. The microcosm results supported the Tier 1 and Tier 2 findings that conditions were favorable for natural attenuation at several of the sites. Biodegradation was observed in matrices from most sites without the addition of organic carbon (electron donor) or nutrients.

Bench-scale column studies can also be used to evaluate biodegradation rates in simulated natural environments. Using intact cores of sediment, perchlorate degradation can be evaluated in a controlled environment more closely simulating the site. Columns can be planted for phytodegradation studies, or substances added to evaluate competition or enhanced degradation rates. Unamended ambient controls can produce information on natural rates of degradation.

### 4.4.3 Confirmational Field Evaluations

#### 4.4.3.1 *In situ* Columns

The *in situ* column method can be used in portions of the perchlorate plume where there is reasonable expectation that natural attenuation is occurring. Using this procedure, Borden et al. (1997a) showed that decay rates measured in the *in situ* columns provided a better match with plume-scale degradation rates than conventional laboratory microcosms.

During the *in situ* biodegradation studies, a column(s) of soil and groundwater, representative of the aquifer of concern, is isolated from the rest of the formation. The soil and groundwater within the column(s) is then treated with perchlorate so that a known concentration of perchlorate, and potentially the rate of perchlorate biodegradation, can be monitored over time within a controlled environment. Biodegradation rates obtained from the *in situ* biodegradation study may provide another line of evidence with which to evaluate perchlorate MNA.

#### 4.4.3.2 Stable Isotopes

Monitoring isotopic ratios have promise of being a useful tool to measure the extent of perchlorate degradation. Stable isotope analysis provides a method for distinguishing biotic from abiotic attenuation. Microorganisms often preferentially use lighter isotopes in their metabolic processes (Mariotti et al. 1981; Heaton, 1986); and, as a contaminant is degraded, the isotopic composition of the remaining material becomes progressively heavier.

To use stable isotope methods to evaluate perchlorate attenuation at a site, groundwater samples should be collected and assayed for  $\delta^{37}\text{Cl}$  of perchlorate. The sampling locations should include locations where groundwater conditions suggest that perchlorate may be biodegrading as well as background locations for comparison. The data are used to assess spatial variations in  $\delta^{37}\text{Cl}$  to determine if there is significant isotopic fractionation during downgradient transport. If there is clear evidence of isotopic shifts, the extent of perchlorate degradation can be estimated using the fractionation factor. Degradation supported by isotopic measurements provides incontrovertible evidence that perchlorate is biodegrading and MNA is acceptable (Hatzinger et al., 2007).

## 5.0 SUMMARY

Monitored natural attenuation (MNA) of many contaminants has been shown to be a safe and cost-effective technology for remediating groundwater. However, each situation must be evaluated critically and the site-specific conditions considered separately before applying the technology. The guidance for addressing most MNA sites is a result of understanding gained from years of study on both the fate and transport of the many organic solvents that have been released into the environment. By contrast, perchlorate is an inorganic anion of a salt meaning its behavior in the environment is vastly different.

The extent of perchlorate in the environment is becoming more widely acknowledged and its fate and transport are still being studied. Because of the potential health risks associated with its consumption, there is regulatory pressure to establish meaningful and realistic goals for cleanup. As more research is performed, both the regulated and regulatory communities will gain confidence that MNA of perchlorate can be a useful and reliable tool in many groundwater situations.

This document has been prepared to offer the reader guidance on how to approach assessing the potential for natural attenuation of perchlorate. In doing so, it provides information on the use of traditional, innovative and new tools for measuring perchlorate in the environment, and describes a tiered approach for obtaining data to support the conclusion that MNA is occurring. Not all tests need to be performed at all sites, but the tiered approach is a means to develop lines of evidence for the natural attenuation of perchlorate. If systematically and properly applied, MNA of perchlorate can be relied upon to be protective of human and environmental health with just as much confidence as many other more costly groundwater remedies.

## 6.0 REFERENCES

Achenbach, L.A., K.S. Bender, Y. Sun and J.D. Coates, 2006. Chapter 13. The Biochemistry and Genetics of Perchlorate Reduction. In: B. Gu and J.D. Coates (eds.) Perchlorate: Environmental Occurrence, Interactions, and Treatment. Springer. pp. 297-309. ISBN: 978-0-387-31114-2. [www.micro.siu.edu/achenbach/Chapter13\\_2005.pdf](http://www.micro.siu.edu/achenbach/Chapter13_2005.pdf)

Ader M., M.L. Coleman, S.P. Doyle, M. Stroud and D. Wakelin, 2001. *Methods for the Stable Isotopic Analysis of Chlorine in Chlorate and Perchlorate Compounds*. Anal. Chem. 73 (20): 4946-4950.

AFCEE, 1999. *Methyl tert-Butyl Ether (MTBE) – Its Movement and Fate in the Environment and Potential for Natural Attenuation*. Air Force Center for Environmental Excellence.

AFCEE, 2004. *Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents*. Air Force Center for Environmental Excellence, Brooks City-Base, Texas.

Ahad, J.M.E., B.S. Lollar, E.A. Edwards, G.F. Slater and B.E. Sleep, 2000. *Carbon Isotope Fractionation during Anaerobic Biodegradation of Toluene: Implications for Intrinsic Bioremediation*. Environ. Sci. Tech. 34(5): 892-896.

American Petroleum Institute, 2007. *Protocol for Evaluating the Natural Attenuation of MTBE in Groundwater*.

Annable, M.D., K. Hatfield, J. Cho, H. Klammer, B.L. Parker, J.A. Cherry and P. S.C. Rao, 2005. *Field-scale evaluation of the passive flux meter for simultaneous measurement of groundwater and contaminant fluxes*. Environ. Sci. Technol. 39: 7194-7201.

Arcadis G&M, Inc., 2003. *Interim Site-Wide Investigation Technical Report and Work Plan*, May 2003.

ASTM, 2004. Standard Guide for Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites. Standard E 1943-98, Reapproved 2004). American Society for Testing and Materials, West Conshohocken PA.

Böhlke, J.K., N.C. Sturchio, B. Gu, J. Horita, G.M. Brown, W.A. Jackson, J. Batista and P. Hatzinger, 2005. *Perchlorate Isotope Forensics*. Anal. Chem. 77: 7838-7842.

Borden, R.C., C.A. Gomez and M.T. Becker, 1995. *Geochemical Indicators of Intrinsic Bioremediation*. Ground Water 33(2):180-189.

Borden, R.C., M.J. Hunt, M.B. Shafer, M.A. Barlaz, 1997a. *Environmental Research Brief – Anaerobic Biodegradation of BTEX in Aquifer Material*. EPA/600/S-97/003, US EPA, Washington, DC, pp. 9.

Borden, R.C., R.A. Daniel, L.E. LeBrun IV, and C.W. Davis, 1997b. *Intrinsic Biodegradation of MTBE and BTEX in a Gasoline-Contaminated Aquifer*. Water Resources Research, 33(5): 1105-1115.

Borden, R.C, M.T. Lieberman, C. Zawtocky, and W.J. Beckwith, 2006. *Final Report: Edible Oil Barriers for the Treatment of Perchlorate Contaminated Groundwater*. Project No. ER-0221. Environmental Security Technology Certification Program (ESTCP), Arlington, VA.

Borden, R.C., E. Perdue, M.T. Lieberman and S.L. Knox, 2007. *Field and Laboratory Evaluation of the Potential for Monitored Natural Attenuation of Perchlorate in Groundwater, Draft Final Technical Report*. Environmental Security Technology Certification Program (ER-0428), Arlington, VA, April 2007.

Brooks, S.C., D.L. Taylor and P.M. Jardine, 1998. *Thermodynamics of Bromide Exchange on Ferrihydrite: Implications for Bromide Transport*. Soil Sci. Soc. of Amer. J. 62 (5):1275-1279.

CaDHS (California Department of Health Services), 2006. *News Release: State Health Department Announces Proposed Drinking Water Standard for Perchlorate*. (<http://www.dhs.ca.gov>.)

Canas, J.E., 2005. *The Development and Application of Preconcentration/Pre-elution Ion Chromatography Methods for the Detection of Trace Perchlorate in Difficult Matrices*. Ph.D. Dissertation, Texas Tech University, August 2005.

Canas, J.E., R.Patel, K. Tian and T.A. Anderson, 2006. *Development of an Extraction Method for Perchlorate in Soils*. J. Environ. Monitor. 8: 399-405.

Chaudhuri, S.K, S.M. O'Connor, R.L. Gustavson, L.A. Achenbach and J.D. Coates, 2002. *Environmental Factors that Control Microbial Perchlorate Reduction*. Appl. Environ. Microbiol. 68(9): 4425-4430.

Choi, H. and J. Silverstein, 2008. *Inhibition of Perchlorate Reduction by Nitrate in a Fixed Biofilm Reactor*. J. Hazard. Mater. (Epub ahead of print). (<http://www.ncbi.nlm.nih.gov/pubmed/18359562>).

Clay, D.E., Z. Sheng, Z. Liu, S.A. Clay and T.P. Trooien, 2004. *Bromide and Nitrate Movement through Undisturbed Soil Columns*. J. Environ. Qual. 33:338-342.

Coates, J.D. and L.A. Achenbach, 2006. *Chapter 12: The Microbiology of Perchlorate Reduction and its Bioremediative Application*. In: B. Gu and J.D. Coates (eds.) Perchlorate: Environmental Occurrence, Interactions, and Treatment, Springer. pp. 279-295. ISBN: 978-0-387-31114-2

Coates, J.D., U. Michaelidou, R.A. Bruce, S.M. O'Connor, J.N. Crespi, and L.A. Achenbach, 1999. *Ubiquity and Diversity of Dissimilatory (Per)chlorate-Reducing Bacteria*. Appl. Environ. Microbiol. 65 (12): 5234-5241.

Coates, J.D. and J. Pollock, 2003. *Abstract: Potential for In Situ Bioremediation of Perchlorate in Contaminated Environments*. Presented at: In Situ and On-Site Bioremediation, the Seventh International Symposium, Orlando, FL, June 2003.

Coleman, M., M. Ader, S. Chaudhuri, and J.D. Coates, 2003. *Microbial Isotopic Fractionation of Perchlorate Chlorine*. *Appl. Environ. Microbiol.* 69:4997-5000.

Cooley, A., M. Ferrey, M. Harkness, R.R. Dupont, H. Stroo and J. Spain. 2005. *Monitored Natural Attenuation Forum: A Panel Discussion*. *Remediation*: Spring 2005; p 83-95.

Di Rienzo, R.P., K. Lin, T.T. McKay and R.W. Wade, 2004. *Abstract: Analysis of Perchlorate in Drinking Water, Groundwater, Saline Water, Soil, and Biota by LC/MS*. The 20<sup>th</sup> Annual National Environmental Monitoring Conference, Washington, DC. July 19-23.

Environmental News Service (ENS), 2006. *First in the Nation, Massachusetts Perchlorate Standards Take Effect*. ([http://www.stormwaterauthority.org.library/view\\_article.aspx?id=589](http://www.stormwaterauthority.org.library/view_article.aspx?id=589).)

Gillham, R.W., R.C. Starr and D.J. Miller, 1990. *A Device for In situ Determination of Geochemical Transport Parameters; 2 Biochemical Reactions*. *Ground Water* 82: 858-862.

Gingras. T.M. and J.R. Batista, 2002. *Biological reduction of perchlorate in ion exchange regenerant solutions containing high salinity and ammonium levels*. *J. Environ. Monitoring* 4: 96-101.

Gunawan, C., 2007. *Bioremediation for Perchlorate-contaminated Groundwater*. Michigan State Univ., Microbiology & Molecular Genetics, Course 445. *Basic Biotechnology eJournal* 3: 6-13. <http://www.taxonomicoutline.org/index.php/mmg445/article/view/220/274>.

Hatzinger, P.B., M.T. Lieberman, R.C. Borden, N.C. Sturchio, J.K. Böhlke and B. Gu, 2007. *Isotopic Fractionation of Perchlorate and Nitrate during Biodegradation in an EOS® Biobarrier*. Abstract and presentation at the Ninth International In Situ and On-Site Bioremediation Symposium, May 7 - 11, 2007, Baltimore, MD.

Heaton, T.H.E., 1986. *Isotopic Studies of Nitrogen Pollution in the Hydrosphere and Atmosphere: A Review*. *Chemical Geology* 59: 87-102.

Herman, D.C. and W.T. Frankenberger, Jr., 1998. *Microbial-Mediated Reduction of Perchlorate in Groundwater*. *J. Environ. Qual.* 27: 750-754.

Herman, D.C. and W.T. Frankenberger, Jr., 1999. *Bacterial Reduction of Perchlorate and Nitrate in Water*. *J. Environ. Qual.* 28: 1018-1024.

Hines, M.E., F. von Hippel, J. Kennish, M. Mach and D. Pilson, 2002. *Biological Effects of Inadvertent Perchlorate Releases During Launch Operations*. TRW Space & Electronics, Contract No. F04701-00-D-0203.

Hunt, M.J., R.C. Borden, and M.A. Barlaz, 1998. *Determining Anaerobic BTEX Decay Rates in a Contaminated Aquifer*. J. Hydrologic Engineering. October 1998, p 285-293.

ITRC (Interstate Technology and Regulatory Council), 2002. *A Systematic Approach to In Situ Bioremediation in Groundwater Including Decision Trees for In Situ Bioremediation of Nitrates, Carbon Tetrachloride and Perchlorate. Technical/Regulatory Guidelines*. August 2002. pp 92-128. (<http://www.itrcweb.org/user/isb-8r.pdf>).

ITRC (Interstate Technology and Regulatory Council), 2005. *Perchlorate: Overview of Issues, Status, and Remedial Options*. ITRC Perchlorate Team, September 2005. (<http://www.itrcweb.org>).

ITRC (Interstate Technology and Regulatory Council), 2008. *Overview of Remediation Technologies for Perchlorate Contamination in Groundwater and Drinking Water*. ITRC Perchlorate Team, (Publication scheduled for 2008). (<http://www.itrcweb.org>).

Jackson, W.A., M. Jeon, J.H. Pardue, and T.A. Anderson, 2002. *Enhanced Natural Attenuation of Perchlorate in Soils Using Electrokinetic Injection*. (<https://www.denix.osd.mil/denix/Public/Library/Water/Perchlorate/Jackson/jackson.html>)

Jackson, W.A., P. Joseph, P. Laxman and K. Tan. 2005. *Perchlorate Accumulation in Forage and Edible Vegetation*. J. Agric. Food Chem. 53: 369 – 373.

Johnston, J.J., R.C. Borden, and M.A. Barlaz, 1996. *Anaerobic Biodegradation of Hazardous Organics in Groundwater Down Gradient of a Sanitary Landfill*. J. Contaminant Hydrology 23(4): 263-283.

Ju, X., J.A. Field, R. Sierra-Alvarez, M. Salazar, H. Bentley, and R. Bentley, 2007. *Chemolithotrophic Perchlorate Reduction Linked to the Oxidation of Elemental Sulfur*. Biotech. Bioeng. 96: 1073-1082.

Karr, J.D., W.J. Showers, J.W. Gilliam, A.S. Andres, 2001. *Tracing Nitrate Transport and Environmental Impact from Intensive Swine Farming using Delta Nitrogen-15*. J. Environ. Qual. 30(4): 1163-1175.

Kennedy, L., J. Everett and J. Gonzales, 2000. *Aqueous and Mineral Intrinsic Bioremediation Assessment (AMIBA) Protocol*. Air Force Center for Environmental Excellence.

Kesterson, K.E., P.S. Amy and J.R. Batista, 2005. *Limitations to Natural Bioremediation of Perchlorate in a Contaminated Site*. Bioremediation Journal 9: 129-139.

Kirk, A.B., E.E. Smith, K. Tian, T.A. Anderson and P.K. Dasgupta, 2003. *Perchlorate in milk*. Environ. Sci. Technol. 37:4979-4981.

Knox, S.L., M.T. Lieberman, R.C. Borden, S. Jorgensen and W. Lucas, 2007. *Lines of Evidence for Natural Attenuation of Perchlorate*. Poster presented at Partners in Environmental Technology, Technical Symposium & Workshop. SERDP-ESTCP, Washington, DC. Dec 4 -6.

Kolhatkar, R., T. Kuder, P. Allen, and J.T. Wilson, 2002. *Use of Compound-Specific Stable Carbon Isotope Analyses to Demonstrate Anaerobic Biodegradation of MTBE in Groundwater at a Gasoline Release Site*. Environ. Sci. Tech. 36(23): 5139-5146.

Kramer, U., 2005. *Phytoremediation: Novel Approaches to Cleaning Up Polluted Soils*. Current Opinions Biotechnol 16:133-141.

Krauter, P.W., B. Daily, V. Dibley, H. Pinkart and T. Legler, 2005. *Perchlorate and nitrate remediation efficiency and microbial diversity in a containerized wetland bioreactor*. Internat. J. Phytoremed. 7:113-128

Lieberman, M.T., S.L. Knox, R.C. Borden and R.J. Cramer, 2007. *Approaches for Evaluating the Monitored Natural Attenuation of Perchlorate in Groundwater*. Paper submitted for publication in Proceedings of the Ninth International In Situ and On-Site Bioremediation Symposium, May 7 - 11, 2007, Baltimore, MD.

Logan, B.E., 2001. *Assessing the Outlook for Perchlorate Remediation*. Environ. Sci. Tech 35 (23): 482A- 487A.

Logan, B.E., H.S. Zhang, P. Mulvaney, M.G. Milner, I.M. Head and R.F. Unz, 2001. *Kinetics of Perchlorate- and Chlorate-Respiring Bacteria*. Appl. Environ. Microbiol. 67: 2499-2506.

Lollar, B.S., G.F. Slater, M. Witt, G.M. Klecka, M. Harkness and J. Spivack, 2001. *Stable Carbon Isotope Evidence for Intrinsic Bioremediation of Tetrachloroethene and Trichloroethene at Area 6, Dover Air Force Base*. Environ. Sci. Tech. 35(2): 261269.

Mariotti, A., J.C. Germon, P. Hubert, P. Kaiser, R. Letolle, A. Tardieux and P. Tardieux, 1981. *Experimental Determination of Nitrogen Kinetic Isotope Fractionation: Some Principles: Illustration for the Denitrification and Nitrification Processes*. Plant and Soil 62: 413-430.

Min, B., R.J. Evans, A.K. Chu and B.E. Logan, 2004. *Perchlorate Removal in Sand and Plastic Media Bioreactors*. Water Res. 38(1): 47-60.

Motzer, W.E., 2001. *Perchlorate Problems, Detection, and Solutions*. Environmental Forensics 2(4): 301-311.

Mwegoha, W., O.S.Mbuya, A. Jain, N.H. Ugochukwu and M.D. Abazinge, 2007. *Use of Chicken Manure Extract for Biostimulation and Enhancement of Perchlorate Rhizodegradation in Soil and Water Media*. Bioremediation Journal 11: 61-70.

NDCEE, 2004. "NDCEE Demonstrates a Field-Based Perchlorate Measurement Instrument". NDCEE Newsletter, National Defense Center for Environmental Excellence, Winter 2005. ([www.denix.osd.mil](http://www.denix.osd.mil))

Newell, C.J., H.S. Rifai, J.T. Wilson, J.A. Connor, J.A. Aziz, M.P. Suarez, 2002. *Calculation and Use of First-Order Constants for Monitored Natural Attenuation Studies*. EPA/540/S-2/500.

Nzengung, V.A., C. Wang and G. Harvey, 1999. *Plant-mediated transformation of perchlorate into chloride*. Environ. Sci. Technol. 33:1470-1478.

Nzengung, V.A., M.T. Lieberman and H.F. Stroo, 2008 (submitted for publication). *Emerging Technologies for Perchlorate Bioremediation*. In: Stroo, H.F., C. Vogel and C.H. Ward (Eds). *In Situ Bioremediation of Perchlorate in Groundwater*. Springer.

NASA, 2006. "Perchlorate (ClO<sub>4</sub>) Treatment Technologies Literature Review, Operable Unit 1 Expanded Treatability Study." National Aeronautics and Space Administration, Pasadena, CA, June 2006.

Nzengung, V.A. and S.C. McCutcheon, 2003. *Phytoremediation of Perchlorate*. Chapter 29 In McCutcheon, S.C. and J.L. Schnoor (eds). *Phytoremediation: Transformation and Control of Contaminants*. Wiley-Interscience Publishers, Pages 863-885.

Nzengung, V.A., H. Penning and W. O'Niell, 2004. *Mechanistic Changes During Phytoremediation of Perchlorate Under Different Root Zone Conditions*. Internat. J. Phytorem. 6:63-83.

O'Toole, S.S., P. Breen, D.T. Canavan, 2004. *Evaluating Plume Capture Through Mass Flux Estimates*. Abstract of poster presented at the Eleventh Conference on the Geology of Long Island and Metropolitan New York, Stony Brook University, NY, April 17, 2004. (<http://www.geo.sunysb.edu/lig/Conferences/abstracts-04/canavan/canavan.htm>.)

Penfold, L., 2004. "Critical Issues for Definitive Analysis of Low Concentrations of Perchlorate in the Environment" (briefing).

Pennington, J.C., R. Bowen, J.M. Brannon, M. Zakikhani, D.W. Harrelson, D. Gunnison, J. Mahannah, J. Clarke, T.F. Jenkins and S. Gnewuch, 1999. *Draft Protocol for Evaluating, Selecting, and Implementing Monitored Natural Attenuation at Explosives-Contaminated Sites*. Technical Report EL-99-10, U.S. Army Engineer Research Center, Vicksburg, MS. September 1999.

Pilon-Smits, E., 2005. *Phytoremediation*. Ann Rev Plant Biol 56:15-39.

Radtke, C. and D.B. Blackwelder, 2005. *Flow-Through Bioreactor for the In Situ Assessment of Remediation Strategies in Vadose and Saturated Zones*. Idaho National Laboratory. ([www.inl.gov/factsheets/rd100/in-situ\\_bioreactor.pdf](http://www.inl.gov/factsheets/rd100/in-situ_bioreactor.pdf))

Renner, R., 2006. *Perchlorate Found in Produce Worldwide*. Environ. Sc. & Technol. News 40 (Iss. 11): 3447-3448.

<http://pubs.acs.org/subscribe/journals/esthag/40/ill/html/060106news4.html>.

Rikken, G.B., A.G.M. Kroon and C.G. van Ginkel. 1996. *Transformation of (Per)chlorate into Chloride by a Newly Isolated Bacterium: Reduction and Dismutation*. Appl. Microbiol. Biotechnol. 45: 420-426.

Robertson, W.D., C.J. Ptacek and S.J. Brown, 2007. *Geochemical and Hydrogeological Impacts of a Wood Particle Barrier Treating Nitrate and Perchlorate in Ground Water*. Ground Water Monitoring & Remediation 27 (2): 85-95, Spring 2007.

Sandrin, S. K., M.L. Brusseau, J.J. Piatt, A.A. Bodour, W.P. Blanford, and N.T. Nelson, 2004. *Characterizing Spatial Variability of In-Situ Microbial Activity: Biotracer Tests*. Ground Water 42: 374-383, 2004.

Schaefer, C.E., M.E. Fuller, C.W. Condee, J.M. Lowey and P.B. Hatzinger, 2007. *Comparison of Biotic and Abiotic Treatment Approaches for Co-mingled Perchlorate, Nitrate and Nitramine Explosives in Groundwater*. J. of Contam. Hydrol. 89: 231-250.

Schnoor, J.L., L. Licht, S. McCutcheon, N. Wolfe, and L. Carreira, 1995. *Phytoremediation of Organic and Nutrient Contaminants*. Environ. Sci. Technol. 29:318A-323A.

Schnoor, J.L., G.F. Parkin, B. van Aken and J.D. Strout, 2002. *Final Report: Phytoremediation and Bioremediation of Perchlorate at the Longhorn Army Ammunition Plant*. (<http://clu-in.org/download/contaminantfocus/perchlorate/LHAAPfinalSchnoor.pdf>)

Slater, G.F., B. S. Lollar, B.E. Sleep and E.A. Edwards, 2001. *Variability in Carbon Isotopic Fractionation during Biodegradation of Chlorinated Ethenes: Implications for Field Applications*. Environ. Sci. Technol. 35(5): 901-907.

Stroo, H.F., C.C. Cosentini, T. Ronning and M. Larsen, 1997. *Natural Biodegradation of Wood Preservatives*. Remediation 7:77-93.

Sturchio, N.C., K.K. Bohlke, B. Gu, J. Horitz, G.M. Brown, A.D. Beloso, Jr., L.J. Patterson, P.B. Hatzinger, W.A. Jackson and J. Batista, 2006. *Chapter 5. Stable Isotopic Composition of Chlorine and Oxygen in Synthetic and Natural Perchlorate*. In: Gu, B. and J.D. Coates (eds.), 2006. Perchlorate: Environmental Occurrence, Interactions and Treatment. Springer.

Sturchio, N.C., P.B. Hatzinger, M.D. Arkins, C. Suh and L.J. Heraty, 2003. *Chlorine Isotope Fractionation During Microbial Reduction of Perchlorate*. Environ. Sci. Technol. 37: 3859-3863.

Susarla, S., S. Bacchus, N.L. Wolfe and S. McCutcheon, 1999. *Phytotransformation of Perchlorate and Identification of Metabolic Products in Myriophyllum aquaticum*. Internat. J. Phytoremediation 1:96-107.

- Susarla, S., S. Bacchus, G. Harvey and S. McCutcheon, 2000. *Phytotransformation of Perchlorate Contaminated Waters*. Environ. Technol. 21:1055-1065.
- Tan, K., T.A. Anderson and W.A. Jackson. 2004a. *Degradation Kinetics of Perchlorate in Sediments and Soils*. Water, Air and Soil Pollution 151: 245 – 259.
- Tan, K., W.A. Jackson, T.A. Anderson and J.H. Perdue. 2004(b). *Fate of Perchlorate-Contaminated Water in Upflow Wetlands*. Water Research 38: 4173-4185.
- Tan, K., T.A. Anderson and W.A. Jackson. 2005. *Temporal and Spatial Variation of Perchlorate in Streambed Sediments: Results from In-Situ Dialysis Samplers*. Environmental Pollution 136: 283–291.
- Tan, Z. and B. Reinhold-Hurek, 2003. *Dechlorosoma suillum* Achenbach et al. 2001 is a later subjective synonym of *Azospira oryzae* Reinhold-Hurek and Hurek 2000. Internat. J. System. Evol. Microbiol. 53: 1139-1142.
- Thorn, P.G., 2004. *Field Screening Method for Perchlorate in Water and Soil*. ERDC/CRREL TR-04-8. Hanover, NH: U.S. Cold Regions Research And Engineering Laboratory. ([www.crrel.usace.army.mil/techpub/CRREL\\_Reports/reports/TR02-1\(ERDC-CRL\).pdf](http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/TR02-1(ERDC-CRL).pdf).)
- Tipton, D.K., D.E. Rolston and K.M. Scow, 2003. *Transport and Biodegradation of Perchlorate in Soils*. J. Environ. Qual. 32: 40-46.
- Urbansky, E.T., 1999. *Issues in Managing the Risks Associated with Perchlorate in Drinking Water*. J. Environ. Management 56: 79-95.
- USEPA, 1997. OSWER Directive 9200.4-17, Interim Final, December 1, 1997. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*.
- USEPA, 1999. Final Directive. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*.  
<http://www.epa.gov/swerust1/directiv/d9200417.htm>
- USEPA 2004. [http://www.epa.gov/fedfac/pdf/releases\\_04\\_29\\_04-with-datesDB.pdf](http://www.epa.gov/fedfac/pdf/releases_04_29_04-with-datesDB.pdf).
- USEPA, 2005a. EPA Superfund Record of Decision Amendment: Apache Powder Company, St. David, AZ. EPA/AMD/R09-05/049.
- USEPA, 2005b. *Perchlorate Treatment Technology Update: Federal Facilities Forum Issue Paper*. EPA No. 542-R05-015. InfoNational Service Center for Environmental Protection, Solid Waster and Emergency Response (5102G), Cincinnati, OH, May 2005. ([www.epa.gov/tio/tsp](http://www.epa.gov/tio/tsp))

USEPA, 2006. *Assessment Guidance for Perchlorate*. Memorandum from S.P. Bodine, Asst. Administrator, to Regional Administrators. January 26, 2006.

Wiedemeier, T.H., M.J. Barden, P.E. Haas and W.Z. Dickson, 2006. *Chapter 9. Designing Monitoring Programs to Effectively Evaluate the Performance of Natural Attenuation*. In: Nielsen, D.M. (ed.), Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring, 2nd edition, CRC Press, Boca Raton, FL.

Wiedemeier, T.H., C.J. Newell, H.S. Rifai, and J.T. Wilson, 1999. *Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface*. John Wiley and Sons, NY, NY

Wiedemeier, T.H., J.T. Wilson, D.H. Kampbell, R.N. Miller and J.E. Hansen, 1995. *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater, Volume II*. Air Force Center for Environmental Excellence, Brooks Air Force Base, TX. November 1995.

Wiedemeier, T.H., M.A. Swanson, D.E. Moutoux, E.K. Gordon, J.T. Wilson, B.H. Wilson, D.H. Kampbell, J.E. Hansen, P.E. Haas and F.H. Chappelle, 1998. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*. Air Force Center for Environmental Excellence, Brooks Air Force Base, TX.  
EPA/600/R-98/128 (<ftp://ftp.epa.gov/pub/ada/reports/protocol.pdf>).

Wilson, J.T., 2000. *Natural Attenuation of MTBE in the Subsurface under Methanogenic Conditions*. Air Force Center for Environmental Excellence. USEPA. EPA/600/R-00/006.

Wilson, J.T., P.M. Kaiser and C. Adair, 2005. *Monitored Natural Attenuation of MTBE as a Risk Management Option at Leaking Underground Storage Tank Sites*. Report No. EPA/600/R-041/1790. Environmental Protection Agency, Cincinnati, OH.  
([http://www.clu-in.org/download/remed/mna\\_for\\_risk\\_%20management\\_of\\_mtbe.pdf](http://www.clu-in.org/download/remed/mna_for_risk_%20management_of_mtbe.pdf))

Wu, J., R.F. Unz, H. Zhang and B.E. Logan, 2001. *Persistence of Perchlorate and the Relative Numbers of Perchlorate- and Chlorate-Respiring Microorganisms in Natural Waters, Soils and Wastewater*. *Bioremediation Journal* 5: 119-130.

Xu, J. and B.E. Logan, 2003. *Measurement of Chlorite Dismutase Activities in Perchlorate Respiring Bacteria*. *J. Microbiol. Meth.* 54: 239-247.

Xu, J., Y. Song, B. Min, L. Steinberg and B.E. Logan, 2003. *Microbial Degradation of Perchlorate: Principles and Applications*. *Environ. Engineering Science* 20: 405-422.

Yifru, D.D. and V.A. Nzungung, 2007a. *Use of Dissolved Organic Carbon to Enhance Rhizodegradation and Minimize Uptake of Perchlorate ( $\text{ClO}_4^-$ )* (In Press).

Yifru, D.D. and V.A. Nzungung, 2007b. *Use of Dissolved Organic Carbon to Biostimulate Rapid Rhizodegradation of Perchlorate: Soil Studies*. *Environ. Sci. Technol.* (submitted 2006)

## 7.0 POINTS OF CONTACT

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone/Fax/email	Role in Project
M. Tony Lieberman, R.S.M.	Solutions-IES 1101 Nowell Rd. Raleigh, NC 27607	919-873-1060 919-873-1074 (fax) tlieberman@solutions-ies.com	Principal Investigator; Project Manager
Dr. Robert C. Borden, P.E.	North Carolina State Univ. Dept. of Civil, Construction and Environmental Engineering Raleigh, NC 27609	919-515-1625 919-873-1074 (fax) rborden@eos.ncsu.edu; rborden@solutions-ies.com	Co-Principal Investigator
Sheri L. Knox, P.E.	Solutions-IES 1101 Nowell Rd. Raleigh, NC 27607	919-873-1060 919-873-1074 (fax) sknox@solutions-ies.com	Asst. Project Manager
Dr. Andrea Leeson	ESTCP 901 N. Stuart Suite 303 Arlington, VA 22203	703-696-2118 703-696-2114 andrea.leeson@osd.mil	Environmental Restoration Program Manager
Erica Becvar	AFCEE 3300 Sidney Brooks Brooks City-Base, TX 78235-5112	(210) 536-4314 DSN 240 (210) 536-5989 (fax) Erica.Becvar@brooks.af.mil	Contracting Officer's Representative (COR)

## **APPENDIX**

**CASE HISTORY 1**

**NAVAL SURFACE WARFARE CENTER, INDIAN HEAD, MD**

**A Case Study for Perchlorate MNA at Indian Head, Maryland**  
**Solutions-IES, Inc., Raleigh, NC 27607**  
**ESTCP ER-0428**

**Background**

This case study site is located within the Naval Surface Warfare Center near Indian Head, Maryland, approximately 30 miles south of Washington, D.C. The Indian Head site consists of approximately 2 acres of grassy land containing a small drum storage building (Building 1419) and numerous groundwater monitoring wells. Building 1419 was once used to clean out or “hog out” solid propellant containing ammonium perchlorate from various devices, including rockets and ejection seat motors, that had exceeded their useful life span. The hog out process and former waste handling methods impacted the groundwater with elevated concentrations of perchlorate. The groundwater flow direction suggests that perchlorate-contaminated groundwater migrates approximately 400 ft until reaching Mattawoman Creek, a large, tidally influenced tributary of the Potomac River.

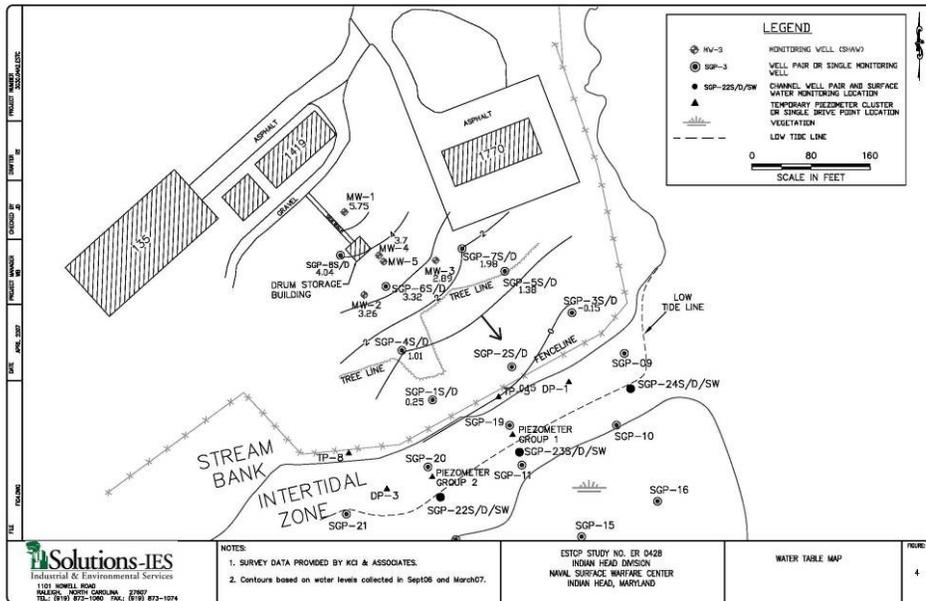
To evaluate the use of MNA of perchlorate as a groundwater remedy at the Indian Head site, a tiered approach was used. This approach is similar to that used to evaluate MNA of volatile organic compounds (VOCs).

**Application of MNA Evaluation**

*Tier 1 – Perchlorate Plume Stability and Geometry.*

At the onset of the evaluation, a monitoring well network was already in place at the Indian Head site. The well network had been installed to monitor the extent of perchlorate contamination and evaluate a pilot test of enhanced *in situ* bioremediation initiated in 2002 by Shaw Environmental near Building 1419. The prior work indicated that perchlorate concentrations decreased with distance away from the presumed source at Building 1419. However, perchlorate was not monitored beyond the pilot test area, which was located midway between the presumed source area and Mattawoman Creek, where the perchlorate plume was expected to discharge.

In 2005, with funding by ESTCP (Project No. ER-0428), Solutions-IES commenced its evaluation of the potential for MNA at the site. After baseline monitoring was performed, it became apparent that additional monitoring well/piezometer installation would be required to fully assess the plume geometry including areas closer to the creek. Additional monitoring wells and piezometers were installed in three portions of the site: 1) on land downgradient of the source area and closer to the Creek; 2) in the intertidal zone and mudflat area (subtidal shallows) along the bank of Mattawoman Creek; and 3) a subtidal channel located between the intertidal zone and mudflats.



**Figure 1. Site map showing locations of monitor wells and piezometers showing general groundwater flow direction toward Mattawoman Creek.**

Figure 1 shows the monitor well and piezometer network that was used in this evaluation and a general groundwater flow direction. Water level information and analytical results gathered during the *Tier 1* evaluation indicated that perchlorate laden groundwater flows to the southeast from the source area near Building 1419, eventually rising up through an intertidal zone, and ultimately discharging to Mattawoman Creek. The groundwater flow direction varies daily and seasonally according to tide levels in the freshwater creek. Figure 2 shows the tidal flats in winter when vegetation has died back; Figure 3 shows the same general area in summer.

At high tide, water flows downward into the aquifer from the creek. At low tide, groundwater flows upward through the organic rich sediments before discharging to the surface as a series of small springs and seeps. The groundwater discharge area occurs primarily in an intertidal area adjoining a small subtidal channel.



**Figure 2. View of the tidal flats in winter.**



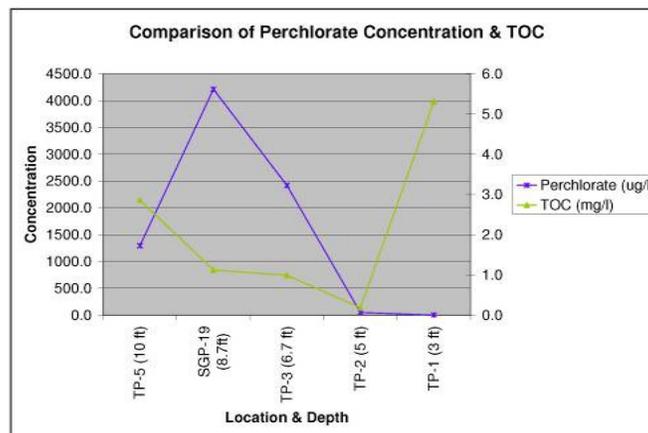
**Figure 3. View of intertidal channel in summer.**

Concentrations as high as 93,000  $\mu\text{g/L}$  were measured near Building 1419; concentrations 400 ft downgradient beneath the bank of the creek remain over 10,000  $\mu\text{g/L}$ . By extending the well network into the tidal flats and monitoring at different depths, cross-sections of the intertidal zone and perchlorate distribution were constructed that showed concentrations decreasing by over 99% as groundwater migrates upward through the organic rich sediments near the creek. However, because of the complicated groundwater flow regime, groundwater monitoring alone could not demonstrate that observed decline in perchlorate was solely due to biodegradation.

### *Tier 2- Bio-geochemical Conditions for Perchlorate Biodegradation*

Site-specific bio-geochemical monitoring is the best understood and most widely employed evidence of perchlorate MNA. Concurrent with the *Tier 1* evaluation, bio-geochemical parameters including dissolved oxygen (DO), oxidation-reduction potential (ORP), total organic carbon (TOC), methane, nitrate, sulfate, temperature, and pH were monitored to help determine if conditions within the groundwater at the Indian Head site were conducive for perchlorate biodegradation. Detailed monitoring of bio-geochemical conditions within the intertidal zone showed that TOC and methane concentrations increase and ORP measurements decrease as groundwater migrates upward through organic rich sediments in this area (Figure 4). These changes occur at the same depth that perchlorate concentrations decrease providing supporting, but indirect, evidence of perchlorate biodegradation.

Although *Tier 1* and *Tier 2* data suggested strongly that perchlorate was attenuating naturally, additional evidence was needed to show more conclusively that this was occurring and to attribute the mechanism to biodegradation of the contaminant.



**Figure 4. Comparison of perchlorate and total organic carbon concentrations in wells located in the tidal flats.**

### Tier 3-Microbiological Indicators of Perchlorate Biodegradation

To provide direct evidence of the biological component of perchlorate biodegradation, various laboratory and field tests were employed. Both microcosm and macrocosm incubations were set up using site soil and groundwater. The microcosm setup utilized soil and groundwater from MW-2, a well located close to Building 1419. The macrocosm setup utilized soil from the intertidal zone and groundwater from a well located near the edge of the intertidal zone. In the microcosms, perchlorate was reduced to below detection limits in less than 60 days while the macrocosms showed at least a 40% reduction in perchlorate in less than 15 days.

Enzyme studies were also used. During the initial investigation at the Indian Head site, groundwater collected from MW-2 showed the presence of the chlorite dismutase (CD) gene which mediates dismutation of chlorite, the final step in reduction of perchlorate to chloride and oxygen. This indicated that the capability to biodegrade perchlorate was present in indigenous microbial communities in groundwater at the site, but did not indicate the activity of the enzyme *in situ*.

Molecular analysis showed that high numbers of DNA-based perchlorate reductase (*pcrA*) genes occur in the intertidal zone. *PcrA* is involved in the degradation of perchlorate to chlorate and chlorite. Figure 5 shows the detected number of *pcrA* genes copies, and the corresponding perchlorate concentrations, in 17 wells/piezometers located along the intertidal channel. The data indicate that, in general, higher numbers of gene copies were reported in locations with lower perchlorate concentrations, suggesting that perchlorate is biodegrading as a result of perchlorate reductase activity.

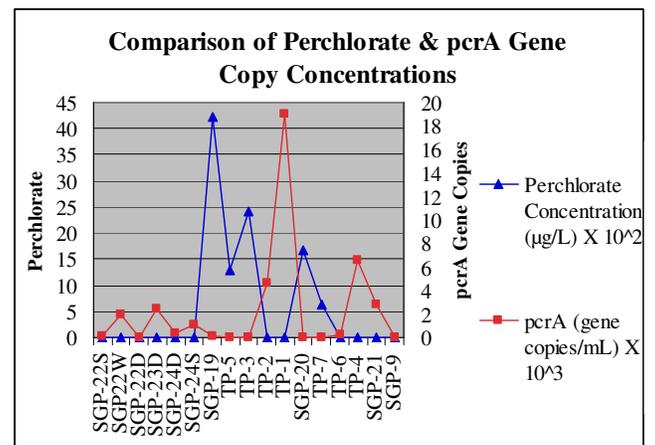


Figure 5. Comparison of *pcrA* gene copies and perchlorate



Figure 6. View of *in situ* columns installed in tidal flats with adjacent piezometers.

*In situ* field tests were also used to track reduction in perchlorate due to biodegradation. At the Indian Head site, *in situ* columns were installed within the intertidal zone to provide a direct measure of bioactivity. The *in situ* columns were constructed such that a column of soil within the intertidal zone is isolated from the surrounding soil and water with an open ended PVC pipe (Figure 6). Groundwater is slowly pumped upward through the column at rates comparable to the natural groundwater flow velocity. First-order biodegradation rates were estimated that range from 24 to 61 per year.

## Summary

A tiered approach was employed to demonstrate MNA of perchlorate at the Indian Head site. *Tier 1* results showed that perchlorate concentrations slowly decrease as the groundwater moves away from the source and rapidly decrease as the contaminant moves vertically through the organic rich intertidal zone near Mattawoman Creek. *Tier 2* results showed that the rapid decline in perchlorate concentration within the intertidal zone occurred at the same depth that TOC and methane increased, and ORP decreased, providing supporting, but indirect evidence of perchlorate biodegradation. Together, the plume configuration suggested several controlling factors including dilution, dispersion and biodegradation were responsible for the observed attenuation of the contaminant.

Microcosm and macrocosm incubations (*Tier 3*) constructed with groundwater and soil from the Indian Head site demonstrated perchlorate biodegradation in a short period of time. DNA enzyme assays performed on groundwater samples collected within the intertidal zone show that high numbers of *pcrA* genes occur where perchlorate concentrations decline. *In situ* columns, installed in the stream bed to provide a direct measure of *in situ* biodegradation, measured first-order biodegradation rates from 24 to 61 per year.

The trends in groundwater flow, bio-geochemical parameters, microbial populations and perchlorate concentrations provide multiple lines of evidence that perchlorate is biodegrading at the Indian Head site prior to discharge to Mattawoman Creek. The findings, when considered together, could be used to form the basis of a recommendation that perchlorate MNA may be an acceptable remedy at this site.

**CASE HISTORY 2**

**ALLIANT TECHSYSTEMS, LLC, ELKTON, MD**

# A Case Study for Perchlorate MNA at Elkton, Maryland

## Solutions-IES, Inc.

### ESTCP ER-0428

#### **Introduction**

This case study site is located at the Alliant Techsystems (ATK) facility approximately 60 miles northeast of Baltimore, MD, near Elkton in Cecil County, MD. The ATK facility has been used for multiple industrial purposes, such as fireworks manufacturing, munitions production, pesticide production, and research and manufacturing of solid propellant rockets. Ammonium perchlorate was used in rocket engine testing and manufacturing at the facility. Soil and groundwater investigations were initiated during the 1980s when trichloroethene (TCE) was detected in two production wells at the facility. The area of focus for these investigations is designated the Perchlorate/TCE SWMU (the site).

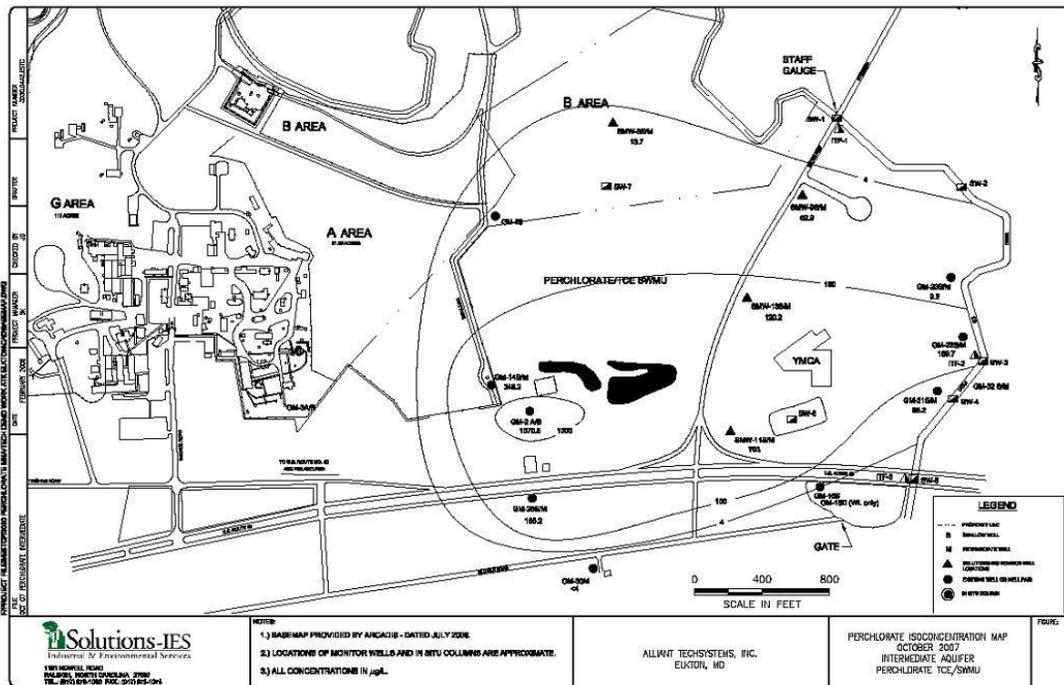
To demonstrate the use of MNA of perchlorate at the ATK site as a groundwater remedy, a tiered approach was adapted: *Tier 1*- determine the spatial and temporal distribution of perchlorate; *Tier 2*- characterize the suitability of bio-geochemical conditions for perchlorate biodegradation; and *Tier 3*- confirm microbiological indicators of perchlorate biodegradation.

#### **Application of MNA Evaluation Approach**

##### *Tier 1 – Perchlorate Plume Stability and Geometry.*

Most of the perchlorate contamination within the Perchlorate/TCE SWMU was previously defined using a network of monitoring wells screened in the shallow, intermediate, and deep aquifers. The perchlorate contamination is largely confined to the shallow and intermediate aquifer within the Perchlorate/TCE SWMU. The highest concentrations of perchlorate detected are in the vicinity of the SWMU with concentrations in this area as high as 1030 µg/L. The perchlorate and TCE groundwater plume extends from west to east beyond the ATK property, approximately 3000 ft from the presumed source. The distal extent appears to be limited by interception at Little Elk Creek (Figure 1). Data obtained during routine monitoring of the site indicate that perchlorate is below detection limits east of Little Elk Creek. However, some TCE has migrated beyond the creek suggesting that possibility that perchlorate may have attenuated prior to discharging to the creek.

After baseline monitoring was performed for the demonstration in 2005, additional monitoring wells were installed to fill out the network and help assess plume geometry. These monitoring wells were located just east of Elkton Road (SMW-9S/M, SMW-13S/M, and SMW-11S/M), and north of the SWMU area (SMW-8S/M). Figure 1 shows monitoring well locations and isoconcentration contours of perchlorate in the intermediate aquifer derived from the baseline sampling results.



**Figure 1. Site map showing shallow and intermediate-depth monitoring wells and the intermediate perchlorate isoconcentration contours.**

Each of the monitoring well pairs included a monitoring well in the shallow aquifer installed to a depth of approximately 30 feet below ground surface (bgs), and a monitoring well in the intermediate aquifer at a depth of approximately 60 feet bgs.

Water level information and analytical results gathered from this *Tier 1* evaluation indicate that groundwater typically flows to the east prior to discharge to Little Elk Creek. Little Elk Creek is a shallow stream that traverses a zone of undeveloped land covered with shrubs, vines and trees. The width of the naturally occurring buffer on the west side of the creek is approximately 50 feet including the stream bank which is an alluvium deposit composed of sand and gravel.



**Figure 2. Sample collection along the shore of Little Elk Creek using the filter stack method for perchlorate.**

Groundwater analytical results utilized as part of the *Tier 1* evaluation indicated that perchlorate tends to concentrate in the intermediate aquifer as groundwater flows to Little Elk Creek. Figure 2 shows perchlorate sampling activities near Little Elk Creek. However, as perchlorate nears Little Elk Creek, the intermediate aquifer thins, and the perchlorate concentrations tend to increase as it begins to flow through the shallow aquifer. Groundwater analytical results indicated that the plume geometry had changed very little since Solutions-IES began monitoring for this demonstration project in 2006 and that the plume is generally stable.

### Tier 2- Bio-geochemical conditions for Perchlorate Biodegradation

The collection of site-specific bio-geochemical information is the best understood and most widely employed step to provide supporting evidence of MNA of perchlorate. Concurrent with the *Tier 1* evaluation, bio-geochemical parameters such as dissolved oxygen (DO), oxidation-reduction potential (ORP), total organic carbon (TOC), methane, nitrate, chloride, temperature, and pH were monitored to help determine if conditions within the groundwater at the ATK site, especially near the discharge point at Little Elk Creek, were conducive to the biodegradation of perchlorate. DO concentrations near Little Elk Creek historically were below 2.5 ppm with some locations closer to 1 ppm; ORP measurements were generally less than +60 mV. These conditions are not optimal for perchlorate reduction, but may still support the growth and activity of perchlorate-reducing microorganisms.

### Tier 3-Microbiological Indicators of Perchlorate Biodegradation

To provide direct evidence of the biological component of perchlorate biodegradation, both laboratory and field tests were performed at or on matrices from the ATK site. Laboratory microcosms were set up utilizing sediment and groundwater from GM-22S, a monitoring well located close to Little Elk Creek along the plume centerline. The microcosm results showed a reduction in low starting concentrations of perchlorate under ambient conditions to detection limits in about 120 days and a zero-order degradation rate of 0.92 mg/L/yr (Figure 3).

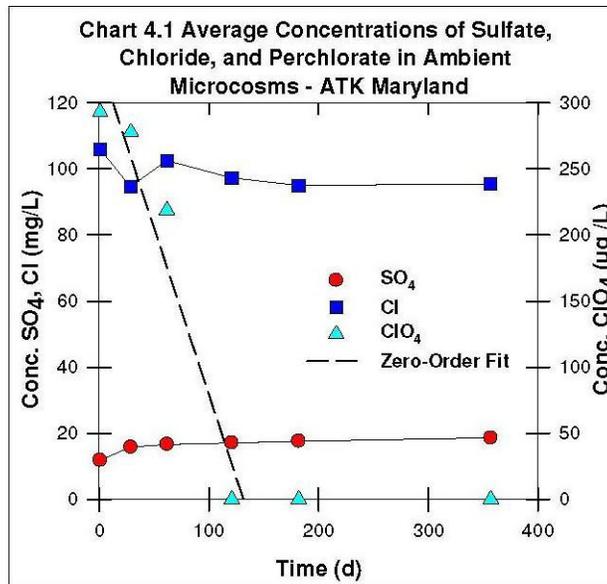


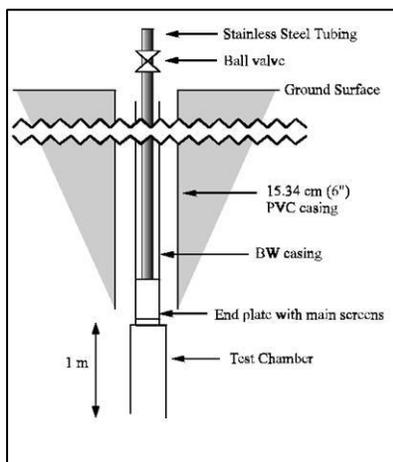
Figure 3. Biological reduction of perchlorate in ambient microcosm treatments.

Other laboratory testing for direct evidence biodegradation of perchlorate was performed on a soil boring sample of sediment near Little Elk Creek. The chlorite dismutase (CD) enzyme assay showed a positive genetic potential to produce CD and, therefore, a potential to degrade perchlorate under the appropriate conditions.

The DNA-based qPCR perchlorate reductase (*pcrA*) gene assay was also utilized at the site to determine if the genetic potential is present to biodegrade perchlorate. *PcrA* gene copies were detected in four of the 23 groundwater samples collected. Of these four samples, two of the samples were collected from the shallow aquifer in monitoring wells located along the Little Elk Creek suggesting that perchlorate may be biodegrading in the riparian buffer zone along Little Elk Creek.

In addition to laboratory tests, field tests were also utilized to help identify perchlorate biodegradation. Three *in situ* columns were installed near the creek bed close to the center line of the perchlorate plume (GM-22 S/M). Two of the columns were live biotic columns and the other column was inhibited with nitric acid. The design of the columns is similar to the system used by Gillham et al. (1990) and Borden et al. (1997a), and consists of a 3-foot long stainless steel test chamber allowing sediment and groundwater to be isolated from the surrounding environment (Figure 4a). Tubing is attached to the top of each column to allow for the injection of a known concentration of perchlorate into each column, and as a sampling port (Figure 4b). Each of the columns was injected with perchlorate at a concentration of approximately 150  $\mu\text{g/L}$  in June of 2007. After monitoring groundwater samples collected from the *in situ* columns over a period of approximately one-half year, perchlorate decreased from 133  $\mu\text{g/L}$  to below the analytical detection limit with first-order biodegradation rates ranging from 7 to 9 per year (Figure 5).

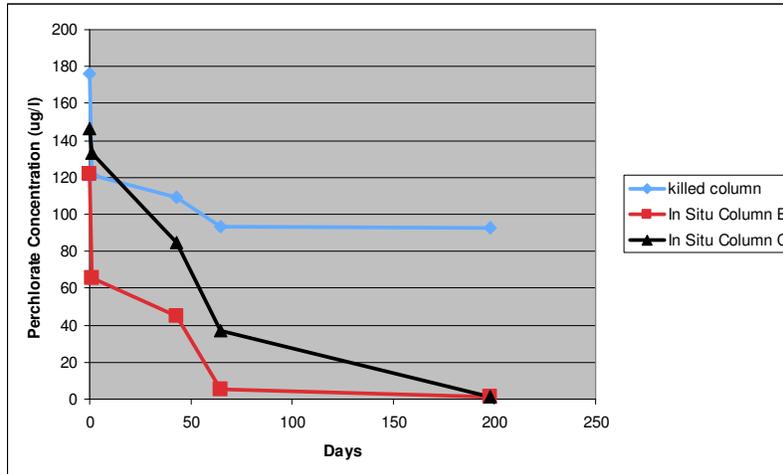
**Figure 4: Schematic of *in situ* column design**



**Figure 4a. *In situ* column construction.**



**Figure 4b. Photograph of *in situ* columns in place.**



**Figure 5. Decline in perchlorate concentration versus time in live columns (B and C) compared to no degradation in killed column.**

**Summary:**

The tiered approach was employed to document the MNA of perchlorate. In *Tier 1* of the evaluation, the perchlorate plume was shown to be stable with evidence that perchlorate may be degrading near Little Elk Creek. The *Tier 2* evaluation of biogeochemical parameters indicated that conditions were not optimal, but were adequate to support natural attenuation in near the creek.

The *Tier 1* and *Tier 2* results, alone, were not sufficient to thoroughly document MNA so additional *Tier 3* testing was conducted to demonstrate perchlorate biodegradation. In laboratory microcosms constructed with groundwater and soil from near the creek, perchlorate was biodegraded to below the analytical detection limit in less than 120 days. DNA enzyme assays performed on groundwater samples demonstrated that microorganisms capable of perchlorate biodegradation are present in the aquifer. Gene copies associated with the enzyme used to degrade perchlorate were highest in the riparian buffer near the creek. Field column tests demonstrated *in situ* biodegradation of perchlorate to below detection 200 days in with a first-order biodegradation rate of 7 to 9 per year.

The case study at the ATK site illustrates the use of the tiered approach for demonstrating MNA of perchlorate in groundwater. These findings could be used to support the use of MNA as the recommended remedy at this site.

# ESTCP Cost and Performance Report

(ER-200428)



## Monitored Natural Attenuation of Perchlorate in Groundwater

September 2010



ENVIRONMENTAL SECURITY  
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense



**TABLE OF CONTENTS (continued)**

	<b>Page</b>
5.2.3 Pre-Demonstration Testing .....	21
5.2.3.1 Groundwater and Soil Sampling .....	21
5.2.3.2 Laboratory Studies .....	22
5.3 DEMONSTRATION APPROACH.....	23
5.3.1 Additional Site Characterization and Performance Monitoring .....	23
5.3.2 Site Hydrogeology and Plume Configuration.....	23
5.4 PERFORMANCE ASSESSMENT .....	24
5.4.1 Tier 1 and Tier 2 Evaluations.....	25
5.4.1.1 Current Source Conditions.....	25
5.4.1.2 Mid-Plume Conditions (Transect 1) .....	25
5.4.1.3 Mid-Plume Conditions (Transect 2) .....	25
5.4.1.4 Presumed Discharge Zone (Transect 3 and Interface Samples).....	25
5.4.2 Tier 3 Evaluation.....	27
5.5 MANUFACTURING SITE COST ASSESSMENT .....	28
6.0 COST COMPARISON .....	29
6.1 COST DRIVERS .....	29
6.2 COST COMPARISON—INDIAN HEAD VERSUS THE MANUFACTURING SITE DEMONSTRATIONS .....	29
6.3 COST COMPARISONS: PERCHLORATE MNA AND ENGINEERED REMEDATION APPROACHES.....	31
6.4 CONCLUSIONS.....	35
7.0 REFERENCES .....	37
APPENDIX A      POINTS OF CONTACT.....	A-1

## LIST OF FIGURES

	<b>Page</b>
Figure 1.	Perchlorate biodegradation pathway..... 4
Figure 2.	Map showing the Indian Head Project Site and vicinity at the Naval Surface Warfare Center, Indian Head, MD..... 10
Figure 3.	Perchlorate concentration map at the Indian Head Project Site (April 2008)..... 13
Figure 4.	Appearance of Littoral Zone in winter and summer at the Indian Head Project Site..... 14
Figure 5.	Geochemical changes in groundwater and sediment pore water beneath the four geomorphological zones at Indian Head Project Site..... 16
Figure 6.	Horizontal extent of the commingled TCE and perchlorate plume at the Maryland manufacturing site. .... 20
Figure 7.	Location of GM-22S/M near the wooded riparian buffer on the west side of Little Elk Creek..... 21
Figure 8.	Perchlorate concentrations in microcosms versus time using soil and groundwater from the TCE/perchlorate plume (ESTCP, 2007). .... 22
Figure 9.	Transects for estimating mass flux across the TCE/perchlorate plume..... 24
Figure 10.	Mass flux versus distance from source. .... 27

## LIST OF TABLES

		<b>Page</b>
Table 1.	Summary of first-order biodegradation rates in perchlorate plume matrices from the Indian Head Site. ....	17
Table 2.	Summary of biodegradation rates in TCE/perchlorate plume matrices from the Maryland manufacturing site. ....	28
Table 3.	Cost breakdown of overall ESTCP Project ER-200428. ....	30
Table 4.	Cost components for perchlorate MNA – base case. ....	33
Table 5.	Comparison of capital costs and NPV of costs for operation, maintenance, and monitoring of various technologies for perchlorate-impacted groundwater. ....	34

## ACRONYMS AND ABBREVIATIONS

---

bgs	below ground surface
CD	chlorite dismutase (enzyme)
<i>cld</i>	chlorite dismutase
CVOC	chlorinated volatile organic compound
DO	dissolved oxygen
DoD	Department of Defense
DPRB	dissimilatory perchlorate-reducing bacteria
EOS <sup>®</sup>	Emulsified (Edible) Oil Substrate
ESTCP	Environmental Security Technology Certification Program
IRZ	In Situ Reactive Zone
ITRC	Interstate Technology & Regulatory Council
MBT	molecular biological tool
MDE	Maryland Department of the Environment
MNA	monitored natural attenuation
NPV	net present value
NSWC	Naval Surface Warfare Center
ORP	oxidation-reduction potential
P&T	pump-and-treat
<i>pcrA</i>	perchlorate reductase
RAO	remedial action objective
SCM	site conceptual model
Shaw	Shaw Environmental, Inc.
SWMU	Solid Waste Management Unit
TBC	to be considered
TCE	trichloroethene
TOC	total organic carbon
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compound

*This page left blank intentionally.*

## ACKNOWLEDGEMENTS

Solutions-IES gratefully acknowledges and appreciates the financial and technical support provided by the Environmental Security Technology Certification Program (ESTCP), including the guidance provided by Dr. Andrea Leeson (ESTCP Environmental Restoration Program Manager), Erica Becvar (Contracting Officer's Representative), and the ESTCP reviewers. Solutions-IES team members contributing to this project include M. Tony Lieberman (Principal Investigator and Senior Project Manager); Dr. Robert C. Borden, P.E. (co-Principal Investigator and Senior Engineering Consultant); Sheri L. Knox, P.E (Project Manager); Walter J. Beckwith, P.G. (Senior Hydrogeologist); Jessica D. Keener, P.G.; Brian Rebar; Sean Jarvah; Dawn Marshall; and Robert P. Rogero, P.G. Laboratory analysis and macrocosm studies were performed by David Black and Aaron Weispfenning at the Laboratory of Environmental Engineering in the Department of Civil, Construction and Environmental Engineering at North Carolina State University. Solutions-IES appreciates the cooperation and assistance by Carey Yates, Sean Jorgensen, and Mark Yeaton at the Naval Surface Warfare Center, Indian Head, MD, who facilitated site access and the field work discussed in this report. Similar appreciation is extended to Mr. William Lucas, P.E., and Mr. Rich Zambito, P.E., the former and current engineering manager, respectively, at the manufacturing facility in Maryland who facilitated site access and the field work at that site.

*Technical material contained in this report has been approved for public release.  
Mention of trade names or commercial products in this report is for informational purposes only;  
no endorsement or recommendation is implied.*

*This page left blank intentionally.*

## 1.0 EXECUTIVE SUMMARY

Solutions-IES identified and tested the processes and methods needed to obtain lines of evidence to support monitored natural attenuation (MNA) as a remedy for perchlorate contaminated groundwater. The information and observations were compiled in a guidance document, which was then applied to two field demonstration sites in Maryland for validation. The first site was located on the Naval Surface Warfare Center (NSWC), Indian Head, MD, and the second at a manufacturing facility in Maryland. The work was funded by the ESTCP Project ER-200428.

The goals of this project were to provide Department of Defense (DoD) managers and industry professionals with the tools needed to demonstrate to regulatory agencies that MNA can be an effective remedy for managing the environmental impacts of perchlorate contaminated groundwater. To assess the demonstration sites, the project used the tiered approach developed and described in the Perchlorate MNA Protocol (ESTCP, 2008) prepared during this project. The Protocol guides the end user through the process of developing multiple lines of evidence to support perchlorate MNA. It includes the following steps:

- Tier 1 - Plume stability and geometry
- Tier 2 - Biogeochemical parameters and biological indicators
- Tier 3 - Biodegradation rates

At the Indian Head site, trends in groundwater flow, biogeochemical parameters, microbial populations, and perchlorate concentrations indicated that perchlorate attenuates mostly as a result of nonbiological mechanisms near the presumed source and areas downgradient from the source but prior to discharge to Mattawoman Creek, a large tributary of the Potomac River. As contaminated groundwater moves away from the source area toward the discharge zone along the creek bank, perchlorate was shown to biologically degrade in the intertidal, organic-rich Littoral Zone. Low oxidation-reduction potential (ORP), elevated total organic carbon (TOC), reduced competition with nitrate,  $\text{pH} > 5.5$  and the presence of perchlorate-reducing bacteria provided conditions conducive to biodegradation. Biodegradation rates were calculated by several methods and were generally reproducible, providing supporting lines of evidence for natural bioattenuation.

At the Maryland manufacturing site, the perchlorate in a commingled trichloroethene (TCE)/perchlorate plume on the east side of the manufacturing facility has attenuated slowly over time. There is some evidence that perchlorate has decreased in several source area wells, but TCE appears to have remained largely unchanged for over 3400 ft from the source. The apparent decrease in perchlorate is likely a result of the combination of abiotic attenuation processes, an ongoing pump-and-treat system in the area, and enhanced anaerobic reductive dechlorination from a bioremediation pilot study conducted years ago. There is little change in perchlorate in the mid-plume area, but as the plume approaches its end at Little Elk Creek, the intermediate and shallow aquifers merge and contaminated groundwater migrates vertically until it discharges to the creek. The conditions within the riparian buffer alongside the creek are not optimal for biodegradation of perchlorate, but are nonetheless more conducive to biodegradation than the areas downgradient of the source and throughout the mid-plume. Consequently, sufficient biodegradation of perchlorate was observed to keep it from entering the creek, while TCE was transformed minimally throughout the same area and was reported both in and just

beyond the creek. Perchlorate biodegradation rates were calculated, but bioattenuation time frames were measured in decades.

MNA of perchlorate is often less costly than engineered passive and active remediation systems. As shown at the manufacturing site, changes in mass flux across the site can be competitive with pump-and-treat, whose effectiveness is limited by the pumping radius of influence and changes to contaminant loading. The laboratory and field demonstrations performed as part of this project demonstrated the potential for using MNA as a groundwater remedy for perchlorate. The site conditions favorable to perchlorate biodegradation were defined and tested in the field to confirm their usefulness in MNA evaluations. The key favorable factors include mildly to strongly reducing conditions ( $ORP < +100$  mV), the absence of strongly acidic groundwater ( $pH > 5.5$ ), relatively low nitrate concentrations, and the presence of TOC to supply electrons for perchlorate reduction ( $TOC > 4$  to 6 mg/L). MNA of perchlorate can be protective of human health and the environment and should be considered during a remedial alternatives evaluation as a potential remedy for remediating perchlorate contamination in groundwater.

## 2.0 INTRODUCTION

This Cost and Performance Report summarizes two demonstrations of perchlorate MNA. The work was funded by ESTCP Project No. ER-200428. The demonstrations evaluated the effectiveness of MNA as a technology for remediating and managing perchlorate contaminated groundwater. The demonstrations were conducted near Building 1419 at Indian Head NSWC in Indian Head, MD (Indian Head Site), and at the TCE/Perchlorate Solid Waste Management Unit (SWMU) field site at a manufacturing facility in Maryland. These sites were selected from a list of 120 DoD or DoD-related sites that were contacted by Solutions-IES. Samples from seven sites were subjected to laboratory testing and microcosm studies to estimate potential bioactivity on perchlorate.

While planning for the demonstrations, Solutions-IES prepared a Protocol for perchlorate MNA based on the lessons learned during preliminary field work completed at the demonstration sites (ESTCP, 2008). Both demonstrations were implemented following the tiered approach described in the Protocol to develop multiple lines of evidence related to perchlorate MNA. Separate technical reports were prepared for each site (ESTCP, 2010a, 2010b). The designs, concepts, results, discussions, and conclusions provided in these project reports are used without further citation in this Cost and Performance report to provide the reader a summary of the performance of the technology at each site and to provide the basis of the cost comparisons.

## 2.1 BACKGROUND

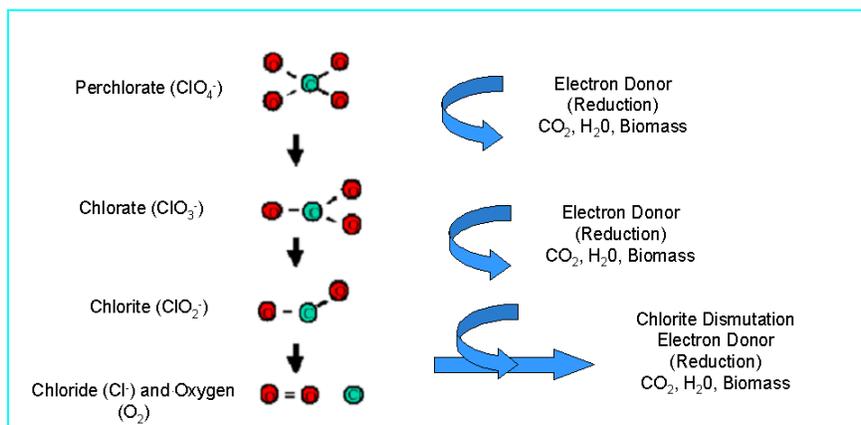
MNA is a potential alternative for management of large diffuse perchlorate plumes in a cost-effective manner. Natural attenuation is defined by the U.S. Environmental Protection Agency (USEPA) as the “biodegradation, diffusion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the environment” (USEPA, 1999). The term MNA refers to the reliance on natural attenuation processes, within the context of a carefully controlled and monitored site cleanup, to achieve site-specific remedial goals.

As contaminants emerge and are considered during a review of remedial strategies, MNA can be evaluated as an alternative if there is a thorough understanding of how MNA can be applied successfully. Specifically, groundwater contamination by perchlorate ( $\text{ClO}_4^-$ ) has become a major environmental issue for DoD. In many cases, perchlorate has entered groundwater through the release and/or disposal of ammonium perchlorate, a strong oxidant that is used extensively in solid rocket fuel, munitions, and pyrotechnics. Perchlorate is highly soluble in water, sorbs poorly to mineral surfaces and can persist for decades under aerobic conditions. Treatment technologies applied to perchlorate contamination often include groundwater extraction with ion exchange or aboveground bioreactors to remove the contaminant (ITRC, 2005). The cost associated with these technologies can be very expensive compared to MNA, even when considering the long-term monitoring often required by MNA.

The potential for use of MNA is evident since a variety of studies have shown that microorganisms from a wide variety of sources (Coates and Pollock, 2003; Coates et al., 1999; Logan, 2001; Gingras and Batista, 2002) can utilize perchlorate as an electron acceptor and

anaerobically biodegrade perchlorate when organic carbon is available (Logan, 1998; Hunter, 2002; Zhang et al., 2002; Waller et al., 2004; Hatzinger, 2005).

The biodegradation pathway of perchlorate is illustrated in Figure 1. Perchlorate biodegradation can occur under strict anaerobic conditions as well as facultative anaerobic conditions. The breakdown of perchlorate to chlorate and then to chlorite is governed by perchlorate reductase enzymes. Final breakdown of chlorite to chloride and oxygen is controlled by the chlorite dismutase (CD) enzyme. In addition, some facultative anaerobic microorganisms are capable of both aerobic respiration under low oxygen tension and anaerobic respiration when oxygen is not present. This metabolic versatility suggests that environments exist that can support a variety of perchlorate-reducing microbial populations. This combination would presumably increase the potential that MNA can occur.



**Figure 1. Perchlorate biodegradation pathway.**

The key to perchlorate MNA is to establish the appropriate lines of evidence to support MNA during early phases of the remedial evaluation. Solutions-IES used the Protocol to guide this process at both demonstration sites to evaluate use of perchlorate MNA as a remedial alternative.

## 2.2 PROJECT OBJECTIVES

The overall goal of this project was to evaluate the potential for MNA of perchlorate and identify conditions for use of MNA as a remedial technology, more specifically:

- Demonstrate to regulatory agencies through field study that perchlorate MNA can be an effective method for managing impacts of perchlorate released to the environment
- Provide DoD managers with the tools needed to evaluate whether MNA may be appropriate for management of perchlorate-impacted groundwater on their site(s).

With this information, regulators and site owners can evaluate MNA along with other alternatives as a remediation strategy for groundwater impacted by perchlorate.

### **2.3 REGULATORY DRIVERS**

Sampling performed by USEPA in 2004 revealed that over 11 million people in the United States had greater than 4 µg/L in their drinking water (Stroo et al., 2009). It appears that the primary exposure to perchlorate in the United States is through consumption of food (USFDA, 2007). This is a significant concern because high levels of perchlorate interfere with iodide uptake by the thyroid (NRC, 2005).

As of 2009, USEPA has not established a maximum contaminant level for perchlorate in drinking water (USEPA, 2009). However, in January 2006, the USEPA issued “Assessment Guidance for Perchlorate” identifying 24.5 µg/L as the recommended “to be considered” (TBC) value and preliminary remediation goal for perchlorate (USEPA, 2006). Since then several states have identified advisory levels that range in concentration from 1 µg/L to 18 µg/L (Hatzinger, 2005). Massachusetts promulgated the first state drinking water standard in 2006, at 2 µg/L (MADEP, 2006), and California has established a drinking water standard of 6 µg/L (CDHS, 2006). In 2008, Maryland adopted 2.6 µg/L as the drinking water standard (Maryland Department of the Environment [MDE], 2008).

*This page left blank intentionally.*

## **3.0 TECHNOLOGY DESCRIPTION**

### **3.1 MONITORED NATURAL ATTENUATION**

An integral component of any MNA remedy for groundwater is a clear understanding of the hydrogeologic conditions present in the site area. A site conceptual model (SCM) should be formulated and then calibrated against local data. Physical conditions of the aquifer, groundwater flow characteristics (e.g., flow velocity, dilution, and dispersion), and contaminant concentration data must be obtained and evaluated. It is also important to understand the interactions between contaminant and background geochemistry, including major aquifer anions and cations along with organic or anthropogenic sources of carbon. Finally, for MNA to be accepted, the practitioner must demonstrate biological activity on the contaminant to an extent that can affect the desired reduction in concentration.

USEPA and others have developed protocols and guidance documents for implementing MNA for specific contaminants. Published methods for evaluating MNA of petroleum hydrocarbons (Wiedemeier et al., 1995; USEPA, 1999) and chlorinated solvents (USEPA, 1998) have been in use for many years. These documents describe systematic steps for delineating contaminant plumes, describing trends in contaminant fate and transport, monitoring site geochemistry, testing site biology and even scoring the site for its potential to support natural attenuation (USEPA, 1998). Prior to current work, MNA of perchlorate had not been systematically tested in the field. To address this need, Solutions-IES developed an MNA Protocol for perchlorate (ESTCP, 2008) that used a tiered approach.

- Tier 1 - Plume stability and geometry
- Tier 2 - Geochemical parameters and biological indicators
- Tier 3 - Biodegradation rates

This tiered approach was then applied to evaluate MNA of perchlorate at each demonstration site.

### **3.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY**

#### **3.2.1 Cleanup Objectives**

The objective of all remediation approaches is to return groundwater to its beneficial uses whenever practicable. MNA is an appropriate remediation method when its use is protective of human health and the environment and it is capable of achieving site-specific remediation objectives within a time frame that is reasonable compared to other alternatives. If cleanup objectives are out of alignment with risks, use of MNA as a stand-alone technology may not be appropriate.

#### **3.2.2 Advantages and Limitations of MNA**

Natural attenuation is a combination of physical, chemical, and biological processes. Because perchlorate is an inorganic salt, it is very soluble and mobile in groundwater. It is subject to greater dilution than many organic contaminants. High solubility is both an advantage and

disadvantage. Flushing and dilution can reduce concentrations rapidly, but solubility can result in extended plumes with low concentrations that are difficult to capture and expensive to treat. As paraphrased from Wiedemeier et al. (1998), primary advantages of using MNA to remediate contaminants of concern in groundwater, including perchlorate, are:

- Reduced potential for cross-media transfer of contaminants commonly associated with ex situ treatment (i.e., no active remediation equipment)
- Reduced risk of human exposure to contaminants, contaminated media, and other hazards
- Destruction of contaminants via natural attenuation processes
- Less disturbance to site operations and ecological receptors
- No artificial or secondary impact to groundwater geochemistry and biology
- Applicability to all or a portion of a site depending on site characteristics and goals
- Usefulness in combination with other technologies
- Lower capital costs with low, if any, maintenance costs.

The limitations of MNA include:

- Potentially longer life cycles to reach remediation goals compared to active remediation measures at the site
- Need for more detailed site characterization to demonstrate attenuation, which may mean more complex and costly up-front investigation
- May require institutional controls to ensure long-term protection
- Long-term performance monitoring generally more expensive and for a longer time period
- Potential for continued contaminant migration, and/or cross-media transfer of contaminants
- May require a re-evaluation of MNA over time because of changing site conditions
- Public acceptance possibly more difficult and costly to obtain.

Although perchlorate remains an emerging contaminant of concern, sufficient methods are in place to obtain reliable data that can be used to evaluate the potential for MNA of perchlorate in groundwater. The cost drivers related to the advantages and disadvantages of perchlorate MNA specific to the Indian Head and Elkton site demonstrations are described in greater detail in Section 6.0.

## **4.0 INDIAN HEAD DEMONSTRATION SITE**

### **4.1 PERFORMANCE OBJECTIVES**

The Indian Head site was selected as one of the two sites for testing the potential for MNA of perchlorate in groundwater based on site conditions, microcosm studies, site logistics, and cost considerations. The SCM suggested that perchlorate-contaminated groundwater from the source near Building 1419, the former “hog-out” facility, was migrating approximately 300 to 400 ft toward Mattawoman Creek, a large tidally influenced creek that is a tributary of the Potomac River. Just prior to reaching the creek, perchlorate-laden groundwater migrates upward through highly organic sediments of the intertidal Littoral Zone where conditions are suitable for the anaerobic biodegradation. Wetlands and similar organic-rich environments at groundwater/surface interfaces have been shown to be important zones for anaerobic biodegradation and, therefore, the reduction of chlorinated volatile organic compounds (CVOCs) and other compounds (Lorah et al., 1997; Lorah and Olsen, 1999).

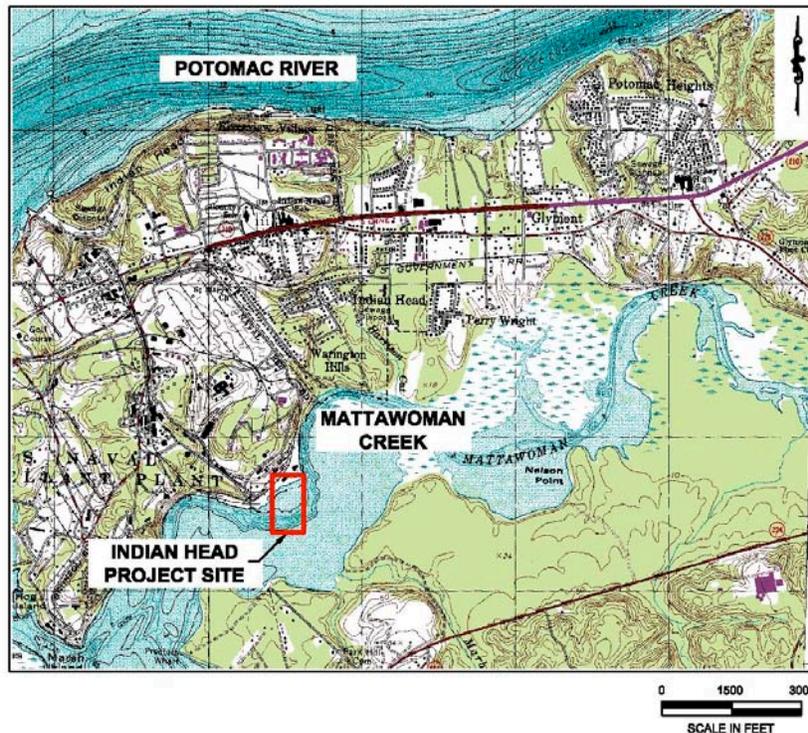
The objectives of the technical demonstration the Indian Head site were to:

- Further develop and evaluate lines of evidence established during the site selection process for their applicability to MNA in the field
- Evaluate the use of various biological indicators of perchlorate biodegradation
- Compare biodegradation rates established in microcosm studies with biodegradation rates in the field
- Evaluate the cost-effectiveness of MNA of perchlorate at the Indian Head site
- Validate the approach identified in the Protocol.

### **4.2 SITE BACKGROUND**

#### **4.2.1 Location and Current Conditions**

The Town of Indian Head, MD, and the NSWC are located approximately 30 miles south of Washington, DC, on a narrow peninsula (neck) of land bounded to the north by the Potomac River and to the south by Mattawoman Creek (Figure 2). Both the Potomac River and Mattawoman Creek are tidal estuaries of the Chesapeake Bay estuary system. The surficial (water table) aquifer consists of more recent saturated alluvial soil resting on top of the Patapsco clay that is encountered at approximately 16 ft below ground surface (bgs). The surficial aquifer is unconfined and varies in its position seasonally in response to precipitation and evapotranspiration. The water table surface generally slopes similar to the land surface topography, with the effect that upland areas generally serve as groundwater recharge areas and low areas generally serve as groundwater discharge areas. The demonstration area consists of approximately 2 acres extending from a former perchlorate clean-out or “hog-out” building (Building 1419) to Mattawoman Creek.



**Figure 2. Map showing the Indian Head Project Site and vicinity at the Naval Surface Warfare Center, Indian Head, MD.**

(Image from U.S. Geological Survey, 7.5 Minute Topographic Map, Indian Head, MD-VA, 1966, Photorevised 1978; Bathymetry added 1982)

#### 4.2.2 Previous Remediation Studies

In 2001, ESTCP funded an independent study at the same location to demonstrate and validate the use of passive flux meters to determine groundwater and perchlorate fluxes at the Indian Head site (ESTCP, 2006). The study showed that perchlorate flux did not change over time from 2002 through 2005, suggesting the presence of a persistent source of perchlorate since no perchlorate-contaminated hog-out wastewater had been discharged since 1996. Measurements of vertical perchlorate flux suggested the possibility of a vadose zone source that would continuously release perchlorate to the aquifer by recharge induced by rainfall. This phenomenon could be used to explain high temporal variability of perchlorate concentrations in wells located 180 and 125 ft downgradient from the presumed source area near Building 1419.

In 2002, Shaw Environmental, Inc. (Shaw) conducted an enhanced in situ bioremediation pilot study (Cramer et al., 2004; Hoponick, 2006) at the Building 1419 site. In the Test Plot amended with >100 mg/L lactate and buffer, the results demonstrated that:

- “Naturally occurring perchlorate-degrading bacteria are present in the groundwater underlying [the Bldg. 1419 site]
- These organisms can be stimulated to degrade perchlorate from more than 50 mg/L to below detection using lactate as a food source

- The pH of the aquifer must be buffered to achieve optimal perchlorate biodegradation”
- Lactate lasted just about one month in the aquifer after its injection was stopped.

### **4.2.3 Pre-Demonstration Testing**

Prior to initiating the current field demonstration, several tasks were completed to assess the current groundwater conditions.

#### **4.2.3.1 Task 1: Groundwater and Soil Sampling**

In February 2005, Solutions-IES collected groundwater samples from existing monitor wells MW-1, MW-2, and MW-4, used previously to monitor the Shaw pilot test, and saturated soil samples from immediately adjacent to MW-2 and MW-4. These samples were analyzed for TOC, a complete suite of biogeochemical parameters, and presence of the CD enzyme. From these results, Solutions-IES concluded that:

- The long-term impact from the Shaw lactate injection would not likely complicate the perchlorate MNA technical demonstration as there was little indication of residual TOC in groundwater in proximity of the pilot test treatment cell.
- In general across the site, perchlorate concentrations in groundwater remain elevated.
- A strong positive indication (+++) of CD was reported from soil collected near MW-2; a more variable indication (+/-) was reported from sediments in the vicinity of MW-4.

#### **4.2.3.2 Task 2: Laboratory Studies**

Solutions-IES created 250-mL microcosm bottles using sediment and groundwater obtained from the vicinity of MW-2 to test three conditions: (1) natural attenuation of perchlorate (ambient conditions) starting at relatively low concentrations (i.e., ~100 to 200 µg/L); (2) natural attenuation of perchlorate starting at relatively high concentrations (i.e., ~5,000 µg/L); and, (3) for comparison, enhanced attenuation in the presence of added simple and complex electron donors, i.e., lactate and Emulsified (Edible) Oil Substrate (EOS<sup>®</sup>)<sup>1</sup> solutions, respectively. The treatments testing natural attenuation received no amendments unless perchlorate had to be added to achieve the desired starting concentration.

The Treatability Report (ESTCP, 2007) indicated that perchlorate declined slowly but measurably over the 1-year incubation period in unamended microcosms with both high and low starting concentrations. In the presence of EOS<sup>®</sup>, the concentration of perchlorate quickly decreased below detection indicating that bacteria with perchlorate-reducing capacity were present in the environment and could be readily stimulated to achieve high rates of biodegradation. The first-order biodegradation rate for low perchlorate starting concentration

---

<sup>1</sup> EOS<sup>®</sup> is a registered trademark of EOS Remediation LLC, Raleigh, NC. The product, EOS<sup>®</sup> 598 B42, was provided by the manufacturer for use in this study.

without donor amendment was calculated to be 0.01/d (3.7/yr). In the killed control microcosms, the concentrations of perchlorate and other electron acceptors (nitrate and sulfate) remained constant over time further supporting the conclusion that the observed reduction in perchlorate in ambient microcosms was due to biological activity and the site was a good candidate for demonstrating the potential for perchlorate MNA.

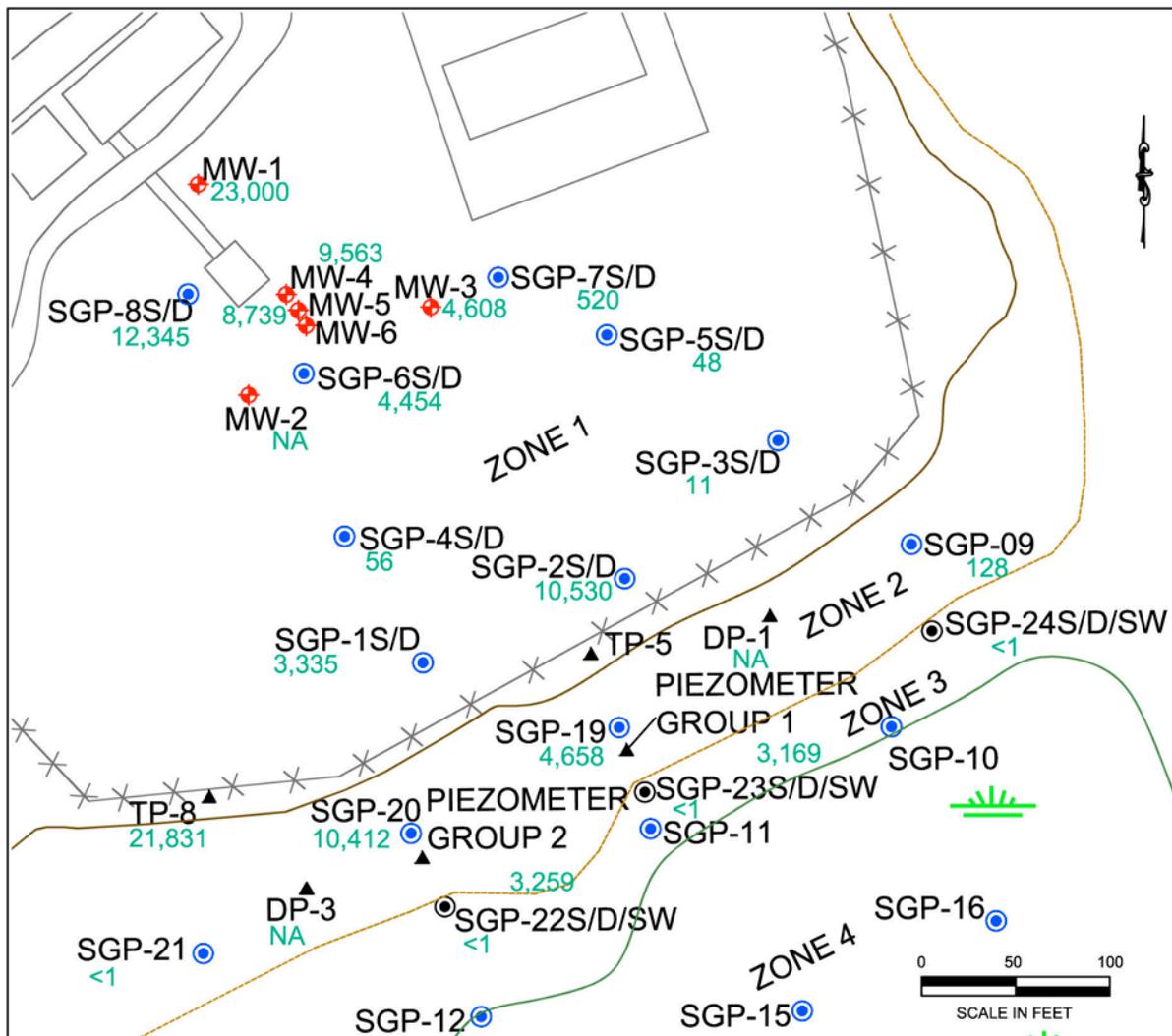
### **4.3 DEMONSTRATION APPROACH**

#### **4.3.1 Additional Site Characterization and Performance Monitoring**

Analytical methods are available to monitor the concentration of perchlorate in the environment with high sensitivity and selectivity; geochemical tests can indicate whether ambient conditions are conducive to perchlorate biodegradation; and molecular biological tools (MBTs) are available to monitor the activity and sustainability of perchlorate-reducing bacterial populations. With some minor exceptions, the tiers outlined in the Protocol were followed to help the planning and selection of tasks to address specific challenges. An additional 35 monitor wells and 10 piezometers were installed across the site and into Mattawoman Creek to characterize the site and facilitate data collection.

#### **4.3.2 Site Hydrogeology and Plume Configuration**

Figure 4 shows the monitor well network across the project site from Building 1419 to Mattawoman Creek. The four geomorphological zones are identified from the land surface into the creek. The SCM hypothesized that perchlorate entered the water table aquifer near the former “hog-out” building, and has moved advectively with groundwater to the south toward the creek. Along the flow path, it has been subjected primarily to dispersion and dilution. Sorption to the aquifer matrix is minimal because of its high solubility and poor sorption characteristics. In addition, the underlying Patapsco clay restricts downward movement of dissolved perchlorate so that most of the remaining perchlorate mass moves horizontally with groundwater flow towards Mattawoman Creek. The plume is at least 400 ft wide along the creek bank, and dispersion of the plume has resulted in similar perchlorate concentrations being observed throughout the thickness of the surficial aquifer. The perchlorate concentrations reported across the site in April 2008 are also shown on Figure 3.



**Figure 3. Perchlorate concentration map at the Indian Head Project Site (April 2008).**

The land area south of Building 1419 is referred to as Land Zone 1. Cramer et al. (2004) described fill soils beneath Land Zone 1 as having been previously placed in various areas of the site. The fill was described as gravel and silty sand containing some organic matter and debris. Thickness ranged from <1 ft to approximately 4 ft. Underlying the fill is 13 to 16 ft of silty sandy-sandy silt containing thin (1 to 2 inches thick) discontinuous sand lenses. The units vary both horizontally and vertically and rest on 12- to 18-inches of coarse alluvial sand and gravel. The coarse alluvium also appears to be variable in thickness and location.

Solutions-IES identified similar subsurface conditions also further south of the Shaw pilot test, but the coarse alluvium was not identified in two borings located closer to Mattawoman Creek. At these locations, the basal portion of the alluvium consists of fine-grained sand without the gravel, resting on dark gray clay, which extends to a depth of at least 24 ft bgs. The clay encountered beneath the alluvium in the land borings appears to be extensive and was reported at other locations across the NSWC.

Zones 2 through 4 are located within Mattawoman Creek. Zone 2, the Littoral Zone, is defined as the region that is above the low-water mark and below the high-water mark, i.e., exposed to air at low tide and submerged at high tide (Figure 4). Zone 3, the Subtidal Channel, is a relatively narrow channel-like depression that parallels the creek bank at the edge of the Littoral Zone, and Zone 4 (the Subtidal Shallows) is an expanse of accreted sediment located south of the Subtidal Channel along an inside meander of Mattawoman Creek. Zone 4 is submerged with 6 to 18 inches of water at low tide. The monitoring well/ piezometer network was sampled up to five times during the 38-month performance monitoring period.



**Figure 4. Appearance of Littoral Zone in winter and summer at the Indian Head Project Site.**

#### **4.4 INDIAN HEAD PERFORMANCE ASSESSMENT**

The Tier 1 and Tier 2 evaluations are summarized together as they are both derived from contaminant and biogeochemical information collected during performance monitoring. The Tier 3 evaluation includes specialized laboratory testing and the installation, data collection, and analysis of in situ columns designed to derive biodegradation rates, so it is summarized separately.

#### **4.4.1 Tier 1 and 2 Evaluations**

The performance monitoring data are presented in tables in the Indian Head Technical Report (ESTCP, 2010a). Figure 5 illustrates selected groundwater parameters beneath the four zones as groundwater moves toward the discharge area along the creek bank. As illustrated by the figure, elevated perchlorate concentrations are present in the groundwater beneath the land surface and partly beneath the Littoral Zone (dark red color). However, the perchlorate concentration decreases rapidly (orange) as it moves vertically through the Littoral Zone and into the Subtidal Channel (yellow).

##### **4.4.1.1 Zone 1 (Land)**

The pH of the groundwater beneath the Land Zone is acidic and below optimal for the growth of many bacteria, although populations of  $10^4$  to  $10^5$  eubacteria/mL were measured in both the shallow and deep portions of the surficial aquifer. Generally positive ORPs were measured throughout and only low concentrations of methane were detected, suggesting somewhat oxidative conditions with limited bioavailable TOC. Based on these biogeochemical conditions, residual elevated perchlorate concentrations throughout the vertical groundwater profile beneath the Land Zone would not be unexpected. However, in several wells located in the upgradient portion of the plume near the source area, a statistically significant decrease in the perchlorate concentration with time was measured. Estimated time to reach the cleanup standard of 24.5  $\mu\text{g/L}$  was also calculated using the best fit linear regression and varied from 11 to 27 years. Much of these declines could be attributed to flushing of highly soluble perchlorate out of the aquifer by incoming groundwater, but some contribution by biodegradation remains possible, despite the less than optimal conditions.

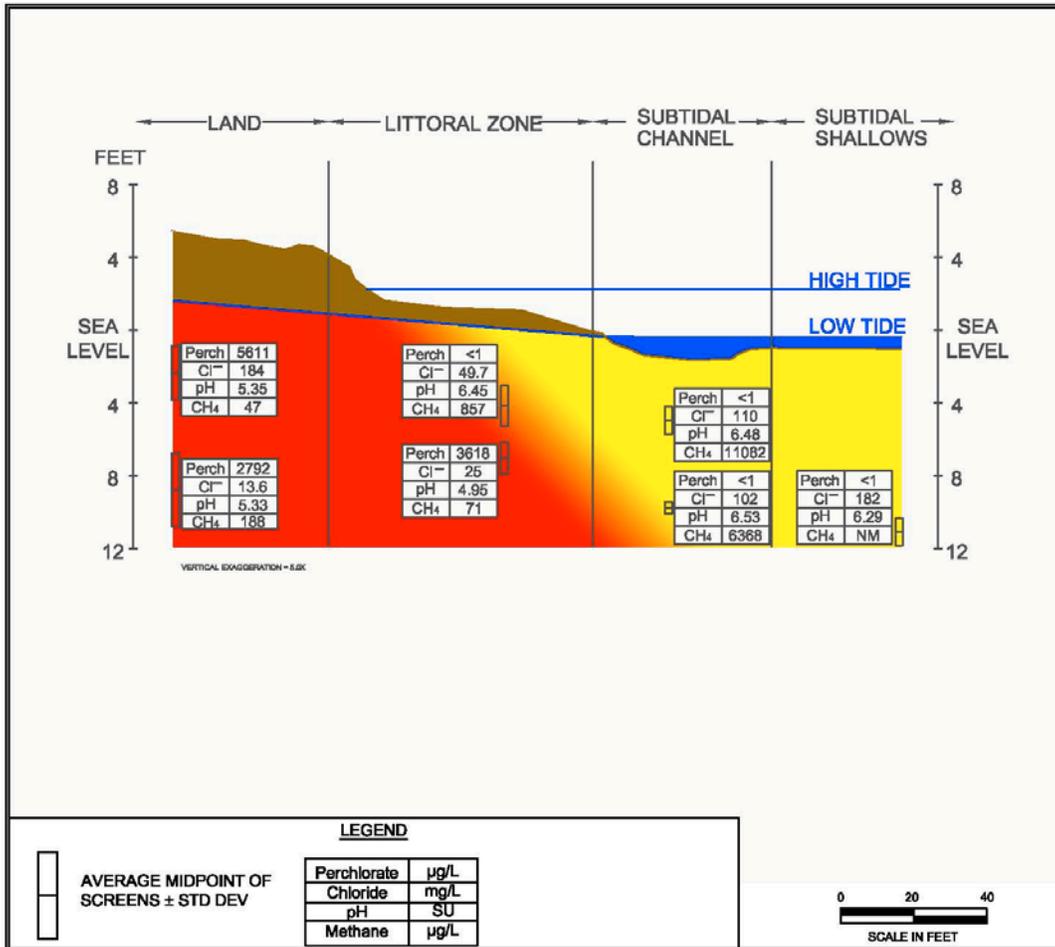
##### **4.4.1.2 Zone 2 (Littoral – Intertidal)**

The Littoral Zone is subject to tidal cycles, is heavily vegetated with grasses in the spring and summer, and subject to plant deposition and decay in the fall and winter. This zone is also subject to mixing of surface water with groundwater. Pore water within the deeper Littoral Zone sediment is more characteristic of groundwater beneath the land, whereas shallow pore water within the Littoral Zone is a mixture of groundwater and surface water.

Biogeochemical conditions in the deeper pore water are also similar to those in groundwater beneath the land. Perchlorate is still present at concentrations similar to that measured in wells along the shoreline as suggested by the dark red color in Figure 5. The pH of the water collected in the deeper portions of the Littoral Zone is also generally lower than optimal for bacterial growth, but there are high populations of bacteria ( $>10^6$  eubacteria/mL) nonetheless. The positive ORP and absence of methane production suggest generally oxidative conditions. These are conditions that do not favor perchlorate-reducing bioactivity and are corroborated by the relative absence of reportable concentrations of perchlorate reductase (*pcrA*) gene copies in 67% of the locations tested.

However, pore water in the shallow sediment would be expected to be influenced by the cyclical growth, death and decay of plant matter resulting in deposition of organic carbon and formation of the muck layer that was observed. The data from the nutrient-rich Littoral Zone showed this

relationship as there is increased TOC, a drop in ORP to a more favorable range (i.e., ORP<50 mV) for dissimilatory perchlorate-reducing bacteria (DPRB) and methanogenesis to occur, and a pH closer to pH 6. Even higher populations of eubacteria (>10<sup>7</sup> eubacteria/mL) were enumerated with up to 19,000 *pcrA* gene copies reported in the shallow sediment. Perchlorate mass flux decreased from 10 mg/d/linear ft as groundwater moves laterally from beneath the Land Zone to beneath the Littoral Zone to less than 0.0002 mg/d/linear ft as groundwater moves vertically just below the mud bottom of the creek. As a result, perchlorate concentrations in the shallow groundwater beneath the Littoral Zone are nondetect.



**Figure 5. Geochemical changes in groundwater and sediment pore water beneath the four geomorphological zones at Indian Head Project Site.**

**4.4.1.3 Zone 3 (Subtidal Channel) and Zone 4 (Subtidal Shallows)**

Regulatory agencies require that contaminant plumes are stable or shrinking before MNA can be employed as the primary groundwater remediation technology. The data show no evidence of an increase in perchlorate concentrations over time in the deep wells in the Littoral Zone and further downgradient migration of perchlorate in groundwater beyond the Littoral Zone is limited by the organic rich sediments beneath the creek. The conditions observed in the shallow and deep sediment beneath the Subtidal Channel and Subtidal Shallows are conducive for the

biodegradation of perchlorate. The perchlorate concentration was less than 1 µg/L in monitoring points within the Subtidal Channel indicating perchlorate was not migrating underneath or into the Subtidal Channel. DPRB, as enumerated by quantitative polymerase chain reaction count of the number of copies of the *pcrA*, are present in this nutrient-rich environment and would be expected to degrade any residual perchlorate that might migrate via discharging groundwater beyond the Littoral Zone. In this project, perchlorate was reduced to below detectable levels in every sample with greater than 10<sup>2</sup> *pcrA* copies/mL.

The Tier 2 evaluation showed that groundwater conditions are conducive to perchlorate biodegradation beginning in the nutrient-rich shallow groundwater beneath the Littoral Zone and continuing out into Mattawoman Creek. However, because of the complex hydrogeology and the complicating potential contribution of the mixing and dilution to the observed perchlorate attenuation, additional steps were taken to provide direct evidence of perchlorate-reducing bioactivity. The Tier 3 evaluation describes additional lines of evidence obtained from studies designed to obtain biodegradation rate measurements

#### 4.4.2 Tier 3 Evaluation

Macrocosm and in situ column studies were designed for the Tier 3 evaluation. The set-up details and results are provided in the Technical Report (ESTCP, 2010a). The first-order biodegradation rates ranged from 0.12 to 0.63/day (Table 1). The rates and corresponding half-lives generated in macrocosms, in situ columns, and piezometers are similar. This supports the use of these tests for estimating biodegradation in the natural environment. The results also support the information obtained in Tier 1 and 2 as additional lines of evidence for the natural attenuation of perchlorate. The findings, when considered together, support the SCM and could be used to form the basis of a recommendation that perchlorate MNA is potentially an acceptable remedy for this site.

**Table 1. Summary of first-order biodegradation rates in perchlorate plume matrices from the Indian Head Site.**

Test	Rate Constant (per day)	Half-Life (days)
Macrocosms	0.12	5.8
In situ columns	0.12 to 0.63	5.8 to 1.1
Piezometers	0.27	2.6

#### 4.5 INDIAN HEAD COST ASSESSMENT

The total cost of the Indian Head test demonstration was approximately \$509,100 (ESTCP, 2010a). Primary cost elements included:

- Technical Demonstration Plan, White Papers/Design: ~\$51,300 (10%)
- Additional Characterization: ~\$103,600 (20%)
- Performance Monitoring & Data Acquisition for Tiers 1 & 2: ~\$209,300 (41%)
- Tier 1 and 2 Data Evaluation: ~\$14,900 (3%)
- Tier 3 Data Acquisition and Evaluation: ~\$60,000 (12%)
- Technical Reporting: ~\$70,000 (14%)

Large portions of the demonstration costs were associated with performance monitoring and site characterization, which included the installation of 35 additional monitoring wells and piezometers in the Littoral Zone, Subtidal Channel and Subtidal Shallows in Mattawoman Creek in order to evaluate the complex hydrogeology. The Tier 3 evaluation also cost more in comparison to other elements of the demonstration because of the complexity of installation and data collection from the in situ columns in the Littoral Zone and construction of and additional monitoring of the macrocosms. Project costs not directly related to the individual technical demonstrations such as project management and technical transfer, site screening and treatability study, and protocol development are not included in the cost summary.

## **5.0 MARYLAND MANUFACTURING FACILITY DEMONSTRATION SITE**

### **5.1 PERFORMANCE OBJECTIVES**

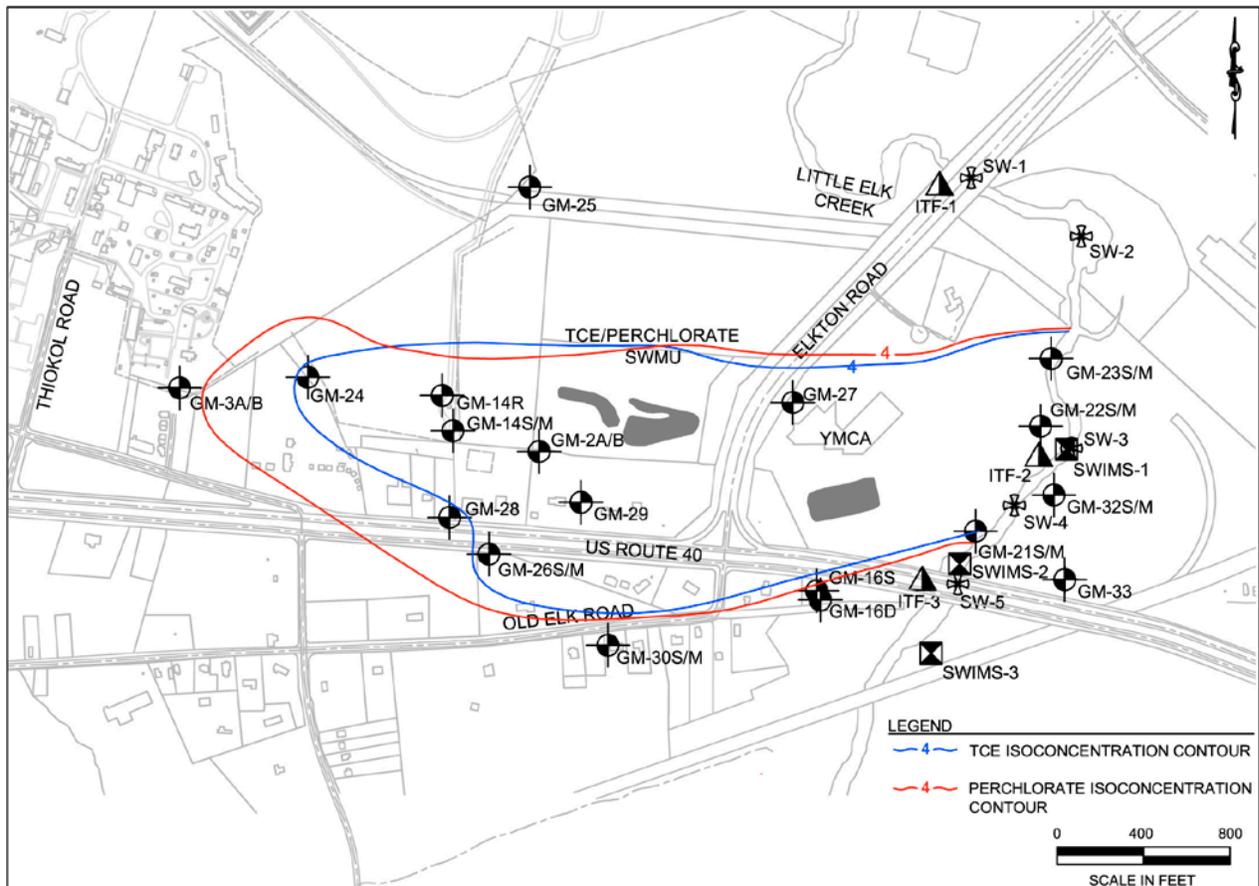
The goal at this site was to show that the tiered approach could be used effectively at a second, different site to demonstrate the potential for natural attenuation of perchlorate. The demonstration objectives were the same as those for the Indian Head project (see Section 4.1), but the SCM for this location was slightly different. At the Maryland manufacturing site it was hypothesized that perchlorate-contaminated groundwater migrates primarily through an intermediate aquifer (from 20 to 70 ft bgs) from the presumed source area almost 3400 ft prior to discharge to Little Elk Creek. As the contaminated groundwater moves toward the creek, the deeper intermediate aquifer thins and merges with the shallow aquifer, which passes beneath a wooded riparian buffer just prior to discharge into the creek. The data suggested that conditions close to the discharge area were sufficient to naturally attenuate perchlorate, but TCE commingled with perchlorate was reported both in and just beyond the creek without complete removal. This indicated that conditions were probably suboptimal for anaerobic reductive dechlorination of CVOCs.

### **5.2 SITE BACKGROUND**

#### **5.2.1 Location and Current Conditions**

The manufacturing facility covers approximately 600 acres. It is bounded on the south by U.S. Route 40, commercial properties, and residential areas. The facility extends to the east to Maryland Highway MD 279 (Elkton Road). The north and northeast property line is formed by Little Elk Creek, which traverses the entire facility from the northwest portion all the way to Elkton Road. To the north and west, the site is surrounded by agricultural areas. The facility has been used for industrial purposes, such as fireworks manufacturing, munitions production, pesticide production, and research and manufacturing of solid propellant rockets since the 1930s. Ammonium perchlorate continues to be used to manufacture and test rocket engines at the facility. The surrounding areas also have a diverse history of industrial activities.

Recent investigations have identified perchlorate in groundwater and showed that the commingled TCE and perchlorate plume extending eastward from the manufacturing area goes off site to the east under Elkton Road and all the way to Little Elk Creek beyond the neighboring YMCA property, and to the south side of U.S. Route 40. The horizontal extent of the TCE and perchlorate in groundwater is shown in Figure 6. In the absence of a defined source, this entire plume is considered to be a SWMU and is called the TCE/Perchlorate SWMU.



**Figure 6. Horizontal extent of the commingled TCE and perchlorate plume at the Maryland manufacturing site.**

## 5.2.2 Previous Remediation Activities

### 5.2.2.1 A-82 Pump-and-Treat System

As an interim remedial measure, in 1997 recovery well GM-14R and a shallow-tray air stripper system were installed to capture, withdraw, and treat contaminated groundwater from the intermediate aquifer in the vicinity of the source. Treated water is discharged through a pipe carrying the water approximately 1800 ft north to the closest point along Little Elk Creek. Discharge is allowed by a National Pollution Discharge Elimination System permit.

The pump-and-treat (P&T) system has operated since 1998, effectively accounting for the removal of over 800 lb of volatile organic compounds (VOCs) from the aquifer. Perchlorate recovered by the system was reported in the influent waste stream occasionally during the years of monitoring. For example, 31 lb of perchlorate were recovered in 2003 and 12 lb in 2007, but perchlorate is not treated by air stripping and likely remained in the discharge water.

### **5.2.2.2 In Situ Bioremediation Pilot Test**

In 2004, ARCADIS performed a pilot test to demonstrate the effectiveness of injection of a molasses solution into the aquifer to promote in situ bioremediation of CVOCs and perchlorate. The In Situ Reactive Zone (IRZ) pilot test was installed in the vicinity of monitor wells GM-14S/M where TCE and perchlorate levels were 1000 and 1240  $\mu\text{g/L}$ , respectively, at the beginning of the test. The test was monitored for about 1 year during which time TCE concentrations at GM-14M fluctuated but never dropped appreciably. By contrast, the concentration of perchlorate dropped from the baseline level to nondetect after approximately 7 months. Once the added carbon was depleted, mass flux of perchlorate from shallow upgradient portions of the plume caused a rebound in perchlorate levels.

### **5.2.3 Pre-Demonstration Testing**

#### **5.2.3.1 Groundwater and Soil Sampling**

The wells of interest during the site screening process included GM-3B, GM-14M, GM-2B, GM-22S and GM-22M. As shown on Figure 6, these wells generally form a line starting close to the plant and moving east (i.e., downgradient) toward the eastern leg of Little Elk Creek. During the site-selection process, samples were collected from these wells and a soil sample was collected from 3 to 5 ft bgs (below the water table) from adjacent to GM-22S (Figure 7).



**Figure 7. Location of GM-22S/M near the wooded riparian buffer on the west side of Little Elk Creek.**

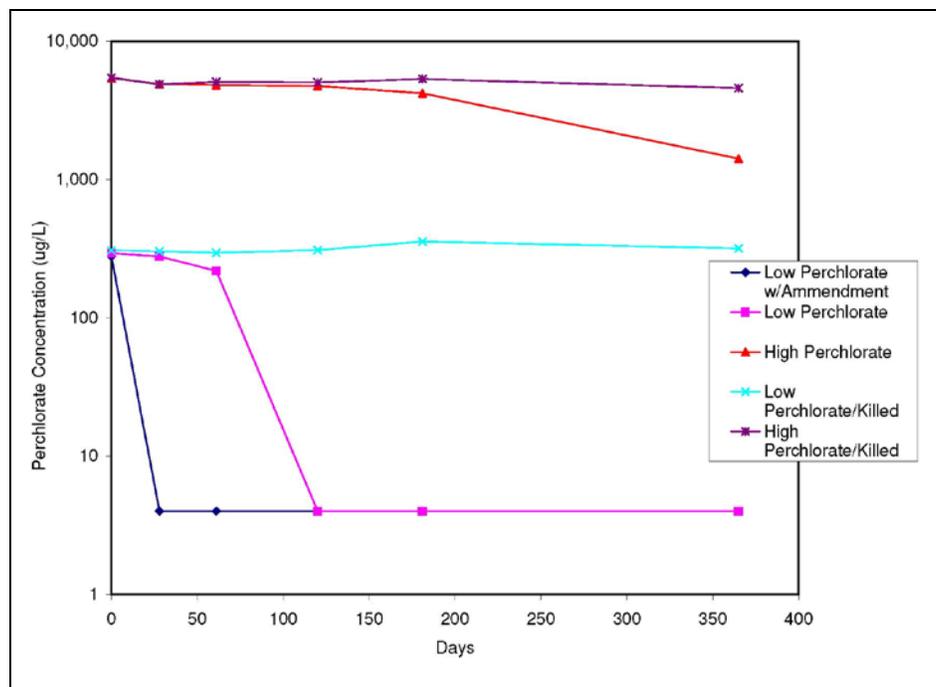
Perchlorate concentrations ranged from 1200  $\mu\text{g/L}$  near the presumed source to an average of 215  $\mu\text{g/L}$  at GM-22S/M, about 30 ft from the creek. TCE concentrations actually showed an increase from 1300  $\mu\text{g/L}$  near the source to an average of 2015  $\mu\text{g/L}$  at GM-22S/M. Groundwater pH was generally below 6, ORP was +130 to +220 mV across the plume, and TOC and methane were absent. However, the CD enzyme assay from soil near GM-22S was positive. Despite the appearance of conditions suboptimal for natural attenuation of TCE, the decrease in

perchlorate downgradient of the source and the positive enzyme assay result were sufficient to continue the evaluation of this plume as a demonstration site.

### 5.2.3.2 Laboratory Studies

Microcosm studies were performed with soil and groundwater collected from the vicinity of GM-22S. The bottles were prepared to test three conditions: (1) natural attenuation of low starting perchlorate ( $\sim 100 \mu\text{g/L}$ ); (2) natural attenuation of perchlorate starting at relatively high concentrations ( $\sim 5000 \mu\text{g/L}$ ); and (3) enhanced attenuation in the presence of added simple and complex electron donors (i.e., lactate and EOS<sup>®</sup> solutions, respectively).

In the microcosms spiked to contain a high elevated perchlorate starting concentration, nitrate decreased to below detection while sulfate, chloride, and dissolved oxygen (DO) remained constant over time. The average perchlorate concentration declined from  $5400 \mu\text{g/L}$  to  $1416 \mu\text{g/L}$ , a 70% reduction over the one-year incubation period (Figure 8). In one of the high perchlorate microcosm replicates, perchlorate was reduced to below the detection limit. In the low and high perchlorate killed microcosms, perchlorate, chloride, sulfate, and DO remained constant showing no biodegradation.



**Figure 8. Perchlorate concentrations in microcosms versus time using soil and groundwater from the TCE/perchlorate plume (ESTCP, 2007).**

In microcosms with low starting perchlorate, a lag lasting  $\sim 61$  days was observed followed by a rapid decrease in perchlorate concentration. The zero-order rate between Day 61 and Day 120 was  $3.6 \mu\text{g/L/day}$  and the first-order degradation rate for the same period was  $0.068/\text{day}$ . At high starting concentrations, the best fit curve was shown to be zero-order resulting in an ambient perchlorate degradation rate of approximately  $9.7 \mu\text{g/L/day}$ . Although slow, the decrease in perchlorate concentration over one year under ambient conditions and the accelerated

degradation in the presence of substrate demonstrate that microorganisms capable of perchlorate reduction are present in soil and groundwater near the presumed plume discharge area in the vicinity of Little Elk Creek.

### **5.3 DEMONSTRATION APPROACH**

#### **5.3.1 Additional Site Characterization and Performance Monitoring**

Solutions-IES augmented the existing monitor well network by installing several new monitor wells to further delineate the plume geometry, fill in gaps in coverage, and provide additional sources of data from which to evaluate MNA and perchlorate mass flux. Four additional monitoring well pairs were constructed in December 2006: three monitoring well pairs east of Elkton Road on the property owned by the YMCA (designated SMW-9S and 9M, SMW-11S and 11M, SMW-13S and 13M) and one well pair west of Elkton Road (SMW-8S and SMW-8M). A well in each well pair was terminated within the shallow and intermediate aquifers. The shallow monitoring wells were generally terminated so that the screen interval was approximately 20 to 30 ft bgs, and each intermediate monitoring well was terminated so that the screen interval was approximately 50 to 60 ft bgs. The new and existing monitoring wells were sampled up to five times during the 23-month performance monitoring period from May 2006 and April 2008 to evaluate aquifer conditions and how those conditions might affect the potential for natural biodegradation of perchlorate.

#### **5.3.2 Site Hydrogeology and Plume Configuration**

ARCADIS (2007) described the site hydrogeology as consisting of three units: a shallow unconfined aquifer (depths less than -20 ft msl), the intermediate Potomac Group (depths between -20 and -70 ft msl), and the deep saprolite unit (depths greater than -70 ft msl). The depth to bedrock ranges from about 90 to 150 ft bgs between the plant area and Little Elk Creek to the east. The thickness of the overlying saprolite ranges from 5 to 64 ft. The saprolite is micaceous, silty, and friable, becoming more cohesive and resistant to drilling with depth.

The sediments of the Potomac Group overlie the bedrock/saprolite. A layer of predominantly fine sandy silt (varying in thickness from 18 to 35 ft) was encountered at the base of the Potomac in boreholes throughout the site. The Potomac sediments above the basal silt are much more variable in composition. Interstratified sands, silts and clays make up the majority of sediments, with occasional peat or gravel beds included. Lateral discontinuity within the Potomac Group renders correlation of most beds uncertain, even over short distances. Most historical site data have indicated that the plume is migrating east/southeast primarily in the intermediate zone of the Potomac Group. The flow direction basically follows the surface topography. A pumping test on GM-14R located near the presumed source within the TCE/Perchlorate SWMU calculated the hydraulic conductivity ranging from 9.0 ft/d to 31 ft/d. With a reported gradient of 0.002, and effective porosity of 0.20, the groundwater velocity ranges from 0.1 ft/d to 0.3 ft/d (36 ft/yr. to 110 ft/yr.) (ARCADIS, 2003).

Quaternary alluvium overlies the Potomac Group and is composed of heterogeneous mixtures of clay, silt, sand, and gravel. Alluvium is associated with river and estuary depositional environment and occurs along Little Elk Creek and its tributaries. Limited data indicate an

alluvial thickness of 0 to 40 ft; these beds are extremely variable in their horizontal and vertical extent. Information gathered during additional assessment activities generally supports previous work.

During the ARCADIS (1999) perchlorate investigation, surface water samples were collected along the length of Little Elk Creek with three locations being within the presumed plume discharge zone (Figure 6). Each of these surface water samples contained low concentrations of perchlorate and TCE suggesting further that groundwater is discharging to Little Elk Creek.

#### 5.4 PERFORMANCE ASSESSMENT

The potential for perchlorate MNA at the site was evaluated using the tiered approach described in the Protocol (ESTCP, 2008). The plume at the TCE/Perchlorate SWMU was divided into transects, which are illustrated in Figure 9 to aid in the evaluation. Contaminant concentrations, biogeochemical conditions, and MBT enumerations were performed along the entire well network as part of the Tier 1 and Tier 2 evaluations. In Tier 3, specialized studies designed to determine biodegradation rates were conducted only on matrices from closer to Little Elk Creek. The complete data set is provided in the Technical Report for this demonstration (ESTCP, 2010b). The results are summarized below.

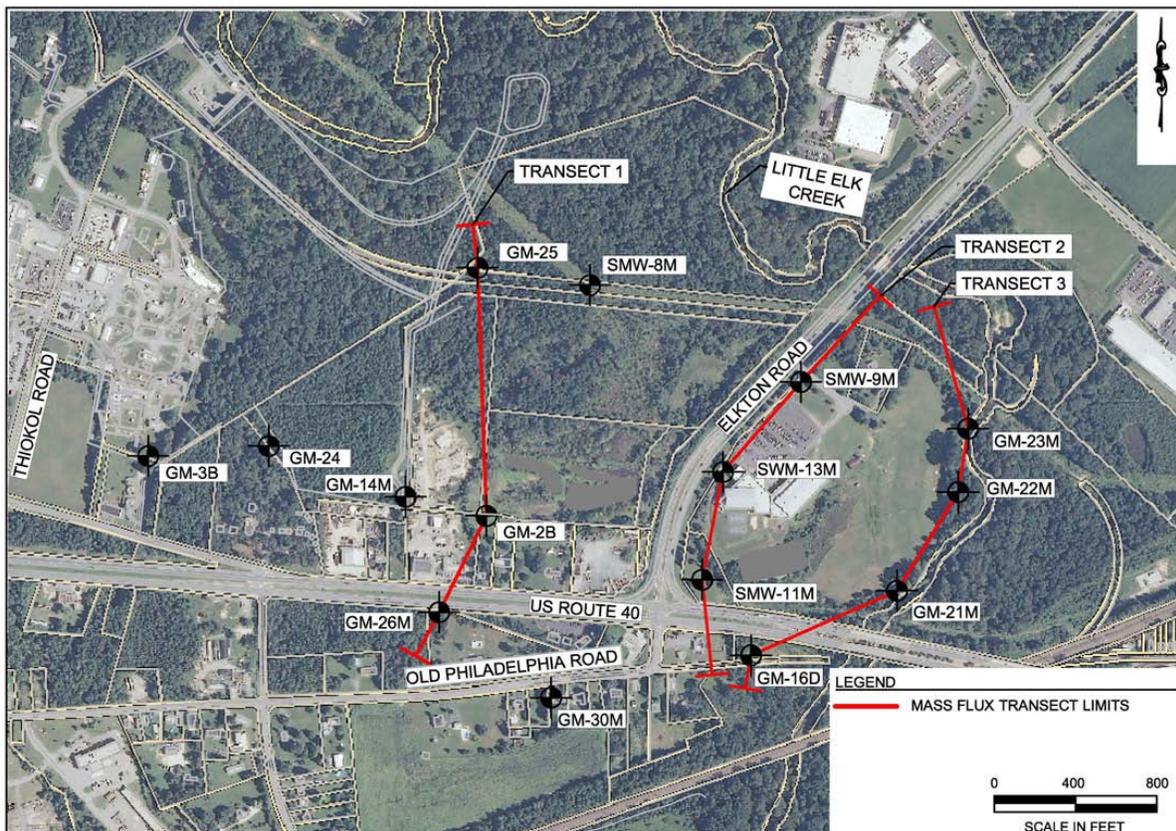


Figure 9. Transects for estimating mass flux across the TCE/perchlorate plume.

## **5.4.1 Tier 1 and Tier 2 Evaluations**

### **5.4.1.1 Current Source Conditions**

The Presumed Source Area is in the vicinity of GM-14S/M. There are currently low concentrations of perchlorate in the groundwater at both depths. In March 2004, prior to the IRZ pilot test, the concentration of perchlorate in GM-14M was 1240 µg/L. It appears that the introduction of organic substrate stimulated perchlorate reduction resulting in an 80 to 90% decrease in concentration. These wells are slightly acidic but contain some residual TOC and show evidence of reducing conditions that could promote further perchlorate degradation. These source area wells also contain measurable populations of bacteria with chlorite dismutase (*clt*) and *pcrA* gene copies. The historical data from several source area wells suggest significant perchlorate decreases over time in this portion of the site. This attenuation could be attributable to a combination of natural abiotic processes, the activity of the pump-and-treat system, and enhanced perchlorate reduction during the former bioremediation pilot study, all in the same general area.

### **5.4.1.2 Mid-Plume Conditions (Transect 1)**

Transect 1 is located approximately 500 to 700 ft downgradient of the presumed source. These wells begin to show the perchlorate contamination pattern that is most prevalent throughout the plume. There is virtually no perchlorate in the shallow portion of the aquifer (<1 to 21 µg/L), but there is elevated perchlorate in the intermediate groundwater (153 to 1053 µg/L). The pH is somewhat acidic, the ORP is oxidative, and there is virtually no TOC present that could enhance biodegradation of perchlorate. There are measureable populations of microorganisms ( $10^3$  to  $10^5$  eubacteria/mL) in both the shallow and deep portions of the aquifer but no detectable perchlorate-reducing bacteria in this environment, although the *clt* assays did indicate some capability. Although the oxidative conditions, low pH, and absence of TOC do not support bioattenuation of perchlorate, abiotic factors such as dilution and dispersion may account for decreases in perchlorate concentrations observed over time. Conversely, a similar decrease in TCE was not observed.

### **5.4.1.3 Mid-Plume Conditions (Transect 2)**

Transect 2 includes three well pairs installed along Elkton Road to fill out the well network for this project. Conditions in the shallow and intermediate aquifer in areas approximately 1000 to 2000 ft downgradient from the presumed source (i.e., mid-plume) are very similar with the exception that there is some perchlorate (67 to 748 µg/L) in the intermediate zone and virtually none detectable (<1 to 70 µg/L) in shallow groundwater. There is no detectable TOC, groundwater is mostly acidic pH, ORPs are oxidative, and there are low bacterial populations with no evidence of *pcrA* activity. These conditions are not conducive to bioattenuation of perchlorate or TCE.

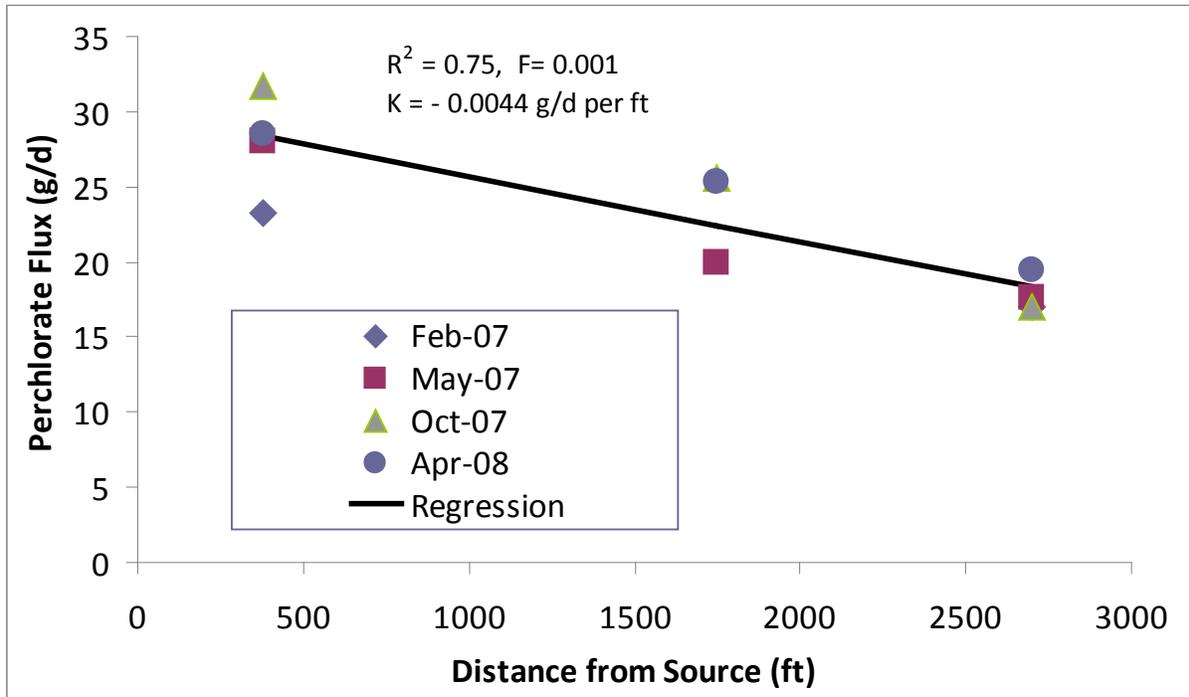
### **5.4.1.4 Presumed Discharge Zone (Transect 3 and Interface Samples)**

The well pairs situated near Little Elk Creek (GM-21S/M, GM-22S/M and GM-23S/M) are located just before the 30-ft-wide wooded zone that forms a buffer between open playing fields and the creek. Shallow and intermediate groundwater merge in this area as deeper water

migrates upward before discharging into the creek. There is some evidence that not all groundwater is controlled by the creek since TCE has been measured in groundwater on the opposite side, but perchlorate has not been detected beyond the creek. Measurable perchlorate and TCE are in all the shallow and intermediate wells in this distal portion of the plume. The data suggest increased *cld* and *pcrA* activity in this area of the aquifer, and some natural perchlorate biodegradation appears to have occurred. Although the biogeochemical conditions may support perchlorate biodegradation, reductive dechlorination of TCE is minimal.

Groundwater conditions change immediately before discharge into Little Elk Creek. The interface samples taken from 1 to 2 ft below the surface along the edge of the creek contained 6 to 19 mg/L TOC with pH closer to 5.9. The ORP in interface sample ITF-1 was -67 mV, suggesting a reducing environment, and methane was reported in all three interface samples. This portion of the plume appears to be the zone most favorable for biodegradation of perchlorate, which is consistent with the absence of perchlorate in the creek. As before, these conditions do not appear to be sufficient to promote TCE biodegradation to the same degree.

The Tier 1 and 2 evaluations show that groundwater conditions are minimally conducive to biological degradation of perchlorate until closer to discharge into Little Elk Creek. Non-biological attenuation mechanisms with limited biological contribution have resulted in decreases in perchlorate concentrations over distance. Perchlorate mass flux during each of the four performance monitoring events is shown Figure 10. Perchlorate mass flux in the intermediate zone declines significantly during groundwater flow from Transect 1 to 3 (i.e., the downward trend is statistically significant at the 99% level;  $F = 0.001$ ). However, there is a substantial increase in the shallow zone mass flux in Transect 3 as groundwater migrates from the intermediate to the shallow zones near Little Elk Creek. Total mass flux declines from an average of 28 g/d to 18 g/d of perchlorate from Transect 1 to 3.



**Figure 10. Mass flux versus distance from source.**

Overall results from analysis of concentration versus time trends in individual wells are: (1) concentrations are declining with time in the source area wells and are projected to reach cleanup standards in a few years, and (2) concentrations in wells near Little Elk Creek do not show any consistent trend with concentrations in some wells increasing and other wells decreasing. This overall pattern is consistent with a pulse of dissolved perchlorate migrating through the aquifer towards Little Elk Creek. Travel time from the source area to Little Elk Creek is estimated to be roughly 45 years. If flushing by ambient groundwater flow is removing perchlorate from near the source area, this effect might not be observed in wells near the creek for several decades. Some of the apparent increase in perchlorate near the creek could be due to the arrival of perchlorate that was released in the 1950s–1960s. Additional biodegradation tests were designed and performed in Tier 3 to corroborate the lines of evidence suggested by the Tier 1 and 2 evaluations.

#### **5.4.2 Tier 3 Evaluation**

Macrocosm and in situ column studies were designed and implemented to estimate perchlorate biodegradation rates in site matrix soil and groundwater from near Little Elk Creek. Macrocosms in 5-gal carboys were constructed on site using shallow soil and groundwater from GM-22S. Replicate carboys were transported to the laboratory and sampled over time for degradation by-products and other indicator parameters. The first-order biodegradation rate calculated from the macrocosm study was 2.9/yr.

In situ columns were installed in the same vicinity and pumped to measure perchlorate degradation during vertical transport through the native aquifer material. First-order biodegradation rates were comparable to the macrocosm rates. As summarized in Table 2, these

tests offer a positive line of evidence supporting the potential for MNA of perchlorate to occur in this area of the TCE/perchlorate contaminant plume.

**Table 2. Summary of biodegradation rates in TCE/perchlorate plume matrices from the Maryland manufacturing site.**

Test	Type	Rate Constant	Half-Life ( $t_{1/2}$ )
Microcosms	Zero-Order	0.92 mg/L/yr.	--
Macrocosms	1 <sup>st</sup> -Order	2.9/yr.	87 days
In Situ Column B	1 <sup>st</sup> -Order	8.5/yr.	30 days
In Situ Column C	1 <sup>st</sup> -Order	7.6/yr.	33 days

In summary, the trends in groundwater flow, biogeochemical parameters, microbial populations and perchlorate concentrations suggest that perchlorate is attenuating and, in some locations, is biodegrading prior to groundwater discharging to Little Elk Creek. The evaluation successfully demonstrated that the perchlorate naturally attenuates, biodegradation is a component of the attenuation, and that perchlorate MNA can be incorporated into the groundwater remediation approach to address perchlorate contamination at the site.

## 5.5 MANUFACTURING SITE COST ASSESSMENT

A cost breakdown and performance analysis was provided in the Technical Report (ESTCP, 2010b). The total cost of the demonstration was approximately \$292,900.

Primary cost elements are summarized below and include:

- Technical Demonstration Plan, white papers/design: ~\$17,000 (6%)
- Additional characterization: ~\$45,000 (15%)
- Performance monitoring and data acquisition for Tiers 1 & 2: ~\$101,900 (35%)
- Tier 1 and 2 evaluations: ~\$21,000 (7%)
- Tier 3 data acquisition and evaluation: ~\$58,000 (20%)
- Technical reporting: ~\$50,000 (17%).

Large portions of the costs were associated with additional site characterization including installation of new monitoring wells pairs and extended performance monitoring. Macrocosm and in situ column studies to confirm biodegradation potential were also large portions of the cost. Project costs not directly related to the individual technical demonstrations such as project management, technical transfer, site screening, treatability study, and protocol development are not included in the cost summary.

## **6.0 COST COMPARISON**

The following sections discuss the cost drivers, compare the costs to evaluate the potential for MNA at the Indian Head and manufacturing facility demonstration sites, and compare costs of other technologies typically used to remediate perchlorate in groundwater. At a minimum, the demonstrations showed that the systematic approach to evaluating perchlorate MNA provided as guidance in the protocol prepared for this project can result in timely and informed application of this remedy at very different sites. The cost comparisons provided in the following sections also demonstrate that MNA of perchlorate can result in life-cycle savings compared to other treatment technologies.

### **6.1 COST DRIVERS**

Components of evaluation of perchlorate MNA that impact cost are listed below:

- More detailed site characterization is needed to demonstrate attenuation, which may mean more complex and costly up-front investigation.
- Specialized testing (e.g., microcosms, macrocosms, in situ columns, stable isotopes) may be needed to corroborate lines of evidence.
- Long-term performance monitoring typically associated with MNA may be more expensive because more parameters may be monitored.
- Potentially longer life cycles to reach remediation goals compared to active remediation measures.
- Changing site conditions over time may require a re-evaluation of MNA and associated additional cost.
- Demonstrating the effectiveness of MNA as protective of human health and the environment to gain public acceptance may be more difficult and therefore, costly.

### **6.2 COST COMPARISON—INDIAN HEAD VERSUS THE MANUFACTURING SITE DEMONSTRATIONS**

Although costs for implementing each of the demonstrations cannot be directly compared due to differences in site conditions, highlighting the cost differences between the Indian Head and the Maryland manufacturing site evaluations leads to a greater understanding of cost drivers and the importance of utilizing the tiered evaluation to systematically evaluate if perchlorate MNA is an appropriate remedial strategy for a particular site. Table 3 summarizes the total project cost and the general allocation of funds between the two sites.

**Table 3. Cost breakdown of overall ESTCP Project ER-200428.**

Project Cost Not Directly Related to Site	Project Management/Technical Transfer		\$105,000
	Site Screening/Treatability Study		\$116,000
	Protocol Development		\$50,000
Site	Indian Head	Manufacturing Site	
Technical Demonstration Plan//White Paper/ Design	\$51,300	\$17,000	\$68,300
Additional Site Characterization	\$103,600	\$45,000	\$148,600
Performance Monitoring/Data Acquisition for Tier 1 & Tier 2	\$209,300	\$101,900	\$311,200
Tier 1 and 2 Evaluations	\$14,900	\$21,000	\$35,900
Tier 3 Data Acquisition & Evaluation	\$60,000	\$58,000	\$118,000
Technical Reporting	\$70,000	\$50,000	\$120,000
<b>Total</b>	<b>\$509,100</b>	<b>\$292,900</b>	<b>Project Total \$1,073,000</b>

Some important considerations when comparing the two demonstration sites are:

- Project costs which are not directly related to site demonstration are approximately 25% of total project cost. These costs are related to project management including various meetings required by ESTCP and technical transfer of the perchlorate MNA technology through webinars, presentations and participation on the Interstate Technology & Regulatory Council (ITRC) Perchlorate Team. These costs also include site screening activities including contacting multiple DoD sites, sampling seven sites, conducting laboratory treatability studies, and writing a Protocol to assist endusers in evaluating the potential of perchlorate MNA. Although the time and cost for project management would be incorporated into any remediation, many tasks performed by Solutions-IES for this project such as site screening and creating the Protocol would not be included in a typical project.
- Demonstration costs cannot be directly correlated to the size of the perchlorate plume but are more related to the complexity of the site. Although the perchlorate plume at the Indian Head site is much smaller than the perchlorate plume at the manufacturing facility site, the higher cost at the Indian Head site appears to be driven by the complexity of well installation and sampling, and by evaluating the impact of tidal hydrogeology on perchlorate degradation, and less dependent on the actual size of the plume.
- Additional site characterization that may be required for a tiered evaluation can add substantial costs. A substantially expanded monitoring well/piezometer network was required at the Indian Head Site once it became apparent that the perchlorate plume was discharging to the Littoral Zone. This added cost to the site characterization and remedial demonstration. Although the TCE/perchlorate plume at the manufacturing site was fully defined prior to starting the demonstration, additional monitoring well pairs were installed to help characterize

mid-plume conditions and provide data for mass flux calculations and attenuation rates.

- Sites with historical monitoring data available can possibly realize cost savings related to the Tier 1 and 2 evaluations if the existing data are relevant to the perchlorate MNA evaluation. Often, however, the Sampling and Analysis Plan must be modified or the well network expanded to include additional parameters and locations important to the Tier 1 and Tier 2 evaluations.
- The manufacturing site performance monitoring costs were lower than the Indian Head monitoring costs because the TCE/perchlorate plume was already delineated and subject to a regular monitoring program. The historical monitoring performed at the Indian Head site was related to the Shaw pilot study in a small defined area. Site-wide monitoring data were not available but were eventually obtained by Solutions-IES at additional cost.
- Performance monitoring at each site involved up to five events over a 2- to 3-year period. If historical data are available, the number of events needed to obtain lines of evidence to support MNA could be reduced, which would reduce cost.
- Tier 3 evaluation provided important lines of evidence supporting the potential for perchlorate MNA at each site. The additional cost to conduct these studies was independent of plume size or complexity of the hydrogeology as the Tier 3 costs for each site are nearly the same.

### **6.3 COST COMPARISONS: PERCHLORATE MNA AND ENGINEERED REMEDIATION APPROACHES**

Costs associated with various in situ remediation technologies for perchlorate are discussed in Stroo and Norris (2009) and Krug et al. (2009), but neither directly addresses or compares potential costs to MNA. There are many similarities, particularly associated with up-front assessment and long-term monitoring activities, but the difference with MNA is the absence of any designed intervention. To employ MNA, the goals of the assessment should merge with the goals of MNA. As an example, when considering MNA as a remedial alternative during the assessment phase, an expanded network of monitoring wells may need to be installed to thoroughly evaluate the nature of the contaminants present and the hydrogeology of the site in question. Once installed, altering the site monitoring program or Sampling and Analysis Plan is often all that is necessary to gather data that meet the objectives of Tier 1 and Tier 2 evaluations.

The Tier 3 evaluation including the biodegradation rate estimates may serve a different purpose when considering active or semipassive remediation versus MNA. For these in situ approaches, these studies may be used to help select a substrate to use and then confirm enhanced bioactivity by the substrate selected. Although interesting and possibly useful for predicting the duration of the remediation, biodegradation rate studies performed for this purpose may not be a critical component of the eventual design. However, biodegradation studies can provide an additional line of evidence supporting MNA, which can be very useful when seeking regulatory approval for the technology. Such studies require additional lab and or field work specifically to demonstrate that bioactivity is responsible for the attenuation that is observed.

The remedial action objectives (RAOs) for a site also can have a significant impact on cost and potentially the ability to use MNA at all as a remedial alternative. End users should work very closely with regulators during the evaluation process to determine realistic objectives for perchlorate remediation that are agreeable to the stakeholders. Results should be achievable for the regulatory agency involved in the cleanup. Cost estimates in the following sections use the federal TBC of 24.5 µg/L perchlorate as the target RAO. Solutions-IES used this target concentration when estimating the time to reach the regulatory limit at Indian Head, but used the MDE drinking water standard of 2.6 µg/L for calculations at the manufacturing site.

Costs of several engineered perchlorate remediation technologies were described by Krug et al. (2009) based on a hypothetical base case scenario. Life-cycle costs were projected for an Active Biobarrier Treatment, Passive Injection Biobarrier, and Extraction and Treatment System using estimates of capital cost, installation, operation and maintenance, and long-term monitoring for the treatment of base case perchlorate plume. Capital costs for the engineered remediation systems include system design, well installation, start-up, and testing. Pre-remedial investigations including treatability studies were not included in the capital costs for the engineered remediation systems.

Based on the current project, Solutions-IES projected the life-cycle costs for MNA for the same base case conditions using the table format created by Krug et al. (2009). This is shown in Table 4. The 3-tiered approach developed in this project was included with the capital costs for the perchlorate MNA estimate because the tiered evaluation may not be included in typical pre-remedial activities. The corresponding tables for the alternative technologies (as taken from Krug et al., 2009) were provided in the Indian Head and Maryland Manufacturing Site Technical Reports (ESTCP, 2010a,b).

**Table 4. Cost components for perchlorate MNA – base case.**

	Year Cost is Incurred							NPV of Cost	Total Costs
	1	2	3	4	5	6	7 to 30		
<b>CAPITAL COSTS</b>									
System design	10,000								10,000
Install expanded well network	15,000								15,000
Tier 1, 2, 3 evaluation	50,000								50,000
Installation/start-up testing	0								0
MNA permit & reporting	30,000								30,000
<b>SUBCOST (\$)</b>	105,000							102,239	105,000
<b>LONG-TERM MONITORING COSTS</b>									
(Quarterly for 5 years, then annually)	46,000	94,800	94,800	94,800	94,800	23,000	23,000 every yr.		1,000,200
<b>SUBCOST (\$)</b>	46,000	94,800	94,800	94,800	94,800	23,000	23,000	752,947	1,000,200
<b>TOTAL COST (\$)</b>	151,000	94,800	94,800	94,800	94,800	23,000	23,000	855,186	1,105,200

\* Net present value (NPV) was calculated based on a 2.7% discount rate

\*\*No start-up and testing costs are included because no operating equipment is left behind following substrate injection.

Table 5 summarizes the estimated costs for the three technologies described by Krug et al. (2009) compared to MNA shown above.

**Table 5. Comparison of capital costs and NPV of costs for operation, maintenance, and monitoring of various technologies for perchlorate-impacted groundwater.**

Technology Alternative	Capital Costs (\$K)	NPV of 30 Years O&M Costs (\$K)	NPV of 30 Years Monitoring Costs (\$K)	NPV of 30 Years of Total Remedy Costs (\$K)	Total 30-Year Remedy Costs (\$K)
Perchlorate MNA	\$105	Included with monitoring	\$753	\$855	\$1105
Passive Injection Biobarrier	\$280	\$990	\$350	\$1610	\$2240
Active Biobarrier	\$430	\$1200	\$350	\$1980	\$2700
Extraction and Treatment	\$490	\$1470	\$350	\$2310	\$3160

Note: Costs in thousands of dollars.

The active biobarrier assumes continuous extraction, reinjection, and recirculation of soluble electron donor. The passive injection biobarrier assumes an initial injection of emulsified vegetable oil to promote biodegradation as perchlorate-contaminated groundwater passes through the injection zone. Groundwater extraction and treatment assumes a row of extraction wells used to bring contaminated groundwater to a small-scale aboveground bioreactor for treatment prior to reinjection into the aquifer. MNA assumes expanding an existing well network to delineate the plume and provide groundwater analyses to meet the requirements of a complete three-tiered evaluation. Perchlorate MNA is a cost-effective and reliable remedial alternative that is feasible for many sites. Conclusions of the technology comparison include:

- MNA is approximately one-half the life-cycle cost of the Passive Injection Biobarrier alternative, and approximately one third the cost of the Extraction and Treatment alternative, even though the cost of monitoring is almost double the long-term monitoring costs for the engineered systems.
- An area of savings associated with perchlorate MNA and MNA in general is the relatively low operations and maintenance costs required.
- The tiered evaluation and reporting comprise 76% of the capital cost of an MNA evaluation, with Tier 3 evaluation costs alone comprising almost half the total capital cost. It is important to note that a Tier 3 evaluation was assumed for the base case. In many instances, the lines of evidence supporting perchlorate MNA may be fully established by earlier tiers, and a Tier 3 evaluation may not be necessary.
- Should the tiered analysis prove insufficient to support perchlorate MNA, the information acquired can be used to help evaluate other more active forms of treatment. For example, if the Tier 3 evaluation suggests that there is not enough carbon or microorganisms to support perchlorate MNA and a passive injection

biobarrier is considered, the substrate addition and bioaugmentation may be considered as alternatives for further evaluation and pilot testing.

- Should the tiered analysis suggest that perchlorate MNA is applicable to a portion of the plume crossing a large site, a remedial strategy can be customized to utilize MNA in concert with more active forms of treatment.

## 6.4 CONCLUSIONS

The principles of MNA that have been used historically to manage and remediate groundwater plumes contaminated with petroleum hydrocarbons and CVOCs were demonstrated to be applicable for perchlorate at two DoD-related facilities. Using expanded monitoring well/piezometer networks to delineate contaminant plumes applies equally well to perchlorate as to other contaminants. Analytical tools and techniques are available to detect low concentrations of perchlorate (i.e.,  $<1 \mu\text{g/L}$ , if desired) and to detect and quantify the presence and activity of DPRB populations in the environment.

The demonstrations also identified the biogeochemical conditions that would be expected to promote natural perchlorate attenuation. The ORP and TOC conditions favorable to perchlorate MNA were similar at each site. At the Indian Head demonstration, groundwater ORP less than +50 mV with TOC greater than 4 mg/L was conducive to perchlorate degradation, whereas in the manufacturing site demonstration, ORP less than +100 mV and TOC greater than 6 mg/L appeared to support the limited biodegradation that was observed. Minimal competing nitrate and  $\text{pH} > 5.5$  were also important for natural attenuation to occur. The observations from the commingled TCE/Perchlorate plume at the Maryland manufacturing site indicated that conditions for perchlorate attenuation are less fastidious than for CVOC attenuation. Where biogeochemical conditions do not provide definitive lines of evidence, there are several ways to confirm bioactivity. These include microcosm, macrocosm and in situ column studies, which can be designed to generate biodegradation rate data. Although not tested in this project, changes to the stable isotope signature of perchlorate may also be useful.

MNA of perchlorate is likely to be considerably less costly than engineered passive and active remediation systems. As shown at the Elkton site, changes in mass flux across the site can be competitive with P&T, which is limited by the pumping radius of influence. MNA of perchlorate can be protective of human health and the environment and should be considered as part of any evaluation of alternatives for remediating perchlorate contamination in groundwater.

*This page left blank intentionally.*

## 7.0 REFERENCES

- ARCADIS. 1999. Perchlorate Investigation Sampling Plan, Prepared by ARCADIS Geraghty & Miller, Inc., April 15, 1999.
- ARCADIS G&M, Inc. 2003. Interim Site-Wide Investigation Technical Report and Work Plan. Prepared by ARCADIS G&M, Inc., June 2003.
- ARCADIS. 2007. Site-Wide Corrective Measures Study Report. Prepared by ARCADIS, Inc. February 2007.
- CDHS. 2006. News Release: State Health Department Announces Proposed Drinking Water Standard for Perchlorate. California Department of Health Services. (<http://www.dhs.ca.gov>.)
- Coates, J.D., U. Michaelidou, R.A. Bruce, S.M. O'Connor, J.N. Crespi, and L.A. Achenbach. 1999. Ubiquity and Diversity of Dissimilatory (Per)chlorate-Reducing Bacteria. *Appl. Environ. Microbiol.* 65 (12): 5234-5241.
- Coates, J.D., and J. Pollock. 2003. Potential for *In Situ* Bioremediation of Perchlorate in Contaminated Environments. Presented at *In Situ* and On-Site Bioremediation, the Seventh International Symposium, Orlando, FL, June 2003.
- Cramer, R.J, C. Yates, P. Hatzinger, and J. Diebold. 2004. Field Demonstration of *In Situ* Perchlorate Bioremediation at Building 1419. NOSSA-TR-2004-001, January 22, 2004.
- ESTCP. 2006. Field Demonstration and Validation of a New Device for Measuring Groundwater and Perchlorate Fluxes at IHDIV-NSWC, Indian Head, MD. Prepared by Purdue University and University of Florida, Project No. ER-0114, Environmental Security Technology Certification Program, Arlington, VA, July 2006.
- ESTCP. 2007. Field and Laboratory Evaluation of the Potential for Monitored Natural Attenuation of Perchlorate in Groundwater, Final Technical Report. Prepared by Solutions-IES, Inc. and North Carolina State University, Project No. ER-0428, Environmental Security Technology Certification Program, Arlington, VA, July 2007.
- ESTCP. 2008. Natural Attenuation of Perchlorate in Groundwater: Processes, Tools and Monitoring Techniques. Prepared by Solutions-IES, Inc., Project No. ER-0428, Environmental Security Technology Certification Program, Arlington, VA, August 2008.
- ESTCP. 2010a. Perchlorate Monitored Natural Attenuation in Groundwater: Building 1419 Site, Naval Surface Warfare Center, Indian Head, MD. Prepared by Solutions-IES, Inc., Project No. ER-0428, Environmental Security Technology Certification Program, Arlington, VA, July 2010.

- ESTCP. 2010b. Perchlorate Monitored Natural Attenuation in Groundwater, Elkton, MD. Prepared by Solutions-IES, Inc., Project No. ER-0428, Environmental Security Technology Certification Program, Arlington, VA, May 2010 (Draft Final, In Progress).
- Gingras, T.M., and J.R. Batista. 2002. Biological Reduction of Perchlorate in Ion Exchange Regenerant Solutions Containing High Salinity and Ammonium Levels. *J. Environ. Monit.* 4:96-101.
- Hatzinger, P.B. 2005. Perchlorate Biodegradation for Water Treatment. *Environ. Sci Technol.* 39: 239A-247A.
- Hoponick, J.R. 2006. Status Report on Innovative *In Situ* Remediation Technologies Available to Treat Perchlorate-Contaminated Groundwater. USEPA, Office of Superfund Remediation & Technology Innovation, Technology Innovation & Field Services Division, Washington, DC, August 2006.
- Hunter, W.J. 2002. Bioremediation of Chlorate or Perchlorate Contaminated Water Using Permeable Reactive Barriers Containing Vegetable Oil. *Curr. Microbiol.* 45: 287-292.
- ITRC. 2005. Perchlorate: Overview of Issues, Status, and Remedial Options. Interstate Technology & Regulatory Council. ITRC Perchlorate Team, September 2005. (<http://www.itrcweb.org>).
- Krug, T.A., C Wolfe, R.D. Norris, and C.J. Winstead. 2009. Chapter 10, Cost Analysis of *In Situ* Perchlorate Remediation Technologies. *In: Stroo, H.F., and C.H. Ward (eds.). In Situ Bioremediation of Perchlorate in Groundwater.* SERDP and ESTCP Remediation Technology Monograph Series, Springer Science+Business Media, LLC, New York, NY, pp 199-218.
- Logan, B.E. 1998. A Review of Chlorate- and Perchlorate-Respiring Microorganisms. *Bioremed. J.* 2: 69-79.
- Logan, B.E. 2001. Assessing the Outlook for Perchlorate Remediation. *Environ. Sci. & Technol.* 35 (23): 482A- 487A.
- Lorah, M.M. and L.D. Olsen, 1999. Natural Attenuation of Chlorinated Volatile Organic Compounds in a Freshwater Tidal Wetland: Field Evidence of Anaerobic Biodegradation. *Water Resources Res.* 35 (12): 3811-3827.
- Lorah, M.M., L.D. Olsen, B.L. Smith, M.A. Johnson, and W.B. Fleck. 1997. Natural Attenuation of Chlorinated Volatile Organic Compounds in a Freshwater Tidal Wetland, Aberdeen Proving Ground, Maryland. *USGS Water-Resources Investigations Report 97-4171*, 95p.

- MADEP. 2006. Inorganic Chemical Maximum Contaminant Levels, Monitoring Requirements and Analytical Methods. Massachusetts Department of Environmental Protection, 310 Code Massachusetts Regulations §22.06.
- MDE. 2008. Cleanup Standards for Soil and Groundwater, Type I and II Aquifers, Interim Final Guidance (Update No. 2.1), Maryland Department of the Environment, June 2008.
- NRC. 2005. Health Implications of Perchlorate Ingestion. National Academies Press, Washington, DC, 276p.
- Stroo, H.F., R.C. Loehr, and C.H. Ward. 2009. Chapter 1, *In Situ* Bioremediation of Perchlorate in Groundwater: An Overview. *In*: Stroo, H.F and C.H. Ward (eds.). *In Situ* Bioremediation of Perchlorate in Groundwater. Doi:10.1007/978-0-387-84921-8\_1, Springer Science + Business Media, LLC, pp. 1-13.
- Stroo, H.F., and R.D. Norris. 2009. Chapter 5, Alternatives for *In Situ* Bioremediation of Perchlorate. *In*: Stroo, H.F and C.H. Ward (eds.). *In Situ* Bioremediation of Perchlorate in Groundwater. Doi:10.1007/978-0-387-84921-8\_1, Springer Science + Business Media, LLC, pp. 79-90.
- USEPA. 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water. EPA/600/R-98/128. Washington, DC: ORD.
- USEPA. 1999. Final Directive: Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. OSWER Directive 9200.4-17P. (<http://www.epa.gov/swrust1/directiv/d9200417.htm>).
- USEPA. 2006. Assessment Guidance for Perchlorate. Memorandum from S.P. Bodine, Asst. Administrator, to Regional Administrators. January 26, 2006.
- USEPA. 2009. 2009 Edition of the Drinking Water Standards and Health Advisories, Environmental Protection Agency, EPA 822-R-09-011.
- USFDA. 2007. 2004-2005 Exploratory Survey Data on Perchlorate in Food. U.S. Food and Drug Administration, Posted May 2007. (<http://www.cfscan.fds.gov/~dms/clo4data.html>)
- Waller, A.S., E.E. Cox, and E.A. Edwards. 2004. Perchlorate-Reducing Microorganisms Isolated from Contaminated Sites. *Environ. Microbiol.* 6: 517-527.
- Wiedemeier, T.H., M.A. Swanson, D.E. Moutoux, E.K. Gordon, J.T. Wilson, B.H. Wilson, D.H. Kampbell, P.E. Haas, R.N. Miller, J.E. Hansen, and F.H. Chapelle. 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater. EPA 600-R-98-128.

Wiedemeier, T.H., J.T. Wilson, D.H. Kampbell, R.N. Miller, and J.E. Hansen. 1995. Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater, Volume II. Air Force Center for Environmental Excellence, Brooks Air Force Base, TX, November 1995.

Zhang, H., M.A. Bruns, and B.E Logan. 2002. Perchlorate Reduction by a Novel Chemolithoautotrophic, Hydrogen-Oxidizing Bacterium. *Environ. Microbiol.* 4: 570-576.

## APPENDIX A

### POINTS OF CONTACT

Point of Contact	Organization	Phone Fax E-Mail	Role
Dr. Andrea Leeson	ESTCP Office 901 North Stuart Street Suite 300 Arlington, VA 22203	Phone: (703) 696-2118 Fax: (703) 696-2114 E-mail: andrea.leeson@osd.mil	Environmental Restoration Program Manager
M. Tony Lieberman, R.S.M.	Solutions-IES 1101 Nowell Road Raleigh, NC 27607	Phone: (919) 873-1060, Ext. 117 Fax: (919) 873-1074 E-mail: tlieberman@solutions-ies.com	Principal Investigator; Senior Project Manager
Dr. Robert C. Borden, P.E.	Solutions-IES 1101 Nowell Road Raleigh, NC 27607	Phone: (919) 873-1060, Ext. 123 (919) 515-1625 (office) E-mail: rcborden@eos.ncsu.edu	Co-Principal Investigator, Senior Engineering Consultant
Ms. Sheri L. Knox, P.E.	Solutions-IES 1101 Nowell Road Raleigh, NC 27607	Phone: (919) 873-1060, Ext. 174 Fax: (919) 873-1074 E-mail: sknox@solutions-ies.com	Project Manager
Ms. Erica Becvar	Air Force Center for Engineering and the Environment 2261 Hughes Avenue, Suite 155 Lackland AFB, TX 78236-9853	Phone: (210) 395-8424 Fax: (210) 536-5989 E-mail: erica.becvar.1@us.af.mil	Contracting Officer's Representative



**ESTCP Office**

901 North Stuart Street  
Suite 303  
Arlington, Virginia 22203

(703) 696-2117 (Phone)  
(703) 696-2114 (Fax)

E-mail: [estcp@estcp.org](mailto:estcp@estcp.org)  
[www.serdp-estcp.org](http://www.serdp-estcp.org)

# FINAL REPORT

Evaluation of Potential for Monitored Natural Attenuation of  
Perchlorate in Groundwater (Indian Head)

ESTCP Project ER-200428

JULY 2010

Tony M. Lieberman  
**Solutions IES, Inc.**

Sheri L. Knox  
**Solutions IES, Inc.**

Robert C. Borden  
**Solutions IES, Inc.**

*This document has been cleared for public release*



# Table of Contents

1.0	Introduction.....	1
1.1	Background.....	1
1.2	Objectives of the Demonstration .....	2
1.3	Regulatory Drivers .....	3
1.4	Stakeholder/End-User Issues .....	3
2.0	Technology Description.....	5
2.1	Monitored Natural Attenuation (MNA) Development .....	5
2.2	Advantages and Limitations of the Technology .....	5
2.2.1	Cleanup Objectives .....	5
2.2.2	Advantages of MNA .....	5
2.2.3	Limitations of MNA.....	6
3.0	Demonstration Design and Evaluation .....	7
3.1	Performance Objectives for the Demonstration .....	7
3.2	Site Selection Process.....	7
3.2.1	Indian Head Site Description .....	8
3.2.2	Previous Remediation Studies.....	11
3.2.2.1	Source Identification.....	11
3.2.2.2	Enhanced Perchlorate Biodegradation .....	12
3.2.3	Pre-Demonstration Testing .....	13
3.2.3.1	Groundwater and Soil Sampling .....	13
3.2.3.2	Laboratory Microcosm Studies .....	14
3.2.4	Selection Criteria for Building 1419 Site, NSWC, Indian Head.....	17
3.3	Demonstration Approach.....	17
3.4	Field Methods .....	18
3.4.1	Determination of Geomorphologic Zones.....	18
3.4.2	Boring and Monitoring Well Installation .....	24
3.4.2.1	Zone 1 - Land Borings and Monitor Wells .....	25
3.4.2.2	Zone 2 – Littoral Zone Monitor Wells and Piezometers .....	26
3.4.2.3	Zone 3 – Subtidal Channel and Surface Water Monitoring Points.....	27
3.4.2.4	Zone 4 - Monitoring Well Installation in the Subtidal Shallows.....	27
3.4.3	Groundwater and Creek Sediment Pore Water Sampling .....	27
3.4.4	Measurement of Hydraulic Head in Wells and Piezometers.....	28
3.4.5	Determination of Aquifer Hydraulic Conductivity .....	28
3.5	Laboratory Methods .....	28
3.5.1	Sampling for Standard Analyses .....	30
3.5.2	Groundwater Collection for Perchlorate Analysis .....	30
3.5.3	Biological Assays –qPCR Analysis .....	30
3.6	<i>In Situ</i> Biodegradation Testing .....	31
3.6.1	<i>In Situ</i> Columns.....	31
3.6.2	Macrocosms .....	34
3.6.3	Stable Isotope Analysis .....	35
3.7	Residuals Handling.....	35
4.0	Site Area Hydrogeology .....	37
4.1	Regional Hydrogeology.....	37
4.2	Local Subsurface Conditions.....	38
4.2.1	Subsurface Conditions in the Site Area.....	39
4.2.2	Hydraulic Conductivity of the Surficial Aquifer.....	43
4.3	Groundwater Flow at the Site.....	44
4.3.1	Groundwater Flow in Zone 1 - Mainland.....	44

4.3.2	Groundwater Flow in Zones 2 and 3 – Littoral Zone and Subtidal Channel .....	45
4.3.3	Groundwater Flow in Zone 4 - Subtidal Shallows .....	47
4.3.4	Groundwater Discharge Rates.....	47
4.4	Geochemical Indicators of Groundwater Flow Patterns.....	49
4.4.1	Temperature .....	49
4.4.2	Chloride.....	49
4.4	Generalized Hydrogeologic Model .....	51
5.0	Conceptual Model of Perchlorate Transport and Fate .....	54
6.0	Field MNA Evaluation Program.....	59
6.1	Tier 1 Evaluation – Plume Geometry and Stability.....	59
6.1.1	Plume Geometry.....	59
6.1.2	Plume Stability .....	61
6.1.3	Effect of Dilution on Perchlorate Concentrations .....	62
6.1.4	Source Area Attenuation .....	64
6.1.5	Mass Flux .....	65
6.1.6	Summary of Plume Geometry and Stability Evaluation (Tier 1).....	69
6.2	Tier 2 Evaluation – Biogeochemical Parameters and Biological Indicators .....	69
6.2.1	Total (or Dissolved) Organic Carbon.....	73
6.2.2	Oxidation-Reduction Potential.....	74
6.2.3	Dissolved Oxygen .....	76
6.2.4	Nitrate.....	77
6.2.5	Iron .....	77
6.2.6	Methane.....	78
6.2.7	pH.....	78
6.2.8	Temperature .....	79
6.2.9	Chloride, Chlorate and Chlorite .....	80
6.2.10	Microbial Populations .....	80
6.2.11	Summary of Biogeochemical Evaluation (Tier 2) .....	84
6.3	Tier 3 Evaluation – Biodegradation Rates.....	85
6.3.1	Macrocosm Study.....	85
6.3.2	<i>In Situ</i> Column Biodegradation (IC) Study.....	88
7.0	Performance Assessment .....	94
7.1	Primary Performance Objectives.....	94
7.2	Secondary Performance Objectives.....	94
8.0	Cost Assessment .....	96
8.1	Cost Drivers.....	96
8.2	Indian Head Demonstration Costs and Long-term Cost Model .....	96
8.3	Cost Comparison: MNA vs. Passive <i>In Situ</i> and Active Pumping Technologies.....	98
8.3.1	Basis of Cost Comparison .....	98
9.0	Implementation Issues .....	103
9.1	Environmental Checklist .....	103
9.2	Other Regulatory Issues.....	103
9.3	End-User Issues .....	103
10.0	References.....	104

## Figures

- 1-1 Perchlorate Biodegradation Pathway
  
- 3-1 Aerial View of Indian Head NSWC
- 3-2 Demonstration Area Showing NSWC Vicinity and the Indian Head Project Site
- 3-3 Site Map with Building Locations
- 3-4 Shaw Test Plot and Select Monitoring Well Locations
- 3-5 Microcosm Bottles Used in the Laboratory Studies
- 3-6 Biodegradation of Perchlorate in Laboratory Microcosms
- 3-7 Aerial View of the Demonstration Area
- 3-8 Open Grassy Area Southeast of Drum Storage Building
- 3-9 Wooded Area Looking Northeast from Mattawoman Creek
- 3-10 Creek Bank and High Tide Line
- 3-11 Vegetation Covering the Littoral Zone during the Summer Months
- 3-12 Littoral Zone without Vegetation during the Winter Months
- 3-13 Organic Muck in the Littoral Zone
- 3-14 Subtidal Channel
- 3-15 Physiographic Zones in the Demonstration Area
- 3-16 Monitor Well and Piezometer Network
- 3-17 Piezometer Installation in the Littoral Zone using a Slide Hammer
- 3-18 *In Situ* Column Locations in the Littoral Zone
- 3-19 *In Situ* Columns IC-3 and IC-4 adjacent to Piezometer Group 1
- 3-20 *In Situ* Column Construction
- 3-21 Preparing Macrocosms in 5-Gallon Carboys
  
- 4-1 Generalized Stratigraphic and Hydrologic Framework of the Indian Head Area
- 4-2 Section A-A'
- 4-3 Section B-B'
- 4-4 Section C-C'
- 4-5 Water Table Contour Map (April 2008)
- 4-6 Variation in Water Elevations from Oct. 24 to Nov. 1, 2006 in Piezometer Group SGP-23 Installed in the Subtidal Channel
- 4-7 Measured Hydraulic Gradients between Different Depths in Piezometer Groups 1 and 2 on Three Dates
- 4-8 Temperature Fluctuations in Surface, Shallow and Deep Groundwater
- 4-9 Chloride Concentrations in March 2007 at Different Sampling Locations
- 4-10 Vertical Profiles of Chloride Concentration vs. Depth in Littoral Zone (Piezometer Groups 1 and 2) and Subtidal Channel (SGP-23 and SGP-24).
- 4-11 Flow Net for Study Area
  
- 5-1 Presumed Source and Conceptual Discharge Areas
- 5-2 Conceptual Model of Perchlorate Transport
- 5-3 Photograph Showing Organic Muck Layer

- 6-1 Perchlorate Concentration Map (April 2008)
- 6-2 Geochemical Changes in Shallow and Deep Groundwater and Sediment Pore Water
- 6-3 Perchlorate ( $\text{ClO}_4$ ) and Chloride ( $\text{Cl}$ ) Concentration vs. Depth in Piezometer Groups 1 and 2
- 6-4 Perchlorate Concentration vs. Time Curve Fit for MW-4
- 6-5 Mass Flux Evaluation Area
- 6-6 Orientation of Mass Flux Transects
- 6-7 Changes in Total Organic Carbon along Transects B-B' and C-C'
- 6-8 Oxidation-Reduction (Redox) Potential for Degradation Processes
- 6-9 Changes in Oxidation-Reduction (ORP) Potential along Transects B-B' and C-C'
- 6-10 Map of pH Concentrations in Deep Groundwater/Pore Water beneath the Site
- 6-11 Perchlorate Concentration and *pcrA* Gene Copies in Monitor Wells in August 2008
- 6-12 Relationship between Perchlorate Concentration and *pcrA* Gene Copies
- 6-13 Relationships between Number of *pcrA* Gene Copies, ORP, and pH in Monitor Wells in August 2008
- 6-14 Nitrate, Perchlorate, and Electron Acceptor Concentration vs. Time in Five Replicate Macrocosms Constructed with Littoral Zone Sediment
- 6-15 Regression Analysis of Nitrate, Perchlorate and Electron Acceptor Concentration vs. Time
- 6-16 Locations of *In Situ* Columns
- 6-17 Comparison of Macrocosm and *In Situ* Column Rates

## Tables

- 3-1 Performance Objectives
- 3-2 Groundwater Chemistry and Perchlorate Concentrations in Monitor Wells
- 3-3 Performance Monitoring Schedule
- 3-4 Sample Collection and Analysis Details
  
- 4-1 Aquifer Test Results
- 4-2 Average and Range of Horizontal Hydraulic Conductivity in Zones 1 to 4
  
- 6-1a Perchlorate Concentrations ( $\mu\text{g/L}$ ) in Littoral Zone Points
- 6-1b Perchlorate Concentrations ( $\mu\text{g/L}$ ) in Littoral Zone Piezometer Groups
- 6-1c Perchlorate Concentrations ( $\mu\text{g/L}$ ) in Subtidal Channel Monitoring Points
- 6-2 Groundwater and Surface Water Mixing Ratios in Piezometer Groups 1 and 2
- 6-3 First-Order Concentration vs. Time Attenuation Rates in Zone 1 Wells
- 6-4a Groundwater Flux Calculations
- 6-4b Perchlorate Mass Flux Calculations
- 6-5 Performance Monitoring in Shallow Wells
- 6-6 Performance Monitoring in Deep Wells
- 6-7 Comparison of DO, Iron, and Methane Levels in SGP-22D, -23D and -24D
- 6-8 Dissolved Iron Concentrations in Shallow and Deep Groundwater
- 6-9 Seasonal Groundwater Temperature Comparison
- 6-10 Nitrate, Perchlorate, and Electron Acceptor Degradation Rates in Littoral Zone Macrocosms
- 6-11 Analytical Results of Groundwater Samples Collected from *In Situ* Columns during Pumping
- 6-12 Biodegradation Rates Calculated from *In Situ* Biodegradation Study at IC-1
- 6-13 Summary of Perchlorate Concentrations at Equivalent Time
- 6-14 Summary of First-Order Biodegradation Rates
  
- 8-1 Actual and Estimated Future Costs for Implementation of Perchlorate MNA for the Indian Head Site
- 8-2 Summary of Site Characteristics and Design Parameters for Biological Treatment of Perchlorate-Impacted Groundwater
- 8-3 Cost Components for Passive Injection Biobarrier Treatment of Perchlorate-Impacted Groundwater
- 8-4 Cost Components for Extraction and Treatment of Perchlorate-Impacted Groundwater
- 8-5 Cost Components for Perchlorate MNA
- 8-6 Summary of Capital Costs and NPV of Costs for Operation and Monitoring for Biological Treatment of Perchlorate-Impacted Groundwater

## **Appendices**

Appendix A	Monitoring Well/Piezometer Construction Details & Select Boring Logs
Appendix B	Historical Water Level Measurements
Appendix C	Performance Monitoring Data
Appendix D	Natural Attenuation Rate Calculations
Appendix E	Mass Flux Calculations
Appendix F	Macrocosm Study Results
Appendix G	Points of Contact

## List of Abbreviations and Acronyms

AFCEE	Air Force Center for Engineering and the Environment
AP	Ammonium Perchlorate
BOD	Biochemical Oxygen Demand
CD	Chlorite Dismutase Enzyme
<i>cld</i>	Chlorite Dismutase Gene
CVOCs	Chlorinated Volatile Organic Compounds
CSIA	Compound Specific Isotope Analysis
DO	Dissolved Oxygen
DoD	Department of Defense
DPRB	Dissimilatory Perchlorate-Reducing Bacteria
ESTCP	Environmental Security Technology Certification Program
ft bgs	Feet Below Ground Surface
IC	<i>In Situ</i> Column
IDW	Investigation-Derived Waste
K	Hydraulic Conductivity Constant
MDE	Maryland Department of the Environment
MNA	Monitored Natural Attenuation
MBT	Molecular Biology Tool
mRNA	Messenger Ribonucleic Acid
NCSU	North Carolina State University
NSWC	Naval Surface Warfare Center
NPV	Net Present Value
O&M	Operation and Maintenance
ORP	Oxidation-Reduction Potential
PCE	Tetrachloroethene (Tetrachloroethylene)
<i>pcrA</i>	Perchlorate Reductase Gene A
PI	Principal Investigator
PID	Photoionization Detector
PPE	Personal Protective Equipment
PV	Pore Volume
PVC	Polyvinyl Chloride
qPCR	Quantitative Polymerase Chain Reaction Analysis

RAO	Remedial Action Objective
sq. ft.	Square Feet
SW	Surface Water
SWMU	Solid Waste Management Unit
TBC	To Be Considered Regulatory Standard
TCE	Trichloroethene
TOC	Total Organic Carbon
USEPA	United States Environmental Protection Agency
USGS	United States Geologic Service
VOA	Volatile Organic Analysis
VOC	Volatile Organic Compound

## **Acknowledgements**

Solutions-IES gratefully acknowledges the financial and technical support provided by ESTCP. We appreciate the guidance provided by Dr. Andrea Leeson (ESTCP Environmental Restoration Program Manager), Erica Becvar (Contracting Officer's Representative), and the ESTCP reviewers. Solutions-IES team members contributing to this project include: Dr. Robert C. Borden, P.E. (Principal Investigator), M. Tony Lieberman (co-Principal Investigator), Sheri L. Knox, P.E (Project Manager) with support by Walt Beckwith, P.G., Jessica L. Keener, P.G., Sean Jarvah, Dawn Marshall, and Brian Rebar. Laboratory analysis and macrocosm studies by David Black and Aaron Weispenning at North Carolina State University are also appreciated as well as the molecular biology analyses provided by Microbial Insights, Inc. and Dr. Kate Scow at University of California - Davis. Solutions-IES extends thanks to Carey Yates, Sean Jorgensen and Mark Yeaton at Indian Head Naval Surface Warfare Center for their cooperation and assistance and who facilitated site access and the field work discussed in this report.

## **Executive Summary**

### **Introduction**

Solutions-IES conducted a demonstration of the potential for Monitored Natural Attenuation (MNA) to be used as a groundwater remedy for perchlorate at a site located on the Naval Surface Warfare Center near Indian Head, MD. The work was funded by the Environmental Security and Technology Certification Program (ESTCP Project ER-0428). The overall objectives of this project were to provide Department of Defense (DoD) managers with the tools needed to: (1) identify sites where MNA may be appropriate for management of perchlorate releases; and (2) demonstrate to regulatory agencies that perchlorate MNA can be effective for controlling adverse impacts to the environment. The project used a tiered approach described by Solutions-IES in a Protocol also prepared as part of this project. The Protocol, titled “Natural Attenuation of Perchlorate in Groundwater: Processes, Tools, and Monitoring Techniques” (ESTCP, 2008), guides the end user through the process of developing multiple lines of evidence to support perchlorate MNA.

After a detailed site-selection process, the Indian Head project site was chosen for the demonstration. The Indian Head site consists of approximately 2 acres of grassy land bounded on the east and south by Mattawoman Creek, a large, tidally influenced tributary of the Potomac River. Two buildings are on the site: Building 1419 and a small drum storage building. Building 1419 was once used to clean out or “hog-out” solid propellant containing ammonium perchlorate from various devices, including rockets and ejection seat motors that had exceeded their useful life span. The hog-out process and former waste handling methods impacted the groundwater with elevated concentrations of perchlorate. The groundwater flow direction suggested that perchlorate-contaminated groundwater migrates approximately 460 ft until reaching Mattawoman Creek,

### **Demonstration**

At the onset of the evaluation a small monitoring well network was already in place. This network had been installed to monitor the source of perchlorate contamination and evaluate a pilot test of enhanced *in situ* bioremediation in 2002 by Shaw Environmental near Building 1419. The prior work indicated that perchlorate concentrations decreased with distance away from the presumed source at Building 1419. However, perchlorate was not monitored beyond the pilot test area, which was located midway between the presumed source area and Mattawoman Creek, where the perchlorate plume was expected to discharge.

In 2005, Solutions-IES commenced its evaluation of the potential for MNA at the site. After baseline monitoring was performed, it became apparent that additional monitoring well/piezometer installations would be required to fully assess the plume geometry including areas closer to the creek. Additional monitoring wells and piezometers were installed in four geomorphologic areas of the site: a) on land downgradient of the source area and closer to the creek; b) in the Littoral Zone, c) in the Subtidal Shallows, and d) in the Subtidal Channel located between the Littoral Zone and Subtidal Shallows.

Originally, perchlorate concentrations as high as 93,000 µg/L were measured in groundwater near Building 1419; concentrations 460 ft downgradient beneath the bank of the creek remain over 10,000 µg/L. The Site Conceptual Model suggested that the changes in perchlorate concentration in groundwater beneath the land were controlled mostly by groundwater flow, dilution and dispersion, with a limited biological component. The model also hypothesized that the majority of the 99% decrease in perchlorate concentration occurred as groundwater migrates upward through the organic rich sediments in the Littoral Zone near the creek, with biodegradation as a significant mechanism for removal in this zone. The tiered approach presented in the Protocol was used to develop lines of evidence to support the Site Conceptual Model and evaluate MNA as a groundwater remedy for perchlorate at this site.

### *Tier 1 – Perchlorate Plume Geometry and Stability.*

The well network was used to define current perchlorate conditions across the site. Where available, historical data were used to supplement current findings to examine attenuation of perchlorate. Monitoring results show the perchlorate plume is generally stable and there is no evidence of continuing downgradient migration. Within the Littoral Zone, perchlorate concentrations decline much more rapidly than would be expected based on dilution alone indicating biodegradation within the organic rich sediments is the dominant attenuation mechanism. Mass flux calculations indicate that over 99.9% of the perchlorate mass is degraded during migration through the organic rich sediments of the shallow Littoral Zone. In several source area monitor wells, perchlorate concentrations are gradually declining with time. If current trends continue, perchlorate concentrations in these wells will drop below the “To Be Considered” value of 24.5 µg/L established by the USEPA within 30 years.

### *Tier 2- Biogeochemical Parameters and Biological Indicators*

As part of the *Tier 2* evaluation, bio-geochemical parameters and biological indicators were monitored in wells throughout the perchlorate plume. Monitoring results indicated that biogeochemical conditions in many of the land wells were not conducive to perchlorate biodegradation including: (a) low TOC levels; (b) positive ORP values, and (c) elevated nitrate concentrations. In contrast, biogeochemical conditions in the shallow Littoral Zone wells are excellent for perchlorate biodegradation: (a) TOC is above 2 mg/L; (b) ORP drop below +50 mV; (c) nitrate declines below the analytical detection limit; (d) dissolved iron and methane are elevated; and (e) very high numbers of perchlorate degrading bacteria are present in the zone where perchlorate concentrations decline rapidly.

### *Tier 3-Biodegradation Indicators*

Additional laboratory and field tests were employed to provide direct evidence of perchlorate biodegradation and estimate biodegradation rates. Macrocosm incubations were set up using soil from the Littoral Zone and groundwater from a nearby well. Macrocosms showed at least a 40% reduction in perchlorate in less than 10 days which is equivalent to a 1<sup>st</sup>-order biodegradation rate of 0.12 per day.

*In situ* columns were installed within the Littoral Zone to provide a direct measure of bioactivity. The columns were constructed to isolate a column of soil from the surrounding soil and water. Groundwater was slowly pumped upward through each open-ended column to induce a controlled flow through the organic rich zone. Perchlorate concentrations at the bottom and top of the column during pumping were compared and 1<sup>st</sup>-order biodegradation rates were estimated ranging from 0.12 to 0.63 per day.

Biodegradation rates in the macrocosms and *in situ* columns were consistent with observed rates of perchlorate disappearance in monitor wells installed within the littoral zone, suggesting these approaches may be useful for estimating field scale attenuation rates.

## **Summary**

Data on groundwater flow, plume configuration, site-specific biogeochemical conditions, microbial populations and perchlorate attenuation by both abiotic and biological processes provided multiple lines of evidence that perchlorate is naturally attenuating at the Indian Head site prior to discharge to Mattawoman Creek. The Tier 1, 2 and 3 evaluations demonstrated that MNA was effective in meeting all primary and secondary performance objectives established in the demonstration plan. Biogeochemical conditions in the shallow Littoral Zone wells are excellent for perchlorate biodegradation, resulting in greater than 99.9% decline in mass flux prior to discharge. Perchlorate concentrations were reduced below the USEPA primary remediation goal prior to discharge to Mattawoman Creek. When conditions are appropriate, a MNA evaluation is relatively simple to implement and reliable, with few scale up constraints. The MNA process does not generate significant process wastes. The estimated life-cycle cost for implementation of MNA is estimated to be approximately one half the cost of a Passive Injection Biobarrier and one third the cost of Extraction and Treatment.

The project met the objectives by identifying, evaluating, and utilizing lines of evidence as a tool to evaluate perchlorate MNA as a remedial strategy for the Indian Site. These lines of evidence, now established, can be used to demonstrate perchlorate MNA is effective for controlling adverse impacts to the environment at the Indian Head Site and support acceptance of MNA as the groundwater remedy.

## **Lessons Learned**

- In this demonstration project, Tier 1, 2 and 3 evaluations were performed to demonstrate perchlorate attenuation. However at typical sites, a Tier 3 evaluation may not always be required and Tier 1 and 2 evaluations may be sufficient to demonstrate perchlorate MNA.

- Monitoring data collected during this study suggest that field measurements of dissolved oxygen did not provide a reliable indicator of *in situ* redox conditions and the potential for perchlorate reduction.
- In this project, perchlorate was reduced to below detectable levels in every sample with greater than  $10^2$  *pcrA* copies/mL ( $>10^5$  *pcrA*/L). The absence of detectable perchlorate when there is  $>100$  *pcrA*/mL constitutes strong evidence for effective natural attenuation due to biodegradation. Monitoring for this gene is a useful indicator of perchlorate biodegradation.

## **1.0 Introduction**

Monitored Natural Attenuation (MNA) is a potential alternative for management of large diffuse perchlorate plumes in a cost-effective manner. Natural attenuation is defined by the USEPA as the “biodegradation, diffusion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility or volume to levels that are protective of human health and the environment”(USEPA, 1997). The term MNA refers to the reliance on natural attenuation processes, within the context of a carefully controlled and monitored site cleanup, to achieve site-specific remedial goals.

Perchlorate is an important contaminant of concern, particularly to the Department of Defense (DoD) as a result of historical use, release and/or disposal of solid rocket fuel and munitions containing ammonium perchlorate. To evaluate whether natural attenuation of perchlorate occurs in the field, lines of evidence need to be established and validated. As part of this project funded by the Environmental Security Technology Certification Program (ESTCP Project No. ER-0428), two sites were selected for field demonstrations to evaluate the potential for perchlorate MNA as a groundwater remedy: 1) near Building 1419 at the Naval Surface Warfare Center (NSWC), Indian Head, Maryland (Indian Head site) and 2) a TCE/Perchlorate Solid Waste Management Unit (SWMU) at an industrial facility in Elkton, Maryland. The two overall goals of this project were:

1. Document the extent of perchlorate natural attenuation in the field and the effectiveness in controlling adverse impacts to the environment; and
2. Provide DoD managers with the tools needed to evaluate whether MNA may be appropriate for management of perchlorate-impacted groundwater on their site(s).

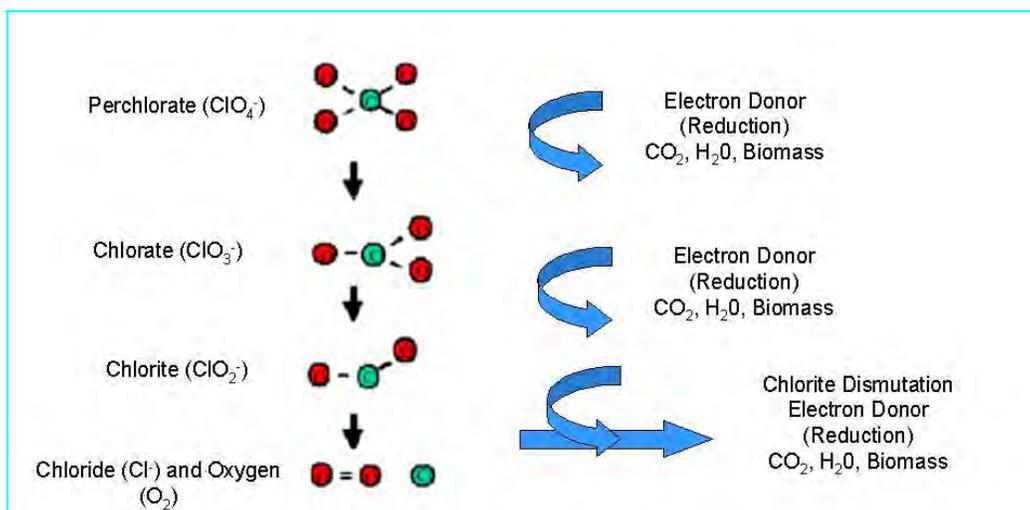
MNA of perchlorate in groundwater was evaluated using a tiered approach described in the technical Protocol developed by Solutions-IES, Inc. in 2008 (ESTCP, 2008). The tiers include: 1) plume stability and geometry assessment; 2) biogeochemical parameter and biological indicator evaluation; and 3) biodegradation rate estimation. This technical report documents the evaluation of MNA of perchlorate contamination in groundwater at the Indian Head site. Documentation of perchlorate MNA at the Elkton, MD site is presented in a separate report.

### **1.1 Background**

Releases of perchlorate have resulted in extensive contamination of surface and groundwater supplies. Perchlorate is a highly mobile, soluble anion that sorbs poorly to most aquifer material. There are a wide variety of microorganisms can degrade perchlorate to chloride and oxygen under oxygen limiting conditions (Coates et al., 1999; Coates and Pollock, 2003; Coates and Jackson, 2009). Perchlorate-reducing organisms are widespread in the environment (Coates et al., 1999; Logan, 2001; Coates and Jackson, 2009) and can use a variety of different organic substrates (e.g., acetate, propionate, lactate, etc.) as electron donors for perchlorate reduction (Herman and Frankenberger, 1998; Coates et al., 1999). Perchlorate biodegradation can occur under anoxic and strongly reducing anaerobic conditions. In addition, some facultative perchlorate reducers are capable of both aerobic respiration under low oxygen tension and anaerobic respiration when oxygen is not present. This metabolic versatility suggests that

perchlorate reducing microorganisms will be active in a variety of environments, increasing the potential for perchlorate MNA.

Oxygen is an inhibitor of perchlorate reduction, but the absence of oxygen alone is not enough to induce the perchlorate-reducing enzymes to function. Facultative anaerobic perchlorate metabolism is inhibited by dissolved oxygen (DO) concentrations in excess of 2 mg/L (Rikken et al., 1996; Chaudhuri et al., 2002). Nitrate can also negatively affect the activity of perchlorate reductase enzymes. However, when sufficient biodegradable organic substrate is present, the available DO and nitrate will be rapidly consumed and perchlorate will biodegrade (Coates and Jackson, 2009). Trace amounts of molybdenum are also required due to its functional role in the biochemistry of the perchlorate reductase enzyme (Chaudhuri et al., 2002). The biodegradation pathway of perchlorate is illustrated below (**Figure 1-1**).



**Figure 1-1. Perchlorate Biodegradation Pathway**

Work by Coates et al. (1999), Chaudhuri et al. (2002), and Bender et al. (2002) indicates that the *Dechloromonas* and *Azospira* groups represent the primary chlorate and dissimilatory perchlorate reducing bacteria (DPRB) in the environment, but more than 30 different strains of perchlorate-reducing microbes have been identified (USEPA, 2005). The rate-limiting step in the three-step degradation process is the conversion of perchlorate to chlorate by a perchlorate reductase enzyme (Coates and Jackson, 2009). Subsequent conversion of chlorate to chlorite is also catalyzed by a perchlorate reductase enzyme. Chlorite removal by the chlorite dismutase (CD) enzyme is the final step in perchlorate reduction.

Where applicable, MNA is will often be the least costly groundwater remediation technology. However, practitioners should first document the rate and extent of perchlorate attenuation in the field through multiple lines of evidence.

## 1.2 Objectives of the Demonstration

A list of potential demonstration sites was generated through a questionnaire sent to knowledgeable representatives at approximately 120 potential DoD or DoD-related sites nationwide. By comparing the responses received to the selection criteria in the Technology Demonstration Plan, these were pared down to seven potential sites for further study. Samples

were then collected from each of these sites and microcosm studies were then performed to measure attenuation of perchlorate in a laboratory setting. The details of the site selection process and results of microcosm testing were documented in a prior report titled “Field and Laboratory Evaluation of the Potential for Monitored Natural Attenuation of Perchlorate in Groundwater, Final Technical Report” (i.e., Treatability Report; ESTCP, 2007). Based on the microcosm studies, site logistics, and cost considerations, two sites in Maryland were selected to evaluate the potential for MNA of perchlorate in groundwater. This report describes the field demonstration at the Indian Head site. The objectives of the technical demonstrations were to:

- Further develop and evaluate lines of evidence established during the site selection process for their applicability to MNA.
- Evaluate the use of microbiological indicators of perchlorate degradation.
- Compare biodegradation rates measured in microcosm studies with biodegradation rates in the field.
- Evaluate the cost-effectiveness of MNA of perchlorate at the Indian Head site.
- Transfer the knowledge gained about perchlorate MNA to the regulatory community.

### **1.3 Regulatory Drivers**

The discharge of perchlorate to the environment can impact ground and surface water with the potential for human consumption through direct (drinking water) and indirect (crop uptake from irrigation water) pathways. Sampling performed by the USEPA in 2004 revealed that over 11 million people in the United States had greater than 4 µg/L in their drinking water (Stroo et al., 2009). It appears that the primary exposure to perchlorate in the United States is through consumption of food (USFDA, 2007). This is a concern because high levels of perchlorate interfere with iodide uptake by the thyroid (NRC, 2005)

Through 2005, a federal cleanup standard for perchlorate in groundwater or soil had not been promulgated (USEPA, 2005; ITRC, 2005). However, in January 2006, the USEPA issued “Assessment Guidance for Perchlorate” identifying 24.5 µg/L as the “to be considered” (TBC) value and preliminary remediation goal for perchlorate (USEPA, 2006). Since then several states have identified advisory levels that range in concentration from 1 µg/L to 18 µg/L (Hatzinger, 2005). Massachusetts promulgated the first state drinking water standard for perchlorate in 2006, at 2 µg/L (MADEP, 2006) and California has established a drinking water standard of 6 µg/L (CDHS, 2007). During the course of this project, Maryland adopted a perchlorate standard of 2.6 µg/L in drinking water (MDE, 2008).

### **1.4 Stakeholder/End-User Issues**

An overall goal of this project was to develop a protocol that could be used to evaluate MNA of perchlorate as a remedial strategy. The technical demonstrations at the Indian Head and Elkton, MD sites were used to evaluate the procedures described in the Protocol “Natural Attenuation of Perchlorate in Groundwater: Processes, Tools and Monitoring Techniques” (ESTCP, 2008). Where MNA is protective of human health and the environmental, it is often the least costly alternative in the short term. However, the process is not fast and the longer project life cycles can sometimes result in greater long-term costs. MNA should not a “no action” approach to groundwater treatment.

In the past, MNA has not been commonly applied for management of perchlorate plumes, in part, because there was no guidance for implementing this technology. The Protocol developed from this study (ESTCP, 2008) helps direct end-users select the correct tools for evaluating use of MNA of perchlorate as a remedial alternative for their particular site. By properly applying the steps described in the Protocol, local regulators and the general public can gain confidence that MNA of perchlorate is protective of the public welfare, human health and the environment.

## **2.0 Technology Description**

### **2.1 Monitored Natural Attenuation (MNA) Development**

In the 1980s and 1990s, field monitoring data indicated that many groundwater plumes were not migrating as far as predicted, and in some cases, were stable or receding. Detailed laboratory and field research demonstrated that the combined action of naturally occurring physical, chemical, and biological processes was limiting downgradient migration and adverse impacts, without any active human intervention. As a result of this work, Monitored Natural Attenuation (MNA) became a widely accepted practice for effective management of groundwater contamination. MNA is the use of these natural processes, along with careful documentation and monitoring, to manage contaminated sites.

The USEPA and others have developed protocols and guidance documents for implementing MNA for specific contaminants. Published methods for evaluating MNA of petroleum hydrocarbons (Wiedemeier et al, 1995; USEPA, 1999) and chlorinated solvents (USEPA, 1998) have been in use for many years. These documents describe systematic steps for delineating contaminant plumes, describing trends in contaminant fate and transport, monitoring site geochemistry, testing site biology and even scoring the site for its potential to support natural attenuation (USEPA, 1998). Wiedemeier et al. (1998) developed a tiered approach to systematize the process of documenting MNA at any given site. The three tiers are as follows:

- Tier 1 - Plume Stability and Geometry Assessment
- Tier 2 - Biogeochemical Parameter and Biological Indicator Evaluation
- Tier 3 - Biodegradation Rate Estimation

Prior to current work, MNA of perchlorate had not been systematically tested in the field. One objective of this demonstration was to identify useful indicators of perchlorate attenuation that would be applicable to field sites. The information gained during this project was also used to demonstrate a technical Protocol for implementing this technology at perchlorate contaminated sites (ESTCP, 2008).

## **2.2 Advantages and Limitations of the Technology**

### **2.2.1 Cleanup Objectives**

The objective of all remediation approaches should be to return groundwater to its beneficial uses within a timeframe that is reasonable given the particular circumstances of the site. MNA is an appropriate remediation method when its use is protective of human health and the environment and it is capable of achieving site-specific remediation objectives within a timeframe that is reasonable compared to other alternatives. Over the short-term, the contaminant plume should be stable or shrinking. Over the long-term, the mass and/or concentration of contaminants should decrease.

### **2.2.2 Advantages of MNA**

Natural attenuation includes a range of physical, chemical and biological processes. Because perchlorate is an inorganic salt, it is very soluble and mobile in groundwater. High solubility is both an advantage and disadvantage. Flushing and dilution can reduce concentrations rapidly,

but solubility can result in extended plumes with low concentrations that are difficult to capture and expensive to treat.

As paraphrased from the Wiedemeier et al. (1998), primary advantages of using MNA as a technology for remediating perchlorate in groundwater are:

- Lower volume of remediation derived wastes ;
- Reduced potential for cross-media transfer of contaminants ;
- Reduced risk of human exposure to contaminants, contaminated media and other hazards;
- Some natural attenuation processes result in *in situ* destruction of contaminants;
- Less disturbance to site operations and ecological receptors;
- No artificial impact to groundwater geochemistry and biology;
- Can be applied to all or a portion of a site depending on site characteristics and goals;
- Can easily be used in combination with other technologies; and
- Lower capital costs and low, if any, maintenance costs.

### **2.2.3 Limitations of MNA**

The primary limitations of MNA include:

- Potential longer life cycles to reach remediation goals compared to active remediation measures;
- More detailed site characterization is needed to demonstrate attenuation which may result in more complex and costly up-front investigation;
- Institutional controls may be required to ensure long-term protectiveness;
- Long-term performance monitoring will often be more expensive and for a longer time period;
- Potential exists for continued contaminant migration, and/or cross-media transfer of contaminants;
- Changing site conditions over time may require a re-evaluation of MNA; and
- Public acceptance may be more difficult and costly to obtain.

### **3.0 Demonstration Design and Evaluation**

#### **3.1 Performance Objectives for the Demonstration**

The overall objective of this project was to evaluate the potential for monitored natural attenuation of perchlorate in groundwater. Once perchlorate attenuation is demonstrated, regulators and site owners can evaluate use of MNA along with other remediation strategies. If natural attenuation processes are not sufficient to prevent significant adverse impacts, other remediation strategies may need to be implemented before application of MNA.

Qualitative and quantitative performance objectives were developed in the Technology Demonstration Plan (Solutions-IES, 2006) to demonstrate the MNA of perchlorate in groundwater. As shown in **Table 3-1**, all the performance objectives were achieved. Sections of the report where each objective is discussed are noted in the table.

#### **3.2 Site Selection Process**

To identify sites for participation in the perchlorate MNA project, three levels of site screening were conducted. Screening Level 1 was performed in the office and involved gathering historical information from approximately 120 perchlorate-impacted sites across the United States. Past remediation activities, if any, were considered. Screening Level 2 included reviewing the gathered information and selecting seven sites for comparative field characterization. The seven sites selected for further screening included:

1. Little Mountain Test Annex Sludge Drying Beds, Hill AFB, Utah
2. ATK Thiokol, Inc., Utah
3. Beale Air Force Base, California
4. John C. Stennis Space Center, Mississippi
5. Redstone Arsenal, Alabama
6. Manufacturing Facility, Elkton, Maryland
7. Naval Surface Warfare Center, Indian Head, Maryland

Level 3 screening included collection and analysis of soil and groundwater samples from the seven field sites selected during the Level 2 screening step. The site matrices collected were analyzed in the laboratory for parameters potentially useful for determining the suitability of the site for MNA of perchlorate. These included field measurements such as pH, DO and oxidation-reduction potential (ORP), and laboratory analysis of perchlorate concentration, total organic carbon (TOC) concentration, CD enzyme analysis, and 6-month biological oxygen demand (BOD<sub>6</sub>). Detailed information about the screening process and the results of the analyses performed at all seven sites is provided in the Treatability Report (ESTCP, 2007). Additional site-matrix sediments and groundwater were collected from perchlorate-impacted areas of each site to use in laboratory microcosm studies. The pre-demonstration findings associated with the selection of the Indian Head site are described in the following sections.

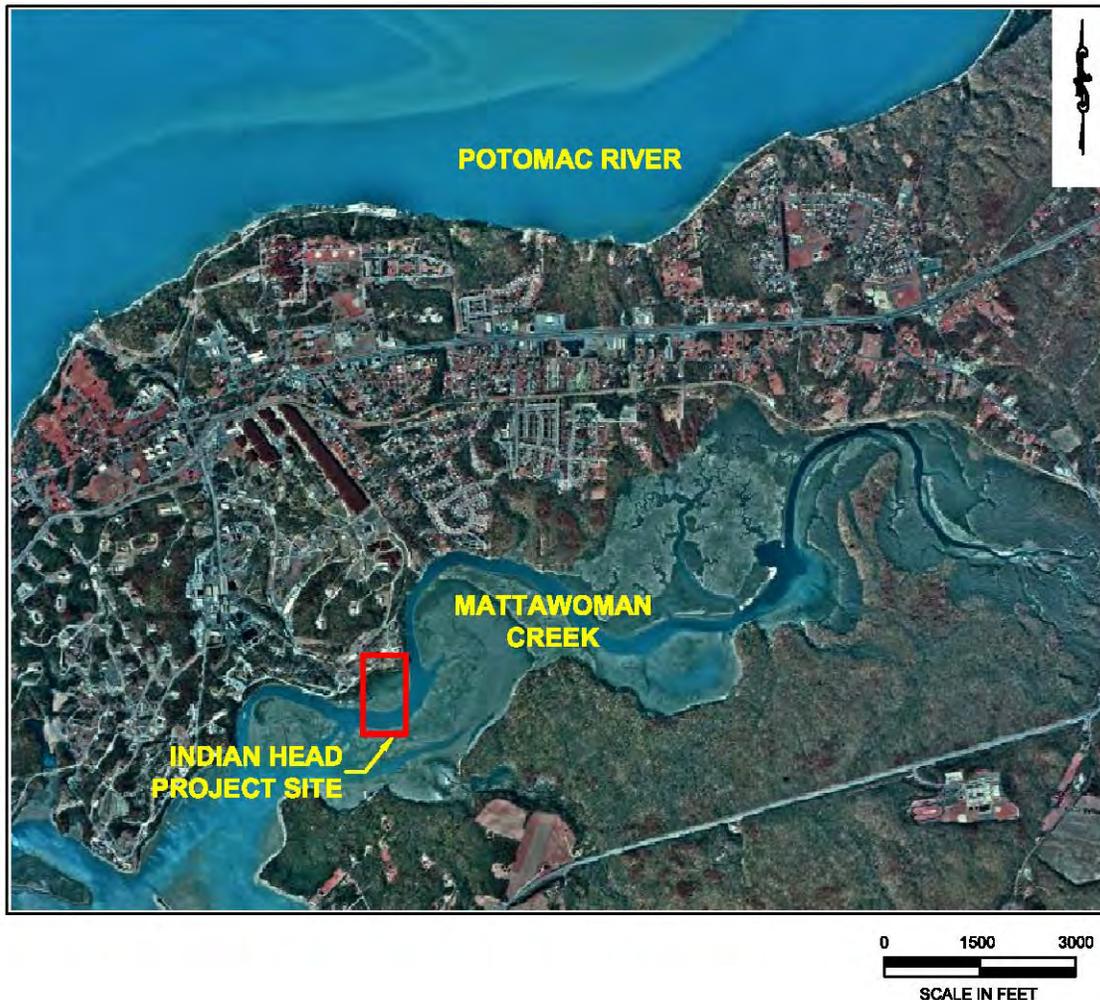
<b>Type of Performance Objective</b>	<b>Primary Performance Criteria</b>	<b>Expected Performance (Metric)</b>	<b>Actual Performance (Objective Met?)</b>	<b>Detailed Discussion</b>
Qualitative	1. Reduce risk	Reduce concentrations and mass flux of perchlorate during downgradient migration	Yes	Section 6.1
	2. Capital costs	Capital costs are significantly lower than active remedial alternatives.	Yes	Section 8.0
	3. Maintenance	Maintenance costs are low and are typical of those associated with maintaining a monitoring well network.	Yes	Section 8.0
	4. Uncomplicated implementation	Implementation is similar to that of a typical monitoring program.	Yes	Sections 3.3, 3.4, 3.5 and 6.0
	5. Regulatory acceptance	MNA approach is generally accepted by regulatory community, with conditions.	Yes	Sections 1.3 and 2.1, 2.2 9.2
	6. Monitoring approach	Monitoring approach is consistent with current industry practice. Results are easy to understand and interpret.	Yes	Sections 3.3, 3.4, 3.5 and 6.0
Quantitative	1. Reduce perchlorate concentrations	> 90% reduction in average perchlorate concentration in wells downgradient of the probable source area.	Yes	Sections 6.1.1 and 6.1.2
	2. Reduce mass flux of perchlorate	Reduce mass flux of perchlorate by >75% between source area and the most downgradient line of monitor wells.	Yes	Section 6.1 and 6.1.5
	3. Multiple lines of evidence	Two or more lines of evidence support perchlorate attenuation.	Yes	Sections 6.1, 6.2 and 6.3
	4. Enzyme activity	RNA levels of perchlorate degraders are elevated at some locations in the plume relative to background locations.	Yes	Section 6.2.10
	5. Meet regulatory standards	Perchlorate concentrations are below regulatory levels at compliance point.	Yes	Sections 6.1 and 6.3

### **3.2.1 Indian Head Site Description**

The following discussion of the history and site conditions are from available literature and site documents made available during preliminary work at Indian Head in 2005. The *Field Demonstration of In Situ Perchlorate Bioremediation at Building 1419* (Cramer et al., 2004) was used as the primary source of historical information about the NSWC. Mr. Mark Yeaton of the

Indian Head Environmental Program Office provided additional history and became the site contact subsequent to Mr. Cramer's departure from the project in 2006.

The Town of Indian Head and the NSWC are located approximately 30 miles south of Washington, DC on a narrow peninsula (neck) of land bounded to the north by the Potomac River and to the south by Mattawoman Creek (**Figure 3-1**).

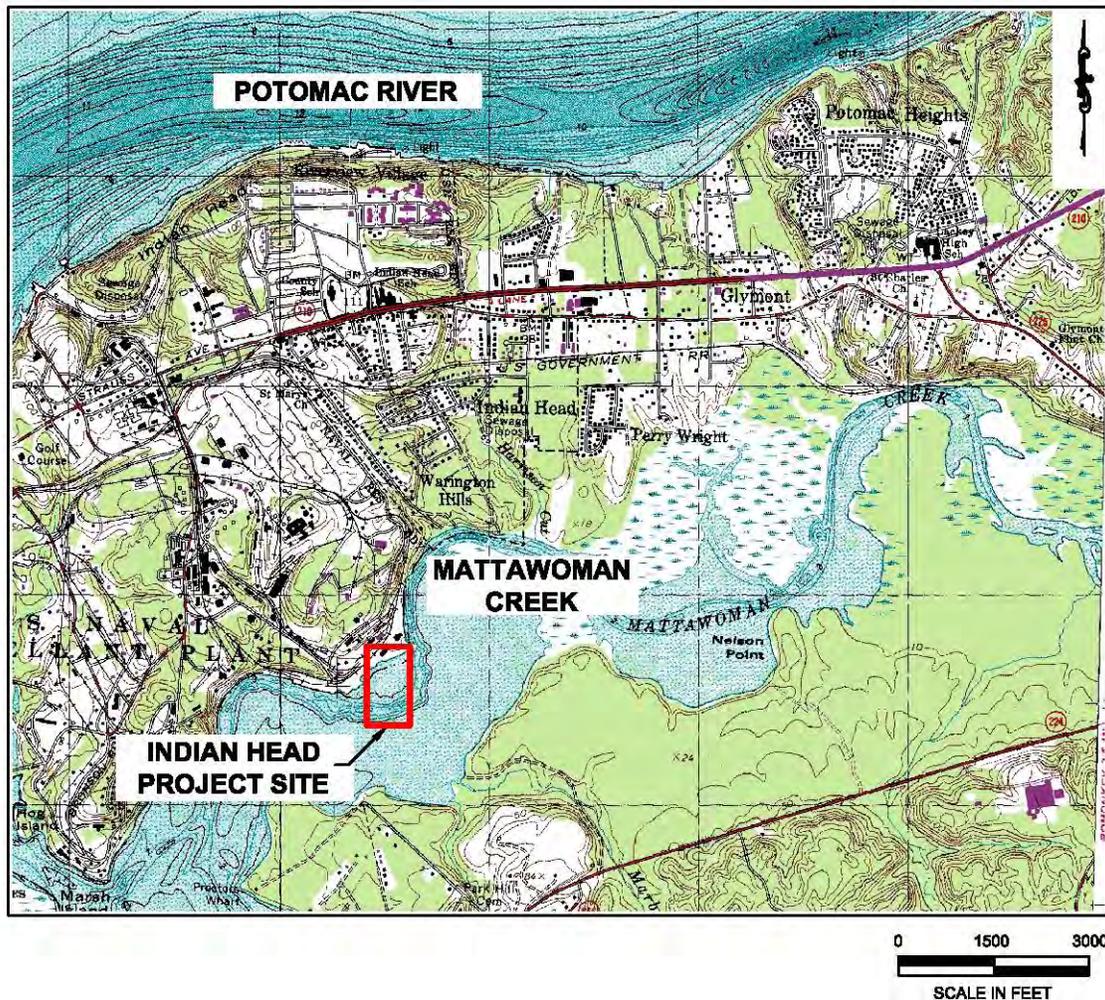


**Figure 3-1. Aerial View of Indian Head NSWC** (Image from U.S. Geological Survey, <http://earthexplorer.usgs.gov/>, modified 10/27/2007)

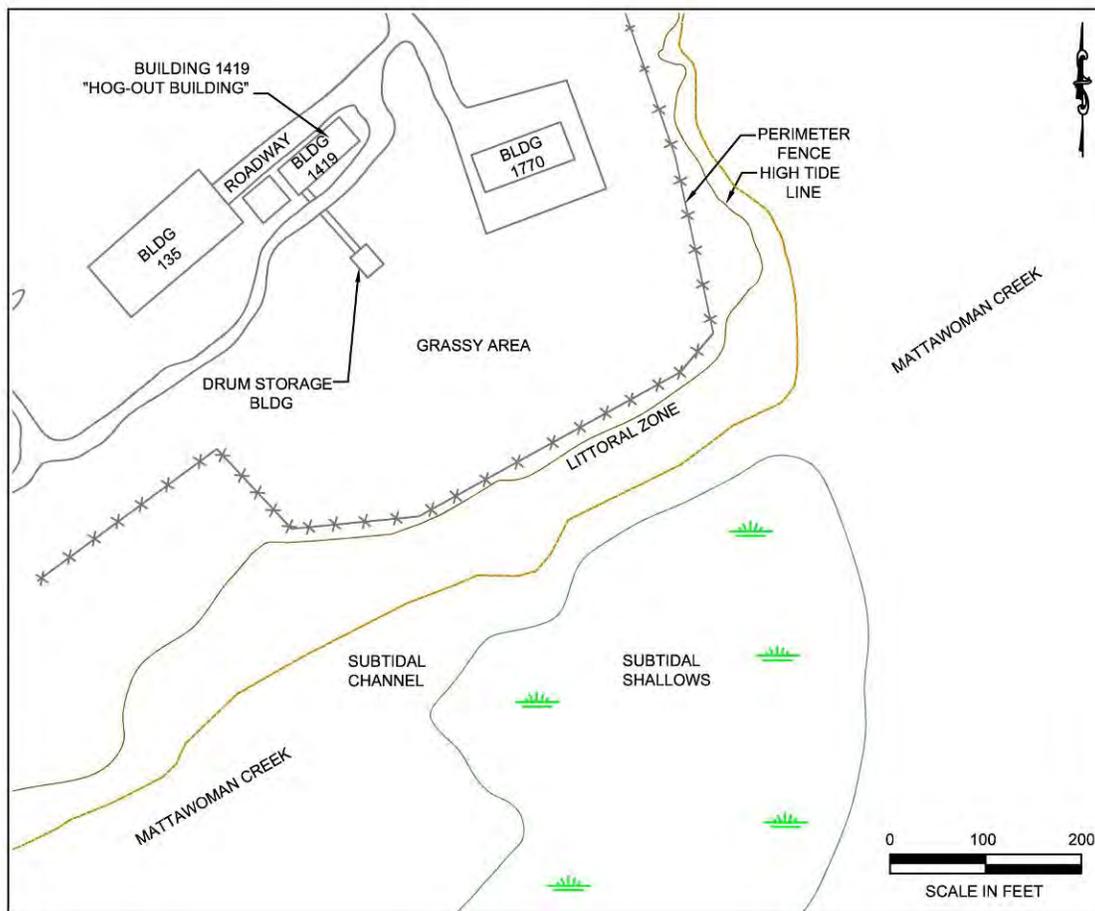
Both the Potomac River and Mattawoman Creek are tidal estuaries of the Chesapeake Bay estuary system. The surficial (water table) aquifer at the site consists of more recent saturated alluvial soil resting on top of the Patapsco clay that is encountered at approximately 16 feet below ground surface (ft bgs). The surficial aquifer is unconfined and varies in its position seasonally in response to precipitation and evapotranspiration. The water table surface generally slopes similarly to the land surface topography with the effect that upland areas generally serve as groundwater recharge areas and low areas generally serve as groundwater discharge areas.

**Figure 3-2** shows portions of the Town of Indian Head and NSWC from the USGS Indian Head 7.5' Topographic Map. The demonstration area lies within the marked rectangle. This area of the NSWC including the Building 1419 site is shown in **Figure 3-3**.

The demonstration area consists of approximately 2 acres starting approximately 60 feet southeast of Building 1419 and extending to Mattawoman Creek. Building 1419 was used to clean out or “hog-out” solid propellant containing ammonium perchlorate from various devices, including rockets and ejection seat motors that have exceeded their useful life span. The hog-out process and former waste handling methods impacted the groundwater near Building 1419.



**Figure 3-2. Demonstration Area Showing NSWC Vicinity and the Indian Head Project Site**  
(Image from U.S. Geological Survey, 7.5 Minute Topographic Map, Indian Head, MD-VA, 1966, Photorevised 1978; Bathymetry added 1982)

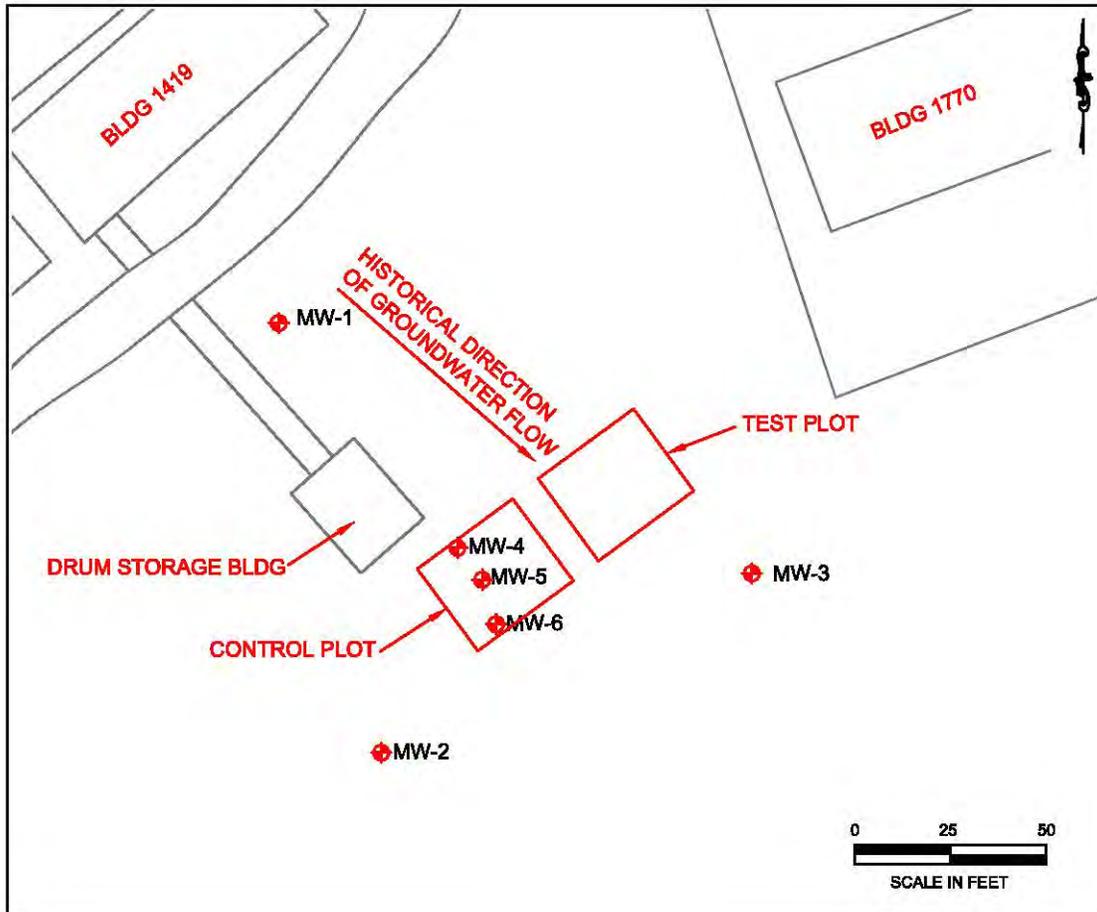


**Figure 3-3. Site Map with Building Locations**

### 3.2.2 Previous Remediation Studies

#### 3.2.2.1 Source Identification

In 2001, ESTCP funded an independent study at this site to demonstrate and validate the use of passive flux meters for measuring groundwater and perchlorate fluxes (ESTCP, 2006). The study showed that perchlorate flux did not change over time from 2002 through 2005, indicating the presence of a persistent source of perchlorate near MW-1 since no perchlorate-contaminated hog-out wastewater had been discharged since 1996. Measurements of vertical perchlorate flux suggested the possibility of a vadose zone source that would continuously release perchlorate to the aquifer by recharge induced by rainfall. This phenomenon could be used to explain high temporal variability of perchlorate concentrations observed in MW-3 and MW-4, located 180 and 125 ft downgradient from the presumed source area near Building 1419, respectively (Figure 3-4).



**Figure 3-4. Shaw Test Plot and Select Monitoring Well Locations**

### 3.2.2.2 Enhanced Perchlorate Biodegradation

In 2002, Shaw Environmental, Inc. (Shaw) investigated the Building 1419 site as part of a pilot study evaluating the use of enhanced *in situ* bioremediation (Cramer et al., 2004; Hoponick, 2006). A perchlorate plume was identified extending approximately from the rear of Building 1419 toward Mattawoman Creek. The limits of the plume were not delineated, but perchlorate concentrations ranging from 8 to 430 mg/L were reported along with pH ranging mostly between 4.2 and 5.6. The groundwater velocity was estimated to be between 0.4 and 1.4 ft/d based on slug test data which indicated an average hydraulic conductivity of 0.012 ft/min (ESTCP, 2006).

The study area used by Shaw for their pilot test is located southeast of Building 1419 and approximately 350 feet northwest of Mattawoman Creek. Shaw constructed a pilot system employing a recirculation cell design consisting of two 30 X 30-ft areas (**Figure 3-4**) approximately 9-ft apart. The surficial geology of the test area was described as consisting of 2 to 4 feet of fill including organic soils, gravel, and silty sand (Cramer et al., 2004). The underlying 11 to 13 feet consisted of mottled light to olive brown clay to sandy silts. The clay and sand fractions of the silts varied horizontally and vertically. Fine-grained sand seams 1 to 2 inches in thickness were seen in many of the boring locations, but the sand seams did not appear to be continuous across the site. A 1.0 to 1.5-ft thick layer of sand and gravel was encountered in the borings at a depth of approximately 15 to 16 ft bgs. The sand and gravel did appear to be

continuous beneath the study area. The sand and gravel was found to be underlain by gray clay, which extended to a depth of at least 20 ft bgs. The saturated thickness was found to be approximately 10 feet in the vicinity of the pilot test. The average hydraulic gradient was 0.023 ft/ft (ESTCP, 2006).

In the test cell, groundwater was extracted from the site, amended with sodium lactate substrate and a bicarbonate/sodium carbonate pH buffer, and then re-injected into the aquifer. Groundwater was extracted and re-injected without substrate or buffer amendment in the control area near MW-6. The study was conducted for 20 weeks. In the Control cell in which only water was circulated, there was no change in perchlorate concentration. In the Treatment cell amended with lactate and buffer, the results demonstrated that:

- “Naturally occurring perchlorate-degrading bacteria are present in the groundwater underlying (the Bldg 1419 site);
- these organisms can be stimulated to degrade perchlorate from more than 50 mg/L to below detection using lactate as a food source; (and)
- the pH of the aquifer must be buffered to achieve optimal perchlorate biodegradation” (Cramer et al., 2004).

Lactate concentrations exceeded 100 mg/L in groundwater in most of the Treatment cell monitoring wells during the course of the recirculation. After 111 days, lactate addition was stopped and by 140 days, no lactate was detected in groundwater.

### 3.2.3 Pre-Demonstration Testing

#### 3.2.3.1 Groundwater and Soil Sampling

In February 2005, Solutions-IES collected groundwater samples from three existing monitor wells (MW-1, MW-2 and MW-4) to evaluate the potential for long-term impacts from the prior in situ bioremediation pilot test. ORP, DO and pH were measured in the field and samples were also submitted to laboratory analysis of perchlorate, chlorinated volatile organic compounds (CVOCs), TOC, methane, ethane, ethene, nitrate, sulfate and chloride. MW-4 was located in the vicinity of the former lactate injection treatment cell. Solutions-IES also collected saturated soil samples using a hand auger immediately adjacent to MW-2 and MW-4. These samples were analyzed for CD enzyme activity and TOC. Semi-quantitative CD enzyme assays were performed by Microbial Insights, Inc. of Rockford, TN.

**Table 3-2** shows the results of the evaluation and compares groundwater conditions in 2002 prior to implementing the Shaw pilot study and the samples collected three years later by Solutions-IES (ESTCP, 2007). Perchlorate concentrations measured in 2005 were noted to be lower than those reported in 2002 in MW-2 and MW-4. There was no change in MW-1 near the source, which is consistent with the mass flux findings reported in ESTCP (2006). CD enzyme assays of soil collected near MW-2 were strongly positive, while CD results on soil collected near MW-4 were more variable (+/-). Changes in MW-4 may be related to proximity to the Shaw Treatment cell in 2002. The near neutral pH in MW-2 likely supported increased biological activity resulting in reduced perchlorate concentrations in this well.

**Table 3-2  
Groundwater Chemistry and Perchlorate Concentrations in Monitor Wells**

Well ID No.	Sample Date	Perchlorate (µg/L)	DO (ppm)	ORP (mV)	pH (SU)	TOC (mg/L)	Methane (µg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)
MW-1	2/5/2002	84,700	1.5	NA	5.0	NA	NA	NA	NA	NA
	2/14/2005	92,820	~1.0	105	4.9	2.2	15.7	113	38.0	16.1
MW-2	2/5/2002	1,900	NR	NA	6.8	NA	NA	NA	NA	NA
	2/14/2005	3	~3.5	< -1000	6.9	4.4	BQL	2.3	64.2	1.4
MW-4	2/5/2002	181,000	1.6	NA	5.0	NA	NA	NA	NA	NA
	2/14/2005	36,263	~8	5.6	5.4	2.2	80.2	8.7	116	11.3

Data from February 5, 2002 from Cramer et al. (2004).

Data from February 14, 2005 from ESTCP (2007).

NA = Not analyzed; NR = No Reading.

There was little indication of residual organic carbon in groundwater in proximity of the Shaw Treatment cell and the sediment near MW-4 contained only 240 mg/kg TOC. By contrast, the sediment near MW-2, which was shown to have lower perchlorate and a more reducing environment, was reported to contain 3,500 mg/kg TOC. In general, perchlorate concentrations remain elevated across the site, indicating that the long-term impact from the lactate injection would not likely complicate a demonstration of perchlorate MNA at the Indian Head site.

### 3.2.3.2 Laboratory Microcosm Studies

Cramer et al. (2004) reported no biodegradation activity in unamended controls in microcosms created from sediment and groundwater from the Building 1419 site. However, the incubation period was for only 71 days. Solutions-IES created 250-mL microcosm bottles using saturated soil from near MW-2 and groundwater from MW-2 to test three conditions: natural attenuation of perchlorate (ambient conditions) starting at relatively low concentrations (i.e., ~100 to 200 µg/L); natural attenuation of perchlorate starting at relatively high concentrations (i.e., ~5,000 µg/L); and, for comparison, enhanced attenuation in the presence of added simple and complex electron donors (i.e., lactate and EOS<sup>®1</sup> solutions, respectively) (**Figure 3-5**). The treatments testing natural attenuation received no amendments unless perchlorate had to be added to achieve the desired starting concentration. Poison/killed controls were used to monitor for abiotic losses.

<sup>1</sup> EOS<sup>®</sup> is a registered trademark of EOS Remediation LLC, Raleigh, NC. The product, EOS<sup>®</sup> 598 B42, was provided by the manufacturer for use in this study.



**Figure 3-5. Microcosm Bottles Used in the Laboratory Studies**

The microcosms were incubated at room temperature and monitored for approximately one year. Samples were tested for the changes in concentration with time of perchlorate, methane, DO, nitrate, sulfate, and chloride, and perchlorate (ESTCP, 2007). The results of the microcosms starting with both high (spiked) and low (background) concentrations of perchlorate are shown in **Figure 3-6**. The results indicate that the concentrations of perchlorate declined slowly, but measurably, in unamended microcosms with both high and low starting concentrations. In the presence of an organic substrate (EOS<sup>®</sup>), the concentration of perchlorate quickly decreased below detection indicating that bacteria with perchlorate-reducing capacity were present in the environment and could be readily stimulated to achieve high rates of biodegradation. Compared with the substrate-enhanced treatment, the unamended, ambient high and low rates were much slower, with first-order biodegradation rates of only 0.002/d (1/yr) and 0.01/d (5/yr), respectively. In the killed control microcosms, the concentrations of perchlorate and other electron acceptors (nitrate and sulfate) remained constant over time substantiating the observed reduction in perchlorate in ambient microcosms was due to biological activity.

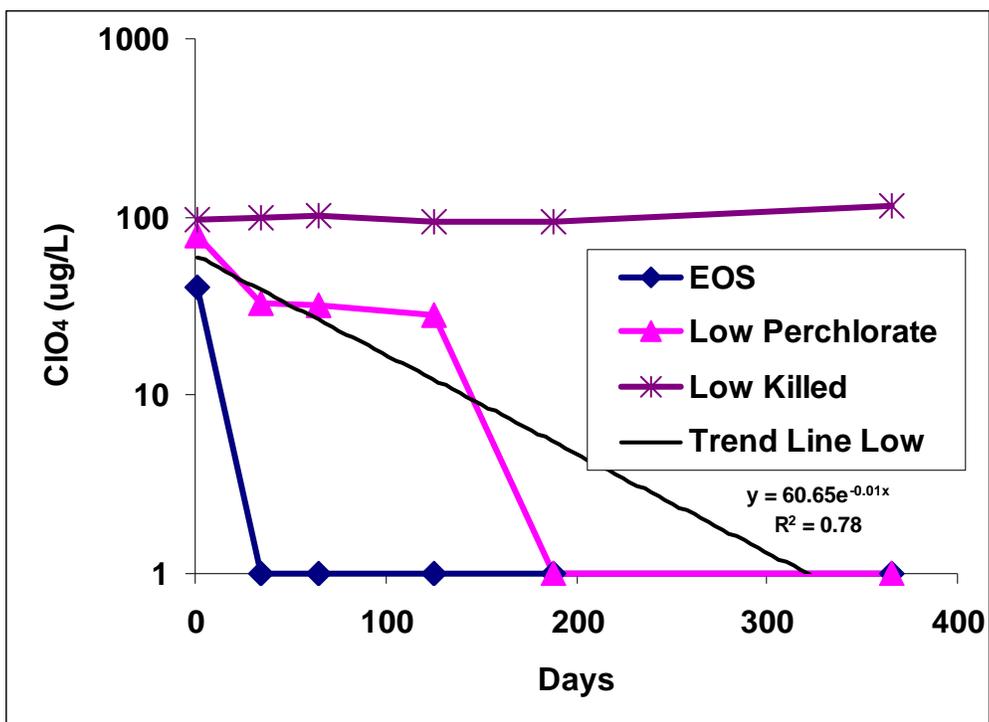
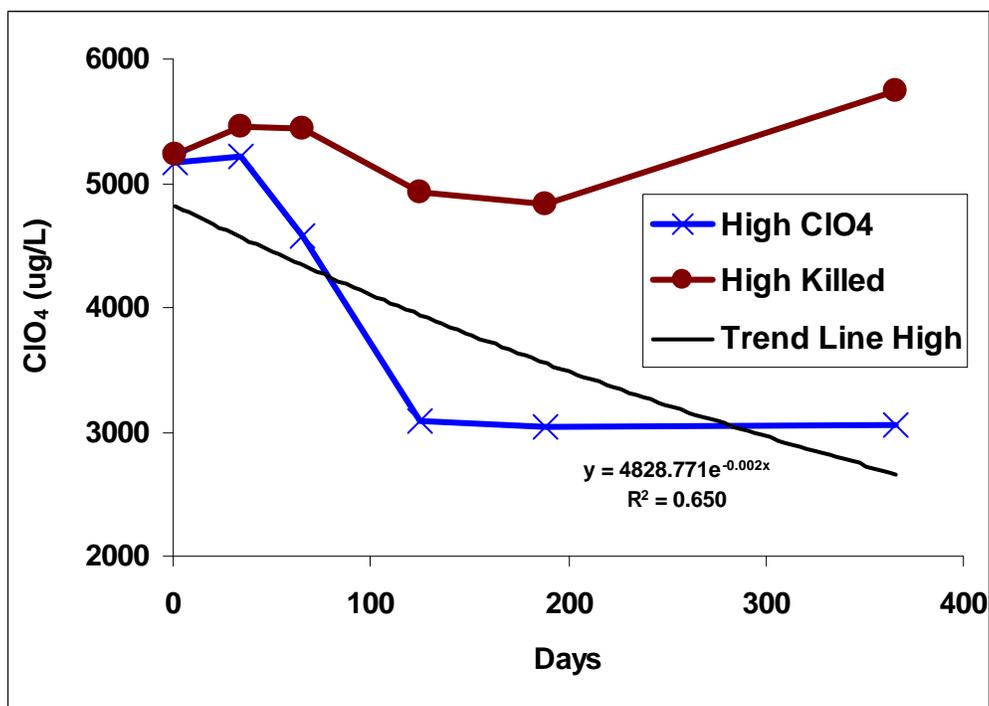


Figure 3-6. Biodegradation of Perchlorate in Laboratory Microcosms (Constructed using Sediment and Groundwater from MW-2) (Source: ESTCP, 2007)

### **3.2.4 Selection Criteria for Building 1419 Site, NSWC, Indian Head**

Subsequent to the sampling activities and laboratory studies performed during Screening Level 3, a scoring system was devised to assist in the evaluation of the seven sites of interest for technical demonstration. In similar fashion to the preliminary screening analysis for evaluating the MNA of chlorinated volatile organic compounds (Wiedemeier et al., 1998), the parameters monitored in Screening Levels 2 and 3 were assigned scores based on the likelihood that each criterion would be conducive to natural attenuation and a successful technical demonstration.

The geochemical data from the Indian Head site that were factored into its selection were obtained from MW-2 and MW-4 as shown in **Table 3-2**. The field monitoring results from the Indian Head site suggest the presence of measurable dissolved oxygen in the groundwater, but the ORP measurements vary widely from strongly oxidative to very reducing. The groundwater pH generally was below optimal, but there were indications that some areas of the site could support biodegradation. Although TOC was low in groundwater, some TOC was reported in sediments and large declines in perchlorate were observed in MW-2 and MW-4 over a 3-year period.

The CD enzyme assay on sediments from the site, along with the positive results in the microcosm study conducted by Solutions-IES, and the pilot study performed by Shaw, support the presence of dissimilatory perchlorate reducing bacteria (DPRB) in the aquifer. In the low perchlorate ambient microcosms constructed with sediment and groundwater from MW-2, nitrate and perchlorate were depleted in all the three replicates suggesting potential for natural perchlorate biodegradation to occur.

Additional criteria were also factored into the evaluation included site logistics such as accessibility, weather, presence of unexploded ordnance and accessible terrain. The depth to groundwater and type of drilling required, which relates to cost, as well as the interest of the base managers in supporting the project were also considered. Based on this analysis, the Indian Head site was selected and approved by ESTCP as one of two demonstration sites.

### **3.3 Demonstration Approach**

Widespread acceptance of MNA will require multiple lines of evidence to demonstrate its value as a remedial alternative. Analytical methods are available to monitor the concentration of perchlorate in the environment with high sensitivity and selectivity, geochemical tests can indicate whether ambient conditions are conducive to perchlorate biodegradation, and molecular biological tools are available to monitor the activity and sustainability of perchlorate-reducing bacterial populations. When properly applied, MNA of perchlorate can be protective of human health and the environment.

The MNA Protocol created during the early stages of the project, was used as guidance in our evaluation of the potential for MNA of perchlorate at the Indian Head site. The objective was to use the three-tiered approach, adopted from the USEPA (1999) and described in the Protocol, to evaluate how this approach would work for perchlorate on a real project site. As noted in Section 2.1 above, the tiers include: 1) plume stability and geometry assessment, 2) biogeochemical parameter and biological indicator evaluation; and 3) biodegradation rate estimation.

With some minor exceptions, the tiers were followed to help guide the planning and selection of tasks to address the challenges at the site.

The demonstration activities included both field and laboratory components. Groundwater sampling activities were performed five times over the course of the performance monitoring period to evaluate aquifer conditions, and how those conditions might affect the potential for natural biodegradation of perchlorate. As described in Section 3.4.2, the well network was expanded during the course of the work. Therefore, not all wells were available or sampled during each event. The groundwater sampling events were conducted over a 3-year period (~38 months) on the dates shown in the **Table 3-3**.

<b>Table 3-3 Performance Monitoring Schedule</b>		
<b>Sampling Date</b>	<b>Days</b>	<b>Months</b>
2/15/2005	0	0
11/17/2005	275	~9
9/28/2006	590	~19
8/9/2007	905	~30
4/17/2008	1,157	~38

### **3.4 Field Methods**

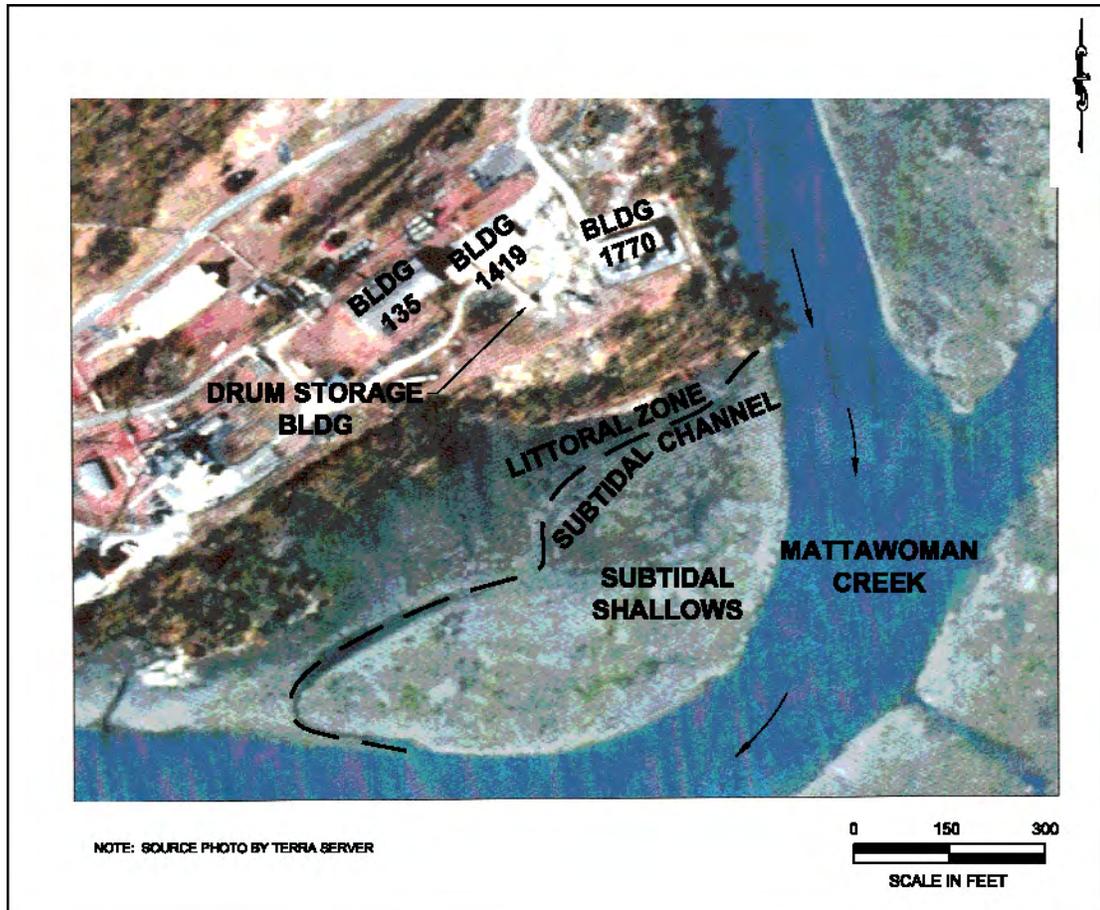
Field activities were adapted to evaluate the fate and transport of perchlorate through different surface conditions encountered as groundwater moves from the area near Building 1419 to Mattawoman Creek. Field methods implemented during the demonstration included the installation of borings, monitor wells and piezometers, instantaneous and continuous water level determinations, measurement of field parameters and hydraulic conductivity, and installation and testing of specialized *in situ* columns to measure perchlorate biodegradation rates. Because of the physical conditions at the site were variable, the following sections describe four different geomorphologic zones at the Indian Head site and serves as a precursor to understanding the groundwater flow conditions and perchlorate attenuation at the site.

#### **3.4.1 Determination of Geomorphologic Zones**

The remediation studies described in Cramer et al. (2004) and ESTCP (2006), as well as the pre-demonstration testing conducted by Solutions-IES (ESTCP, 2007) focused on the area between the presumed source of perchlorate outside Building 1419 and monitor wells and Geoprobe<sup>®</sup> borings approximately 150 ft downgradient. It became evident early in the demonstration that the perchlorate plume was not entirely delineated and likely extended to near Mattawoman Creek. To assess the potential for perchlorate MNA, additional groundwater monitoring points would be needed along the flowpath to Mattawoman Creek and the assessment would have to take into account both surface and aquifer conditions within the land area south of Building 1419 and extending into Mattawoman Creek.

**Figure 3-7** is an aerial view of the demonstration area which includes the following structures: Building 135, incinerator building (Building 1770), and Building 1419 with a sidewalk leading to the small drum storage building. Mattawoman Creek flows along the east side of the site before turning to the west. The creek bank is along the southern extent of the trees (darker

green) in the photograph. The lighter blue-green colored vegetation appearing in the creek consists of wetland plants growing in submerged alluvium that has been deposited on both sides of the creek channel.



**Figure 3-7. Aerial View of the Demonstration Area** (Image from U.S. Geological Survey, Marbury, Maryland, USA, 3/17/1994; downloaded from <http://msrmaps.com>, 2009)

The Indian Head site can be subdivided into four different zones based on land use, geomorphology, physiography and vegetation. The land area south of Building 1419, also referred to as Zone 1, comprises approximately 2 acres from Building 1419 south to the high tide line on the north bank of Mattawoman Creek. The open area just south of Buildings 1419 and 1770 is covered in grass that is mowed periodically (**Figure 3-8**).



**Figure 3-8. Open Grassy Area Southeast of Drum Storage Building**  
(Remnants of Shaw Pilot Study remain on site.)



**Figure 3-9. Wooded Area Looking Northeast from Mattawoman Creek**



**Figure 3-10. Creek Bank and High Tide Line**

Further south, the area is covered with deciduous trees with some evidence (cross ties) of a previous railroad spur line (**Figure 3-9**). The spur was reportedly used to unload rail cars containing nitric and hydrochloric acid. The land surface slopes gently to the south. The facility is surrounded with a perimeter chain link fence that follows the creek bank. Outside the fence the land surface slopes downward 3 to 5 feet to the high tide line forming the creek bank (**Figure 3-10**).

Zones 2 through 4 are located within Mattawoman Creek. The Littoral Zone is defined as the region that is above the low-water mark and below the high-water mark, i.e., exposed to air at low tide and submerged at high tide. The Littoral Zone always includes the intertidal zone and is often used to mean the same as the intertidal zone.

The width of the Littoral Zone ranges between 50 and 100 feet wide (80 feet average). During the warmer months of the year, Zone 2 is covered in vegetation such as *Pontederia cordata* (pickerelweed) and *Zizaniopsis miliacea* (giant cut grass) and other wetland vegetative species (**Figure 3-11**).



**Figure 3-11. Vegetation Covering the Littoral Zone during the Summer Months**

In the winter, Zone 2 is generally devoid of vegetation (**Figure 3-12**). The surficial sediments within Zone 2 are highly organic muck silt and sand (**Figure 3-13**).



**Figure 3-12. Littoral Zone without Vegetation during the Winter Months**



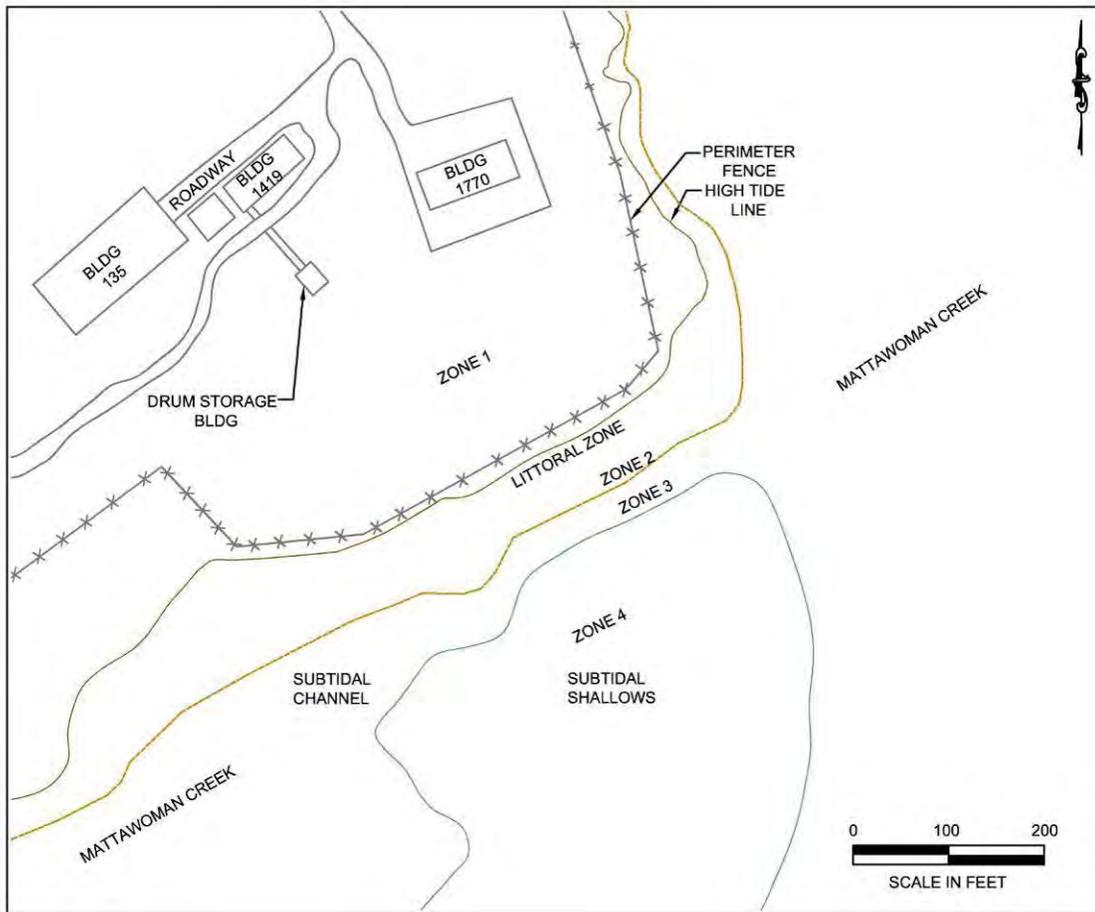
**Figure 3-13. Organic Muck in the Littoral Zone**

The Subtidal Channel (Zone 3) is a relatively narrow channel-like depression that parallels the creek bank at the edge of the Littoral Zone. The channel is between 10 and 20 feet wide and is devoid of vegetation throughout the year (**Figure 3-14**).



**Figure 3-14. Subtidal Channel**

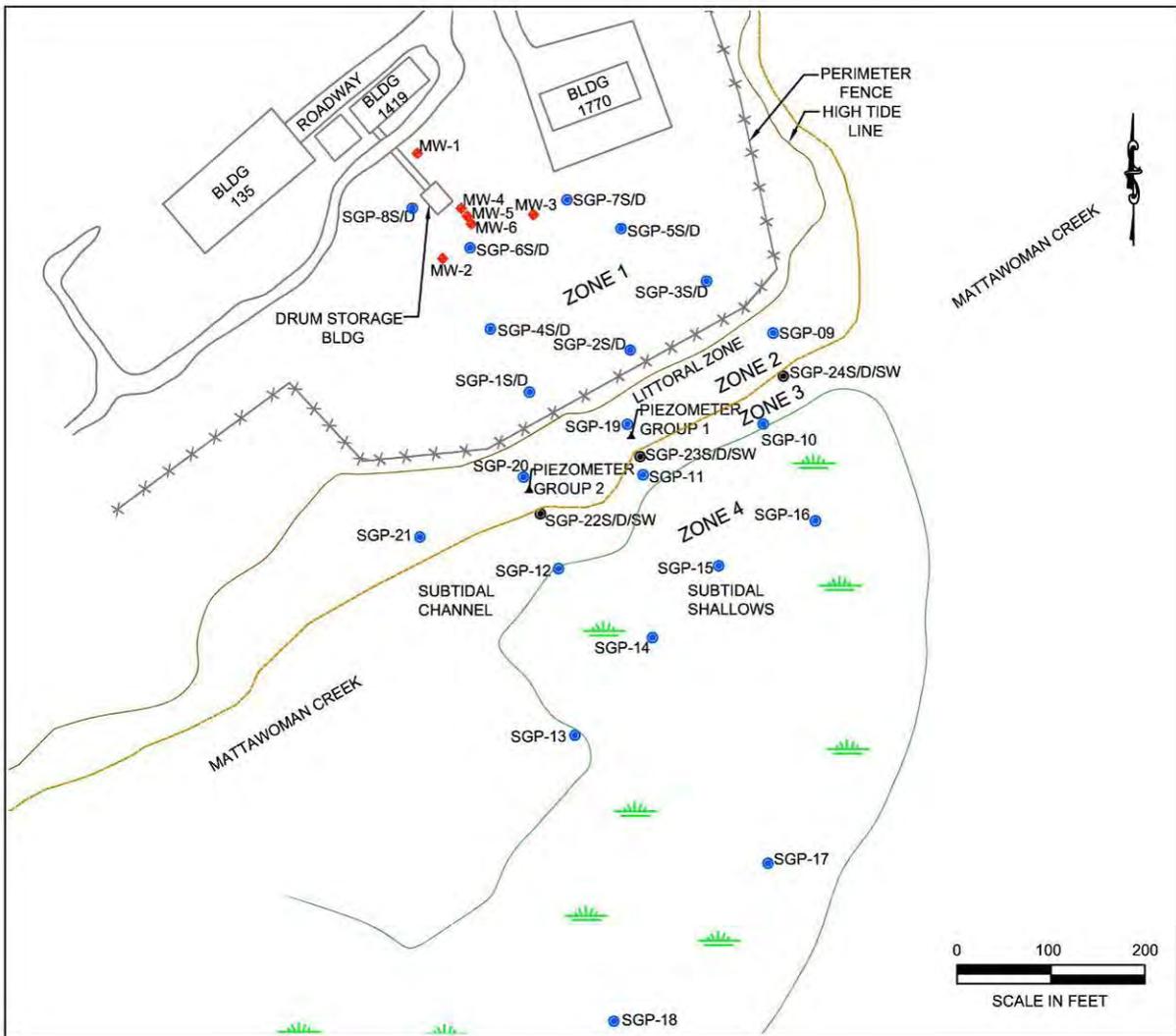
The Subtidal Shallows (Zone 4) is a 400- to 600-ft wide expanse of accreted sediment located south of the Subtidal Channel along an inside meander of Mattawoman Creek. Zone 4 is submerged with 6 to 18 inches of water at low tide and is defined by a covering of *Nelumbo lutea* (American lotus) which are visible beyond the Subtidal Channel in the photograph **Figure 3-14**. The main channel for Mattawoman Creek is located south and west of the Subtidal Shallows and is approximately 200 feet wide. **Figure 3-15** shows the relative position of the four physiographic zones.



**Figure 3-15. Physiographic Zones in the Demonstration Area**

### 3.4.2 Boring and Monitoring Well Installation

An extensive series of groundwater monitoring wells have been installed at the site to evaluate general groundwater conditions and contaminant concentrations. Solutions-IES initial evaluation of site conditions began with evaluating the six monitoring wells (MW-1 through MW-5 and MW-4D) used to monitor the Shaw pilot test. Over the duration of the demonstration, an additional 35 monitor wells and 10 piezometers were installed within the four zones of the site. In order to correlate groundwater levels between wells and the aerial extent of perchlorate in groundwater, the wells were located by survey referenced to mean sea level. **Figure 3-16** shows the network of wells and piezometers installed in the four zones. The well/piezometer construction details are tabulated in **Appendix A**. Additional details of the installation of the network are provided in the following sections. Selected boring logs representing subsurface conditions in the four physiographic zones are included in **Appendix A**.



**Figure 3-16. Monitor Well and Piezometer Network**

**3.4.2.1 Zone 1 - Land Borings and Monitor Wells**

Eight borings, located upgradient, cross-gradient, and downgradient of the presumed perchlorate source area near MW-1 were opened by a Geoprobe® drilling contractor. The soil profile was logged from the boring to establish generalized subsurface conditions. These borings were advanced to 16 to 24 ft bgs, with most terminating in a dark gray clay stratum. Each of these deep borings was then converted to a monitor well with a 2-ft long, 1-inch diameter PVC screen. These wells are denoted with a “D” suffix as “deep” wells. After constructing the deep well at each location, a second Geoprobe® boring was opened a short distance away. The offset borings were extended only a few feet below the water table where a second “shallow” PVC well (denoted by the “S” suffix) was constructed. The shallow wells were constructed with 5-foot long well screens set to approximately 15 ft bgs.

### 3.4.2.2 Zone 2 – Littoral Zone Monitor Wells and Piezometers

Installation of wells and borings in Mattawoman Creek presented unique challenges. Four borings (SGP-9, SGP-19, SGP-20, and SGP-21) were advanced in the Littoral Zone of Mattawoman Creek by driving a Macro-Core<sup>®</sup> sampler using a slide hammer mounted on a tripod. The sampler was recovered after driving and soil contained in the sampler was removed and visually classified. In some borings, sample recovery was minimal because of the soft/loose consistency of the creek sediment. After advancing the borings to termination depths of approximately 8 to 9 ft bgs, a ¾-inch or 1-inch diameter PVC monitor well casing and screen into the boring was pushed into the existing boring before it collapsed. Subsequently, a 4-inch casing was pushed over the monitoring to protect it from the surrounding water.

Piezometers were also installed in the Littoral Zone to evaluate groundwater levels along the creek bank and to evaluate groundwater discharge to the creek bottom by measuring potentiometric head pressures and perchlorate concentrations at different depths. Seven of the piezometers were installed in two locations shown in **Figure 3-16**: three at Piezometer Group 1 and four at Piezometer Group 2. At Piezometer Group 2, TP-4 was screened from 2 to 3 ft bgs, TP-6 was screened from 4 to 5 ft bgs, TP-7 was screened from 5.5 to 6.5 ft bgs and DP-2 was screened from 7 to 9 ft bgs. At Piezometer Group 1, TP-1 was screened from 2 to 3 ft bgs, TP-2 was screened from 4 to 5 ft bgs and TP-3 was screened from 5.8 to 6.8 ft bgs.

The piezometers were constructed of either a 1-ft section of slotted PVC screen and riser or either ¾-inch pipe with a 1-ft stainless steel screen. Both types were driven into the sediment by hand with a slide hammer **Figure 3-17**. Two additional piezometers, TP-5 and TP-8, were installed with a hand auger near the creek bank. Piezometers, DP-1 and DP-3 were constructed using steel pipe and stainless steel drive points.



**Figure 3-17. Piezometer Installation in the Littoral Zone using a Slide Hammer**

### **3.4.2.3 Zone 3 – Subtidal Channel and Surface Water Monitoring Points**

Six monitor wells and three surface water monitoring points were installed by hand as described above in the Subtidal Channel. The locations were accessed using a small boat. These wells were located in three clusters labeled as SGP-22S/D/SW, SGP-23S/D/SW and SGP-24S/D/SW (**Figure 3-16**). Each well cluster consisted of a shallow (S) well screened approximately 2 to 4 feet below the creek bottom, a deep (D) well screened approximately 7 to 8.5 feet below the creek bottom (except SGP-22D), and a surface water (SW) monitoring point from 0 to 1 ft below the creek bottom. The surface water (SW) sampling points were constructed by driving a closed-end section of slotted PVC pipe into the sediment so that the slotted openings were exposed to the water in the creek.

### **3.4.2.4 Zone 4 - Monitoring Well Installation in the Subtidal Shallows**

Solutions-IES installed nine monitor wells (SGP-10 through SGP-18) in the Subtidal Shallows to evaluate pore water conditions within the creek sediment (**Figure 3-16**). Each boring was advanced to a depth of approximately 11 ft below the creek bottom working from a small boat using a slide hammer mounted on a tripod and was later converted to a 1-inch diameter PVC well with a 2-ft screen interval.

### **3.4.3 Groundwater and Creek Sediment Pore Water Sampling**

Water levels were measured in the wells and piezometers prior to the collection of groundwater/pore water samples. When possible, each well that was sampled was purged to remove stagnant water and allowed to recharge from the formation. Because of the anticipated shallow depth to water, the wells were sampled using either a bailer or peristaltic pump. When the monitoring wells were sampled using a low-flow purge and sampling method, an adequate purge was achieved when the pH, specific conductance, and temperature of the groundwater had stabilized as defined in the Technology Demonstration Plan. The parameters measured in wells were altered when necessary in order to collect the volume of sample required for perchlorate analysis.

Purge volumes varied among the wells and piezometers and were noted on the field records. Some wells such as SGP-9 and SGP-20 were noted as being able to produce significant water (five to eight gallons) upon purging. However, most of the site wells and piezometers only produced less than 1 gallon of water before the water level in the well was drawn down into the screen zone.

After an adequate purge was achieved, field measurements were obtained using field meters and groundwater or creek sediment pore water samples were collected for analysis. The field parameters that were typically measured included DO, ORP, pH, temperature and specific conductance. Some of these parameters were not collected if the sample volume was too low.

When groundwater samples were collected using a peristaltic pump, the sample for DO analysis was collected as water flowed out of the sampling tubing by inserting a CHEMetrics<sup>®</sup> (CHEMetrics, Inc, Calverton, VA) self-filling DO ampoule into the end of the tube. The ampoule tip was broken off inside the tube below the flowing water surface, pulling water into the ampoule while being careful to exclude any air. The DO concentration was determined by a visual comparison to color standards.

#### **3.4.4 Measurement of Hydraulic Head in Wells and Piezometers**

Hydraulic head measurements are necessary to understand groundwater flow regimes. Hydraulic head was evaluated in monitor wells and piezometers by direct measurement of the water surface using a water level indicator referenced to the top of the well casing and comparing head values between wells with different screen intervals.

Head measurements were also obtained using three Model 501 Mini-Diver<sup>®</sup> dataloggers manufactured by Schlumberger Water Services, Waterloo, Canada. Each Mini-Diver<sup>®</sup> contains a total pressure transducer combined with battery and data recorder capable of storing 24,000 readings. The readings collected include water level, water temperature, date and time. The pressure data are compensated by comparing the water level data to a separate transducer (Baro-Diver<sup>®</sup> datalogger) placed in a nearby protected location above ground. The Baro-Diver<sup>®</sup> records atmospheric pressure, air temperature, date and time. Water level readings compensated by subtracting the atmospheric pressure from the total pressure recorded by the Mini-Diver<sup>®</sup>. Mini-Diver<sup>®</sup> units were deployed at various times and for varying durations in several wells (SGP-4S, SGP-8S, SGP-10D, SGP-21, SDG-23SW/S/D) and piezometers (TP-3, TP-4, RP-5, TP-6 and TP-7).

#### **3.4.5 Determination of Aquifer Hydraulic Conductivity**

Aquifer tests were conducted in 14 wells to estimate hydraulic conductivity. Tests included four land wells including SGP-6S, SGP-6D, CPMW-2S and CPMW-2D. The latter two wells were installed in the Control Plot (CP) of the Shaw Pilot Study layout in 2002. They are located approximately 20 feet southeast of the Drum Storage building. Wells in the Littoral Zone included SGP-9, SGP-19, SGP-20 and SGP-21. Wells tested in the Subtidal Channel included SGP-22S and D, and SGP-24S and D. Wells located in the Subtidal Shallows included SGP-10 and SGP-11.

Hydraulic conductivity was estimated by determining the yield of the well while pumping at a measured drawdown (specific capacity) of the well (Wilson et al., 1997). The test uses a peristaltic pump to depress the water level in the well. The measured pump discharge rate (i.e., the well recharge rate at the measured drawdown) is then multiplied by a correction factor to estimate hydraulic conductivity.

#### **3.5 Laboratory Methods**

Soil and/or groundwater samples were collected from the land borings/wells, from borings and wells in the Littoral Zone, and in the Subtidal Shallows during five performance monitoring events over a 38-month period. The analytical methods used for each analysis is shown in **Table 3-4**.

**Table 3-4  
Sample Collection and Analysis Details**

<b>Number of Sample Bottles per Sample Location</b>	<b>Containers</b>	<b>Target Constituent/ Method</b>	<b>Field/ Laboratory</b>
<b>Groundwater</b>			
1	250-ml plastic bottle	Specific conductivity, temperature, pH, oxidation-reduction potential/ Field Meters	Field
0	From tubing	Dissolved oxygen/ CHEMetrics™ Field Test Kit	Field
1	0.45 µm filtered sample	Dissolved manganese and iron/ CHEMetrics™ Field Test Kit	Field
2	40-mL VOA vial (no preservative)	Methane/gas chromatography	NCSU CCEE Lab* Raleigh, NC
1	250 ml plastic bottle minimum of 120 ml sample while retaining headspace (no preservative) coupled 1.0µm and 0.45µm filtering setup	Perchlorate/ EPA Method 314 (ion chromatography)	NCSU CCEE Lab Raleigh, NC
1	A minimum of 120 ml (no preservative) coupled 1.0µm and 0.45µm filtering setup confirmation samples (10%)	Perchlorate/Method 332 (Ion chromatography/ tandem mass spectroscopy)	West Coast Analytical Service (formerly Bodycote) Santa Fe Springs, Ca
1	250-mL plastic bottle (preservative)	Chloride, Nitrate, Sulfate, Chlorate, Chlorite, Bromide, and Phosphate (ion chromatography)	NCSU CCEE Lab Raleigh, NC
1	250-mL amber bottle preserved with HCL)	Total organic carbon (groundwater)/Method 9060	Environmental Science Corp. Mount Juliet, TN
1	1-L amber bottle (no preservative)	Chlorite Dismutase/DNA	Microbial Insights, Inc. Rockford, TN
Multiple	enzyme filter traps with a minimum flow through of groundwater (500 mL to 1 L)	Molecular Biology Tools: Perchlorate Reductase/DNA	Microbial Insights, Inc. Rockford, TN
<b>Soil</b>			
1	4-oz jar	Total organic carbon (soil)/EPA Method _415 (Loss on ignition)	Environmental Science Corp., Mount Juliet, TN

NCSU CCEE Lab = North Carolina State University Civil, Construction and Environmental Engineering Laboratory

### 3.5.1 Sampling for Standard Analyses

After purging and field sampling as described in Section 3.4.3 above, the samples were collected in laboratory-prepared sample containers appropriate for the analytical method being used. The sample containers were immediately sealed, labeled, and placed on ice in an insulated cooler for subsequent delivery to the analytical laboratory. Chain-of-custody forms accompanied samples sent to the laboratory. Groundwater/sediment pore water samples collected from monitoring wells during performance monitoring were generally analyzed for perchlorate, TOC, chloride, nitrate, sulfate, and methane as well as dissolved iron and manganese. A small subset of the collected samples was also analyzed for chlorite, chlorate, bromide, and phosphate during some sampling events. As shown in **Table 3-4**, most of the analyses were performed using standard field or laboratory methodologies. However, several relatively new approaches were used for collecting and processing samples for perchlorate and microbial testing. These special methods are described in the following sections.

### 3.5.2 Groundwater Collection for Perchlorate Analysis

The method for collecting aqueous perchlorate samples was described and illustrated in the Perchlorate MNA Protocol (ESTCP, 2008). After the groundwater is withdrawn from the monitoring well or piezometer, solids within the sample were allowed to settle in a closed plastic container. After the sediment had settled, a 60-ml syringe was used to withdraw the sample from the top to avoid solids. Then, the syringe was used to push approximately 30 mL of groundwater through sequentially stacked 1.0  $\mu\text{m}$  and 0.45  $\mu\text{m}$  filters into a 40-mL unpreserved VOA vial. The remaining headspace in the vial maintains an aerobic environment to eliminate further bioactivity on the sample; the sample was then placed on ice for shipment. The combination of filtration, an aerobic headspace and cooling has been shown to effectively preserve the samples and provide a representative sample for laboratory analysis. All samples were analyzed for perchlorate at the North Carolina State University Civil, Construction and Environmental Engineering (NCSU-CCEE) Laboratory by ion chromatography similar to EPA Method 314. Approximately 10% of groundwater samples were sent to a subcontract laboratory for confirmatory analysis of perchlorate by EPA Method 332.

### 3.5.3 Biological Assays –qPCR Analysis

Molecular biology tools (MBTs) provide a sensitive, rapid approach to quantify (i.e., the qPCR assay) specific microorganisms involved with bioremediation. These methods can be applied selectively to detect and/or enumerate the proportion of active perchlorate reducing bacteria in a total population of bacteria. The quantitative polymerase chain reaction (qPCR) method identifies organisms involved with perchlorate reduction by targeting the specific genes found in these organisms: the perchlorate reductase gene (*pcrA*) that codes for the enzyme that mediates the initial breakdown of perchlorate to chlorate and chlorite, and the chlorite dismutase gene (*clt*) that codes for the single enzyme that mediates breakdown of chlorite, the final step in reduction of perchlorate to chloride and oxygen.

The PCR methods can be applied to different genetic material, i.e., RNA-based and DNA-based PCR assays. The RNA-based assay is used to determine the expression of a particular functional gene based upon the abundance of messenger RNA (mRNA). The perchlorate reducing microorganisms use the mRNA to assemble the CD enzyme, and its abundance in the groundwater sample is a direct indication of enzyme activity and, therefore, the active

biodegradation of perchlorate. While RNA is the best indicator of activity, it degrades rapidly and can be lost during field and lab procedures, and therefore, results may be less reliable.

At the time of this project, the DNA-based PCR assays were considered more stable and less subject to sample collection and matrix variability<sup>2</sup>. For this reason, only the DNA-based PCR assays were used during demonstration at the Indian Head site. The methods enabled the selective enumeration of the bacteria capable of dissimilatory perchlorate reduction by targeting a perchlorate reductase gene (*pcrA*) found in the DNA of these organisms. This method provides a direct measurement of the number of active bacteria capable of producing perchlorate reductase.

For DNA based CD analysis, approximately 1 liter of groundwater was collected from selected monitoring wells in bottles provided by Microbial Insights, Inc., placed on ice and forwarded to Microbial Insights, Inc. For perchlorate reductase analysis, Bio-Flo filters provided by Microbial Insights, Inc. were connected in-line with the peristaltic pump tubing during groundwater sampling. The groundwater was allowed to flow through the enzyme filter trap until 0.5-1 L of groundwater had passed through the filter. In some cases the filters became plugged before the required volume of water had passed through the filter. In these cases, an additional filter was used. The exposed filters were capped and the volume of water passing through each was recorded. The filters were shipped under Chain-of-Custody to Dr. Kate Scow at the University of California - Davis for a DNA based analysis of the perchlorate reductase gene (*pcrA*) using qPCR techniques.

### **3.6 *In Situ* Biodegradation Testing**

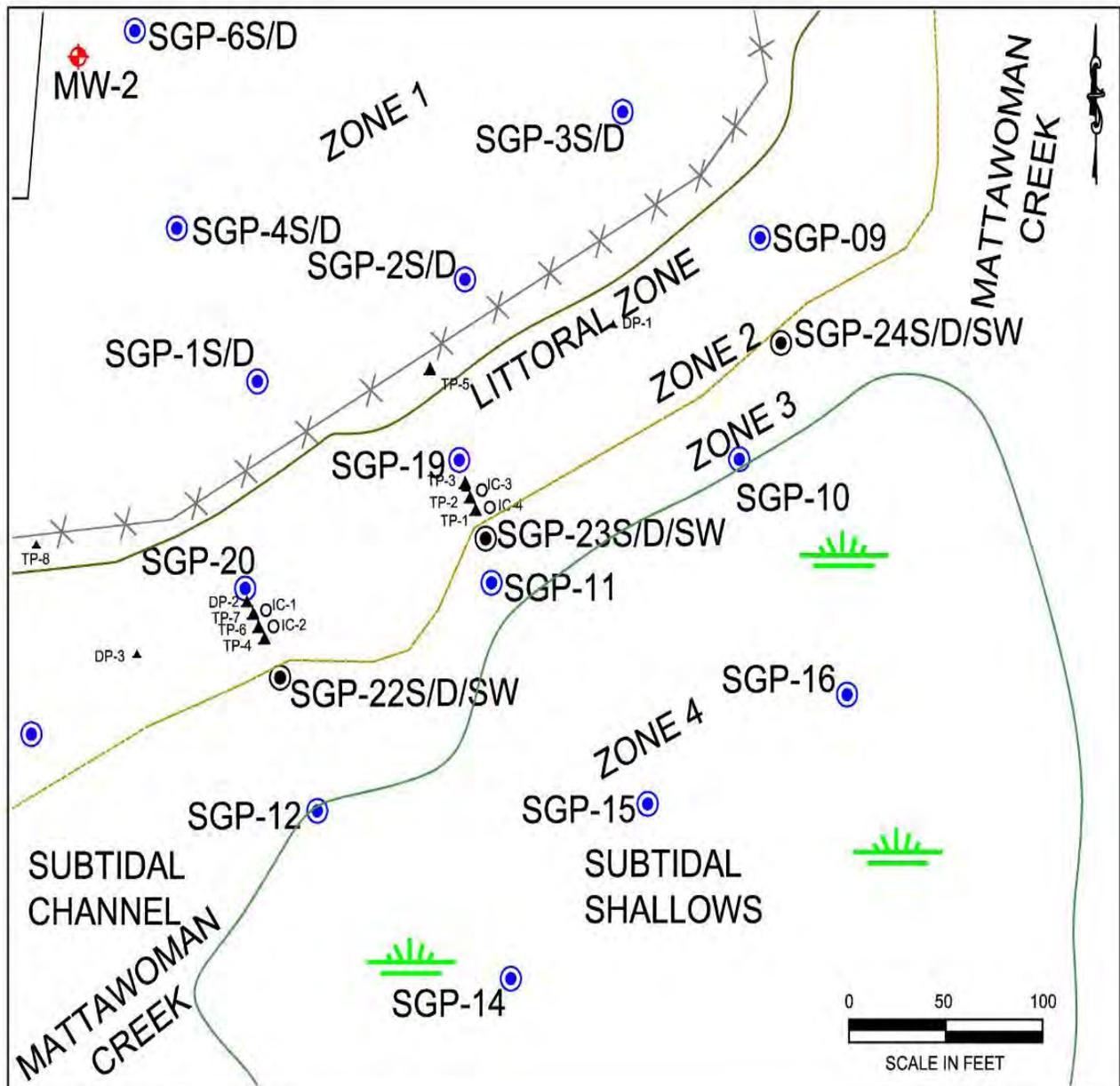
#### **3.6.1 *In Situ* Columns**

*In situ* columns can be used to evaluate contaminant degradation where there is reasonable expectation that natural attenuation is occurring. Using this procedure, Borden et al. (1997) showed that decay rates measured using *in situ* columns provided a better match with plume-scale degradation rates than conventional laboratory microcosms. The application of *in situ* columns for use with perchlorate sites is discussed in the MNA Protocol (ESTCP, 2008).

Four 6-inch diameter *in situ* columns (IC-1, IC-2, IC-3 and IC-4) were installed in the Littoral Zone at the Indian Head site. IC-1 and IC-2 were installed near Piezometer Group 2. IC-3 and IC-4 were installed near Piezometer Group 1 (**Figure 3-18**). A tripod with gasoline engine operated portable cable drum and casing hammer was carried into the Littoral Zone and set up adjacent to each of the piezometer groups (**Figure 3-19**). Two sections of 6-inch (15-cm) diameter schedule 80 PVC pipe were driven into the creek sediment using the casing hammer. The deeper columns (IC-1 and IC-3) were driven to a depth approximately 6.5 feet below the creek bottom (mudline). The shallower columns (IC-2 and IC-4) were driven approximately 3 ft below the creek bottom. The top of each casing was left approximately 6 inches above grade.

---

<sup>2</sup> Personal communication, Microbial Insights, August 2008



**Figure 3-18. *In situ* Column Locations in the Littoral Zone**

A 6-inch section of 1-inch PVC well screen was installed inside the PVC casing just below the bottom so that water samples could be collected from the interior of the 6-inch pipe (**Figure 3-19**). Both the 1-inch and 6-inch casings were then extended approximately 3-ft above grade and capped with a vented well cap. A plastic check valve was installed in the 6-inch casing at the mud line to allow water accumulating within the larger casing to drain during periods of low tide. The design of the check valve was to prevent an inflow of surface water during high tide. However, the check valves became damaged during freezing weather and were eventually removed from all the columns. Surface water appeared to be leaking into the short columns, IC-

2 and IC-4 during initial testing, so additional testing utilizing these columns was discontinued. The biodegradation study continued with the deeper *in situ* columns, IC-1 and IC-3.



Figure 3-19. *In Situ* Columns IC-3 and IC-4 adjacent to Piezometer Group 1

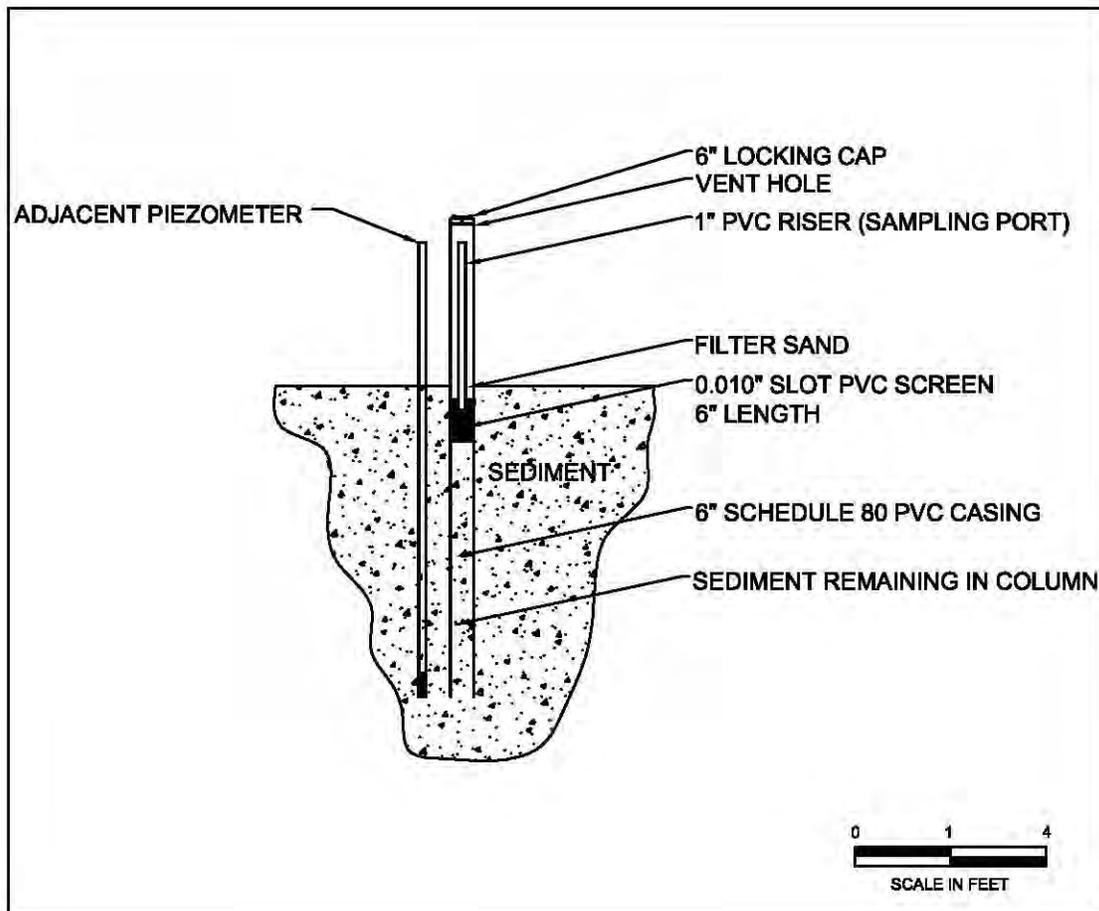


Figure 3-20. *In Situ* Column Construction

The *in situ* columns were designed to allow water contained in the sediment to flow upward through the columns, but to minimize surface water infiltration during testing. By analyzing water from an adjacent deeper piezometer for the perchlorate concentration and measuring perchlorate concentration inside the top of the column, it was possible to evaluate if biodegradation of the perchlorate was occurring as groundwater containing perchlorate moves upward through organic rich sediments. A discussion of the results of the *in situ* column biodegradation study is provided in Section 6.3.2. A discussion of groundwater flow conditions at the site that influenced the design and placement of the columns in Section 4.0.

### 3.6.2 Macrocosms

The microcosm studies performed during the site selection process used soil and groundwater from wells closer to the source in Zone 1. Although these were useful for demonstrating the potential for perchlorate MNA to occur, they did not provide direct evidence of bioactivity in the Littoral Zone (Zone 2), where the majority of biodegradation was presumed to be occurring. For this reason, macrocosms were constructed during the demonstration to evaluate perchlorate biodegradation using soil collected from the Littoral Zone instead of sediment from a land well. To construct the macrocosms, soil was collected from the middle of the Littoral Zone downgradient from SGP-2D. Plant material was removed from the soil, and approximately 85 pounds of soil were removed from a depth of approximately 6 to 30 inches bgs, and randomly placed into five different plastic tubs. The plastic tubs weighed approximately 17 pounds each.

The collected soil was mixed by hand in large plastic tubs until homogenous and large rocks (>0.5 inch diameter) were removed from the soil using a decontaminated spoon or gloved hand. The soil was transferred into separate 5-gallon carboys (**Figure 3-21**). Each carboy was filled approximately half full with groundwater from nearby monitor well SGP-2D while minimizing sample aeration. Air from both the carboy and well were evacuated using argon gas. Once all of the soil was added, the carboy was agitated to release air bubbles, filled completely with groundwater from SGP-2D, and sealed without air bubbles. The carboys were labeled and transferred to the NCSU-CCEE laboratory for incubation and monitoring. Groundwater samples were collected periodically from each macrocosm and tested for chlorite, chloride, nitrite, chlorate, bromide, nitrate, sulfate, phosphate, and perchlorate. Six replicates were prepared. The results are discussed in Section 6.3.1.



**Figure 3-21. Preparing Macrocosms in 5-Gallon Carboys**

### **3.6.3 Stable Isotope Analysis**

Isotopic ratios of chlorine and oxygen atoms in perchlorate ( $^{35}\text{Cl}/^{37}\text{Cl}$  and  $^{16}\text{O}/^{18}\text{O}$ ) can be used as a tool to measure the extent of perchlorate degradation. Stable isotope analysis provides a method for distinguishing biotic from abiotic attenuation. It appears that dissimilatory perchlorate reducing bacteria (DPRB) microorganisms often preferentially use lighter isotopes in their metabolic processes (Coates and Achenbach, 2006). As perchlorate is degraded, the isotopic composition fractionates significantly and the remaining material becomes progressively heavier (Sturchio et al., 2003; McKelvie et al., 2007). If there is clear evidence of an isotopic shift, the extent of perchlorate degradation can be estimated using the fractionation factor. If there is no change in the isotopic ratio despite a change in concentration, then it may be concluded that the attenuation mechanism is abiotic.

Compound specific isotope analysis (CSIA) requires collection of approximately 10 mg of perchlorate in the sample trap from groundwater from locations where conditions suggest that perchlorate may be biodegrading as well as background locations. The large volume of groundwater necessary to perform stable isotope studies could not be practically obtained from the Littoral Zone where perchlorate concentrations were slightly above detection limits and groundwater recharge was slow. Therefore, CSIA was not conducted at the Indian Head site.

### **3.7 Residuals Handling**

Several types of investigation-derived waste (IDW) were generated on this site including:

- Personnel protective equipment (PPE).
- Disposable equipment, such as plastic ground and equipment covers, aluminum foil, tubing, bailers, discarded or unused sample containers, boxes, etc.
- Soil cuttings/Geoprobe<sup>®</sup> Macro-core<sup>®</sup> liners.
- Groundwater/sediment pore water obtained through well development/well purging.
- Decontamination fluids including detergents and wash water.
- Packing and shipping materials.

Based on NSWC (generator) knowledge, the IDW was classified as non-hazardous. Soil cuttings were spread on site in the grassed area south of the Drum Storage building. Groundwater and sediment, as well as fluids derived from well sampling and equipment decontamination, were also disposed of on the land surface in the grassed area south of the Drum Storage building. Solid waste, such as PPE, bailers, tubing, in-line filters, etc., was double-bagged and deposited in a dumpster for transport to a municipal landfill.

## 4.0 Site Area Hydrogeology

### 4.1 Regional Hydrogeology

The town of Indian Head and the NSWC are located on a narrow peninsula of land bounded to the north by the Potomac River and to the south by Mattawoman Creek. Both the Potomac River and Mattawoman Creek are part of the Chesapeake Bay estuary system and are tidally influenced with an average diurnal tide change of less than 1 foot.

According to Hiortdahl (1997), the study area lies within the Coastal Plain Physiographic Province of Maryland approximately 50 miles from its western-most limit. The coastal plain has been formed by the deposition of a sequence of easterly dipping sediments on top of crystalline bedrock. In the vicinity of Indian Head, these sediments are approximately 700 feet thick. They have been mapped (from oldest to youngest) as the Potomac Group, which include the Patuxent, Arundel, and Patapsco formations. The Patapsco formation is overlain by an unnamed sequence of Tertiary-aged deposits, which are in turn, overlain or replaced by Miocene to Pleistocene age fluvial (river) and estuarine (estuary) sediments. During the Pleistocene, multiple periods of glaciation resulted in rivers and streams incising new or deeper channels as sea levels dropped. During these periods, the eroded channels of the Potomac River and its tributaries may have been 60 to 90 feet below their current levels. The eroded channels have now refilled with river and estuary sediment.

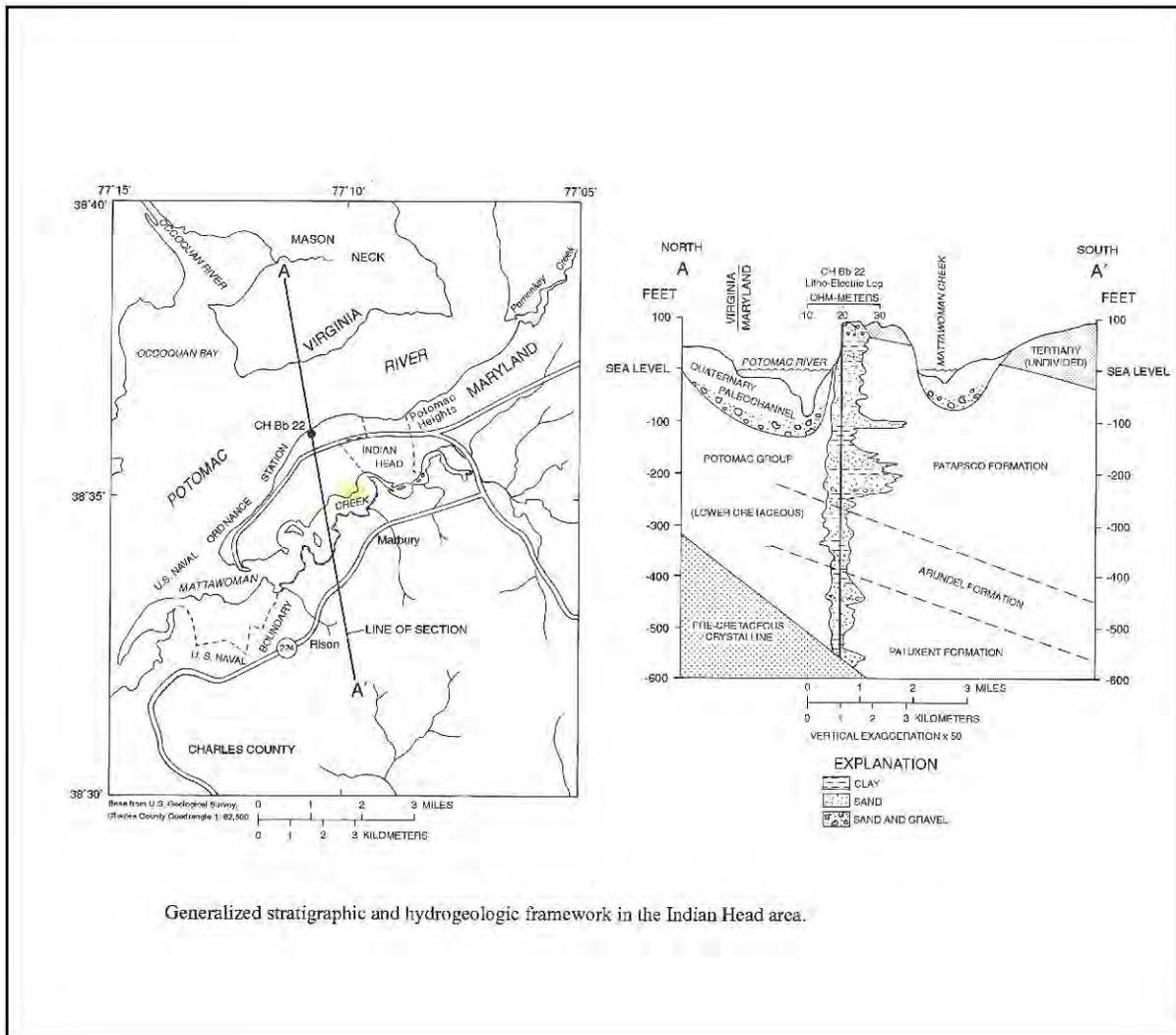
The cross-section in **Figure 4-1** is oriented in a general north to south direction and passes a few miles west of the town of Indian Head. Tertiary-aged sediments are limited to the bluff on the south side of the Potomac River. The former paleochannels of Potomac River and Mattawoman Creek that were eroded into the Patapsco Formation are shown filled with recent sediment.

In the Indian Head area, the Patuxent and Patapsco formations are highly productive aquifers furnishing water of good quality to wells supplying NSWC, the Town of Indian Head, and other municipalities in the area. The Patuxent is confined by the overlying clay of the Arundel Formation and the Patapsco Formation is confined by upper clay beds.

Long-term groundwater use in the vicinity of Indian Head has lowered the hydraulic head in both the Patapsco and Patuxent aquifers. Hydraulic head levels measured in 1989 (the most recent data available) for wells screened in the Patapsco and Patuxent aquifers in the vicinity of the NSWC were 60 to 90 feet below sea level (Hiortdahl, 1997). Increasing chloride concentrations in some wells located in the northern half of the Indian Head peninsula along the Potomac River suggests the Patapsco aquifer and to a lesser extent the Patuxent aquifers are being recharged from the brackish water of the Potomac River through the river bottom sediment.

As opposed to the deeper confined Patapsco and Patuxent aquifers, the surficial (water table) aquifer is unconfined and consists of a relatively thin layer of saturated alluvial soil resting on top of the clayey confining unit of the Patapsco Formation. The water table surface generally slopes similarly to the overlying land surface topography and varies in its vertical position seasonally in response to changes in precipitation and evapotranspiration. Infiltration of precipitation falling within upland areas recharges the surficial aquifer. Some water in the surficial aquifer recharges the underlying confined aquifer, but this recharge is restricted by the

low conductivity of the Patapsco clay, with the result that most of the surficial aquifer discharges to seeps, springs, creeks, and rivers.



**Figure 4-1. Generalized Stratigraphic and Hydrologic Framework of the Indian Head Area (Source: Hiortdahl, 1997)**

#### 4.2 Local Subsurface Conditions

The Project Area is located within the eastern part of the NSWC, in the vicinity of Building 1419. The area south of Building 1419 was investigated by Shaw and others in 2002 as part of a pilot test to study the effects of *in situ* biodegradation of perchlorate. Between 2005 through 2007, Solutions-IES installed a network of 35 monitoring wells and 10 piezometers beginning approximately 150 feet south of Building 1419 and extending in a southerly direction into Mattawoman Creek (**Figure 3-16**).

The following subsections describe hydrogeologic conditions within each of the four zones. Zone 1 and possibly upper portions of Zone 2 during low tide are the only zones where

unsaturated soil conditions and a water table exist. The sediment in Zones 3 and 4 is completely saturated.

#### **4.2.1 Subsurface Conditions in the Site Area**

**Figure 4-2** shows Section A-A' oriented in a north to south direction through the site. The section shows the generalized subsurface conditions extending from the vicinity of the drum storage pad into Mattawoman Creek. Detailed sections B-B' and C-C' oriented north to south through the Littoral Zone (**Figure 4-3 and 4-4**) were constructed to better defined hydrogeologic conditions as perchlorate impacted groundwater discharges through the Littoral zone. As part of this work, a variety of wells and piezometers were installed to evaluate water quality parameters and head pressure variations at different depths within the Littoral Zone sediment. Selected borings logs are included in **Appendix A**.

In previous work, Cramer et al. (2004) described fill soils having been previously placed in various areas of the site. The fill was described as gravel and silty sand containing some organic matter and debris its thickness ranged from less than a foot to approximately 4 feet in thickness. Underlying the fill is 13 to 16 feet of silty sandy-sandy silt containing thin (1 inch to 2 inches thick) discontinuous sand lenses (stringers). The units vary both horizontally and vertically and rest on 12 to 18-inches of coarse alluvial sand and gravel. The coarse alluvium also appears to be variable in thickness and location.

Solutions-IES also identified similar subsurface conditions to be present south of the limit of the Shaw borings. However, the coarse alluvium was not identified in two borings, SGP-2D and SGP-3D located closer to Mattawoman Creek. At these locations, the basal portion of the alluvium consists of fine-grained sand without the gravel. The alluvium rests on dark gray clay, which extends to a depth of at least 24 ft bgs at SGP-2D. The clay, encountered beneath the alluvium in the land borings appears to be extensive and has been identified at other locations within NSFC. Site #57 (Tetra Tech NUS, 2000) also describes the presence of a clay unit beneath alluvium and fill that restricts downward groundwater flow. Based on visual characteristics of the recovered samples, the clay is inferred to be the eroded surface of the Patapsco confining unit.

Borings advanced in the creek were generally terminated at shallow depths of 10 to 11 feet or less. The creek sediments were found to consist of several feet of organic muck (silt and clay) containing an abundance of decayed plant matter underlain by greenish tan to gray silty to clayey fine sand. The soft or loose consistency of the sediments made their recovery using a split spoon difficult. The Patapsco clay that was encountered near the termination of the land borings was not identified in the creek. This may be due to the relatively shallow depth of the borings in the creek and the downward sloping eroded surface of the Patapsco unit.

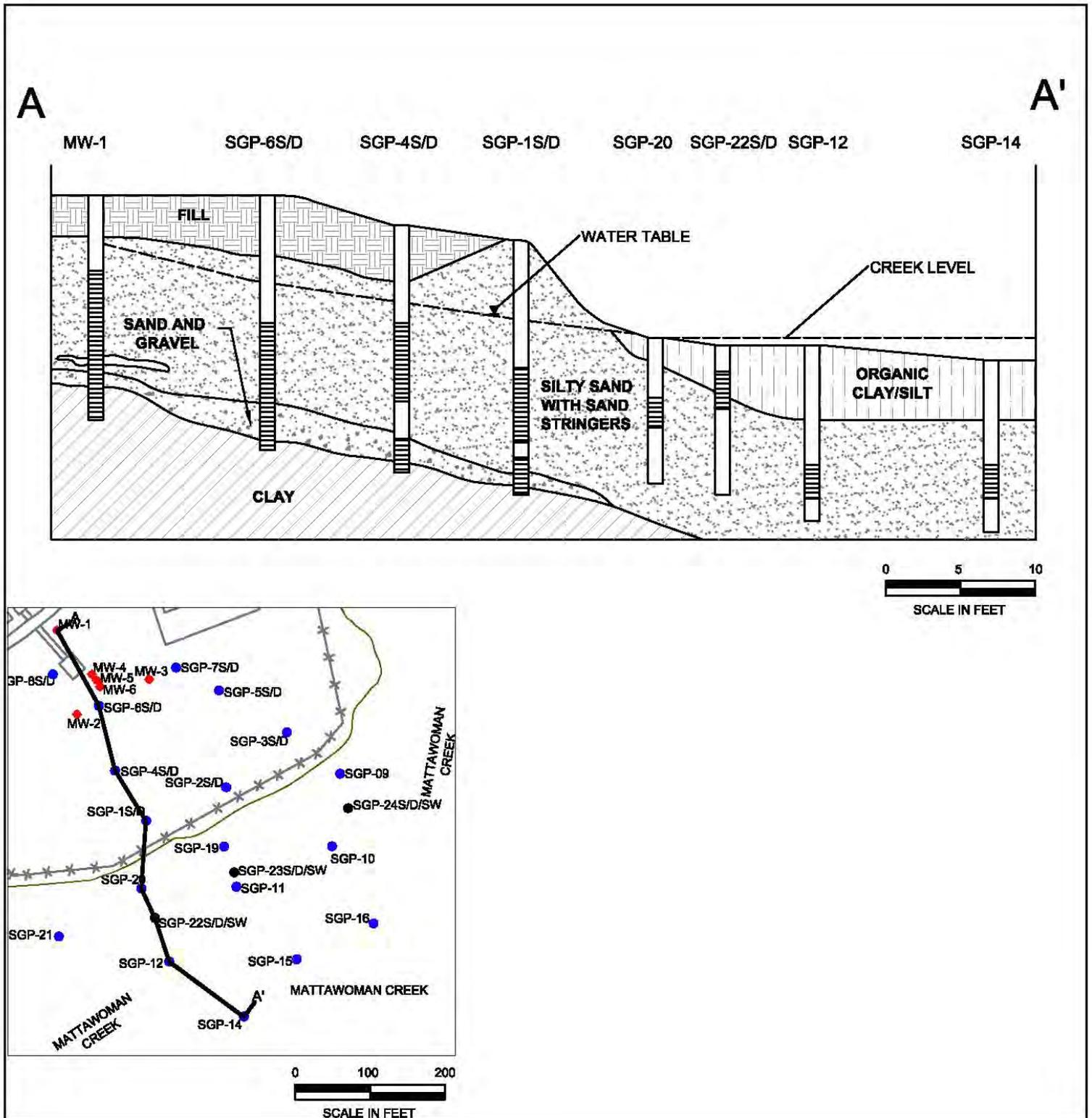


Figure 4-2. Section A-A'

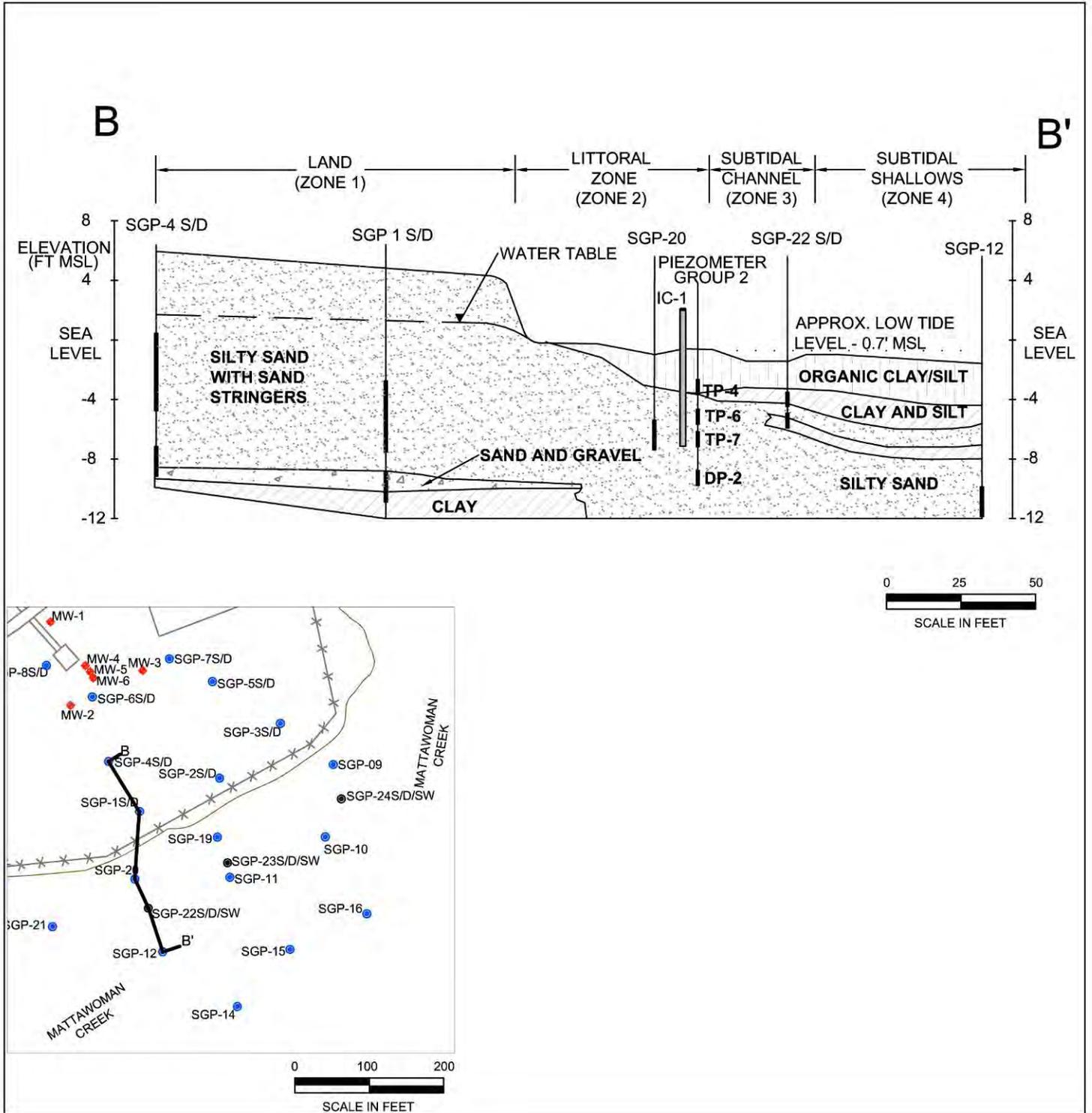


Figure 4-3. Section B-B'

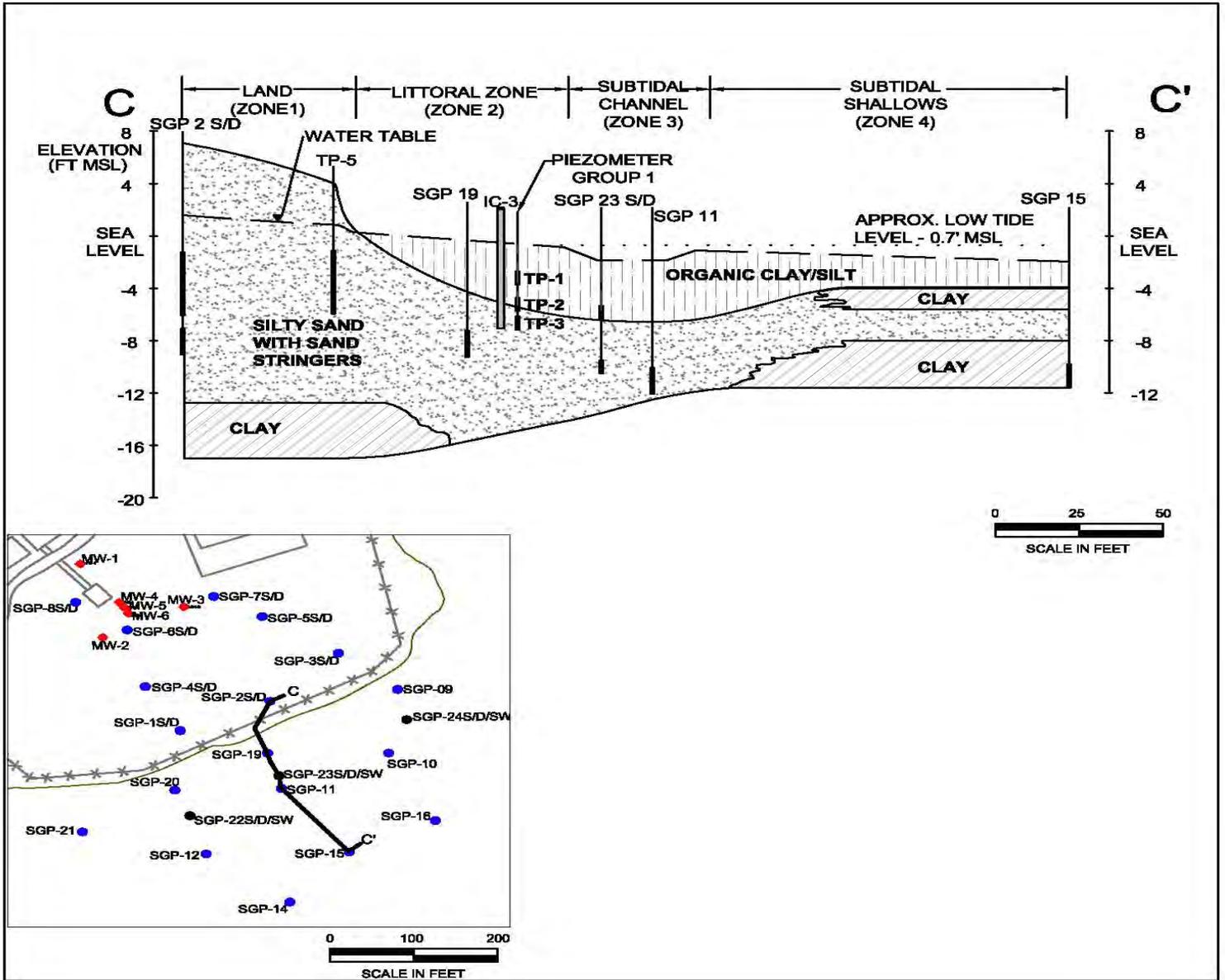


Figure 4-4. Section C-C'

#### 4.2.2 Hydraulic Conductivity of the Surficial Aquifer

As described in Section 3.4.5, aquifer tests were run on 14 wells to determine the hydraulic conductivity (K) of the surficial aquifer and adjoining sediments (Table 4-1). The average and range of K in each of the four zones is presented in Table 4-2. K values in zones 1 to 3 varied from 0.1 to 15 ft/d with an average of 5 ft/d, with no clear difference in the average permeability of the different zones. Measured K in the Mainland Zone is generally consistent with previous reports (ESTCP, 2006; Tetra Tech NUS, 2000). K for the Mainland and Subtidal Channel wells were variable, presumably due to zones of coarser or finer grained alluvium. In contrast, K for the Littoral Zone wells was much less variable.

In contrast to zones 1 to 3, K values in the Subtidal Shallows were significantly lower (average K = 0.07 ft/d). The relatively low conductivity of these sediments was borne out during sampling, where most of the wells produced little water before being dewatered.

<b>Table 4-1</b>			
<b>Aquifer Tests Results</b>			
<b>Well Number</b>	<b>Well Screened Interval</b>		<b>Horizontal Hydraulic Conductivity (ft/d)</b>
	<b>Depth ( ft bgs)</b>	<b>Elevation (ft msl)</b>	
<b>Zone 1 - Mainland</b>			
SGP-6S	8.5 to 13.5	0.26 to - 4.74	0.5
SGP-6D	13.8 to 15.8	-5.09 to -7.09	0.1
CPMW-2S	4.0 to 11.0	5± to 2±	7.6
CPMW-2D	10.5 to 13.5	-0.5 to -4.5	12.4
<b>Zone 2 - Littoral Zone</b>			
SGP-9	6.1 to 8.1	-7.1 to -9.1	2.3
SGP-19	6.7 to 8.7	-7.2 to -9.2	2.1
SGP-20	4.2 to 6.2	-5.3 to -7.3	2.5
SGP-21	2.7 to 7.7	-3.9 to -8.9	3.8
<b>Zone 3 - Subtidal Channel</b>			
SGP-22S	1.8 to 2.8	-3.5 to -4.5	11.3
SGP-22D	3.2 to 4.2	-4.9 to -5.9	0.5
SGP-24S	2.9 to 3.9	-4.3 to -5.3	14.9
SGP-24D	7.6 to 8.6	-9.0 to -10.0	7.2
<b>Zone 4 - Subtidal Shallows</b>			
SGP-11	8.0 to 10.0	-10.1 to -12.1	0.06
SGP-10	8.4 to 10.4	-10.4 to 12.4	0.08

ft bgs = feet below ground surface

ft msl = feet above mean sea level

ft/d = feet per day

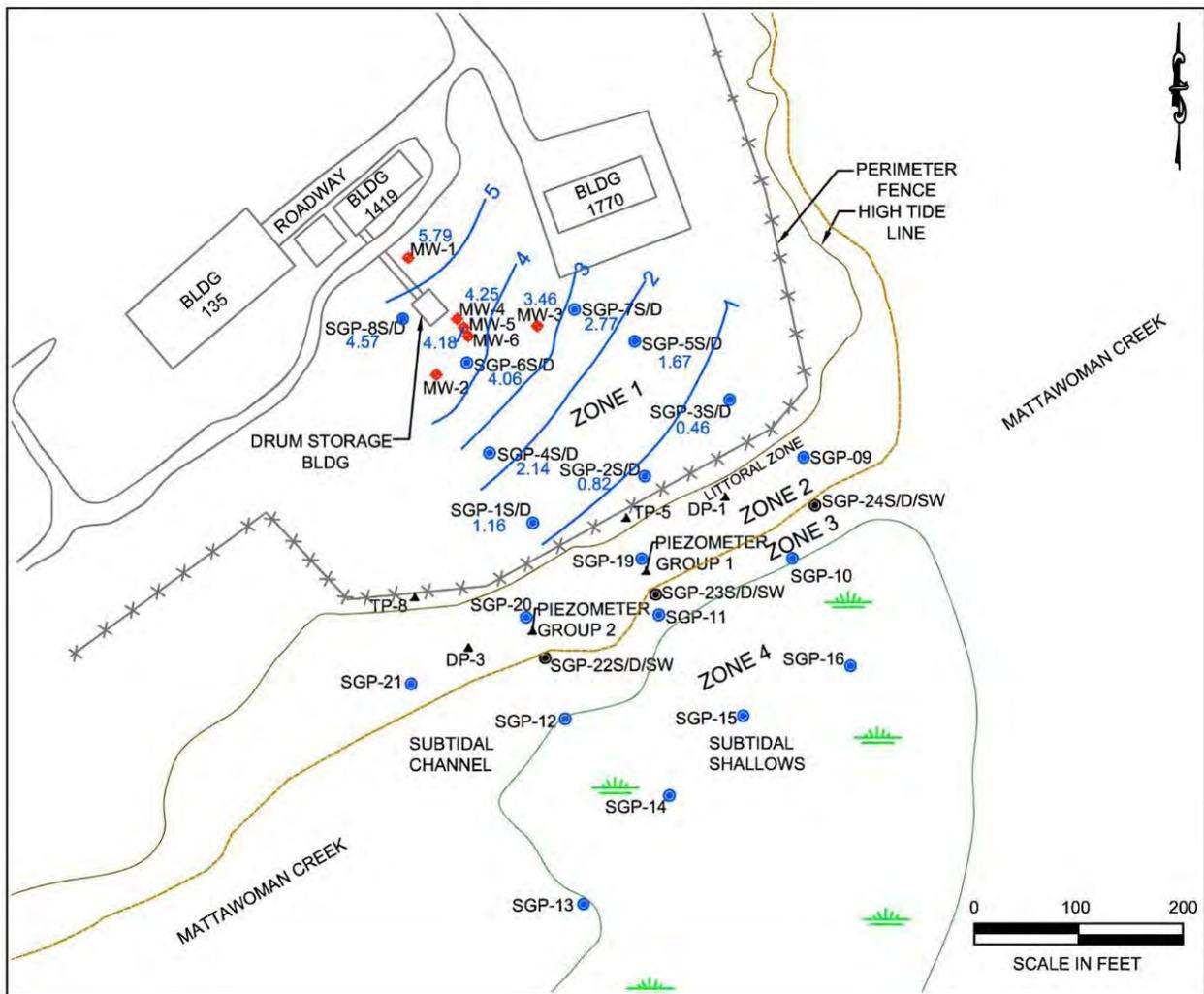
<b>Zone</b>	<b>Hydraulic Conductivity (ft/d)</b>	
	<b>Average</b>	<b>Range</b>
1 – Mainland	5.2	0.1-12.4
2 – Littoral	2.7	2.1-3.8
3 - Subtidal Channel	8.5	0.5-14.9
4 - Subtidal Shallows	0.07	0.06 – 0.08

### **4.3 Groundwater Flow at the Site**

Perchlorate is present in the surficial, water table aquifer at the site and is migrating generally south-eastward towards Mattawoman Creek. During several performance monitoring events, depth to water was measured in wells and piezometers; results are tabulated in **Appendix B**. There is one or more deeper confined aquifer(s) present within the Patapsco and underlying formations. However, these aquifers are separated from the surficial aquifer by the Patapsco clay confining unit and not believed to be impacted by the perchlorate release. All wells constructed at the site are screened in the surficial aquifer and no site-specific information has been developed for the deep aquifers.

#### **4.3.1 Groundwater Flow in Zone 1 - Mainland**

Saturated soils are encountered between 6 and 10 ft bgs south of Building 1419. The surficial aquifer is thin, only 10 to 12 feet in thickness, with the base defined by the Patapsco clay. The water table surface slopes and the depth to the water table decreases to the south and east toward Mattawoman Creek. **Figure 4-5** shows the water table surface as a series of contours as determined from measurements obtained in the site wells in April 2008. The average water table slope (horizontal hydraulic gradient) as measured between wells MW-1 and SGP-2S is approximately 0.018 ft/ft. This is in general agreement with previous monitoring results at the site (Cramer et al., 2004) indicating a gradient of 0.023 ft/ft.



**Figure 4-5. Water Table Contour Map (April 2008)**

### 4.3.2 Groundwater Flow in Zones 2 and 3 – Littoral Zone and Subtidal Channel

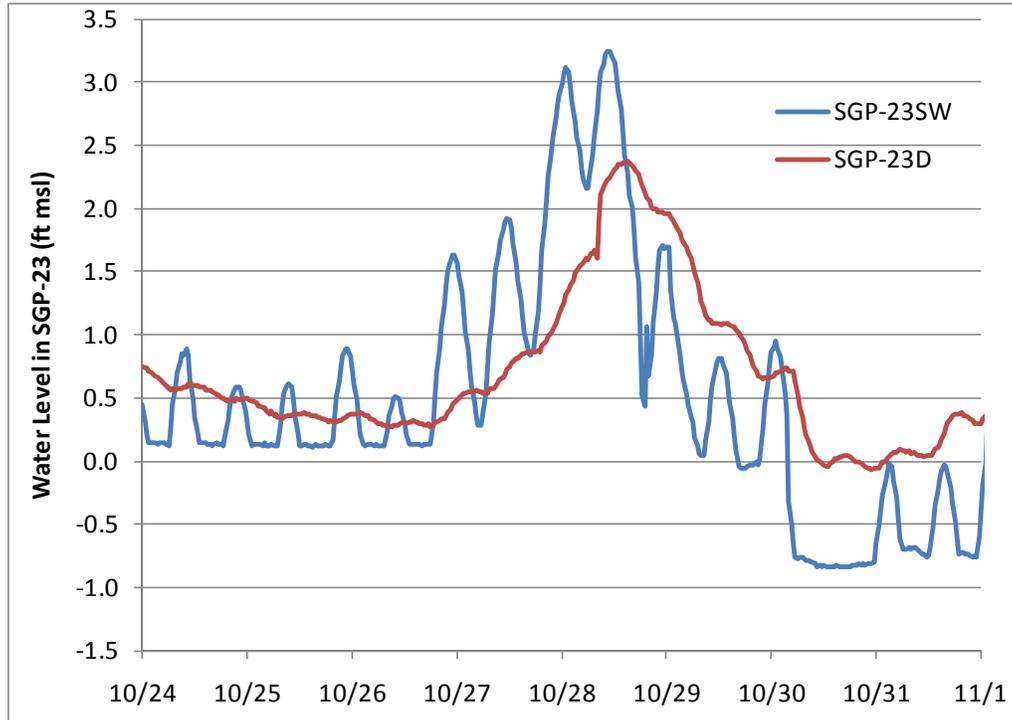
Groundwater flow patterns in zones 2 and 3 are complicated by spatial variations in permeability and tidal fluctuations in Mattawoman Creek. On average, groundwater from the mainland flows the east-southeast and discharges to the Littoral Zone and Subtidal Channel. The Littoral Zone is a relatively narrow fringe along the creek bank that is covered by water during high tide and exposed during low tide. During low tide, the top few inches of sediment along the high tide line may drain and become partially saturated during low tide, exhibiting a “water table” a few inches below the land surface. The partially saturated zone disappears during the next high tide.

Groundwater discharge to receiving streams has been shown a source of nutrients and agricultural pesticides (Li and Jiao, 2003). Quantification of solute transport effects in coastal aquifer systems and the tidal effects on submarine groundwater discharge and beach hydraulics is challenging because of non-linearity resulting from water flow in the unsaturated zone (Li et al., 2008). At Mattawoman Creek, the discharge area likely varies in its width and distance from

the creek bank daily and seasonally according to tidal levels in the creek. At ebb tide, the beach water table may be decoupled from the creek resulting in the formation of a seepage face where groundwater seeps onto the intertidal profile (Uchiyama, 1999). Li et al. (2008) also noted that the major portion of the outward groundwater seepage usually occurs in the shallow part of the submerged beach and the magnitude decreases with distance from the shore. They concluded that on average, the outflow from the seepage face accounts for about half the outflow from the intertidal zone. Groundwater discharge probably ceases during high tide when water in creek recharges the shallow creek sediment. These local circulation cells are formed in the aquifer near the shoreline as a result of tidal fluctuations and the salinity profile is attributable to this circulation (Uchiyama, 1999; Li and Jiao, 2003). The Subtidal Channel probably acts as a collector routing seepage from the edge of the Littoral Zone to the creek channel west of the study area. Based on distance from shore, little groundwater is expected to discharge to the Subtidal Shallows area.

To gain a better understanding of these flow patterns, piezometers were installed at several locations and depths in Zones 2 and 3 and monitored for changes in pressure head with time. **Figure 4-6** shows the variation in water levels in Piezometer Group SGP-23 installed in the Subtidal Channel from late October to early November 2006. SGP-23SW was installed to monitor surface water elevations in the Subtidal Channel. The creek bottom at this location is approximately 2.1 ft below msl. SGP-23D is screened from 9.5 to 10.5 ft below msl (7.4 to 8.4 feet below the creek bottom) and was designed to monitor water levels deeper in the aquifer. From 10/24 to 10/26, there were typical diurnal tides which resulted in a 0.4 to 0.8 ft fluctuation in water levels in the Subtidal Channel. Pressure fluctuations deeper in the aquifer lag the surface water by 1 to 2 hours and were much more muted with head variations of a few hundredths of a foot, suggesting the aquifer at this location behaves in a semi-confined condition. During low tide periods, the head in the aquifer is greater than in the surface water and flow is upward. However, during high tides, head in the surface water is greater, resulting in some flow reversal and the potential for surface water to enter the aquifer. The actual amount of surface water that enters the aquifer is probably limited due to the semi-confined condition. On average, there appears to be a net flow of water from the aquifer into surface water. This discharge was commonly observed during low tide as small seeps and flowing rivulets of water. Creek water re-saturates the surficial sediment on the next rising tide; reducing the hydraulic gradient and slowing groundwater discharge to the creek.

Mattawoman Creek periodically experiences significant wind driven tides. During Oct 27-28, 2006 wind driven tides caused the water level in Mattawoman Creek to rise over 2 feet above normal, resulting in a strong hydraulic gradient from the surface into the aquifer for 1 to 2 days. Once the high wind period ended, water drained out of Mattawoman Creek and there was a period of unusually low surface water levels with a strong hydraulic gradient from the aquifer to surface water. These flow reversals likely result in some mixing of surface and groundwater. However, the exact amount of water that enters the aquifer during flow reversals is impossible to estimate without precise measurements of vertical hydraulic conductivity. In Section 6, field monitoring results will be presented showing that pore water within deeper sediment has chemical characteristics similar to groundwater in Zone 1 – low chloride concentrations and slightly acidic pH. This indicates that mixing of surface and groundwater is limited to the upper few feet of the Littoral Zone and Subtidal Channel.



**Figure 4-6. Variation in Water Elevations from Oct. 24 to Nov. 1, 2006, in Piezometer Group SGP-23 Installed in the Subtidal Channel**

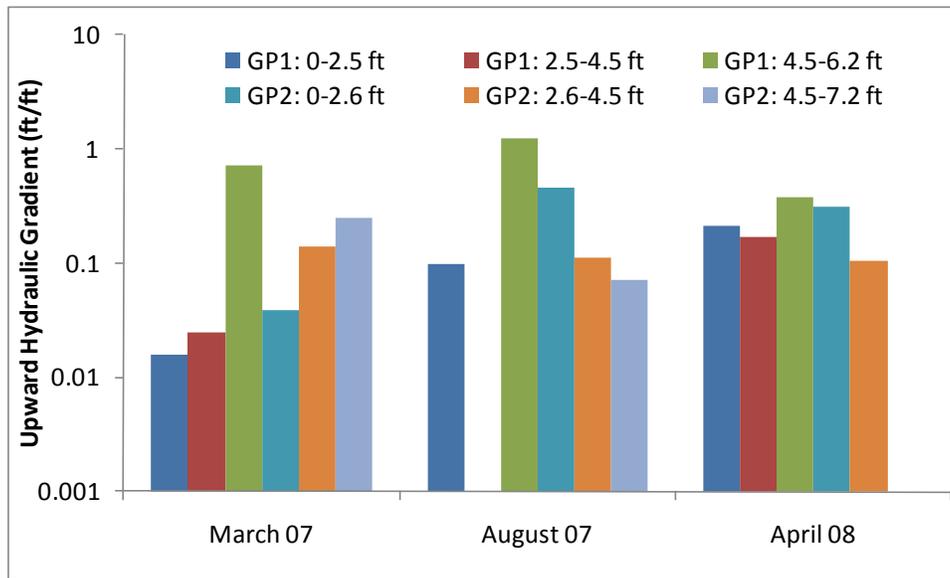
### 4.3.3 Groundwater Flow in Zone 4 - Subtidal Shallows

Groundwater monitoring in the Subtidal Shallows (Zone 4) showed very different chemistry with high levels of methane, dissolved iron and chloride indicating groundwater in this area does not actively communicate with the mainland. This is reasonable to expect given the low hydraulic conductivity of this material and absence of a hydraulic gradient to transmit groundwater.

### 4.3.4 Groundwater Discharge Rates

To gain some understanding of the groundwater discharge rates, water levels in Piezometer Groups 1 and 2 were monitored during low tide periods on three occasions in 2007 and 2008. During low tide, the creek bottom was exposed indicating the piezometric surface was equal to the creek bottom elevation. The depth to water was measured in the piezometers using an electronic water level indicator. In all cases, water levels in the piezometers were above the creek bottom indicating an upward hydraulic gradient.

**Figure 4-7** shows computed hydraulic gradients between different elevations in Piezometer Groups 1 and 2. Gradients were calculated by dividing the difference in measured water levels by the distance from the center of one screen to the next. Salinity levels in the creek and sediment are less than 250 mg/L, so density corrections were not required. The legend indicates the vertical interval used to calculate the gradient so ‘GP1: 0-2.5 ft’ indicates the hydraulic gradient from 0 to 2.5 ft below the creek bottom in Piezometer Group 1.



**Figure 4-7. Measured Hydraulic Gradients between Different Depths in Piezometer Groups 1 and 2 on Three Dates**

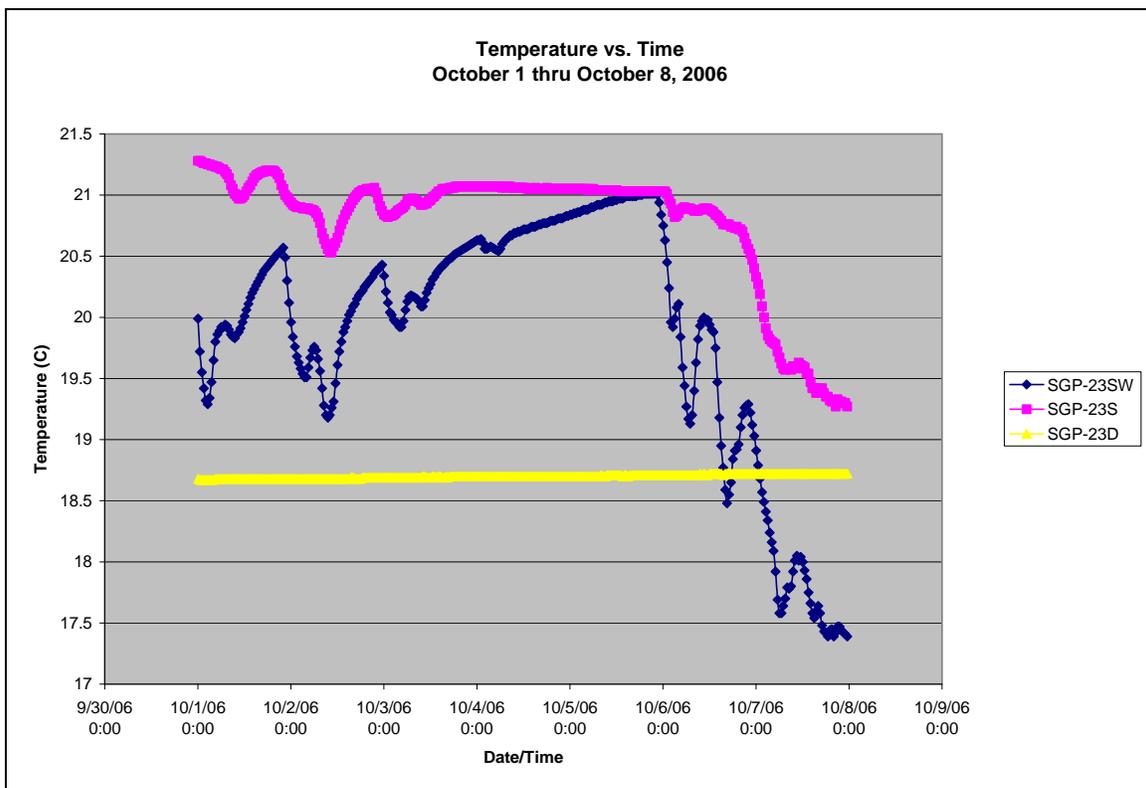
Average hydraulic gradients observed over the three different monitoring dates varied from 0.07 to 0.77 ft/ft, with an overall average of 0.24 ft/ft. All hydraulic gradients were upward from the aquifer to surface water, as expected for low tide periods. In Piezometer Group 1, hydraulic gradients were consistently higher in the 4.5 to 6.2 ft depth interval, implying the presence of a more restrictive layer underlying the shallow organic rich sediments where pressures dissipate more rapidly. In contrast, the hydraulic gradients in Piezometer Group 2 were more consistent and do not indicate the presence of a restrictive layer.

A standard approach is to compute velocity ( $v$ ) using Darcy's Law [ $v = K (\Delta H/\Delta L)/n$ ] where  $K$  is hydraulic conductivity,  $\Delta H/\Delta L$  is hydraulic gradient, and  $n$  is porosity. Horizontal hydraulic conductivity ( $K_H$ ) in the Littoral Zone and Subtidal Channel was measured in eight separate wells/piezometers and varied from 0.5 to 14.9 ft/d with an average of 5.6 ft/d. Assuming the vertical hydraulic conductivity ( $K_V$ ) is 10% of average  $K_H$  and porosity is 0.25, the average vertical velocity during low tide would be 0.5 ft/d. For an average low tide period of 6 hr, groundwater would migrate upward up to 1 to 2 inches (2.5 to 5 cm), before the tide changes and flow reverses. During a 2-day period of wind-driven high tides, the average hydraulic gradient downward might be 0.1 to 0.2 ft/ft (**Figure 4-7**) and the average downward migration of surface water into the aquifer would be 6 to 12 inches.

## 4.4 Geochemical Indicators of Groundwater Flow Patterns

### 4.4.1 Temperature

Temperatures in surface water at the Indian Head site vary daily and seasonally. Pressure transducers installed in selected wells in October 2006 to measure tidal fluctuations also measured water temperature. The surface water temperature (SGP-23SW), shallow pore water (SGP-23S), and deeper pore water (SGP-23D) measured for the first week in October 2006 are shown in **Figure 4-8**. The shallow piezometer (SGP-23S) responds rapidly to changes in surface water temperature. In contrast, the deeper piezometer (SGP-23D) is not affected by changes in surface water temperature, indicating the deeper zone does not rapidly exchange water with the surface.



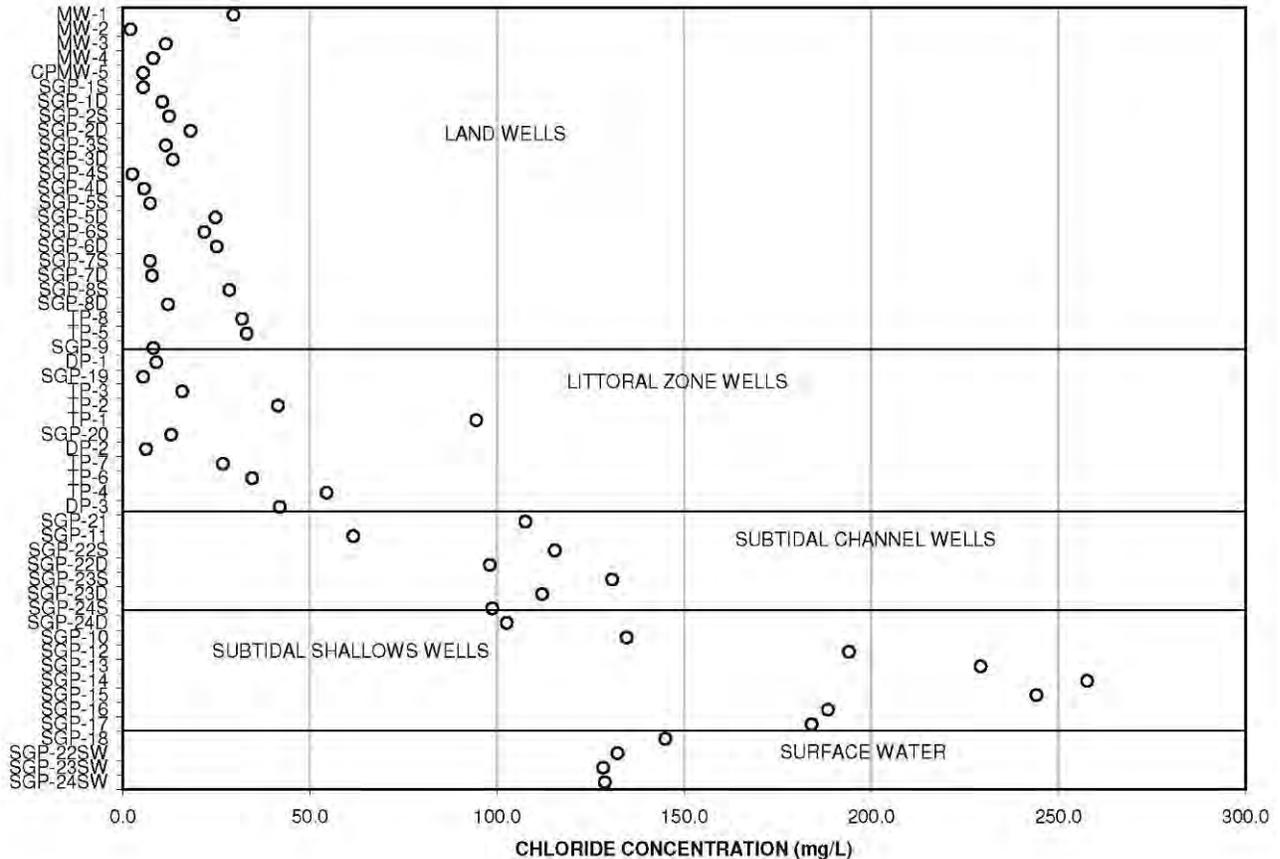
**Figure 4-8. Temperature Fluctuations in Surface, Shallow and Deep Groundwater**

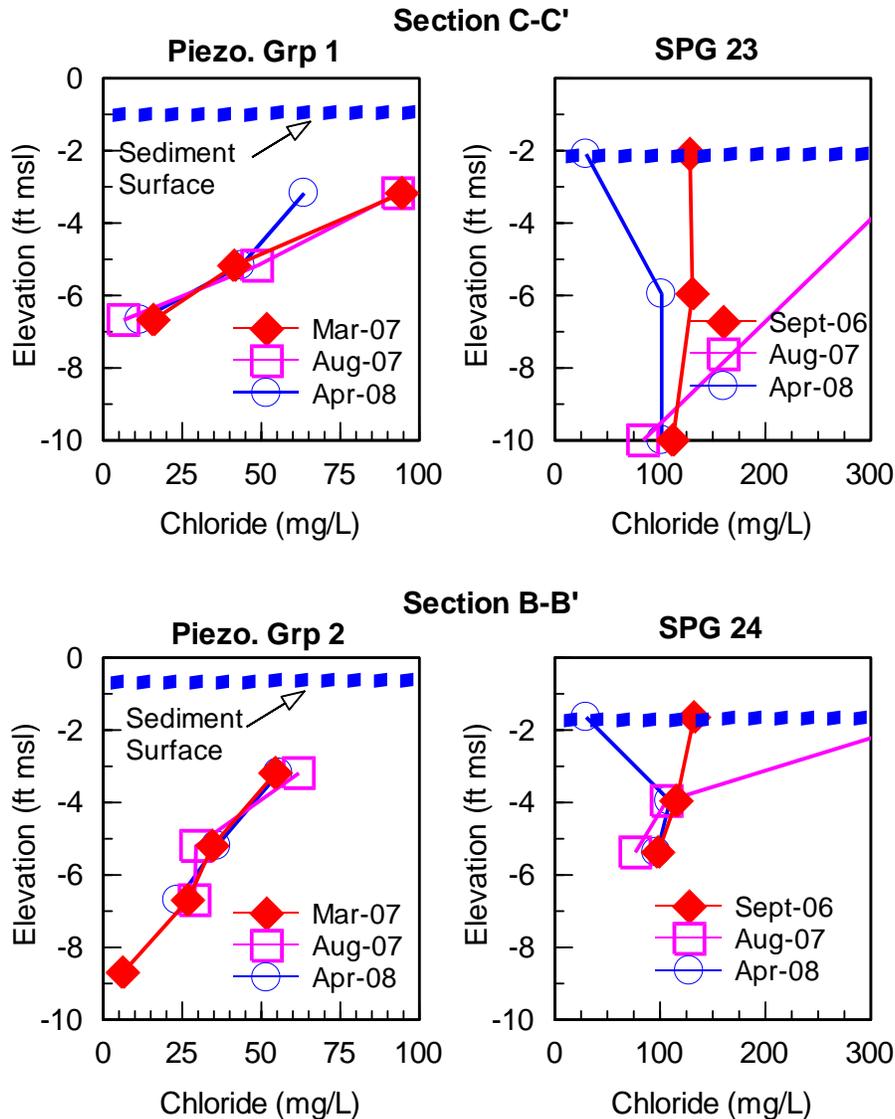
### 4.4.2 Chloride

Chloride concentrations are relatively low in the Mainland wells (typically 5 -30 mg/L) and increase to the southeast towards Mattawoman Creek. Chloride levels in the Potomac River and Mattawoman Creek can vary significantly due to precipitation events and wind-driven tides (Hiortdahl, 1997). Surface water monitoring data collected during this study showed surface water chloride concentrations varying from 27 to 364 mg/L with an average of 148 mg/L (std. dev. = 143 mg/L, n=11).

**Figure 4-9** shows chloride concentrations (mg/L) in March 2007 plotted in different sampling locations throughout the site. Chloride concentrations in the land wells are generally less than 25

mg/L. In the Littoral zone, there appears to be two groups of wells: (a) deep wells with chloride concentrations similar to the land wells; and (b) shallow wells with somewhat more elevated chloride concentrations due to recharge of surface water with elevated chloride. The Subtidal Channel wells all have elevated chloride concentrations indicating a major impact from surface water recharge. The Subtidal Shallows wells had the highest chloride concentrations observed in March 2007, indicating no significant exchange with the land aquifer.





**Figure 4-10. Vertical Profiles of Chloride Concentration vs. Depth in Littoral Zone (Piezometer Groups 1 and 2) and Subtidal Channel (SPG-23 and SPG-24).**

#### 4.4 Generalized Hydrogeologic Model

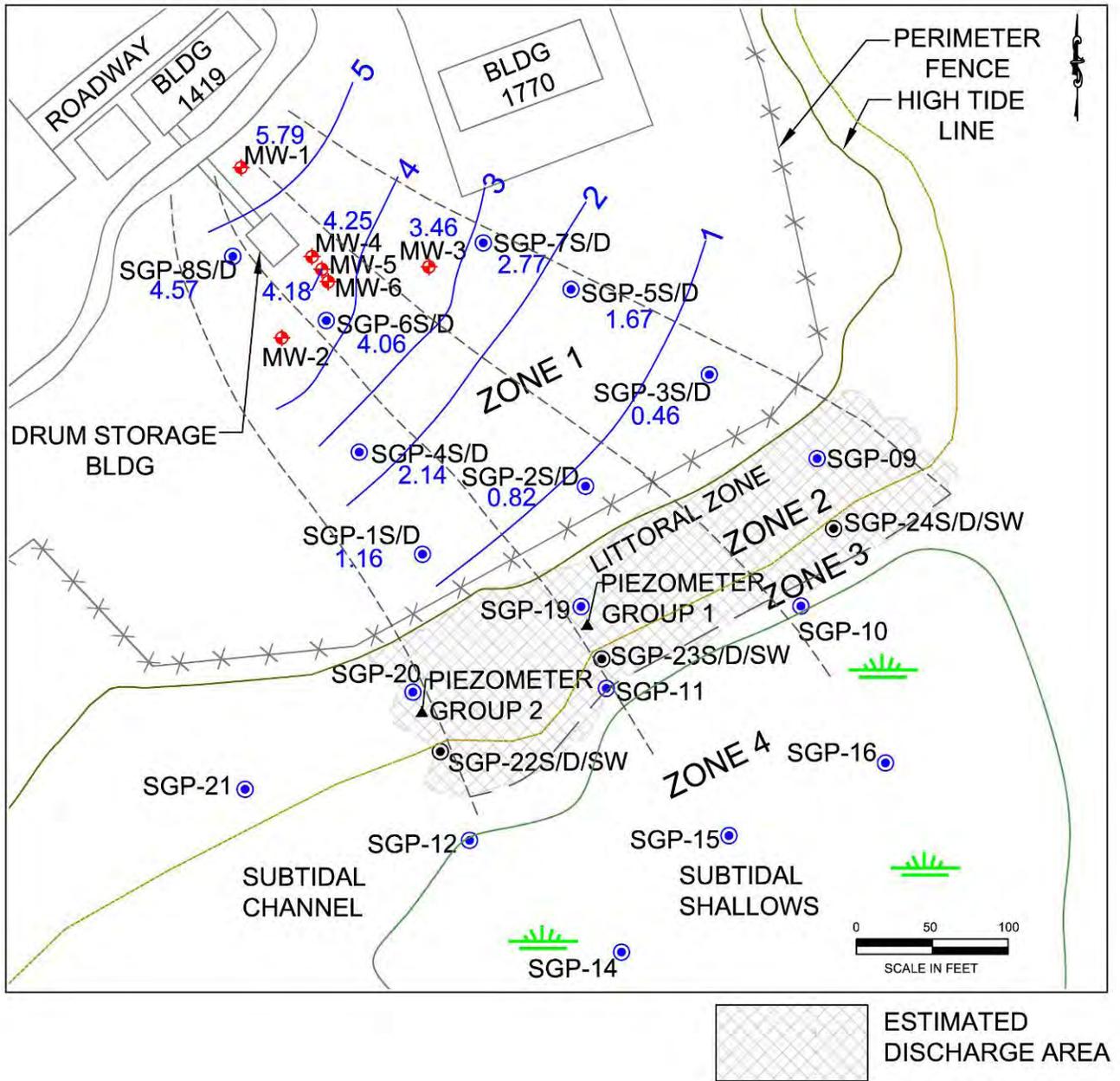
A general conceptual groundwater flow model was formulated for the surficial aquifer at the site based on a groundwater compartment that extends from the topographic high north of Building 1419 to the Littoral Zone within Mattawoman Creek. The base of the compartment occurs at the top of the Patapsco confining unit. With the exception of minor seepage that occurs into the Patapsco confining clay, groundwater within this compartment will eventually discharge to Mattawoman Creek. The deeper confined Patapsco aquifer has not been included in the conceptual model because the low hydraulic conductivity of Patapsco clay restricts recharge of the underlying confined aquifer to a small percentage of the water contained in the surficial aquifer.

Fill and alluvium rest on the eroded surface of Patapsco clay. The base of the alluvium consists of a layer of sand and gravel that have been eroded from upland areas. This is in turn, covered with silty and clayey sand containing sand lenses (stringers). In Mattawoman Creek, the top of the Patapsco has been scoured downward and a thick accumulation of silty sediment has been deposited by the creek as it has meandered within its flood plain. Because of the wetland vegetation present along both sides of the creek channel, the creek sediment is now capped with several feet of soft silty clay (muck) containing abundant decayed organic matter.

Precipitation infiltrates to the water table in the higher land elevations within the study area and to the north. Shallow groundwater in the study area moves toward the south toward the creek. Upon entering the creek sediments, groundwater tends to migrate upward and discharges to the creek within the Littoral Zone and Subtidal Channel. At the creek bank the hydraulic gradient of the aquifer provides the driving force for groundwater discharging through the nearshore sediment to the creek. Short term changes in the gradient occur through tidal loading. This oscillatory change in gradient directly affects the rate of discharge to the creek. Groundwater discharge decreases even ceasing during periods of high tide when water in creek tend to infiltrate and recharge the shallow creek sediment. This cyclic discharge/recharge tends to increase residence time and results in additional dilution and mixing within the shallow creek sediments (Westbrook et al., 2005; Robinson et. al., 1998).

The Subtidal Channel acts as a surface water collector routing seepage from the Littoral Zone to Mattawoman Creek through an outlet west of the study area. The minimal thickness of the surficial aquifer and very low conductivity of the sediment within the Subtidal Shallows restrict groundwater discharge to the Littoral Zone.

**Figure 4–11** shows a flownet developed for the study area based on water levels measured in April 2008. The construction suggests that the gradient flattens from the vicinity of Building 1419 toward the creek and that groundwater has slight radial flow as the flow tubes diverge to the south. Assuming a uniform saturated thickness of 10 ft and horizontal hydraulic conductivity of 5 ft/d, the average discharge from the aquifer to the Littoral Zone/Subtidal Channel would be approximately 300 ft<sup>3</sup>/day (2,244 L/day). Visual observations of the discharge face during low tide indicates the discharge face is between 50 and 100 ft wide. 300 ft<sup>3</sup>/d of discharge would then result in an average upflow velocity in the discharge area of 0.04 to 0.08 ft/d. Organic rich sediments in the Littoral Zone are 2 to 4 ft thick which would result in an average residence time in this organic rich zone of 25 to 100 days.



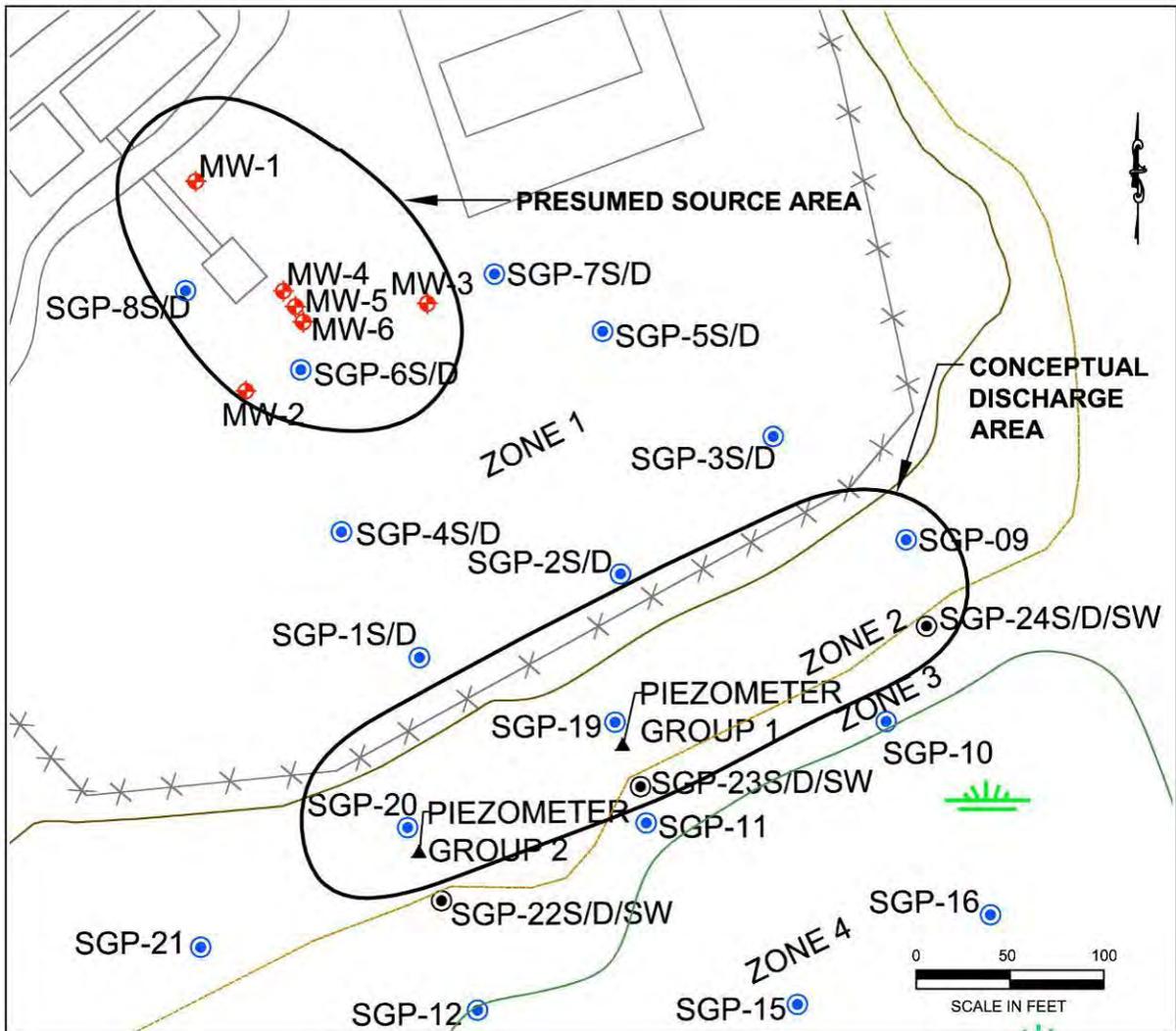
**Figure 4-11. Flow Net for Study Area**

## 5.0 Conceptual Model of Perchlorate Transport and Fate

At the Indian Head site, perchlorate concentrations in groundwater exceed the MDE Drinking Water Standard of 2.6 µg/L. This section presents a general conceptual model for the transport and natural attenuation of perchlorate as it migrates from the source area towards and into Mattawoman Creek.

As described in Section 4.4, groundwater is believed to enter the shallow aquifer as diffuse recharge in upland areas of the site. Building 1419 is reported to have been used to clean out or “hog-out” solid propellant containing ammonium perchlorate from various devices, including rockets and ejection seat motors. This process is thought to have resulted in the discharge of solid perchlorate and/or water containing perchlorate on the soil surface in the general vicinity of Building 1419. Perchlorate present in the soils would then be carried vertically into the shallow water table aquifer by infiltrating rainwater. Sorption of perchlorate to the aquifer matrix is believed to be minimal, so perchlorate could be flushed from the aquifer relatively easily by ambient groundwater flow.

The exact location of the hog-out activities is not known, but is believed to have occurred in the general vicinity of Building 1419 in the northwestern portion of **Figure 5-1**. Elevated concentration of perchlorate in SGP-8 and TP-8 suggest that perchlorate may have entered the aquifer in areas south of the drum storage building. However, the focus of this study is on the transport and fate of perchlorate that entered the aquifer from a ‘source area’ in the general area of MW-1, MW-3 and MW-4.

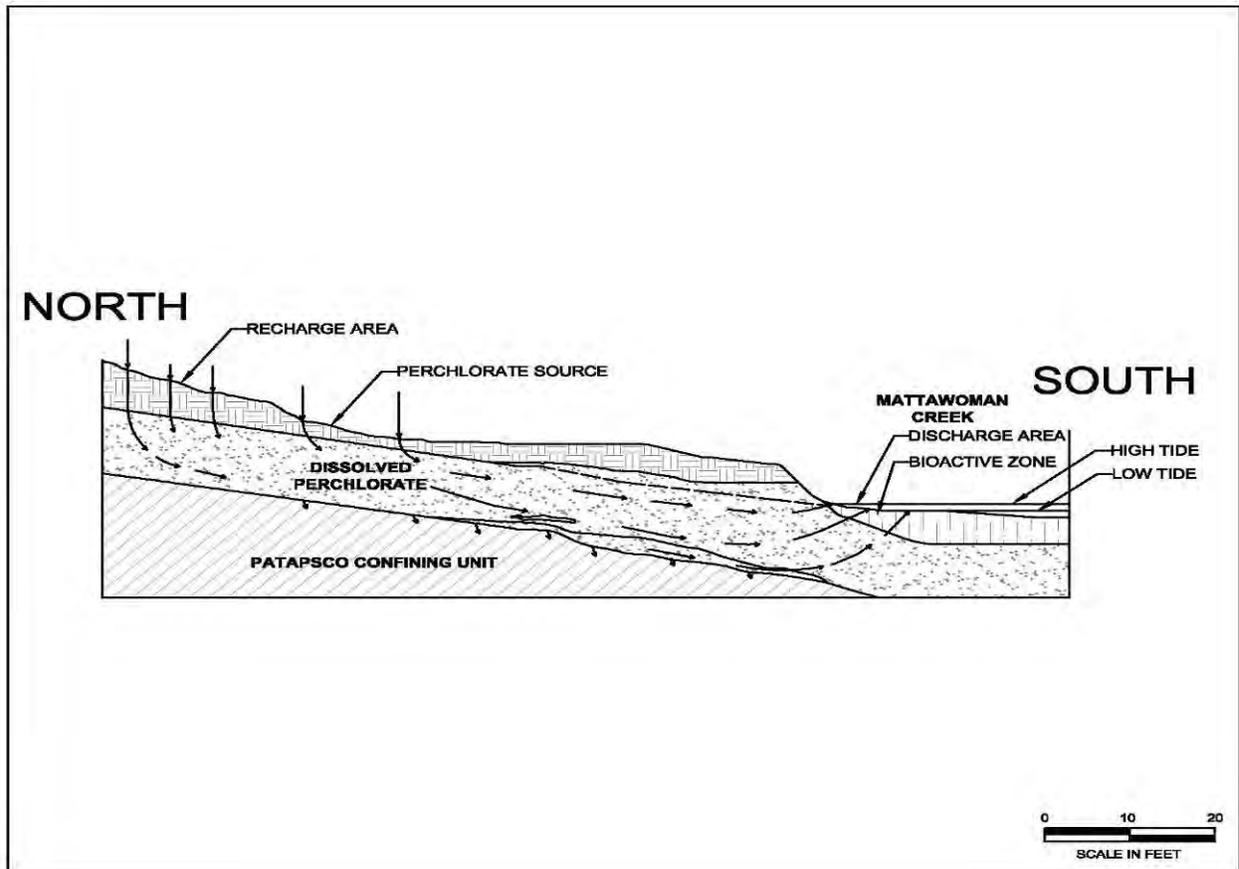


**Figure 5-1. Presumed Source and Conceptual Discharge Areas**

As groundwater migrates from the source area downgradient to the southeast towards Mattawoman Creek, perchlorate concentrations appear to gradually decline with distance. This decline is believed to be due to dilution with uncontaminated groundwater and, possibly, some biodegradation. The underlying Patapsco clay restricts downward movement of dissolved perchlorate so most of the remaining perchlorate mass moves horizontally towards Mattawoman Creek.

In the Littoral Zone adjoining Mattawoman Creek, groundwater begins to rise vertically and eventually discharges to the land surface (**Figure 5-2**). Most of this discharge is concentrated in the intertidal zone, immediately above and below the average water level in the creek (Bokuniewicz, 1992). The long-term average discharge velocity is estimated to be between 0.04 and 0.08 ft/d upward through the Littoral Zone. At low tide, numerous small springs and seeps are evident in the intertidal zone. Discharge rates vary inversely with tide levels, with the highest discharge rate expected to occur during low tides. Groundwater flow reverses during

periods of high tide when water in creek infiltrates a short distance into the Littoral Zone sediment. This cyclic discharge/recharge results in increased mixing of surface water and groundwater in the near-surface Littoral Zone sediments (Westbrook et al., 2005; Robinson et al., 1998). However, chloride concentrations decrease rapidly with depth indicating mixing of surface water and groundwater is limited.



**Figure 5-2. Conceptual Model of Perchlorate Transport**

The shallow sediments in the Littoral and Subtidal Zones appear as organic rich muck (**Figure 5-3**) due to deposition of plant material occurs in these zones. The TOC in shallow and deep sediment samples from the Littoral Zone averaged 9,800 and 2,400 mg/kg, respectively (**Table C1** in **Appendix C**).



**Figure 5-3. Photograph Showing Organic Muck Layer**  
(Eight inches of organic muck obtained by plunging an open ended tube into the creek bottom at the edge of the Subtidal Channel and Subtidal Shallows)

A variety of different pollutants can be anaerobically biodegraded in anaerobic wetland sediments. Lorah et al. (1997) and Lorah and Olsen (1999) found evidence of anaerobic biodegradation of chlorinated VOCs as groundwater migrated from an aerobic sand aquifer upward through anaerobic wetland sediments. Tobias et al. (2001) report that anaerobic, organic-rich, marsh sediments often have high potential rates of nitrate reduction. Portnoy et al. (1998) and Nowicki et al. (1999) also describe the potential for high denitrification rates, but caution that in more sandy, tidal estuaries, rapid groundwater flow through seeps may influence the extent of nitrate removal. Conditions favoring nitrate and perchlorate reduction are similar, suggesting the potential for rapid perchlorate degradation in the organic rich, Littoral Zone sediments at the study site.

Field monitoring data indicate that perchlorate rapidly biodegrades under anaerobic conditions as groundwater migrates upward through the organic-rich Littoral Zone sediments before discharging to the surface. Perchlorate was below the method detection limit ( $< 1 \mu\text{g/L}$ ) in five of six samples collected from shallow monitoring points within the Littoral Zone (TP-1 and TP-4) over the study period. In the one sample above the detection limit ( $6.7 \mu\text{g/L}$  in TP-4 on

3/30/07), perchlorate had been reduced by 99.8% from the value observed 3.5 ft deeper in the aquifer (**Table C2 in Appendix C**)

In Section 6.0, multiple lines of evidence will be used to evaluate and document the natural attenuation of perchlorate in groundwater in the vicinity of Building 1419, Naval Surface Warfare Center, Indian Head, MD.

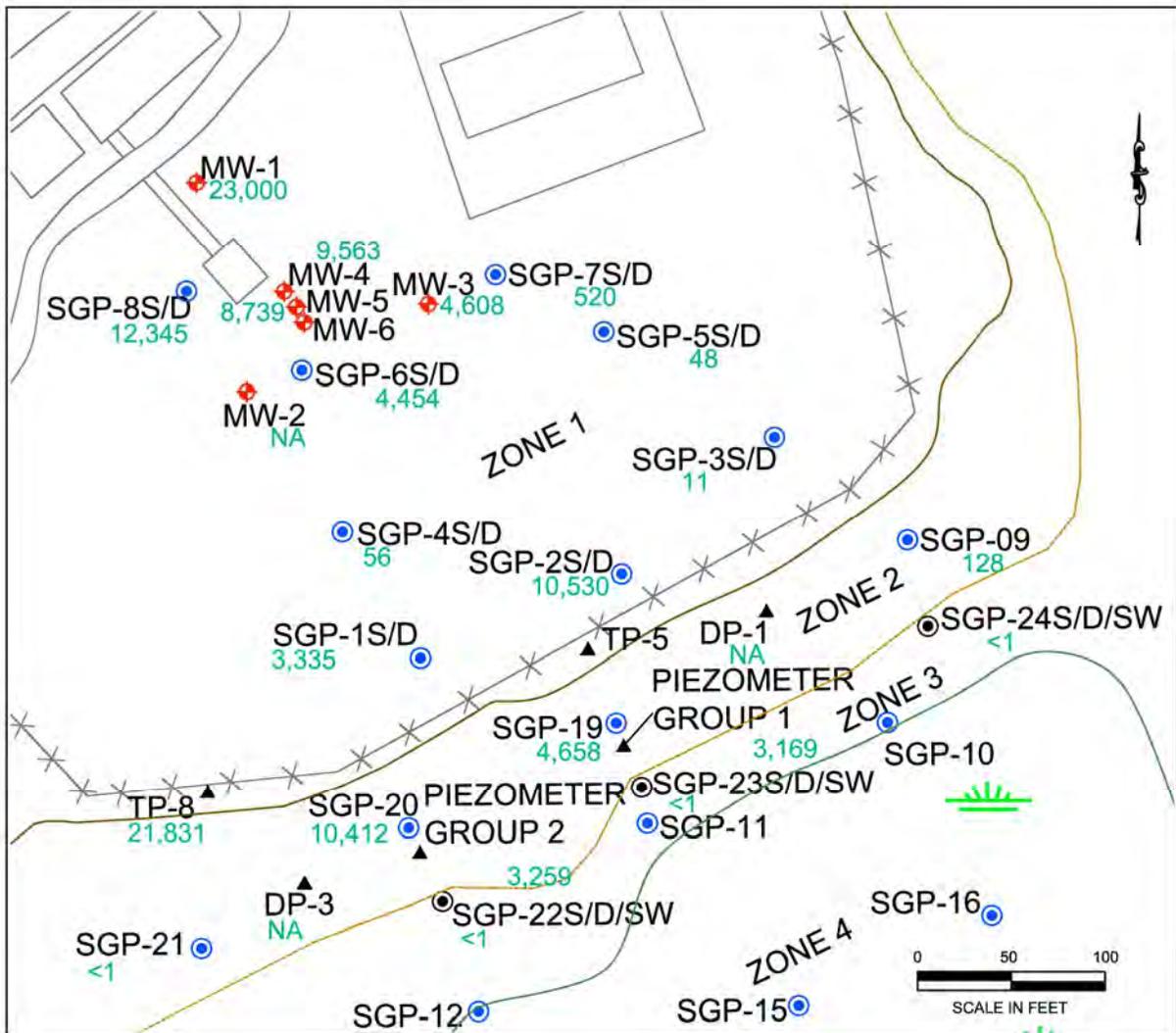
## 6.0 Field MNA Evaluation Program

Acceptance of MNA as a groundwater remedy requires multiple lines of evidence. As discussed in previous sections, analytical methods are available to monitor the concentration of perchlorate in the environment with high sensitivity and selectivity. Geochemical tests can indicate whether ambient conditions are conducive to perchlorate biodegradation, and molecular biological tools are available to monitor the activity and sustainability of perchlorate-reducing bacterial populations. Using these tools and the direction offered in the MNA Protocol, the three tiers of evaluation were applied to the Indian Head site: 1) plume stability and geometry assessment; 2) biogeochemical parameter and biological indicator evaluation; and 3) biodegradation rate estimation (ESTCP, 2008). The following sections summarize our evaluation of the Indian Head site and the lines of evidence supporting the use of MNA as a groundwater remedy.

### 6.1 Tier 1 Evaluation – Plume Geometry and Stability

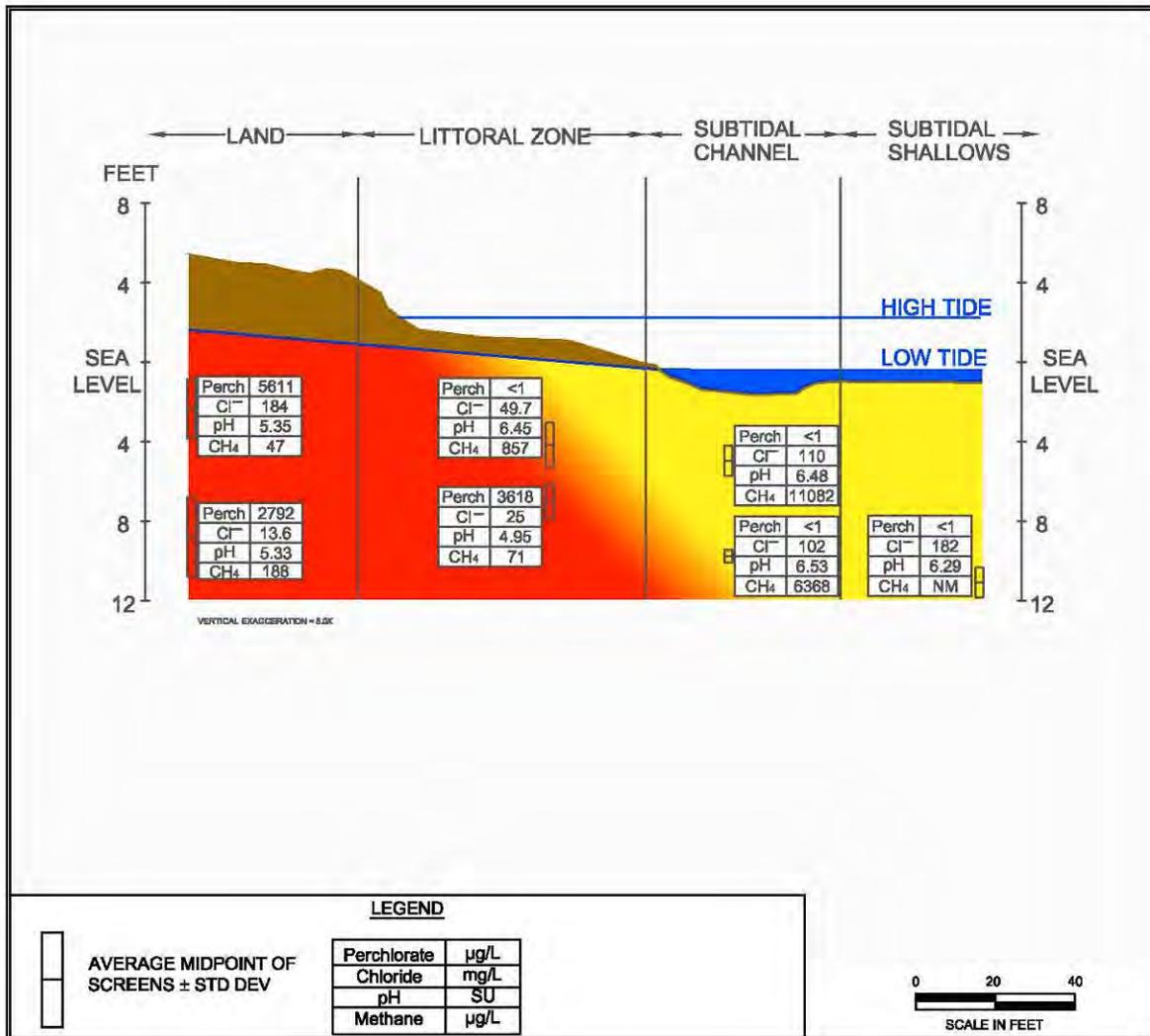
#### 6.1.1 Plume Geometry

Historical data can be used effectively to delineate the extent of the contamination and determine the fate of contaminants of concern. With a properly designed monitor well network, trends in the data can successfully illustrate plume geometry and stability. Ideally, the contaminant plume should be stable or retreating. A stable or shrinking perchlorate plume indicates that natural processes are attenuating perchlorate more rapidly than it is released from the source area. Perchlorate concentrations, summarized from the April 2008 performance monitoring event at the Indian Head site, are shown in **Figure 6-1**. The perchlorate plume extends approximately 460 feet from the Building 1419 area to the Subtidal Channel. The groundwater flow net shown as **Figure 4-11** demonstrates that while the perchlorate is present at the southwest extent of the plume, most of the plume discharges to the south with groundwater to the creek. The data generated during the MNA demonstration suggested that plume geometry has changed very little over time.



**Figure 6-1. Perchlorate Concentration Map (April 2008)**

A longitudinal profile through the different biogeochemical zones is presented graphically in **Figure 6-2** including average levels of perchlorate (Perch), chloride (Cl<sup>-</sup>), methane (CH<sub>4</sub>) and pH in groundwater/pore water in each zone. Perchlorate concentrations are elevated in the both the shallow (avg. = 5,611 µg/L) and deep (avg. = 2,792 µg/L) groundwater on the land and in the deep groundwater beneath the Littoral Zone sediments (avg. = 3,618 µg/L). The transition occurs within the shallow creek sediment in the Littoral Zone where perchlorate is not detected. The loss of perchlorate is the result of both biodegradation and dilution with surface water. The impact of biogeochemical conditions on perchlorate biodegradation is discussed in Section 6.2.



**Figure 6-2. Geochemical Changes in Groundwater (on left) and Sediment Pore Water (on right).**

### 6.1.2 Plume Stability

Many regulatory agencies require that contaminant plumes be stable or shrinking before MNA can be employed as the primary groundwater remediation technology. At Indian Head, downgradient migration of perchlorate is limited by the organic rich sediments adjoining Mattawoman Creek (**Tables 6-1a, b**). Seven of deep monitoring points in the Littoral Zone (SGP-9, SGP-19, SGP-20, TP-3, TP-5, TP-7 and TP-8) have elevated concentrations of perchlorate. However, there is no evidence of an increase in concentration over time. Concentrations in all the shallow and intermediate monitoring points (TP-1, TP-2, TP-4, and TP-6) remained low with no indication of an increase with time, indicating perchlorate is not gradually migrating upward through the Littoral Zone. Perchlorate was less than 1 µg/L in monitoring points within the Subtidal Channel indicating perchlorate was not migrating underneath or into the Subtidal Channel (**Table 6-1c**). No statistically significant trends in concentration versus time were detected for any Littoral Zone or Subtidal Channel well (**Appendix D**).

	SGP-9	SGP-19	SGP-20
June 2006	200	4,400	13,000
Sept 2006	61	4,200	11,000
March 2007	NS	3,400	10,000
August 2007	<1	4,200	1,700
April 2008	130	4,700	10,412

	TP-1	TP-2	TP-3	TP-4	TP-5	TP-6	TP-7	TP-8
March 2007	<1	5.9	2,700	6.7	1800	3.4	3,200	34,000
August 2007	<1	<1	2,400	<1	1300	<1	640	NS
April 2008	<4	<1	3,200	<1	1300	<1	3,300	22,000

NS – Not Sampled

	SGP-21	SGP-22S	SGP-22D	SGP-23S	SGP-23D	SGP-24S	SGP-24D
Sept 2006	<1	<1	<1	<1	<1	<1	<1
August 2007	<1	<1	<1	<1	<1	<1	<1
April 2008	<1	<1	<1	<1	<1	<1	<1

### 6.1.3 Effect of Dilution on Perchlorate Concentrations

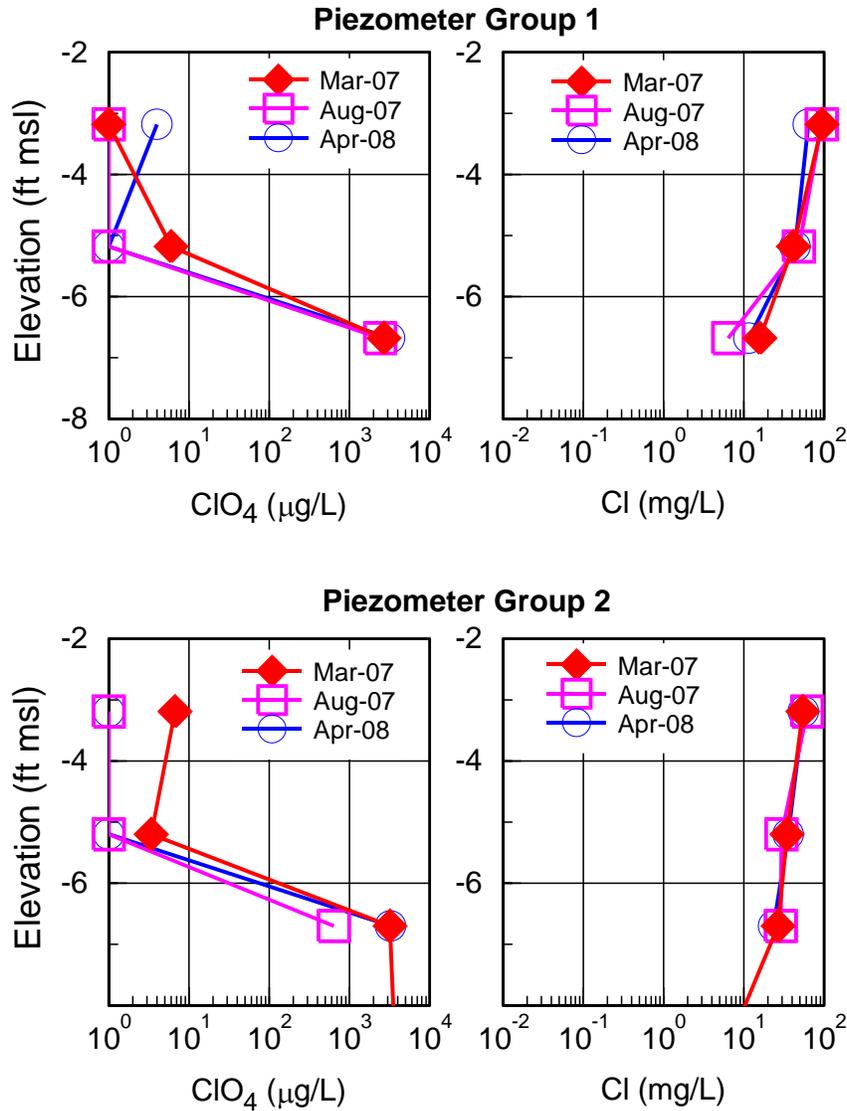
The Littoral Zone monitoring data presented in **Table 6-1b** show that perchlorate concentrations decline from a range between 600 to 3400 µg/L in the deeper monitor points (TP-3 and TP-7) to near the analytical detection limit in the shallow (TP-1 and TP-4) and mid-depth (TP-2 and TP-6) monitoring points. However, some portion of this decline is likely due to dilution with surface water.

One approach for evaluating the relative impact of dilution is to examine changes in chloride concentration with depth. Average chloride concentrations in the deep piezometers are low (11 mg/L in TP-3; 26 mg/L in TP-7) and similar to groundwater near the perchlorate source area (6 to 30 mg/L). In contrast, surface water in the Subtidal Channel had an average chloride concentration of 174 mg/L over the monitoring period. The steady increase in chloride concentration as water flows upward through the Littoral Zone is likely due to tidally driven mixing of surface water and groundwater. By linear interpolation, we can then estimate the relative contribution of groundwater and surface water at each depth. As illustrated in **Table 6-2**, groundwater with an average chloride concentration of 84 mg/L (TP-1) would result from mixing 55% groundwater with 45% surface water. Mixing ratios in TP-2, TP-4 and TP-6 are lower, varying from 79 to 95% groundwater with 21 to 5% surface water.

**Table 6-2  
Groundwater and Surface Water Mixing Ratios in Piezometer Groups 1 and 2**

	<b>Elevation (ft msl)</b>	<b>Average Cl (mg/L)</b>	<b>% Ground -water</b>	<b>% Surface Water</b>	<b>Calculated Cl (mg/L)</b>
<b>Piezometer Group 1</b>					
Surface Water	0	174	0	100	174
TP-1	-3.2	84	55	45	84
TP-2	-5.2	45	80	20	45
TP-3	-6.7	11	100	0	11
<b>Piezometer Group 2</b>					
Surface Water	0	175	0	100	175
TP-4	-3.2	57	79	21	57
TP-6	-5.2	33	95	5	33
TP-7	-6.7	26	100	0	26

As groundwater migrates upward from TP-3 to TP-2, perchlorate declines by three orders of magnitude. At most, 50% of this decline is due to dilution (see Table 6-2), indicating biodegradation is responsible for over 99% of the decline in perchlorate. The large relative change in perchlorate concentration compared to chloride concentration is illustrated in **Figure 6-3**. Perchlorate and chloride concentrations are plotted on a log scale over a four log unit range so changes in perchlorate and chloride can be visually compared. In Piezometer Group 1, perchlorate declines 1000x as groundwater migrates upward from -6.7 ft (TP-3) to -5.2 ft (TP-2), while chloride only increases by 2x. Similar patterns are observed in Piezometer Group 2 where perchlorate declines 1000x while chloride increases by only few percent. These results demonstrate that perchlorate is attenuated much more rapidly than would be expected based on dilution alone.

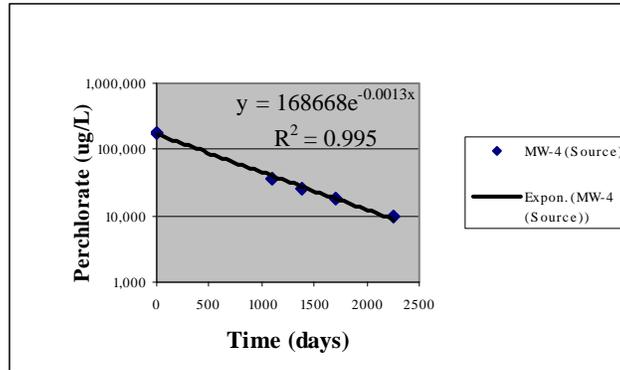


**Figure 6-3. Perchlorate (ClO<sub>4</sub>) and Chloride (Cl) Concentration vs. Depth in Piezometer Groups 1 and 2**

#### 6.1.4 Source Area Attenuation

In contrast to the downgradient wells, many of wells located in the upgradient portion of the plume near the source area have shown significant declines in concentration with time. These declines are likely due to flushing of highly soluble perchlorate out of the aquifer by incoming groundwater.

Attenuation rates in individual wells were calculated by plotting perchlorate concentration versus time and fitting the data to a first-order function [ $C_t = C_i \exp(-K_1 t)$ ] where  $C_t$  is the observed concentration at different times ( $t$ ),  $C_i$  is the fitted initial concentration and  $K_1$  is the estimated 1<sup>st</sup>-order decay rate. **Figure 6-4** is an example of the 1<sup>st</sup>-order attenuation curve fit to the data from MW-4, a well that has been monitored for six years. The attenuation rate constants, time to remediation, and 90% confidence intervals are reported in **Appendix D**.



**Figure 6-4. Perchlorate Concentration vs. Time Curve Fit for MW-4**

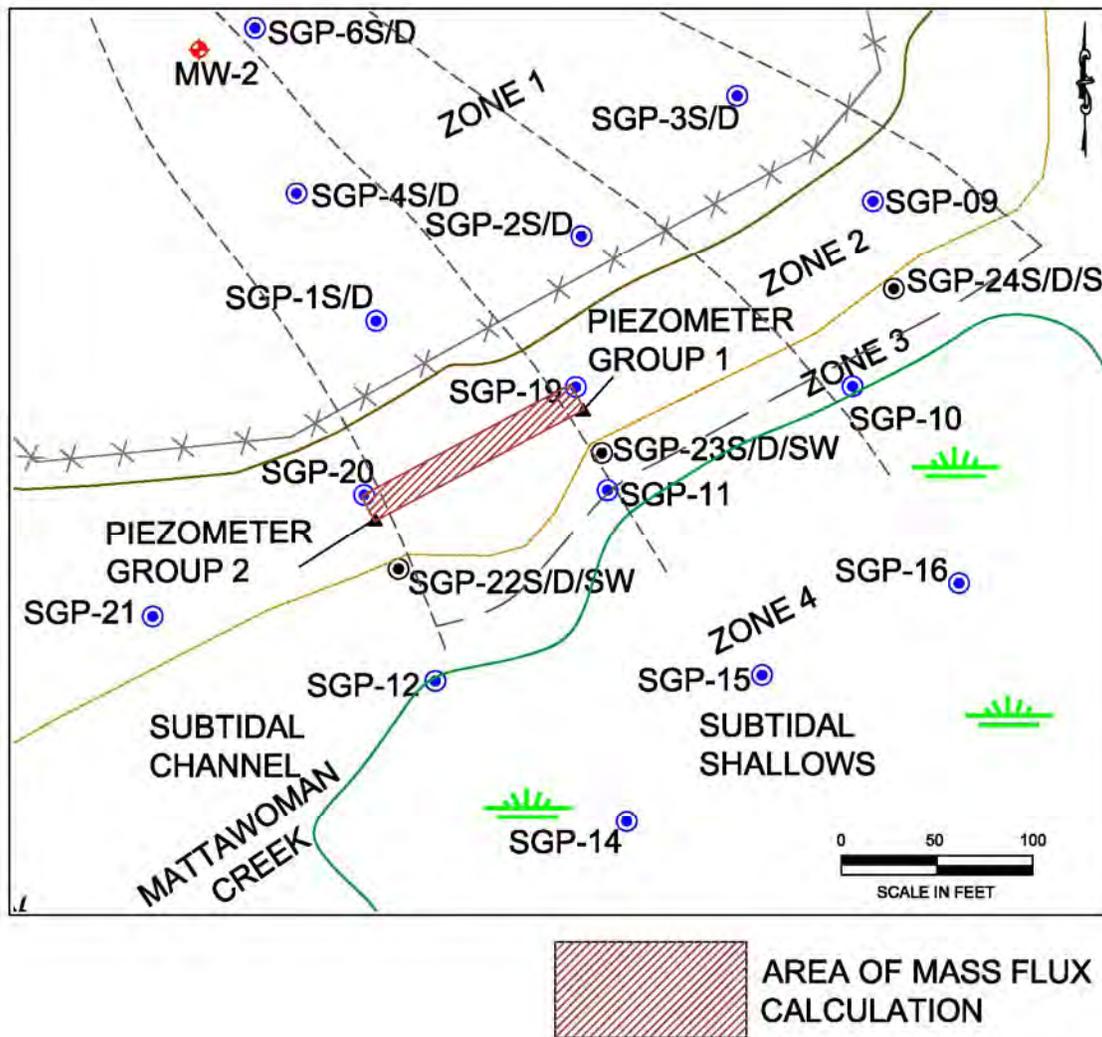
**Table 6-3** summarizes the attenuation rate constants for three monitoring wells near the source area (MW-1, MW-4, and SGP-6S) where the slope of the regression line was statistically significant at the 90% level (F statistics < 0.10). In all wells with a statistically significant trend, the concentration was declining with time. Estimated time to reach the cleanup standard of 24.5 µg/L was also calculated using the best fit linear regression and varied from 11 to 27 years.

Monitoring Well	1 <sup>st</sup> -order Rate (per year)	Correlation Coefficient (R <sup>2</sup> )	F Statistic	Observations	Estimated Years to 24.5 µg/L
MW-1	0.32	0.63	0.06	5	27
MW-4	0.50	0.91	0.003	5	18
SGP-6S	0.57	0.99	0.04	3	11

### 6.1.5 Mass Flux

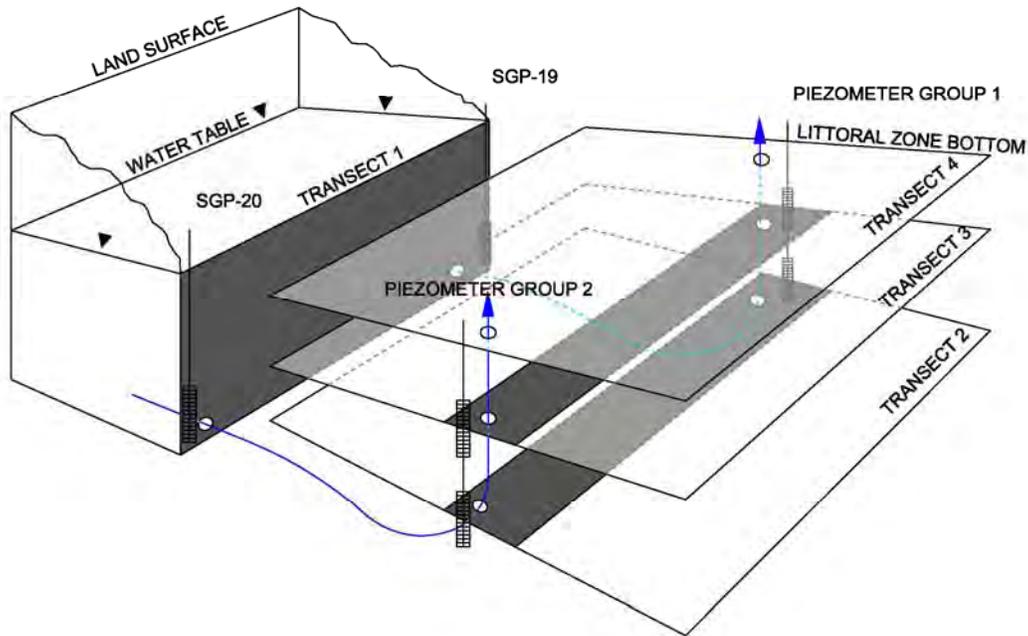
Mass flux is used to describe the contaminant mass discharge rate in a groundwater plume in units of mass per time passing across a plume transect. Contaminant mass flux estimates were determined using the transect method (Newell et al., 2003). The calculations were performed using *The Mass Flux Toolkit* (Farhat et al., 2006) developed under ESTCP to compare different mass flux approaches, calculate mass flux from transect data, and apply mass flux to manage groundwater plumes. The data input and results are included in **Appendix E**.

Mass flux calculations were based on a 100-foot long segment of the plume located within the evaluation area. This segment transects the western-most of the three groundwater flow tubes as shown in **Figure 4-11**. **Figure 6-5** highlights the location of the transects used in the mass flux evaluation.



**Figure 6-5. Mass Flux Evaluation Area**

Four transects were established to analyze groundwater flux. All were oriented approximately normal to the direction of groundwater flow using estimated hydraulic conductivity and average gradients were calculated (transient tidal effects were ignored). **Figure 6-6** shows the location of the four transects in an isometric view. Transect 1 is oriented vertically and is located between wells SGP-19 and SGP-20. Transects 2, 3, and 4 are located between Piezometer Groups 1 and 2. Perchlorate flux calculations for Transect 2 use data from the deeper piezometers TP-3 and TP-7 screened approximately between elevation -6.2 and -7.4 ft msl. Perchlorate flux calculations for Transect 3 use data from intermediate piezometers screened between -4.7 to -5.7 ft msl. Transect 4 is the Littoral Zone creek bottom (mud surface). In evaluating groundwater and perchlorate flux, all of the groundwater entering the Littoral Zone across Transect 1 was assumed to eventually discharge upward across Transect 4 into the creek.



**Figure 6-6. Orientation of Mass Flux Transects**

At Transect 1, groundwater flow is assumed to be horizontal or nearly horizontal and driven by the general water table gradient of 0.020 ft/ft. Aquifer testing of sediment along the bank in the Littoral Zone indicated an average hydraulic conductivity of 2.3 ft/d. The creek bottom occurs at approximately elevation -0.5 ft msl in this area and the thickness of the surficial aquifer was estimated to be approximately 12 feet. The dimensions of Transect 1 input into the *Mass Flux Toolkit* are 12 feet (vertical) by 100 ft (horizontal) for an area of 1,200 ft<sup>2</sup>.

For Transect 1, the calculated groundwater flux ( $Q=K_iA$ ) is 55.2 ft<sup>3</sup> per day. By continuity, the average discharge rate for groundwater passing through Transect 4, entering the creek is also assumed to be 55.2 ft<sup>3</sup> per day with the discharge surface being spread over the distance between the low tide line at the creek bank and the Subtidal Channel, a distance of approximately 50 feet. The dimensions of Transect 4 were input as a length of 50 ft and width of 100 ft, with the width dimension of the transect being oriented parallel to the creek bank. **Table 6-4a** summarizes the groundwater flux calculations.

At Transect 2, the direction of flow is assumed to be upward, but the vector direction is unknown. The hydraulic conductivity was estimated to be approximately 0.4 ft/d (a value selected to be between the estimated vertical  $K_z$  of 0.23 ft/d and the horizontal conductivity  $K_x$  of 2.3 ft/d). By continuity, the gradient was then calculated to be 0.026 ft/ft.

Transect 3 is also located between piezometers TP-2 and TP-6 and is oriented nearly horizontally. The groundwater transect is 100-feet wide by 50-feet long. From continuity, 55.2 ft<sup>3</sup> of groundwater pass through the plane on a daily basis. The hydraulic conductivity was estimated to be 0.3 ft/d and the gradient was calculated to be 0.037 ft /ft.

**TABLE 6-4a**  
**Groundwater Flux Calculations**

Transect Number	1	2	3	4
Orientation of Transect	Vertical	Inclined	Slight Incline	Horizontal
Dimension (ft x ft)	12 x 100	50 x 100	50x100	50 x 100
Gradient (ft/ft)	0.020	*0.026	*0.037	*0.048
Hydraulic Conductivity (ft/d)	2.3	0.4	0.3	0.23
Groundwater Flux (ft <sup>3</sup> /d)	55.2	55.2	55.2	55.2

Notes: \*Gradients (i) were calculated using estimated hydraulic conductivity values (K) from  $Q=KiA$ , where Q was set at 55.2 ft<sup>3</sup>/d and the equation was solved for i.

The calculations for perchlorate mass flux through the transects are summarized in **Table 6-4b**. Transect 1 incorporates the April 2008 perchlorate data from SGP-19 (4,658 µg/L) and SGP-20 (10,418 µg/L). In calculating the perchlorate flux crossing Transect 1, perchlorate concentrations were assumed to be consistent across height of the transect (the aquifer thickness). This was found to be the case in many of the shallow and deeper wells within the land area. The daily perchlorate flux for Transect 1 was calculated by the *Mass Flux Toolkit* to be 12.4 grams (Appendix E). On a per square foot basis (shaded area in **Figure 6-6**) for Transect 1 (1,200 ft<sup>2</sup>), this represents a perchlorate flux of approximately 10 mg/day/ft<sup>2</sup>. Dividing this number by the width of the segment (100 ft) parallel to the creek bank suggests that the perchlorate flux entering the sediment beneath the creek is approximately 124 mg per day per linear foot (mg/d/lin ft) of bank.

Transect 2 also incorporates the April 2008 perchlorate data from TP-3 (3,169 µg/L) and TP-7 (3,259 µg/L). The perchlorate flux calculation was based on an inclined plane with of 100 feet and an inclined length dimension of 2 feet, for an area of 200 ft<sup>2</sup> (the shaded area in **Figure 6-6**). The perchlorate mass flux calculated by the *Mass Flux Toolkit* for the 200 ft<sup>2</sup> area comprising a portion of Transect 2 is 0.208 g/d (Appendix E). This is equivalent to a daily perchlorate flux of 0.001 g/ft<sup>2</sup>/d, or an average perchlorate daily perchlorate flux of approximately 5.2 mg/d/lin ft of creek bank.

Perchlorate has not been detected in either of the two piezometers used to model Transect 3. However, in order to estimate a perchlorate mass flux, concentrations of the laboratory detection limit (1.0 µg/L) for perchlorate were input into the analysis for both of the piezometers. The perchlorate mass flux calculated for the 200 ft<sup>2</sup> portion of Transect 3 is  $6.92 \times 10^{-5}$  grams per day (Appendix E). This is equivalent to a daily perchlorate flux of  $3.46 \times 10^{-7}$  g/ft<sup>2</sup>/d, or an average perchlorate daily perchlorate flux of approximately  $1.73 \times 10^{-2}$  mg/d/lin ft of creek bank. Perchlorate mass flux was not calculated for Transect 4 as perchlorate concentrations are reduced to non-detectable concentrations in Transect 3.

**TABLE 6-4b**  
**Perchlorate Mass Flux Calculations**

<b>Transect Number</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Orientation of Transect</b>	Vertical	Inclined	Slight Incline	Horizontal
<b>Perchlorate Flux Calculations</b>				
Dimension (ft x ft)	12 x 100	2 x 100	2 x 100	Not Evaluated
Perchlorate Flux (g/d)	12.4	0.208**	$6.92 \times 10^{-5}$ **	Non Detect
Perchlorate Flux (mg/d/lin. ft)	124	5.2	$1.73 \times 10^{-2}$	Non Detect

Notes: \*\*Flux calculations shown in Appendix E are based on a 2 x 100 ft segment of the 50 x 100 ft transect plane.

The data show that perchlorate mass flux is reduced to non-detect over a relatively short vertical distance between the screens for the deep piezometers and the intermediate depth piezometers. Data collected from the shallow piezometers confirm that perchlorate concentrations remain below detection.

### **6.1.6 Summary of Plume Geometry and Stability Evaluation (Tier 1)**

Groundwater monitoring data collected as part of the MNA evaluation indicate the following:

- The perchlorate plume is generally stable and there is no evidence of continuing downgradient migration. Concentrations in the most downgradient wells with detectable perchlorate were stable over the monitoring period. Further downgradient, perchlorate concentrations are close to or below the analytical detection limit.
- Within the Littoral Zone, perchlorate concentrations decline much more rapidly than would be expected based on dilution alone. This implies that perchlorate biodegradation within the organic rich sediments is the dominant attenuation mechanism.
- Perchlorate concentrations are gradually declining with time in the source area monitor wells. If current trends continue, perchlorate concentrations will drop below 24.5 µg/L in many of these wells within 30 years.
- The estimated perchlorate mass flux decreased by over 4 orders of magnitude during migration through the organic rich sediments of the shallow Littoral Zone.

### **6.2 Tier 2 Evaluation – Biogeochemical Parameters and Biological Indicators**

Site-specific biogeochemical and biological information can often provide an important indication of the potential for MNA of perchlorate. The following section describes collection and interpretation of biogeochemical and biological monitoring results from the Indian Head site and how this information was used to evaluate the potential for MNA of perchlorate. The results illustrate the use of a tiered approach for evaluating perchlorate MNA as described in “Natural Attenuation of Perchlorate in Groundwater: Processes, Tools and Monitoring Techniques” (ESTCP, 2008).

Perchlorate can be rapidly biodegraded under anaerobic or low oxygen conditions when an external electron donor is present. Biodegradation will be most rapid in the absence of nitrate since many perchlorate degraders are also denitrifiers (Robertson et al., 2007; Herman and Frankenberger, 1999; Coates et al., 1999). Tan et al. (2004a) showed the presence of nitrate can slow perchlorate enzyme activity as it is a competing electron acceptor, but concluded that

because more than one enzyme is involved in the degradation process, nitrate is not a competitive inhibitor of perchlorate reduction. Tan et al. (2004b) and Tan et al. (2005) concluded that organic substrate availability was the limiting factor under high electron acceptor conditions. As a result, the following conditions are expected to be most favorable for perchlorate biodegradation (ITRC, 2002):

- Available organic carbon;
- ORP between 0 and -100 mV;
- Low levels of dissolved oxygen and nitrate;
- Elevated levels of dissolved iron and/or methane;
- pH between 6.5 and 7.5; and
- Active perchlorate-degrading microbial community.

The key geochemical parameters were evaluated in each well or piezometer sampled during the five performance monitoring events over 38 months between February 2005 and April 2008. The methods used were described in **Section 3.5.1**. Additional parameters included chloride, sulfate, phosphate, nitrite, conductivity, temperature, turbidity, dissolved manganese and dissolved iron.

**Tables 6-5** and **6-6** summarize the levels of perchlorate, TOC, ORP, pH, methane and chloride in the monitor wells when most recently sampled. The wells were separated into two groups, shallow and deep, based on the elevation of the well screen. The mid-points of shallow well screens are above -5.9 ft msl (ft above mean sea level). The mid-points of deep well screens are below -6.0 ft msl. The tables also list the relative location of each monitoring point: Zone 1 (Land); Zone 2 (Littoral); Zone 3 (Subtidal Channel); and Zone 4 (Subtidal Shallows).

**Table 6-5  
Performance Monitoring in Shallow Wells**

Location & Transect	Screen Mid-Point* (ft msl)	Well ID	Sample Date	Perchlorate (µg/L)	TOC (mg/L)	ORP (mV)	pH (SU)	Methane (µg/L)	Chloride (mg/L)
Land	-1.17	MW-1	4/17/08	18,000	1.7	127	6.12	7	29
Land	1.22	SGP-7S	4/17/08	520	3.2	44	6.27	<4	2.4
Land	-2.99	MW-2	9/28/06	6	5.1	22	6.73	NA	2.1
Land	-3.25	MW-5	4/17/08	8,800	2.7	48	6.46	6	5.3
Land	-3.36	MW-4	4/17/08	9,600	2.5	101	5.95	92	9.4
Land	-0.40	MW-3	4/17/08	4,100	2.2	89	5.19	<4	5.1
Land	-1.19	SGP-8S	4/17/08	12,000	2.0	163	4.41	250	32
Land	-1.90	TP-8	4/16/08	22,000	2.4	132	3.98	130	28
Land-B	-2.21	SGP-4S	4/17/08	56	2.9	17	6.79	48	1.2
Land	-2.24	SGP-6S	4/17/08	4,500	1.6	89	5.23	16	17
Land	-3.23	SGP-3S	4/15/08	11	1.8	53	4.96	<4	16
Land-C	-3.48	TP-5	4/16/08	1,300	2.5	-31	5.98	150	130
Land-C	-3.58	SGP-2S	4/15/08	11,000	1.1	102	4.39	10	17
Land	-3.46	SGP-7D	4/17/08	390	1.7	152	4.74	17	2.8
Land	0.13	SGP-5S	4/17/08	48	1.1	110	4.44	<4	4.9
Land-B	-5.70	SGP-1S	4/15/08	3,300	1.2	84	4.88	8	3.6
Land	-4.51	SGP-5D	4/17/08	210	1.2	98	4.46	18	11
			<b>Average</b>	<b>5,611</b>	<b>2.1</b>	<b>82</b>	<b>5.35</b>	<b>47</b>	<b>18.4</b>
Littoral-C	-3.18	TP-1	4/16/08	<1	4.9	-59	6.50	2,000	64
Littoral-C	-5.18	TP-2	4/16/08	<1	4.3	4-24	6.39	640	44
Littoral-B	-3.17	TP-4	4/16/08	<1	5.9	-9	6.68	400	56
Littoral-B	-5.17	TP-6	4/16/08	<1	2.4	1.4	6.24	400	36
			<b>Average</b>	<b>&lt;1</b>	<b>4.4</b>	<b>-23</b>	<b>6.45</b>	<b>857</b>	<b>49.7</b>
Channel-B	-3.96	SGP-22S	4/16/08	<1	11.4	-3.9	6.25	4,549	110
Channel-B	-5.38	SGP-22D	4/16/08	<1	4.9	383	3.41	25	97
Channel	-4.81	SGP-24S	4/16/08	<1	11.9	-76	6.54	19,340	130
Channel-C	-5.69	SGP-23S	4/16/08	<1	11.8	-77	6.66	9,356	100
			<b>Average</b>	<b>&lt;1</b>	<b>11.7</b>	<b>-52</b>	<b>6.48</b>	<b>11,082</b>	<b>110</b>

\*Shallow wells have screen mid-point starting at -5.90 ft above mean sea level (ft msl) or above.  
Transects (Sections) are shown on **Figures 4-3 and 4-4**.

**Table 6-6  
Performance Monitoring in Deep Wells**

Location & Transect	Screen Mid-Point*	Well ID	Sample Date	Perchlorate	TOC	ORP	pH	Methane	Chloride
	(ft msl)			(µg/L)	(mg/L)	(mV)	(SU)	(µg/L)	(mg/L)
Land	-12.07	SGP-8D	4/17/08	11	4.5	50	6.24	<4	22
Land	-6.09	SGP-6D	4/17/08	<1	24.4	18	6.35	1,098	26
Land-C	-8.19	SGP-2D	4/16/08	10,000	1.2	91	5.05	9	13
Land	-8.14	SGP-4D	4/17/08	2,400	2.0	78	5.47	7	4.1
Land	-8.42	SGP-3D	4/16/08	210	1.0	104	4.01	6	8.7
Land-B	-9.88	SGP-1D	4/16/08	4,000	1.2	86	4.88	7	7.5
			<b>Average</b>	<b>2,792</b>	<b>5.7</b>	<b>71</b>	<b>5.33</b>	<b>188</b>	<b>13.6</b>
Littoral-C	-8.21	SGP-19	4/16/08	4,700	1.2	13	4.89	<4	6.2
Littoral	-8.10	SGP-9	4/16/08	130	0.9	48	4.90	20	18
Littoral-B	-6.30	SGP-20	9/27/06	10,000	1.6	48	4.25	116	14
Littoral	-6.35	SGP-21	4/17/08	<1	8.0	1	6.22	117	95
Littoral-B	-6.67	TP-7	4/16/08	3,300	1.6	52	4.84	25	24
Littoral-B	-9.17	DP-2	3/30/07	3,700	NA	NA	NA	NA	6.2
Littoral-C	-6.85	TP-3	4/16/08	3,200	1.0	45	4.62	147	12
			<b>Average</b>	<b>3,618</b>	<b>2.4</b>	<b>34</b>	<b>4.95</b>	<b>71</b>	<b>25.0</b>
Channel-C	-10.00	SGP-23D	4/16/08	<1	4.4	-29	6.70	630	100
Channel	-9.53	SGP-24D	4/16/08	<1	4.7	-80	6.36	12,105	100
			<b>Average</b>	<b>&lt;1</b>	<b>4.6</b>	<b>-55</b>	<b>6.53</b>	<b>6,368</b>	<b>100</b>
Shallows	-11.42	SGP-10	9/26/06	<1	7.4	-57	6.05	NA	16
Shallows-C	-11.11	SGP-11	9/26/06	<1	10.0	-83	5.94	NA	62
Shallows	-10.52	SGP-15	9/26/06	<1	13.0	-96	6.34	NA	240
Shallows	-11.90	SGP-16	9/26/06	<1	13.0	-119	6.42	NA	190
Shallows-B	-10.84	SGP-12	9/26/06	<1	14.0	-226	6.22	NA	190
Shallows	-12.50	SGP-13	9/26/06	<1	14.0	-130	6.40	NA	230
Shallows	-10.55	SGP-14	9/26/06	<1	16.0	-151	6.30	NA	260
Shallows	-10.23	SGP-17	9/26/06	<1	32.0	-139	6.46	NA	180
Shallows	-10.67	SGP-18	9/26/06	<1	35.0	-147	6.47	NA	150
			<b>Average</b>	<b>&lt;1</b>	<b>17.2</b>	<b>-127</b>	<b>6.29</b>	<b>NA</b>	<b>180</b>

\*Deep wells have screen mid-point starting at -6.00 ft above msl or deeper  
Transects (Sections) are shown on **Figures 4-3 and 4-4**

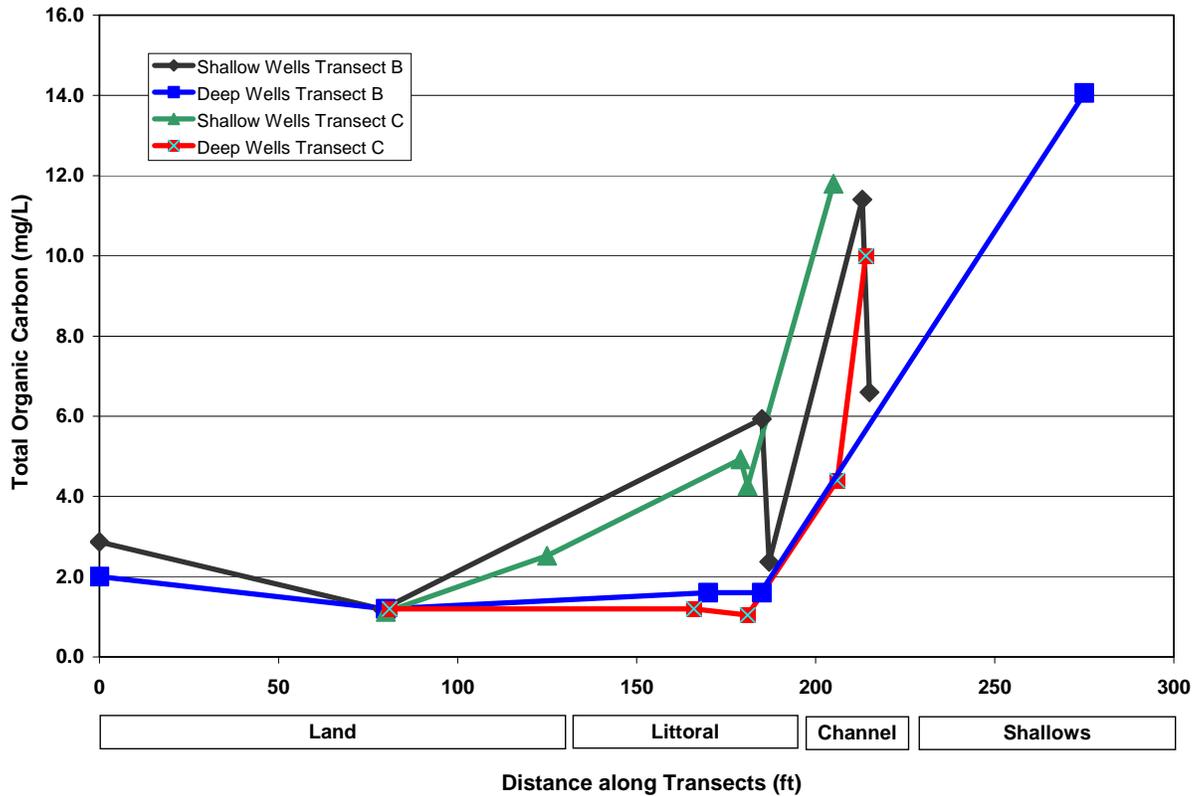
### 6.2.1 Total (or Dissolved) Organic Carbon

Total or dissolved organic carbon in groundwater serves as an electron donor for perchlorate biodegradation, with TOC levels > 2 mg/L considered to be a favorable indicator of perchlorate biodegradation (ESTCP, 2008). Naturally occurring sources of carbon can be found in wetlands, Littoral Zones, and riparian buffers. Rectanus et al. (2007) showed that aquifer sediments can be the source of organic carbon capable of supporting reductive dechlorination of chloroethene compounds. When perchlorate plumes enter carbon-rich environments, there is increased potential for perchlorate MNA.

Beneath the Land Zone, the TOC of shallow and deep groundwater is typically in the range of 2 mg/L (**Tables 6-5** and **6-6**), with the exception one anomalously high value of 24.4 mg/L TOC observed in SGP-6D. The low TOC levels in the Land Zone are less than optimal for perchlorate biodegradation.

The shallow sediments in the Littoral and Subtidal Zones appear as organic-rich muck (**Figure 5-3**). In sediment samples collected during monitor well installation in June 2006, average TOC levels were 9,800 and 2,370 mg/kg in shallow and deep sediment, respectively (**Table C1** in **Appendix C**). Moving away from the shoreline, the TOC in shallow and deeper sediments beneath the Subtidal Shallows averaged 30,700 and 34,400 mg/kg, respectively.

The high sediment TOC results in an increase in groundwater TOC during migration from the land into the Littoral Zone sediments and Subtidal Channel. **Figure 6-7** shows that TOC concentration in groundwater and pore water increases along transects B-B' and C-C' from the land through the Littoral Zone to the Subtidal Channel and Subtidal Shallows. The results are similar in between the two transects. The somewhat higher TOC levels in the shallow sediments (2.4 to 5.3 mg/L) of the Littoral Zone are likely due to deposition and decay of plant material in this area. The largest TOC increases occur at the transition from the Littoral Zone to the Subtidal Channel. TOC concentrations in the shallow groundwater (pore water) beneath the Subtidal Channel range from 4.9 to 11.9 mg/L and in the deep groundwater from 4.4 to 4.7 mg/L. Further increases are noted beneath the Subtidal Shallows. These elevated TOC concentrations would be expected to support rapid biodegradation of any perchlorate that might reach these zones.



**Figure 6-7. Changes in Total Organic Carbon along Transects B-B' and C-C'**

### 6.2.2 Oxidation-Reduction Potential

ORP is a measure of the relative oxidizing or reducing condition of an aquifer. The ORP of groundwater generally ranges from -400 mV to +800 mV. As illustrated in **Figure 6-8**, perchlorate reduction typically begins when ORP drops below about 0 mV (ITRC, 2002). In most cases, the ORP will not drop below -100 mV until all the perchlorate has been consumed.

**Tables 6-5** and **6-6** show the ORP measurements in shallow and deep groundwater in the monitoring network mostly from data collected in April 2008. Some additional dates are used to provide a more comprehensive overview of the data. **Figure 6-9** shows ORP values in transects B-B' and C-C'' relative to distance from the shoreline. In the Littoral Zone, ORP is appropriate for perchlorate biodegradation, and then decreases further in the Subtidal Channel and Shallows once all the perchlorate has been depleted. The ORP in the shallow mainland aquifer is generally oxidative ranging from +17 and +102 mV. Pore water within the creek sediment becomes progressively more reducing with increasing distance from the shore; shallow and deep Littoral Zone (-23 and +34 mV, respectively), shallow and deep Subtidal Channel (-52 and -55 mV, respectively); and deep Subtidal Shallows (-127 mV). Decreasing ORP is correlated with increasing TOC ( $r^2 = 0.71$ ).

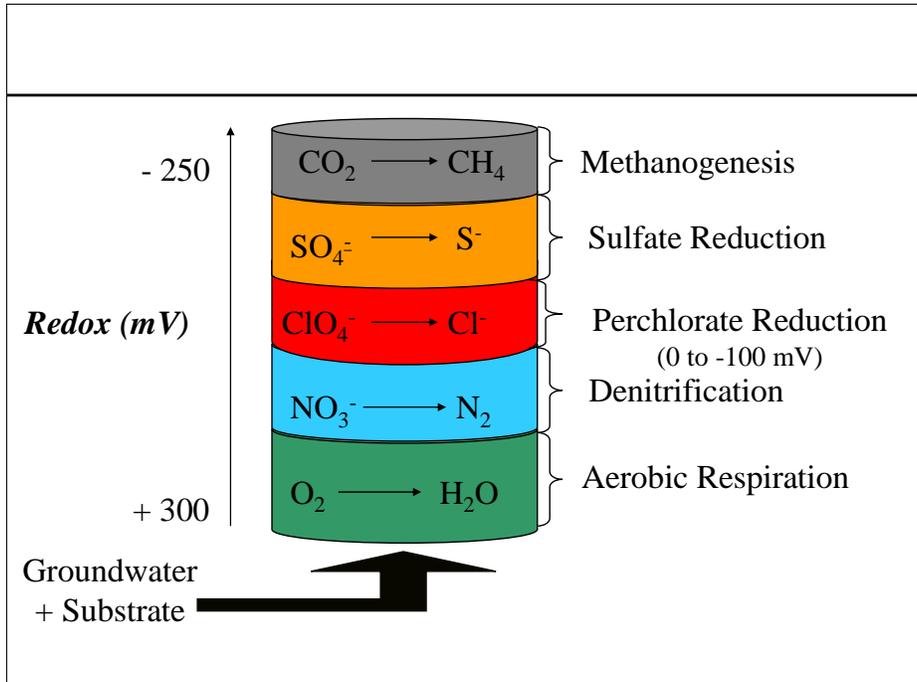


Figure 6-8. Oxidation-Reduction (Redox) Potential for Degradation Processes (ITRC, 2002)

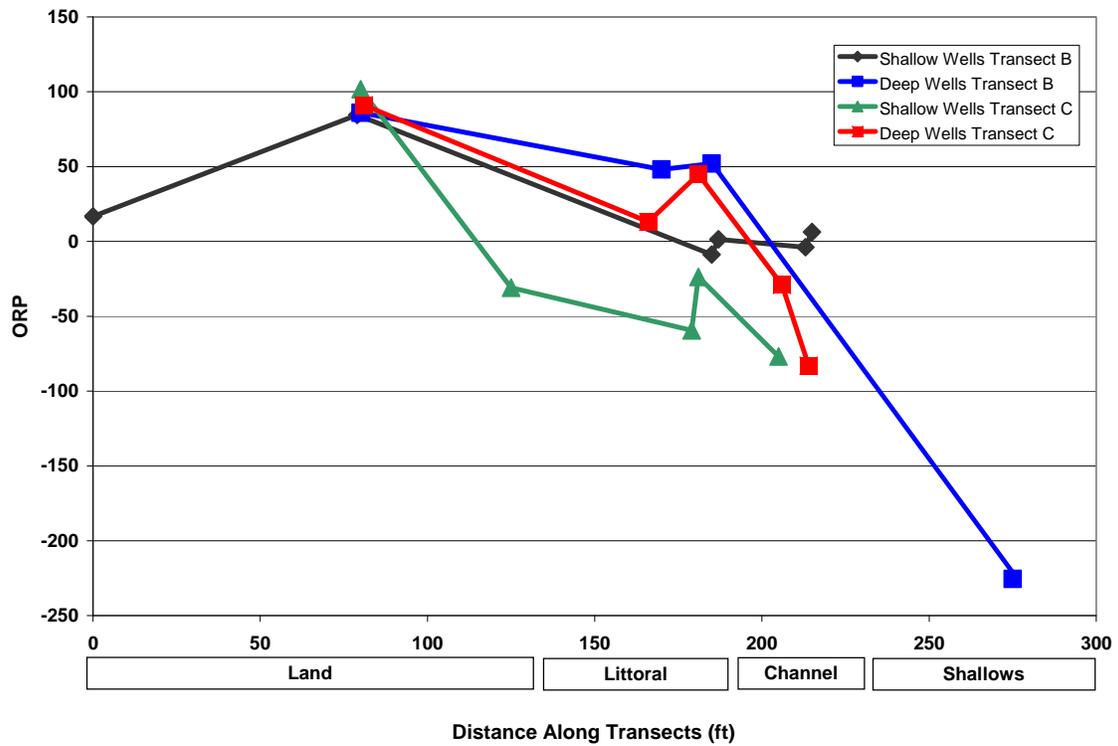


Figure 6-9. Changes in Oxidation-Reduction Potential along Transects B-B' and C-C'

### 6.2.3 Dissolved Oxygen

Perchlorate reduction can be inhibited in some organisms when dissolved oxygen levels exceed 2 mg/L (Coates and Achenbach, 2006; Chaudhuri et al., 2002). So in theory, the presence or absence of dissolved oxygen should be an important indicator of the potential for perchlorate reduction. However in practice, measured dissolved oxygen levels may not be reliable.

Groundwater samples were collected from each well by low flow sampling using a peristaltic pump. Once pH, temperature and conductivity levels stabilized, DO was measured by inserting a CHEMetrics™ high DO ampoule (1.0 – 12 mg/L range) into the end of the plastic tubing as water flowed out. The end of the ampoule was then snapped off, the ampoule mixed, and color change was visually observed to determine oxygen content. When the oxygen concentration was less than 1.0 mg/L, the process was repeated with the low DO range (0.1 mg/L to 1.0 mg/L) ampoules. By inserting the end of the ampoule into the flowing water stream, we had hoped to prevent introduction of atmospheric oxygen into the sample. Unfortunately, this approach does not appear to have been fully effective. Field measurements of dissolved oxygen (DO) concentrations measured in wells during this project are presented in **Table C3** in **Appendix C**.

As described below, wells installed in the Subtidal Channel and Shallows had elevated levels of dissolved iron and methane, indicative of strongly reducing anaerobic conditions. Yet substantial amounts of dissolved oxygen (2 to 5 mg/L) were occasionally observed in these wells. These observations are contradictory since iron reduction and methanogenesis would be strongly inhibited at these DO levels.

**Table 6-7** shows measured values of DO, iron and methane in SGP-22D, -23D and -24D on three different dates. In all three wells on every date, measured DO levels were 0.8 mg/L or greater. If oxygen were actually present in the groundwater at these levels, iron reduction and methanogenesis would be completely inhibited. It seems likely that there was some error in the DO measurements. Potential sources of error include: (a) introduction of oxygen to the aquifer as a result of well installation just prior to sampling on September 27, 2006 and (b) introduction of oxygen to the wells by purging the wells dry before allowing recharge and sampling.

**Table 6-7**  
**Comparison of DO, Iron and Methane Levels in SGP-22D, -23D and -24D**

Monitoring Point	Date	Dissolved Oxygen (mg/L)	Iron (mg/L)	Methane (mg/L)
SGP-22D	9/27/06	4.5	390	NA
	8/8/07	1.5	>300	0.012
	4/16/08	1.0	175	0.025
SGP-23D	9/27/06	5.0	30	NA
	8/8/07	3.5	>300	1.2
	4/16/08	0.8	45	0.63
SGP-24D	9/27/06	2.5	10	NA
	8/8/07	2.0	300	4.4
	4/16/08	0.8	5	12. / 11.

Monitoring data collected during this study suggest that field measurements of dissolved oxygen obtained using low-flow purging techniques may not provide a reliable indicator of *in situ* redox conditions and the potential for perchlorate reduction.

#### 6.2.4 Nitrate

Many DPRBs can reduce nitrate as well as perchlorate (Herman and Frankenberger, 1998) and perchlorate reduction and denitrification (the conversion of nitrate to nitrogen gas) require similar geochemical conditions. Nzengung et al. (2008) observed that indicators of nitrate reduction should also be good indicators of perchlorate reduction. However, high levels of nitrate can inhibit perchlorate reduction (Chaudhuri et al., 2002; Krauter et al., 2005). As a result, low nitrate levels (< 5 mg/L) are preferred for the most efficient perchlorate attenuation. However, the presence of nitrate does not preclude perchlorate reduction since some species of DPRB will degrade perchlorate in the presence of nitrate (Coates and Achenbach, 2006).

In upgradient wells near the source area (MW-1, MW-5, SPG-4S, SPG-8S), nitrate levels are elevated, presumably due to oxidation of ammonia associated with ammonium perchlorate. However, as groundwater migrates downgradient, nitrate levels decline suggesting some biological reduction is occurring. As groundwater enters the Littoral Zone, nitrate levels drop below 5 mg/L and then drop below the analytical detection limit (0.5 mg/L) indicating good conditions for perchlorate reduction.

#### 6.2.5 Iron

An increase in dissolved iron, Fe(II), can be an indicator of a reducing environment conducive to perchlorate degradation. Dissolved iron concentrations greater than 0.5 mg/L suggest conditions favorable for perchlorate biodegradation.

Fe(II) was measured frequently during the performance monitoring using Chemetrics® field test kits. The colorimetric test is semi-quantitative and can be influenced by natural coloration of the water sample. The results of analysis of groundwater collected from wells and piezometers in shallow and deep groundwater along transects B-B' and C-C' are shown in **Table 6-8**.

The increase in Fe(II) and methane concentrations generally follow the decrease in ORP as discussed in previous sections. Fe(II) concentrations in the sediment pore water generally increases with increasing distance south from the creek bank. Fe(II) concentrations are consistently highest in pore water collected from sediment in the Subtidal Channel and Subtidal Shallows, likely a result of being more strongly reducing in these environments that are continuously submerged. There is no distinguishable difference between Fe(II) concentrations measured in shallow or deep wells at any similar location.

<b>Table 6-8 Dissolved Iron Concentrations in Shallow and Deep Groundwater</b>						
<b>Location</b>	<b>Sample Date</b>	<b>Well ID</b>	<b>Dissolved Iron (mg/L)</b>	<b>Sample Date</b>	<b>Well ID</b>	<b>Dissolved Iron (mg/L)</b>
<i>Shallow Groundwater</i>						
	Transect B-B'			Transect C-C'		
Land	4/15/08	SGP-1S	0	4/15/08	SGP-2S	0
Land	4/16/08	TP-8	30	4/16/08	TP-5	20
Littoral	4/16/08	TP-4	7.5	4/16/08	TP-1	5
Littoral	4/16/08	TP-6	5.0	4/16/08	TP-2	15
Channel	4/16/08	SGP-22S	45	4/16/08	SGP-23S	90
Channel	9/27/06	SGP-22D	175			
<i>Deep Groundwater</i>						
	Transect B-B'			Transect C-C'		
Land	4/16/08	SGP-1D	5	4/16/08	SGP-2D	0
Littoral	9/27/06	SGP-20	5	4/16/08	SGP-19	5
Littoral	4/16/08	TP-7	15	4/16/08	TP-3	7.5
Channel				4/16/08	SGP-23D	45
Shallows	9/26/06	SGP-12	0	9/26/06	SGP-11	120

### 6.2.6 Methane

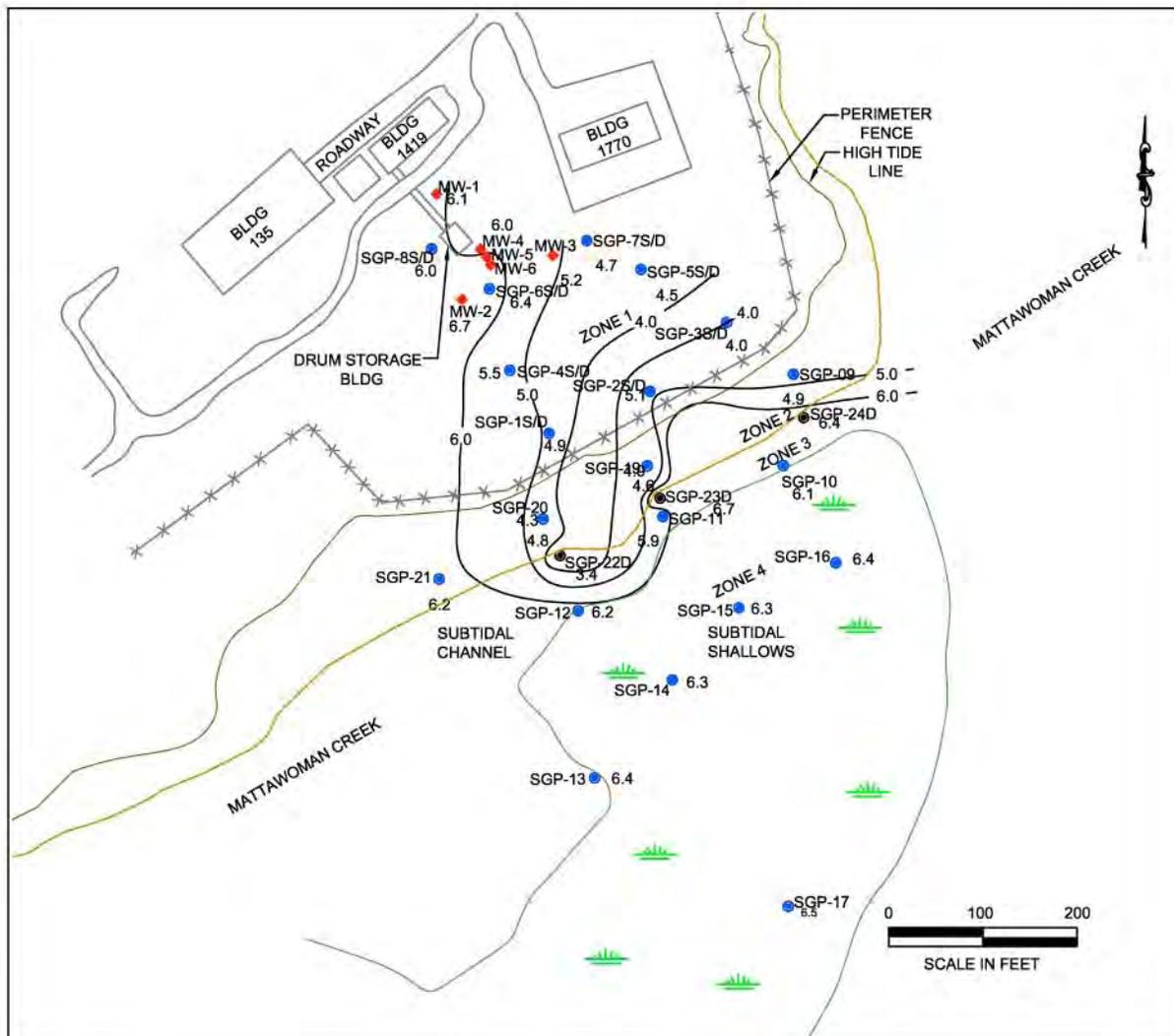
The presence of methane in groundwater is not a prerequisite for perchlorate biodegradation, since methanogenesis requires much more reducing conditions than perchlorate reduction. However, elevated methane levels do indicate the strongly reducing conditions with elevated levels of bioavailable carbon which would result in rapid perchlorate biodegradation.

**Tables 6-5** and **6-6** show methane concentrations in the shallow and deep groundwater beneath the site. Methane concentrations are low throughout the source area. However, methane is occasionally detected in upgradient wells (MW-4, SGP-8S/D) suggesting some potential for perchlorate degradation in the Land area. As groundwater enters the shallow Littoral zone sediments, methane concentrations increase appreciably due to increased TOC, lower ORP and neutral pH. The highest methane concentration is reported in pore water within the shallow Subtidal Channel sediment.

### 6.2.7 pH

The pH in groundwater at the Indian Head site is generally acidic and ranges from 4 to 6 standard units. Perchlorate-reducing bacteria generally grow best at pH values near neutral. However, field studies have shown that some species are capable of growth and perchlorate respiration at pH values as low as 5 (Coates and Achenbach, 2004; 2006). In evaluating the potential for MNA of perchlorate, pH values between 5 and 8 are preferable.

**Figure 6-10** shows is pH isocontours obtained from the monitoring network of deeper wells and piezometers in April 2008. There appears to be an area in the south-southeast portion of the site that is with generally more acidic pH. Historical records indicate this area of the site was previously used to off-load acid from a rail spur. Anecdotal information from site managers suggested that historical spills might have occurred in this area although none appear to be documented. The zone of lower pH extends to the south to the vicinity of SGP-22 located at the edge of the Littoral Zone and the Subtidal Channel.



**Figure 6-10 Map of pH Concentrations in Deep Groundwater/Pore Water beneath the Site**

The average pH of Mattawoman Creek is close to 7.0 (neutral), while the average pH of the shallow and deep portions of the surficial aquifer beneath the Land Zone are pH 5.35 and 5.33, respectively (Tables 6-5 and 6-6). The average pH in the deeper pore water beneath the Littoral Zone is pH 4.95, suggesting that this water is primarily groundwater from the land, with little influence of surface water mixing. Conversely, the average pH in pore water within the shallow Littoral Zone sediment is pH 6.45, which more closely resembles surface water.

### 6.2.8 Temperature

Temperature controls the bacterial metabolic activity. Microbial respiration rates are commonly assumed to roughly double for every 10°C increase in temperature over the temperature range between 5 and 25°C. This general rule is expected to apply to species capable of reducing perchlorate in the environment. Depending on season, there is an 8 to 10°C variation in temperature in the sediment in the Littoral Zone. Table 6-9 shows the water temperatures and corresponding perchlorate concentrations measured in August 2007 (summer temperatures)

compared to measurements in April 2008 (still winter temperatures) for the piezometers in Piezometer Groups 1 and 2. Biological activity is expected to be greater during the summer months when the groundwater is the warmest. Perchlorate was below detection in the upper and middle piezometers in each group, but the deepest piezometers in each group contained lower concentrations in the warmer groundwater in August than in corresponding cooler groundwater from April.

**Table 6-9  
Seasonal Groundwater Temperature Comparison**

Transect B-B'				Transect C-C'			
Piezometer Group 2	Date	Temp(°C)	Perchlorate (µg/L)	Piezometer Group 1	Date	Temp(°C)	Perchlorate (µg/L)
TP-4	8/9/07	24.9	<1	TP-1	8/9/07	28.2	<1
	4/16/08	16.5	<1		4/16/08	16.3	<4
TP-6	8/9/07	23.8	<1	TP-2	8/9/07	25.6	<1
	4/16/08	15.3	<1		4/16/08	15.8	<1
TP-7	8/9/07	25.5	639	TP-3	8/9/07	25.9	2,417
	4/16/08	15.5	3,259		4/16/08	16.7	3,169

### 6.2.9 Chloride, Chlorate and Chlorite

If starting chloride concentrations are low and perchlorate is high, increased levels of chloride can provide a direct indication of perchlorate biodegradation. However at the Indian Head site, chloride concentrations were primarily controlled by mixing with brackish water in Mattawoman Creek. Under these conditions, chloride concentrations were not a reliable indicator of the presence or absence of perchlorate biodegradation.

The biodegradation of perchlorate occurs through sequential, enzymatic removal of oxygen atoms from the perchlorate anion. As shown in **Figure 1-1**, the intermediate breakdown products are chlorate ( $\text{ClO}_3^-$ ) and chlorite ( $\text{ClO}_2^-$ ), leading to the formation of chloride and oxygen. EPA Method 300.1 (Rev 1.0) is an ion chromatography method approved for testing chlorate and chlorite in drinking water. A modification of this ion chromatography method was employed at the NCSU CCEE laboratory to analyze for anions including chlorate and chlorite. The detection limit was 0.5 µg/L. No chlorate or chlorite was reported during any of the sampling events in any of the wells.

The rate controlling step in the biodegradation process is the reduction of perchlorate to chlorate by a perchlorate-reductase enzyme. Chlorate reducers are up to 50 times more abundant than perchlorate reducers, so once formed, chlorate is readily converted to chlorite at rates up to three times faster than the initial step. Chlorite formation could be problematic as it is toxic to bacteria, but the CD enzyme that catalyzes the disproportionation of chlorite to  $\text{O}_2$  and  $\text{Cl}^-$  is the fastest acting enzyme in the sequence. Therefore, no intermediates ordinarily accumulate in solution during perchlorate biodegradation (Magnus XC, 2005; Logan et al., 2001). Thus, like chloride, these intermediates may only be useful indicators when very high concentrations are being degraded, leaving sufficient time for residual concentrations to accumulate.

### 6.2.10 Microbial Populations

Monitoring of microbial populations and their spatial distributions can provide important evidence about contaminant biodegradation. The Perchlorate MNA Protocol (ESTCP, 2008) describes several methods for enumeration of perchlorate-reducing bacteria including anaerobic

plate counts, most probable number enumeration, and molecular biology tools (MBTs). Several different types of MBTs were used to monitor the activity and spatial distribution of perchlorate reducing bacteria at the Indian Head site.

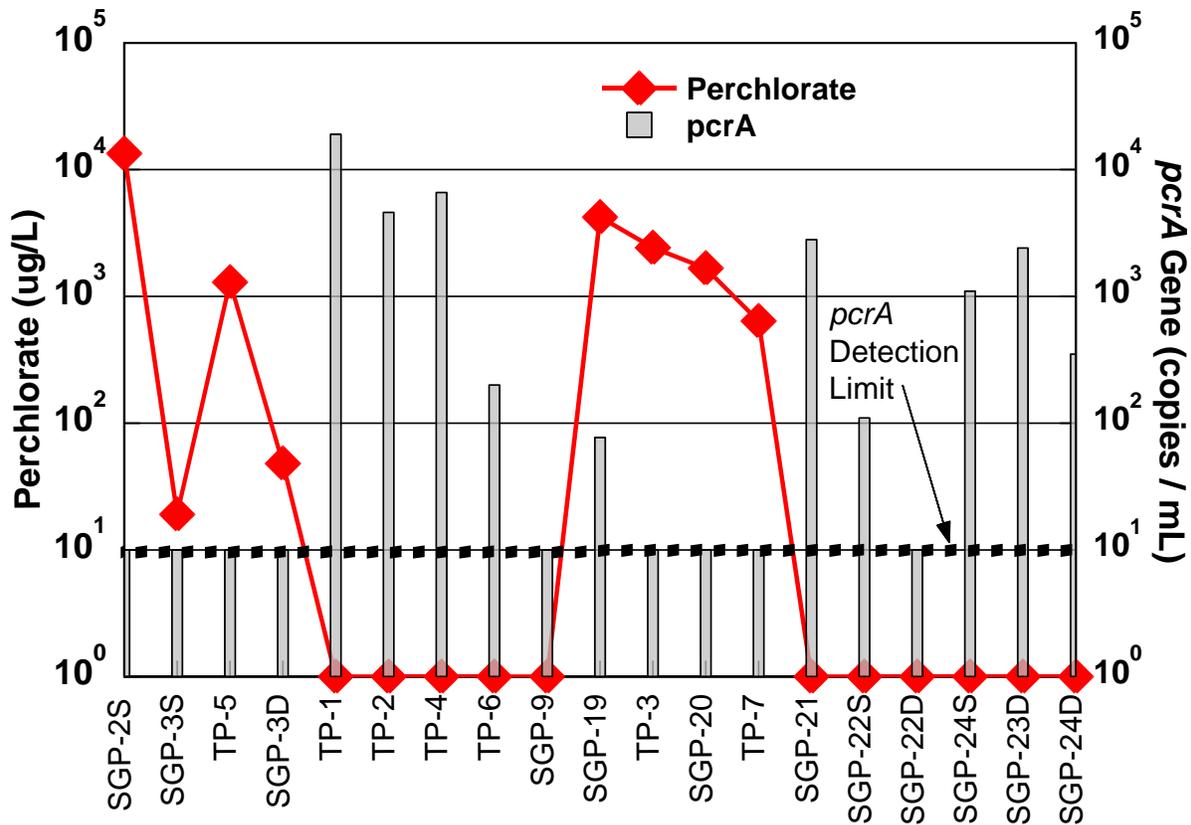
A wide diversity of microorganisms can degrade perchlorate to chloride and oxygen (Coates et al., 1999; Coates and Pollock, 2003). The perchlorate biodegradation pathways are well understood and the microorganisms involved in perchlorate biodegradation are known to use a variety of different organic substrates as electron donors (Nzengung, 2008) including simple organic acids and alcohols, aromatic hydrocarbons, hexoses, reduced humic substances, both soluble and insoluble ferrous iron and hydrogen sulfide (Coates and Achenbach, 2006). DRPB are widespread in the environment (Coates et al., 1999; Logan, 2001) and bioaugmentation is not usually required to stimulate perchlorate reduction (Coates and Achenbach, 2006). The metabolic versatility of these organisms allows many to function as strict or facultative anaerobes and survive and degrade perchlorate even in microaerophilic environments or environments with low levels of other competing electron acceptors.

As noted during the pre-demonstration testing (Section 3.2.3), DNA-based PCR assays were used initially at the Indian Head site to qualitatively monitor for organisms with the genetic capability to biodegrade perchlorate. The PCR assay used during site screening targeted the chlorite dismutase gene (*cld*) which codes for the CD enzyme. The CD enzyme mediates dismutation of chlorite, the final step in reduction of perchlorate to chloride and oxygen (Gunawan, 2007). During site screening, groundwater was collected from monitoring wells MW-2 and MW-4, which are land wells located near the source, and tested for the presence of the *cld* genes. Groundwater from MW-2 was reported as “+++”, a relatively high positive result indicating the presence of the *cld* genes, while the groundwater collected from MW-4 was reported as “+/-“ suggesting mixed results (ESTCP, 2007).

As part of the Tier 2 evaluation, the CD enzyme assay was again applied as a screening tool. In August 2007, groundwater samples were collected from 20 monitoring wells/piezometers at the site and shipped to Microbial Insights to be screened qualitatively for the CD enzyme. Sixteen out of 20 samples were reported as strongly positive (“+++”) with no distinguishable pattern corresponding to location across the site. After conducting their analyses, Microbial Insights sent the samples to the Soil Microbial Ecology Laboratory at the University of California at Davis under the direction of Dr. Kate Scow where the qPCR assay was used to estimate populations of perchlorate-degrading microorganisms in the samples. The DNA-based qPCR assay was performed on each of the samples targeting the *pcrA* gene which is one of the gene subunits that codes for the perchlorate-reductase enzyme known to mediate the initial breakdown of perchlorate to chlorate and chlorite.

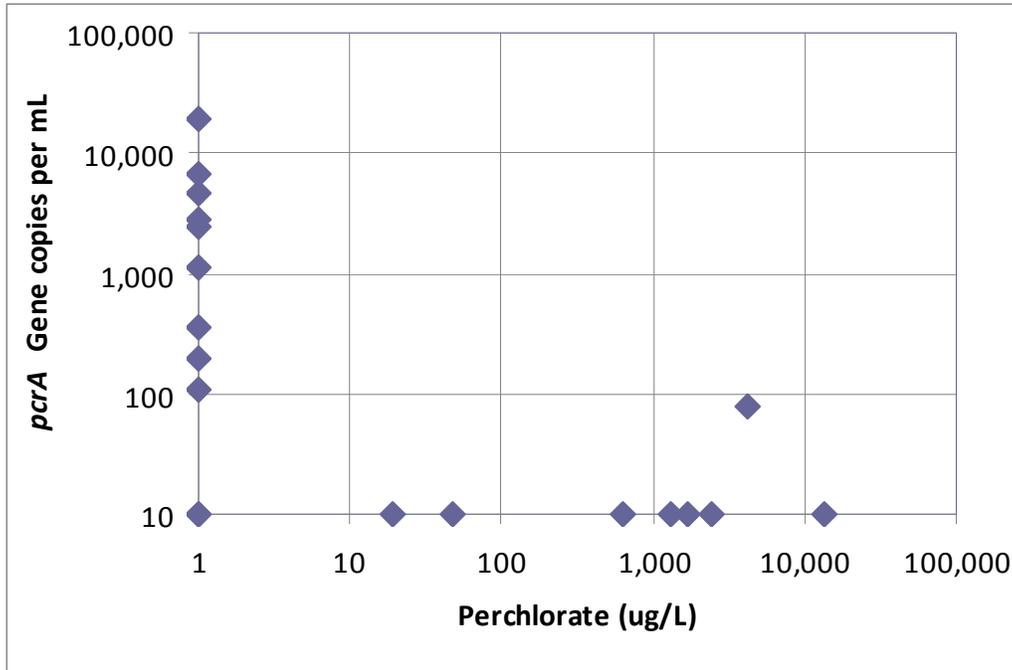
The number of *pcrA* gene copies per mL of groundwater is compared with perchlorate concentrations in the different monitor wells in **Figure 6-11**. The wells are generally arranged with Land Zone wells first, followed by Littoral Zone wells, and Subtidal Channel wells. No samples were collected from any of the wells in the Subtidal Shallows. There is an obvious negative relationship between *pcrA* copies and perchlorate concentrations. In the land wells (SGP-2S, SGP-3S, TP-5, SGP-3D), perchlorate is elevated and *pcrA* copies are below detection (<10 copies/mL). In the shallow wells of the organic-rich Littoral Zone (TP-1, TP-2, TP-4, TP-6), *pcrA* numbers are high resulting in complete depletion of perchlorate (< 1 µg/L). However in the deeper Littoral Zone wells (TP-3, TP-7, SGP-19, SGP-20, SGP-21), organic carbon levels are

low resulting in much lower *pcrA* numbers and high perchlorate concentrations. This same pattern persists in the subtidal channel (SGP-22S, SGP-22D, SGP-24S, SGP-23D, SGP-24D) where *pcrA* numbers are elevated and perchlorate is below detection.



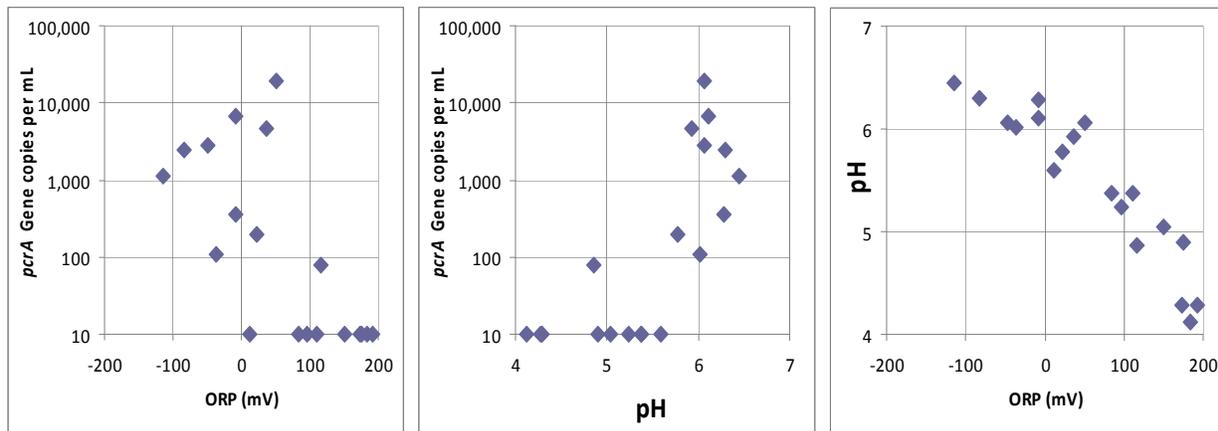
**Figure 6-11. Perchlorate Concentration and *pcrA* Gene Copies in Monitor Wells in August 2008.** (Monitor Wells/Piezometers arranged from land installations on left to Subtidal Channel installations on the right. Detection limit for the *pcrA* gene is 10 gene copies/mL; bars below 10 copies/mL included to show sample BDL)

The presence / absence relationship between perchlorate and the *pcrA* gene is illustrated in **Figure 6-12**. With the exception of one sample (SGP-19,  $\text{ClO}_4 = 4,200 \mu\text{g/L}$ , *pcrA* = 77 copies/mL), whenever the *pcrA* gene is present above the analytical detection limit, perchlorate is BDL. The very strong relationship between *pcrA* levels and perchlorate depletion suggests that *pcrA* levels might be used to identify appropriate conditions for perchlorate attenuation.



**Figure 6-12. Relationship between Perchlorate Concentration and *pcrA* Gene Copies**

**Figure 6-13** shows several comparisons between *pcrA* gene copies, ORP and pH levels in monitor wells within the Littoral Zone and Subtidal Channel in August 2008. *pcrA* levels are elevated in the range of +50 mV to – 100 mV suggesting significant perchlorate degradation may still occur under slightly positive ORP levels. *pcrA* levels are also elevated in the pH range of 6.0 to 6.5. The higher *pcrA* levels above pH 6 could imply that more neutral pH values are required for growth of perchlorate degraders. However, the apparent correlation between pH and *pcrA* levels could also result from the strong correlation between pH and ORP. At lower ORP levels, iron is reduced releasing OH<sup>-</sup> with an associated increase in pH. Regardless of the cause, perchlorate degraders can grow to high levels when pH > 6 and ORP is between 0 and + 50 mV.



**Figure 6-13. Relationships between *pcrA* Gene Copies, ORP and pH in Monitor Wells in August 2008**

### 6.2.11 Summary of Biogeochemical Evaluation (Tier 2)

The biogeochemical evaluation showed that conditions in the land wells could be expected to limit or inhibit perchlorate biodegradation. In contrast, biogeochemical conditions in the shallow Littoral Zone wells are excellent for perchlorate biodegradation.

- In the land wells, TOC levels were low and probably limited perchlorate biodegradation. However in the shallow Littoral Zone, TOC increases to 2.4 to 5.3 mg/L which should enhance perchlorate biodegradation.
- In the land wells, ORP levels typically exceed +50 mV, which probably inhibits perchlorate biodegradation. In the Littoral Zone, ORP levels drop enhancing the potential for perchlorate reduction.
- Nitrate levels are elevated in some source area wells, presumably due to oxidation of ammonium perchlorate. Nitrate levels decline gradually in the land portion of the aquifer indicating some biological reduction potential. Once groundwater enters the shallow Littoral Zone sediments, nitrate declines below the analytical detection limit and perchlorate is depleted.
- Dissolved iron and methane levels are low in most source area wells. However, methane and/or iron are occasionally detected in some land wells suggesting some potential for nitrate and/or perchlorate reduction in the land area. Within the Littoral Zone, elevated levels of dissolved iron and methane are more common indicating more reducing conditions with greater potential for perchlorate biodegradation.
- In much of the aquifer, pH is below optimum for perchlorate reduction. Monitoring of perchlorate reducing populations shows numbers are elevated in the Littoral Zone where the pH increases to near 6 or above.
- During winter months, perchlorate degradation rates may slow due to lower temperatures.
- There is a very strong relationship between perchlorate concentrations in the Littoral Zone and the presence of organisms with the *pcrA* gene which codes for the perchlorate-reductase enzyme. Perchlorate was reduced to below detectable levels in every sample with greater than  $10^2$  *pcrA* copies/mL ( $>10^5$  *pcrA*/L). This

relationship can be very useful in identifying conditions for rapid perchlorate biodegradation.

### **6.3 Tier 3 Evaluation – Biodegradation Rates**

In Tier 1, perchlorate concentrations in groundwater were monitored over several years and demonstrated plume stability, a gradual decline in source area concentrations with time, and a decline in contaminant mass with distance downgradient from the source. In Tier 2, data on geochemical conditions in the aquifer and microbial populations demonstrated that biogeochemical conditions were appropriate for perchlorate biodegradation. In Tier 3, laboratory and field measurements were used to estimate biodegradation rates.

There are a variety of approaches for measuring perchlorate biodegradation and estimating rates including laboratory incubations, *in situ* field experiments, and monitoring changes in stable isotope composition. In this project, two different sets of laboratory incubations were run that provided direct evidence of perchlorate biodegradation. A novel *in situ* column experiment was conducted to measure biodegradation rates under field conditions. Unfortunately, physical constraints prevented collection of sufficient perchlorate mass to measure changes in isotopic composition during biodegradation in the Littoral Zone at Indian Head (Section 3.6.3). The following sections illustrate the utility of laboratory incubations and *in situ* columns for estimating perchlorate biodegradation rates and their use in evaluating MNA as a groundwater remedy.

#### **6.3.1 Macrocosm Study**

A preliminary microcosm study was conducted during the initial site screening to evaluate the potential for natural attenuation of perchlorate at the Indian Head site. Microcosms were constructed with sediment and groundwater from MW-2 in 245-mL serum bottles and incubated for one year. Perchlorate degraded in these incubations with an estimated first-order decay rate of 0.017 per day (ESTCP, 2007).

Much larger volume macrocosms were constructed and monitored as part of the MNA evaluation presented in this report to: (a) estimate biodegradation rates in sediment from the Littoral Zone at Indian Head; and (b) estimate an isotopic fractionation factor ( $\alpha$ ) that would be representative of the Indian Head site. The site specific value of  $\alpha$  would then be used to interpret changes in isotopic composition observed in monitor wells. Five replicate macrocosms were constructed in 5-gallon carboys with 8 kg of Littoral Zone sediment and filled with groundwater from SGP-2D. The large volume of replicate macrocosms was required to generate enough perchlorate for isotopic analysis. However during the course of the project, it became apparent that the isotopic composition of the Littoral Zone groundwater could not be reliably sampled. As a result, isotopic monitoring of the macrocosms was eliminated. However, traditional monitoring for perchlorate and nitrate continued to estimate degradation rates in the Littoral Zone sediment. Additional details on the macrocosm construction, monitoring and analytical results are presented in Section 3.6.2 and **Appendix F**.

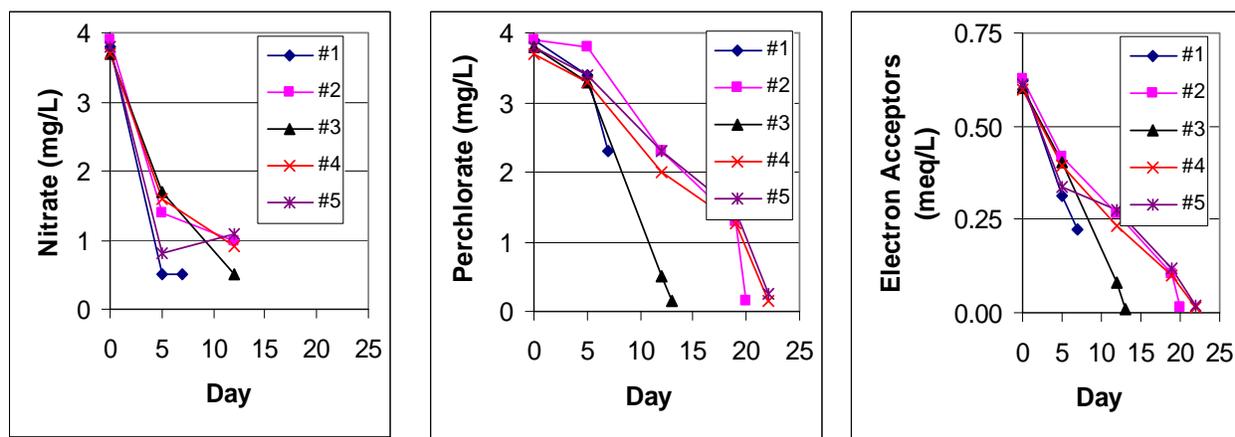
The nitrate and perchlorate sample results for each of the five replicate macrocosms are shown in **Figure 6-14**. All five replicates exhibited the same general behavior. During the first 5 days, perchlorate degradation was slow while nitrate was being consumed. Once nitrate was reduced to roughly 1 mg/L, the perchlorate biodegradation rate increased. Given the apparent relationship

between nitrate and perchlorate degradation, the total electron acceptor concentration was calculated as

$$\text{Electron Acceptors (meq/L)} = 5[\text{NO}_3^-] + 8[\text{ClO}_4^-]$$

Where:  $[\text{NO}_3^-]$  and  $[\text{ClO}_4^-]$  are in units of millimoles per liter.

Perchlorate in Macrocosms #1 and #3 degraded faster than the other three showing there is some variability in the data. By plotting the sum of nitrate and perchlorate together, the apparent lag in biodegradation (for perchlorate) is eliminated.



**Figure 6-14. Nitrate, Perchlorate, and Electron Acceptor Concentrations vs. Time in Five Replicate Macrocosms Constructed with Littoral Zone Sediment (#1 - #5 indicate replicate number)**

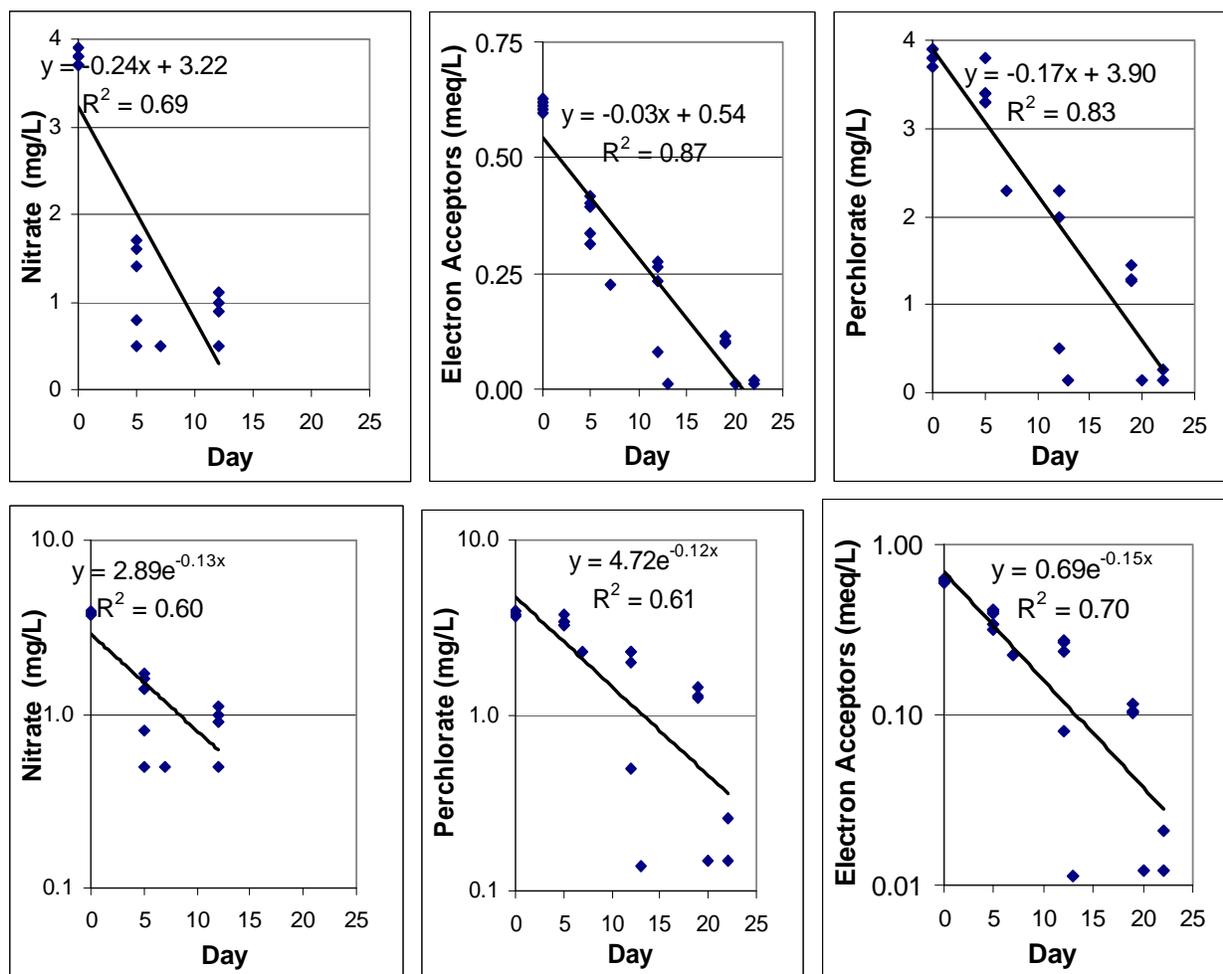
Degradation rates were estimated by pooling data from all replicates together for analysis. Zero-order rates were estimated by regressing measured concentration versus time. First-order rates were estimated by regressing the natural log transform ( $\text{Ln}$ ) of concentration versus time. Estimated zero- and first-order degradation rates for nitrate, perchlorate and total electron acceptors are shown in **Table 6-10** along with the standard error of the estimated rate, correlation coefficients ( $R^2$ ) and statistical significance ( $p$ -value). Each of the regressions is plotted in **Figure 6-15** for comparison.

Zero- and first-order degradation rates for nitrate and perchlorate were similar, consistent with the hypothesis that the same biogeochemical processes were controlling the degradation rate. Correlation coefficients and probability of significance were slightly higher for the zero-order regressions and the total electron acceptor concentration. However, there is a high confidence that all the regressions are significant.

**Table-10**  
**Nitrate, Perchlorate, and Electron Acceptor Degradation Rates**  
**in Littoral Zone Macrocosms**

Compound	Nitrate (mg/L)	Perchlorate (mg/L)	Electron Acceptors (meq/L)
Linear Regression			
Zero-Order Rate*	0.24 mg/L/d $\pm$ 0.05	0.17 mg/L/d $\pm$ 0.02	0.026 meq/L/d $\pm$ 0.002
Correlation Coef. ( $R^2$ )	0.69	0.83	0.87
P-Value	$1 \times 10^{-4}$	$4 \times 10^{-9}$	$3 \times 10^{-10}$
Ln Transformed Regression			
First-Order Rate*	0.13 /d $\pm$ 0.03	0.12 /d $\pm$ 0.02	0.15 /d $\pm$ 0.02
Correlation Coef. ( $R^2$ )	0.60	0.61	0.70
P-Value	$7 \times 10^{-4}$	$2 \times 10^{-5}$	$1 \times 10^{-6}$

\*  $\pm$  value is standard error of estimate



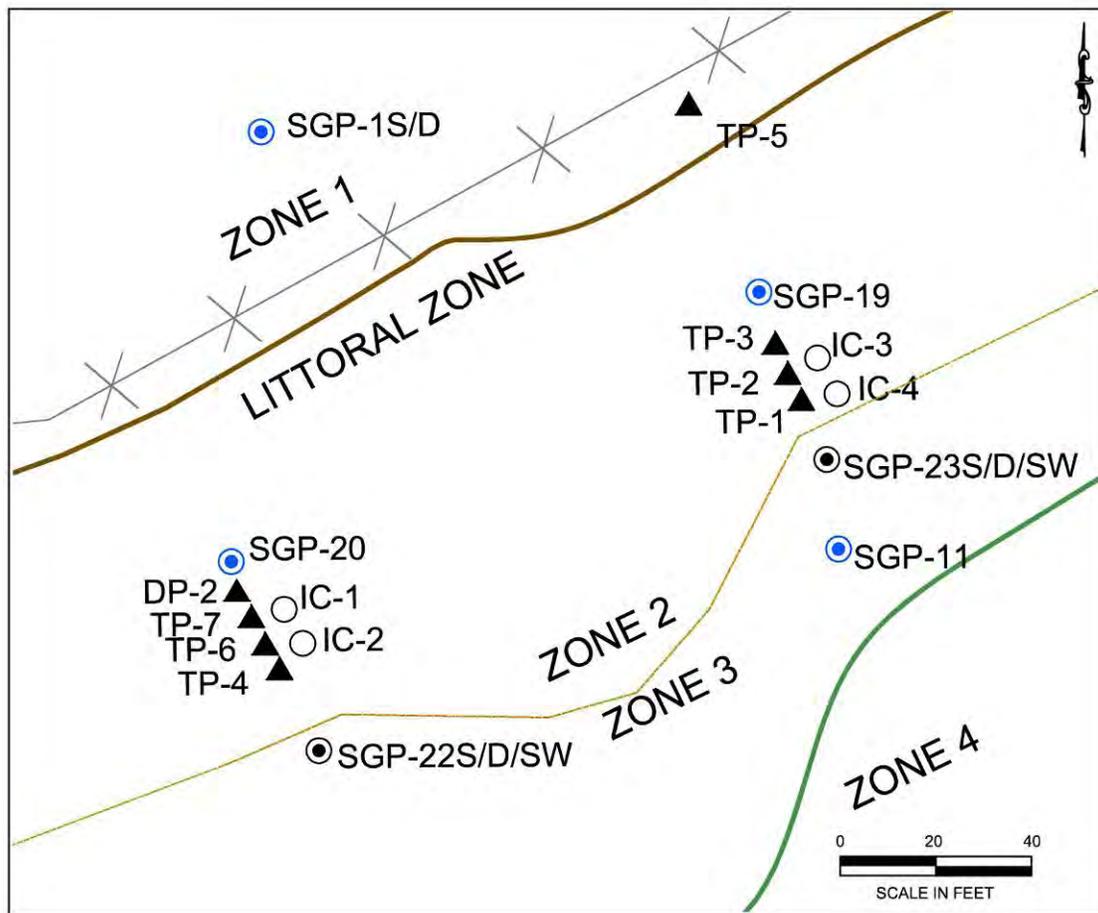
**Figure 6-15. Regression Analysis of Nitrate, Perchlorate and Electron Acceptor Concentration vs. Time**

Degradation rates in the macrocosms constructed with organic rich Littoral zone sediment were roughly an order of magnitude higher than degradation rates observed in the small microcosm experiments constructed with low carbon sediment and groundwater from MW-2.

### **6.3.2 *In Situ* Column Biodegradation (IC) Study**

An *in situ* column (IC) study was conducted at Indian Head to estimate the perchlorate biodegradation rate under representative field conditions. The *in situ* columns were installed in the Littoral Zone at Indian Head because prior monitoring data had shown that perchlorate degradation was most rapid and populations of perchlorate degrading bacteria were highest in this area. The column design employed at the Indian Head site was described in Section 3.6.1. Solutions-IES installed ICs near Piezometer Groups 1 and 2 (**Figure 6-16**). The ICs were situated immediately adjacent to the piezometer clusters so that actual perchlorate concentrations at different depths measured in the piezometers could be extrapolated to the conditions within the ICs.

The columns were installed as shallow and deep pairs. The columns were constructed to allow flow through the columns, but to minimize surface water infiltration during testing. However, during initial testing, surface water appeared to be leaking into the shallow ICs at both locations (IC-2 and IC-4), so additional testing utilizing these columns was halted. The biodegradation study continued using only the deeper columns, IC-1 and IC-3, to collect data. The columns were initially operated under the ambient hydraulic gradient which should have resulted in a hydraulic residence time (HRT) within the ICs of roughly 3 to 4-months. However, with this long HRT, perchlorate was never detected in the column effluent. To provide more accurate estimates of the *in situ* biodegradation rates, Solutions-IES shortened the hydraulic residence time by pumping the IC to induce more rapid flow. Biodegradation rates were then estimated using the reduced HRT.



**Figure 6-16. Locations of *In Situ* Columns**

To perform the test, IC-1 and IC-3 were purged dry and sampled after recharging. The groundwater samples were analyzed for perchlorate, chlorate, chlorite, chloride, bromide, nitrate, nitrite, phosphate, sulfate, methane, and TOC. A peristaltic pump with a timer was connected to each IC to control the pumping rates and volumes. The IC columns were pumped and monitored for 15 days between April 16 and May 1, 2008. During this time, the pump times and pump volumes were recorded and the field parameters were measured. Due to a storm and the resulting loss of electricity, the pumps did not operate for approximately three days during the test period. During the test, except during power loss, the pumps were operated at a flow rate of approximately 10 mL/min, cycled on every 3 or 4 hours for 2 to 3 minutes.

Both columns were driven to a depth of 6.5 feet below the creek bottom. Assuming slight compaction of the soil occurred inside the columns during driving, the pore volume of the columns was calculated to be approximately 7 liters assuming the effective porosity of the soil in the column was 20 percent. The pump cycles were sometimes modified to stabilize the flow rate. The test design included pumping until one complete pore volume (PV) of approximately 7,100 mL had been removed from each IC. During the pumping period, approximately 5,110 mL of water were removed from IC-1 and 1,078 mL of water were removed from IC-3. The laboratory results from the *in situ* biodegradation study are summarized in **Table 6-11**.

**Table 6-11**  
**Analytical Results of Groundwater Samples Collected from *In Situ* Columns during Pumping**

Well ID	Sample Date	Sample Time	Perchlorate		Chloride (mg/L)	Bromide (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Sulfate (mg/L)	TOC (mg/L)
			Method 314 (µg/L)	Method 332 (µg/L)						
Column 3 (IC-3)	8/8/07	NA	< 1	0.06	290	0.9	< 0.5	< 0.5	55	6.2
	12/18/07	NA	< 1	NA	450	1.4	< 0.5	< 0.5	81	NA
	4/15/08	1:00 PM	<1	NA	220	0.8	<0.5	<0.5	39	6.8
	4/18/08	8:35 AM	1,300	NA	NA	NA	NA	NA	NA	NA
	4/23/08	2:20 PM	<1	NA	NA	NA	NA	NA	NA	NA
	4/28/08	8:00 AM	570	NA	NA	NA	NA	NA	NA	NA
Column 1 (IC-1)	8/9/07	NA	< 1	NA	360	1.0	< 0.5	< 0.5	54	6.6
	12/18/07	NA	< 1	NA	560	1.9	2.3	< 0.5	110	NA
	4/15/08	12:50 PM	<4	NA	33	<0.5	1.1	<0.5	18	4.7
	4/16/08	7:40 AM	<1	NA	NA	NA	NA	NA	NA	NA
	4/18/08	8:30 AM	<1	NA	NA	NA	NA	NA	NA	NA
	4/23/08	2:30 PM	750	NA	NA	NA	NA	NA	NA	NA
	4/28/08	8:00 AM	<1	NA	NA	NA	NA	NA	NA	NA
	5/1/08	8:00 AM	40	NA	NA	NA	NA	NA	NA	NA

NA = Not Analyzed

During the test, samples were collected from the sampling port or outlet and analyzed for perchlorate and parameters as described above. The perchlorate concentrations entering the bottom of the column (inlet) were assumed to be equal to measured concentrations in TP-7 (3,200 µg/L) and TP-3 (2,700 µg/L) which were the immediately adjacent to the ICs and screened at the same vertical interval. However, because only 15% of the PV in IC-3 had actually been pumped, IC-3 was not used for calculations of biodegradation rates. Since 72 % of the PV in IC-1 was pumped, further evaluation of the biodegradation rates in the Littoral Zone was performed on data from this IC.

The biodegradation rates in IC-1 were estimated by comparing the change in the perchlorate concentration at the column inlet (i.e., 3,200 µg/L) and with the perchlorate concentration measured at the *in situ* column sampling point or outlet taking into the amount of pumping time. To account for possible dilution within the column, a “worst case” dilution by volume was calculated based on the concept that any water pumped out the column was replaced with surface water. Although there was no evidence to suggest that IC-1 was leaking during the test, to be conservative in the analysis, the worst case scenario was used in the calculation of the biodegradation rate. It was assumed that if 40% of the volume of the column was removed by pumping, and 40% of the column was replaced with surface water, then the starting concentration within the column would be ~60% of the inlet groundwater concentration of 3,200 µg/L, which would be 1,920 µg/L.

First-order biodegradation rates (k) were estimated from the following first-order equation (Newell et al., 2002):

$$[C] = [C_o]e^{-kt}$$

Where: [C] = concentration measured at the top of the IC  
[C<sub>o</sub>] = presumed concentration at the bottom of the column corrected for “worst-case” dilution by surface water.  
“t” = pump time

Corresponding perchlorate first-order half-lives were calculated from:

$$t_{1/2} = 0.693/k$$

For comparison, zero-order degradation rates were calculated using the following equation:

$$[C] = [C_o] - Kt$$

The results for IC-1 are summarized in **Table 6-12**. On 4/28/08, the measured concentration [C] was below detection (<1 µg/L) and rates were calculated using 1 µg/L to represent this non-detect. First-order rates varied from 0.12 to 0.63/day. In contrast, the zero-order rates were more consistent, varying from 90 to 150 µg/L/day.

**Table 6-12**  
**Biodegradation Rates Calculated from *In Situ* Biodegradation Study at IC-1**

	t			[C]	[C <sub>0</sub> ]	k	t <sub>1/2</sub>	k
Date Sampled	Total Pump Time (hrs)	Total Volume Pumped <sup>(2)</sup> (ml)	% Dilution by Volume <sup>(1)</sup>	Measured Perchlorate Concentration (µg/L)	Calculated Starting Concentration (µg/L) <sup>(3)</sup>	1 <sup>st</sup> -Order Rate (per day)	1 <sup>st</sup> -Order Half-Life (days)	Zero-Order Rate (µg/L/d)
4/23/2008	190	2,863	40	754	1,920	0.12	5.8	150
4/28/2008	274	4,093	58	<1	1,344	0.63	1.1	120
5/1/2008	338	5,110	60	40	1,280	0.25	2.8	90

(1) Assumes that volume of water pumped is replaced with surface water causing dilution.

(2) Total column volume is 7,100 mL

(3) If starting concentration is 3,200 µg/L, then diluted concentration is 60% x 3,200 = 1,920 µg/L (with no biodegradation).

The ambient perchlorate degradation rate in the Littoral Zone was calculated using measured perchlorate concentrations in TP-4, TP-6 and TP-7 (March 30, 2007, Piezometer Group 2) with an estimated vertical flow velocity of 0.06 ft/d. **Table 6-13** shows estimated travel times for groundwater to move upward from ~6.5 ft bgs in TP-7 to ~5 ft bgs in TP-6 (25 days) and upward from ~6.5 ft bgs to ~3 ft bgs in TP-4 (58 days).

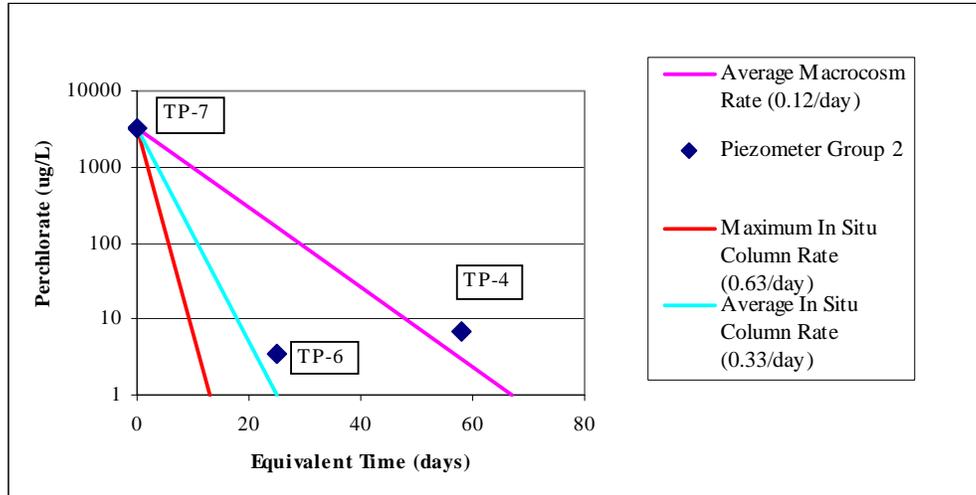
**Table 6-13**  
**Summary of Perchlorate Concentrations at Equivalent Time**

Piezometer ID	Perchlorate (µg/L) <sup>a</sup>	Piezometer Depth (ft bgs)	Equivalent Travel Time (days) <sup>b</sup>
TP-7	3,200	6.5	0
TP-6	3.4	5.0	25
TP-4	6.7	3.0	58

a. Perchlorate concentrations reported on March 30, 2007.

b. Calculated as: (Depth of TP-7 minus Depth of target TP)/ vertical flow velocity = # days

The perchlorate concentrations in the piezometers were plotted against the equivalent time to derive a rate of biodegradation that could be compared with the rates estimated from the IC study. As shown in **Table 6-12** and **Figure 6-17**, there is a large decrease in perchlorate concentration between TP-7 (3,200 µg/L) and TP-6 (3.4 µg/L) and little change between TP-6 and TP-4 (6.7 µg/L). The apparent first-order biodegradation rate estimated from the change in perchlorate over the equivalent 25 days travel time from TP-7 to TP-6 was 0.27/d. This field rate is well within the range observed in the *in situ* column study (0.12 to 0.63/d) and similar to the rate observed in the laboratory macrocosms (0.12/d).



**Figure 6-17. Comparison of Macrocosm and *In Situ* Column Rates**

**Table 6-14** summarizes the first-order biodegradation rates obtained in the Tier 3 evaluation. The similarity in the observed rates supports the use of macrocosms and *in situ* columns as methods for estimating biodegradation in the natural environment. The results support the information obtained in Tier 1 and 2 as definitive lines of evidence for the natural attenuation of perchlorate.

<b>Table 6-14 Summary of First-Order Biodegradation Rates</b>		
<b>Test</b>	<b>Rate Constant (per day)</b>	<b>Half-Life (days)</b>
Macrocosms	0.12	5.8
<i>In Situ</i> Columns	0.12 to 0.63	5.8 to 1.1
Piezometers	0.27	2.6

## 7.0 Performance Assessment

Primary and secondary performance objectives were established in the Technical Demonstration Plan (Solutions-IES, 2006). The ability of MNA to meet these objectives at the Indian Head site is discussed below.

### 7.1 Primary Performance Objectives.

#### ***Criterion: Reduce perchlorate concentration***

The perchlorate plume was delineated from the presumed source to Mattawoman Creek. The perchlorate concentration was reduced by >99.9 % during downgradient transport from the source area to Mattawoman Creek. Average concentrations of perchlorate in shallow wells adjoining Mattawoman Creek (TP-1, TP-2, TP-4, and TP-6) were statistically different from wells in the source area (MW-1 and MW-3) at the 95% level.

#### ***Criterion: Reduce contaminant mass flux***

The results showed natural attenuation rates could be calculated from the source near the hog-out Building 1419 moving southward toward Mattawoman Creek. Mass flux of perchlorate was reduced by > 75% between the most downgradient line of wells in the Land Zone and the Littoral Zone.

#### ***Criterion: Factors Affecting Performance***

The biogeochemical evaluation showed that conditions in the land wells can be expected to result in limited perchlorate biodegradation. In contrast, biogeochemical conditions in the shallow Littoral Zone wells are excellent for perchlorate biodegradation.

#### ***Criterion: Ease of Use***

The monitor well network was expanded from six to 39 additional monitoring wells/piezometers. The wells on the land were adequate to collect representative groundwater samples; new wells and piezometers installed on the land and into the creek sediments provided additional monitoring points from which to monitor changes in four geomorphological zones and collect samples from different depths in each zone.

Wells/piezometers were relatively simple to install, although some additional effort and health & safety-related precautions were required to install them in the creek bottom. Wells were not replaced during the demonstration, but placing wells in the creek would eventually become problematic.

#### ***Criterion: Maintenance***

No special operation and/or maintenance steps were needed to maintain the network for the duration of the study.

### 7.2 Secondary Performance Objectives

#### ***Criterion: Biodegrade Perchlorate***

There are a variety of conventional and innovative methods available to demonstrate perchlorate biodegradation including biogeochemical monitoring, MBTs, microcosm and macrocosm studies, *in situ* column experiments, and monitoring for compound specific stable isotopes. Except for

stable isotopes, these techniques were used extensively and effectively in the Indian Head demonstration to confirm bioactivity as a line of evidence for MNA. Biogeochemical parameters indicated good conditions for perchlorate biodegradation in the Littoral zone. This was supported by qPCR measurements showing very high numbers of perchlorate degraders in this same zone. Perchlorate degradation rates were measured in the macrocosms and *in situ* columns were consistent with field observations.

***Criterion: Meet Regulatory Standards***

Perchlorate concentrations were reduced from over 10,000 µg/L in the source area to below the USEPA preliminary remediation goal of 24.5 µg/L prior to discharge to Mattawoman Creek. Concentrations were also frequently, but not always, reduced to below the Maryland Department of Environment (MDE) drinking water standard of 2.6 µg/L.

***Criterion: Contaminant Mobility***

Implementation of the MNA evaluation did not have any detectable impact on contaminant mobility. Significant amounts of water were not withdrawn or injected into the aquifer, so assessment activities did not impact contaminant mobility.

Site hydrology and associated transport processes did have a major impact on how the MNA evaluation was conducted. Diurnal tidal fluctuations influence the rate of perchlorate discharge to Mattawoman Creek. Extensive studies were conducted to document these effects and to account for the potential for dilution of perchlorate by mixing contaminated groundwater with surface water.

***Criterion: Process Waste and Hazardous Materials***

MNA is a passive remedial strategy. Therefore waste generation was limited to soil cuttings from well installation and groundwater from well development and purging. Perchlorate assessment and remediation activities can be conducted without extraordinary health and safety handling precautions. MNA does not produce or use hazardous materials as part of the treatment technology. Level D PPE provides adequate protection.

***Criterion: Reliability, Versatility and Scale-up Constraints***

When site conditions are appropriate, MNA provides a reliable and versatile approach for management of perchlorate plumes. The successful demonstration of MNA requires a monitoring well network designed to illustrate attenuation downstream from the source and prior to intercepting sensitive receptors. There are no scale-up restraints since the MNA evaluation is conducted at full scale.

## 8.0 Cost Assessment

### 8.1 Cost Drivers

Costs associated with various *in situ* remediation technologies for perchlorate are discussed in Stroo and Norris (2009) and Krug et al. (2009), but neither directly addresses or compares potential costs to MNA. There are many similarities, particularly associated with up-front assessment and long-term monitoring activities, but the difference with MNA is the absence of any designed intervention with the groundwater conditions. To employ MNA, the goals of the assessment should merge with the goals of MNA. When considering MNA as a remedial alternative, an expanded network of monitoring wells may be installed during the assessment phase to characterize the contaminant distribution and site hydrogeology. Once installed, altering the site monitoring program may be needed to gather additional data to complete the Tier 1 and Tier 2 evaluations. Tier 3 biodegradation rate studies may be helpful for demonstrating perchlorate biodegradation at unusual sites, but may not be necessary in many cases.

The Remedial Action Objectives (RAO) for a site also can have a significant impact on cost and potential applicability of MNA as a remedial alternative. End users should work closely with regulators during the evaluation process to determine realistic objectives for perchlorate remediation that are agreeable to the stakeholders. Results should be achievable for the regulatory agency involved in the cleanup. Cost estimates in the following sections use the federal TBC of 24.5 µg/L as the target RAO. Natural attenuation rates estimated for the upland portions of the aquifer at the Indian Head site used 24.5 µg/L as the target RAO (Section 6.1.2). More and more agencies are promulgating standards for perchlorate to take the place of the TBC concentration. For example, during the course of this demonstration the MDE established a perchlorate drinking water standard of 2.6 µg/L (MDE, 2008).

### 8.2 Indian Head Demonstration Costs and Long-term Cost Model

When estimating the cost of implementing MNA for the base case, we assumed that a tiered evaluation including all three tiers is required. However, at many sites, a Tier 3 evaluation may not be required. After the tiered evaluation, and assuming the monitoring well network is in place, the primary cost driver for MNA of perchlorate is long-term monitoring.

**Table 8-1** summarizes the life-cycle cost components of the Indian Head site. The layout of the table is derived from Krug et al. (2009). The table includes both known costs associated with implementing the demonstration and estimated costs for going forward with MNA at this site. The level of assessment associated with the demonstration completed at the Indian Head site was likely beyond that which might be required for a typical site. However, to accurately portray the overall costs, the actual costs associated with monitoring wells that were installed in the Land Aquifer and in the Littoral Zone and Subtidal Channel are included. The costs associated with the tiered evaluation are also included.

The costs for preparing the present report overlap with an estimate of the costs that would be incurred to take the data derived from this demonstration and use them to prepare a permit application for MNA for the site and gain regulatory approval of this technology as the long-term groundwater remedy. Long-term costs include semi-annual monitoring and reporting. The Net Present Value of the estimated costs is calculated for up to 30 years using a 2.7% interest rate.

**Table 8-1**  
**Actual and Estimated Future Costs for Implementation of Perchlorate MNA for the Indian Head Site**

	2005	2006	2007	2008	2009	2010						
	Yearly Costs Incurred										NPV of Cost	Total Costs
	1	2	3	4	5	6	7	8	9	10 to 30		
<b>CAPITAL COSTS</b>												
Complete Assessment on Land	41,400											
Subtidal Channel Assessment		14,700										
Littoral Zone Assessment			20,900									
<b>SUBCOST (\$)</b>	<b>41,400</b>	<b>14,700</b>	<b>20,900</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>				
<b>TIERED EVALUATION</b>												
Tier 1			11,000									
Tier 2				3,900								
Tier 3					5,200							
Evaluation Reporting/Permitting					24,000							
<b>SUBCOST (\$)</b>	<b>41,200</b>	<b>14,700</b>	<b>31,900</b>	<b>3,900</b>	<b>29,200</b>						<b>112,700</b>	<b>120,900</b>
<b>PERFORMANCE MONITORING COSTS <sup>(1)</sup></b>												
Sampling/Analysis/Reporting		27,200	27,600	27,100		54,600 <sup>(2)</sup>	54,600	54,600	54,600	54,600 every year		
<b>SUBCOST (\$)</b>		<b>27,200</b>	<b>27,600</b>	<b>27,100</b>		<b>54,600</b>	<b>54,600</b>	<b>54,600</b>	<b>54,600</b>	<b>1,147,500</b>	<b>986,200</b>	<b>1,447,800</b>
<b>TOTAL COST (\$)</b>	<b>41,200</b>	<b>41,900</b>	<b>59,500</b>	<b>31,000</b>	<b>29,200</b>	<b>54,600</b>	<b>54,600</b>	<b>54,600</b>	<b>54,600</b>	<b>1,147,500</b>	<b>1,098,900</b>	<b>1,568,700</b>

Notes:

(1) Project Semi-annual monitoring starting in 2010

(2) Average monitoring cost

NPV-Net Present Value; calculated based on 2.7% discount rate

### 8.3 Cost Comparison: MNA vs. Passive *In Situ* and Active Pumping Technologies

#### 8.3.1 Basis of Cost Comparison

To compare costs directly between the several remediation scenarios, a base case was prepared using hypothetical site conditions. The characteristics summarized in **Table 8-2** are those used by Krug et al. (2009) and were used for this evaluation in order to simplify the comparison with MNA.

**Table 8-2**  
**Summary of Site Characteristics and Design Parameters for**  
**Biological Treatment of Perchlorate-Impacted Groundwater**  
 (Source: Krug et al., 2009)

Design Parameter	Units	Characteristics
Plume Width	feet	400
Plume Length	feet	800
Porosity		0.25
Gradient		0.008
Hydraulic Conductivity	ft/d	2.83
Upgradient Perchlorate Concentrations	µg/L	2,000
Downgradient Perchlorate Concentrations	µg/L	1,100
Nitrate Concentration	mg/L	15
Dissolved Oxygen Concentration	mg/L	5
Depth to Water	ft bgs	10
Vertical Saturated Thickness	ft	30
Groundwater Seepage Velocity	ft/year	33
Perchlorate Treatment Objective	µg/L	24.5
Assumed Number of Pore Volumes to Flush Plume		2
Number of Barriers Perpendicular to Groundwater Flow		1
Groundwater Travel Time to Barriers	years	24
Years to Clean Up Groundwater	years	48

The cost estimate for the base case includes an estimate of capital cost, operations and maintenance, and long-term monitoring for the treatment of base case perchlorate plume. Capital costs for the engineered remediation systems include system design, well installation, start-up and testing. Pre-remedial investigations including treatability studies were not included in the capital cost for the engineered remediation systems. However, a tiered evaluation (Tier 1, 2 & 3) and reporting were included with the capital costs for the perchlorate MNA estimate because the tiered evaluation may not be included in typical pre-remedial activities.

**Tables 8-3 through 8-5** summarize the life cycle cost for the Passive Injection Biobarrier, the Extraction and Treatment System, and Perchlorate MNA alternatives, respectively, as applied to the Base Case site conditions.

**Table 8-3**  
**Cost Components for Passive Injection Biobarrier Treatment of Perchlorate-Impacted Groundwater**  
 (Source: Krug et al., 2009)

	Year Cost is Incurred								NPV* of Cost	Total Costs
	1	2	3	4	5	6	7	8 to 30		
<b>CAPITAL COSTS</b>										
System Design	68,100								68,100	68,100
Well Installation (30 1" PVC Wells)	32,713								32,713	32,713
Substrate Injection	175,784								175,784	175,784
Start-up and Testing**									0	0
<b>SUBCOST (\$)</b>	<b>276,597</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>276,597</b>	<b>276,597</b>
<b>OPERATION AND MAINTENANCE COSTS</b>										
Substrate Injection				166,284			166,284	166,284 every 3 yrs	985,956	1,496,556
<b>SUBCOST (\$)</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>166,284</b>	<b>0</b>	<b>0</b>	<b>166,284</b>	<b>166,284</b>	<b>985,956</b>	<b>1,496,556</b>
<b>LONG TERM MONITORING COSTS</b>										
Sampling/Analysis/Reporting (Quarterly through 5 years then Annually)	35,240	35,240	35,240	35,240	35,240	11,780	11,780	11,780 every yr	348,483	470,700
<b>SUBCOST (\$)</b>	<b>35,240</b>	<b>35,240</b>	<b>35,240</b>	<b>35,240</b>	<b>35,240</b>	<b>11,780</b>	<b>11,780</b>	<b>11,780</b>	<b>348,483</b>	<b>470,700</b>

<b>TOTAL COST (\$)</b>	<b>311,837</b>	<b>35,240</b>	<b>35,240</b>	<b>201,524</b>	<b>35,240</b>	<b>11,780</b>	<b>178,064</b>	<b>178,064</b>	<b>1,611,036</b>	<b>2,243,853</b>
------------------------	----------------	---------------	---------------	----------------	---------------	---------------	----------------	----------------	------------------	------------------

\*NPV- Net Present Value calculated based on 3% discount rate.

\*\*"No Start-up and Testing" costs are included because no operating equipment is left behind following substrate injection

**Table 8-4**  
**Cost Components for Extraction and Treatment of Perchlorate-Impacted Groundwater**  
 (Source: Krug et al., 2009)

	Year Cost is Incurred							NPV of Cost	Total Costs
	1	2	3	4	5	6	7 to 30		
<b>CAPITAL COSTS</b>									
System Design	90,611							90,611	90,611
Well Installation	86,292							86,292	86,292
System Installation	292,362							292,362	292,362
Start-up and Testing	25,000							25,000	25,000
SUBCOST (\$)	494,265	0	0	0	0	0	0	494,265	494,265
<b>OPERATION AND MAINTENANCE COSTS</b>									
System Operation and Maintenance	49,009	74,009	74,009	74,009	74,009	74,009	74,009 every year	1,469,127	2,195,270
SUBCOST (\$)	49,009	74,009	74,009	74,009	74,009	74,009	74,009	1,469,127	2,195,270
<b>LONG TERM MONITORING COSTS</b>									
Sampling/Analysis/Reporting  (Quarterly through 5 years then Annually)	35,240	35,240	35,240	35,240	35,240	11,780	11,780 every year	348,483	470,700
SUBCOST (\$)	35,240	35,240	35,240	35,240	35,240	11,780	11,780	348,483	470,700
<b>TOTAL COST (\$)</b>	<b>578,514</b>	<b>109,249</b>	<b>109,249</b>	<b>109,249</b>	<b>109,249</b>	<b>85,789</b>	<b>85,789</b>	<b>2,311,875</b>	<b>3,160,235</b>

\*NPV-Net Present Value calculated based on a 3% discount rate.

**Table 8-5  
Cost Components for Perchlorate MNA**

	Year Cost is Incurred										NPV of Cost	Total Costs	
	1	2	3	4	5	6	7	8	9	10 to 30			
<b>CAPITAL COSTS</b>													
System Design	10,000											10,000	
Install Expanded Well Network	15,000											15,000	
Tier 1, 2, 3 Evaluation	20,000											20,000	
Installation/Start-up Testing	0											0	
MNA Permit & Reporting	24,000											24,000	
<b>SUBCOST (\$)</b>	<b>69,000</b>											<b>67,185</b>	<b>69,000</b>
<b>LONG TERM MONITORING COSTS</b>													
(Quarterly for 5 years then, annually)	46,000	\$94,800	\$94,800	\$94,800	\$94,800	\$23,000	\$23,000	\$23,000	\$23,000	\$23,000	\$23,000 every yr	\$1,000,200	
<b>SUBCOST (\$)</b>	<b>\$46,000</b>	<b>\$94,800</b>	<b>\$94,800</b>	<b>\$94,800</b>	<b>\$94,800</b>	<b>\$23,000</b>	<b>\$23,000</b>	<b>\$23,000</b>	<b>\$23,000</b>	<b>\$23,000</b>		<b>752,947</b>	<b>\$1,000,200</b>
<b>TOTAL COST (\$)</b>	<b>\$115,000</b>	<b>\$94,800</b>	<b>\$94,800</b>	<b>\$94,800</b>	<b>\$94,800</b>	<b>\$23,000</b>	<b>\$23,000</b>	<b>\$23,000</b>	<b>\$23,000</b>	<b>\$23,000</b>		<b>820,320</b>	<b>\$1,069,200</b>

\*\* "No Start-up and Testing" costs are included because no operating equipment is left behind following substrate injection

**Table 8-6**  
**Summary of Capital Costs and NPV of Costs for Operation, Maintenance and Monitoring for Biological Treatment of Perchlorate-Impacted Groundwater**

Alternative	Capital Costs	NPV of 30 Years of O&M Costs	NPV of 30 Years of Monitoring Costs	NPV of 30 Years of Total Remedy Costs	Total 30-Year Remedy Costs
Perchlorate MNA	\$69	Included with monitoring	\$753	\$820	\$1,069
Passive Injection Biobarrier	\$280	\$990	\$350	\$1,610	\$2,240
Extraction and Treatment	\$490	\$1,470	\$350	\$2,310	\$3,160

Note: Costs in thousands of dollars.

**Table 8-6** summarizes the estimated costs for the three technologies described in **Tables 8-3, 8-4** and **8-5**. Perchlorate MNA is approximately one half the life-cycle cost of the Passive Injection Biobarrier alternative, and approximately one third the cost the Extraction and Treatment alternative even though the cost of monitoring is almost double the long-term monitoring for the engineered systems. The expectation would be similar at the Indian Head site.

## **9.0 Implementation Issues**

### **9.1 Environmental Checklist**

The environmental checklist includes a number of items that are useful both before and during the evaluation of a perchlorate-contaminated site for MNA. In general, the before proceeding down the path toward, it is important to plan an approach to obtain the following key information:

- Identification of the source area
- Time of release
- Historical Data
- Plume Delineation
- Sensitive Receptors
- Subsurface Geochemistry
- Subsurface Microbiology

Once a plan has been developed, data gaps can be addressed in order to complete the steps outlined in the tiered evaluation of MNA.

### **9.2 Other Regulatory Issues**

The groundwater criteria for many CoCs is well documented, but the recent information gathered about perchlorate at a wide range of sites nationwide has led to new interest in the issues associated with human health, and its environmental fate and transport. However, regulatory standards for perchlorate in groundwater have not been established in all states. For example at the beginning of this project, Maryland did not have a drinking water or groundwater standard for perchlorate. The federal TBC remains 24.5 µg/L. Maryland issued a drinking water advisory limit 1.0 µg/L which was recently replaced with a standard of 2.6 µg/L (MDE, 2008). Other states are in the process of developing standards.

### **9.3 End-User Issues**

Potential end users of the technology include a variety of agencies within the federal government (Dept. of Defense, Dept. of Energy, and Environmental Protection Agency), state and local governments, and private industry. Potential end user concerns may include:

- Permitting
- Community acceptance
- Receptors
- Confirm state specific target concentrations when considering MNA.
- Potentially long life cycles

Local concerns about perchlorate, the threat of perchlorate and the acceptance of MNA of perchlorate may vary. We have demonstrated that under the proper conditions and with a strategically planned, step-wise approach, end-users can gain assurance that MNA of perchlorate will be protective of human health and the environment.

## 10.0 References

- Bender, K.S., S.M. O'Connor, R. Chakraborty, J.D. Coates, and L.A. Achenbach, 2002. Sequencing and Transcriptional Analysis of the Chlorite Dismutase Gene of *Dechloromonas agitata* and Its Use as a Metabolic Probe. *Appl. Environ. Microbiol.* 68(10): 4820-4826.
- Borden, R.C., M.J. Hunt, M.B. Shafer and M.A. Barlaz, 1997. *Environmental Research Brief - Anaerobic Biodegradation of BTEX in Aquifer Material*. EPA/600/S-97/003, US Environ. Protect. Agency, Washington, DC, pp. 9.
- Bokuniewicz, H. J., 1992. Analytical Descriptions of Subaqueous Groundwater Seepage. *Estuaries* 15(4): 458-464.
- CDHS (California Department of Health Services), 2007. Maximum Contaminant Levels – Inorganic Chemicals. 22 California Code of Regulations §64431.
- Chaudhuri, S.K., S.M. O'Connor, R.L. Gustavson, L.A. Achenbach, and J.D. Coates, 2002. Environmental Factors that Control Microbial Perchlorate Reduction. *Appl. Environ. Microbiol.* 68(9): 4425-4430.
- Coates, J.D. and L.A. Achenbach, 2004. Microbial Perchlorate Reduction: Rocket Fuelled Metabolism. *Nat. Rev. Microbiol.* 2: 569-580.
- Coates, J.D. and L.A. Achenbach, 2006. *Chapter 12: The Microbiology of Perchlorate Reduction and its Bioremediative Application*. In: B. Gu and J.D. Coates (eds.) Perchlorate: Environmental Occurrence, Interactions, and Treatment, Springer. pp. 279-295. ISBN: 978-0-387-31114-2.
- Coates, J.D. and W.A. Jackson, 2009. Chapter 3, Principles of Perchlorate Treatment. In Stroo, H.F and Ward, C.H. (eds). In Situ Bioremediation of Perchlorate in Groundwater. Doi:10.1007/978-0-387-84921-8\_1, Springer Science + Business Media, LLC, pp. 29-52.
- Coates, J.D., U. Michaelidou, R.A. Bruce, S.M. O'Connor, J.N. Crespi, and L.A. Achenbach, 1999. Ubiquity and Diversity of Dissimilatory (Per)chlorate-Reducing Bacteria. *Appl. Environ. Microbiol.* 65 (12): 5234-5241.
- Coates, J.D. and J. Pollock, 2003. Potential for *In Situ* Bioremediation of Perchlorate in Contaminated Environments. Presented at: *In Situ* and On-Site Bioremediation, the Seventh International Symposium, Orlando, FL, June 2003.
- Cramer, R.J, C. Yates, P Hatzinger and J. Diebold, 2004. Field Demonstration of *In Situ* Perchlorate Bioremediation at Building 1419. NOSSA-TR-2004-001, January 22, 2004.

- ESTCP, 2006. Field Demonstration and Validation of a New Device for Measuring Groundwater and Perchlorate Fluxes at IHDIV-NSWC, Indian Head, MD. Prepared by Purdue University and University of Florida, Project No. ER-0114, Environmental Security Technology Certification Program, Arlington, VA, July 2006.
- ESTCP, 2007. Field and Laboratory Evaluation of the Potential for Monitored Natural Attenuation of Perchlorate in Groundwater, Final Technical Report. Prepared by Solutions-IES, Inc. and North Carolina State University, Project No. ER-0428, Environmental Security Technology Certification Program, Arlington, VA, July 2007.
- ESTCP, 2008. Natural Attenuation of Perchlorate in Groundwater: Processes, Tools and Monitoring Techniques. Prepared by Solutions-IES, Inc., Project No. ER-0428, Environmental Security Technology Certification Program, Arlington, VA, August 2008.
- Farhat, S.K., C.J. Newell and E.M. Nichols, 2006. User's Guide: Mass Flux Tool Kit. Available at <http://www.estcp.org/Technology/upload/ER-0430-MassFluxToolkit.pdf>
- Gunawan, C., 2007. *Bioremediation for Perchlorate-contaminated Groundwater*. Michigan State Univ., Microbiology & Molecular Genetics, Course 445. Basic Biotechnology eJournal 3: 6-13.  
<http://www.taxonomicoutline.org/index.php/mmg445/article/view/220/274>.
- Hatzinger, P.B., 2005. Perchlorate Biodegradation for Water Treatment. *Environ. Sci Technol.* 39: 239A-247A.
- Herman, D.C. and W.T. Frankenberger, Jr., 1998. Microbial-Mediated Reduction of Perchlorate in Groundwater. *J. Environ. Qual.* 27: 750-754.
- Hiortdahl, S.N., 1997. Geologic Framework, Hydrogeology and Ground-Water Quality of the Potomac Group Aquifer System, Northwestern Charles County, Maryland, USGS Water-Resources Investigations Report 91-4059. Baltimore, Maryland.
- Hoponick, J.R., 2006. Status Report on Innovative *In Situ* Remediation Technologies Available to Treat Perchlorate-Contaminated Groundwater. USEPA, Office of Superfund Remediation & Technology Innovation, Technology Innovation & Field Services Division, Washington, DC, August 2006.
- ITRC (Interstate Technology & Regulatory Council), 2002. A Systematic Approach to *In Situ* Bioremediation in Groundwater Including Decision Trees on *In Situ* Bioremediation for Nitrates, Carbon Tetrachloride, and Perchlorate. *In Situ* Bioremediation Team. Washington, D.C., Interstate Technology & Regulatory Council, August 2002.
- ITRC (Interstate Technology & Regulatory Council), 2005. Perchlorate: Overview of Issues, Status, and Remedial Options. PERCHLORATE-1. Washington, D.C., Interstate Technology & Regulatory Council, Perchlorate Team, September 2005.  
(<http://www.itrcweb.org>).

- Krauter, P.W., B. Daily, V. Dibley, H. Pinkart and T. Legler, 2005. Perchlorate and Nitrate Remediation Efficiency and Microbial Diversity in a Containerized Wetland Bioreactor. *Internat. J. Phytoremed.* 7:113-128
- Krug, T.A., C Wolfe, R.D. Norris and C.J. Winstead, 2009. Chapter 10, Cost Analysis of *In Situ* Perchlorate Remediation Technologies. *In: Stroo, H.F. and Ward, C.H. (eds.), In Situ Bioremediation of Perchlorate in Groundwater.* SERDP and ESTCP Remediation Technology Monograph Series, Springer Science+Business Media, LLC, New York, NY, pp 199-218.
- Li, H., M.C. Boufadel, and J.K. Weaver, 2008. Tide-Induced Seawater-Groundwater Circulation in Shallow Beach Aquifers. *J. Hydrol.* 352: 211-224.
- Li, H. and J.J. Jiao, 2003. Review of Analytical Studies of Tidal Groundwater Flow in Coastal Aquifer Systems. *In: Proceedings of the International Symposium on Water Resources and the Urban Environment.* Wuhan, P.R. China, Nov 9-10, p 86-91.
- Logan, B.E, 2001. Assessing the Outlook for Perchlorate Remediation. *Environ. Sci. Technol.* 35 (23): 482A- 487A.
- Logan, B.E., J. Wu and R.F. Unz, 2001. Biological Perchlorate Reduction in High-Salinity Solutions. *Wat. Res.* 35 (12): 3034-3038.
- Lorah, M.M. and L.D. Olsen, 1999. Natural Attenuation of Chlorinated Volatile Organic Compounds in a Freshwater Tidal Wetland: Field Evidence of Anaerobic Biodegradation. *Water Resources Res.* 35 (12): 3811-3827.
- Lorah, M.M., L.D. Olsen, B.L. Smith, M.A. Johnson, and W.B. Fleck, 1997. Natural Attenuation of Chlorinated Volatile Organic Compounds in a Freshwater Tidal Wetland, Aberdeen Proving Ground, Maryland. USGS Water-Resources Investigations Report 97-4171. 95p.
- MADEP (Massachusetts Department of Environmental Protection), 2006. Inorganic Chemical Maximum Contaminant Levels, Monitoring Requirements and Analytical Methods. 310 Code Massachusetts Regulations §22.06.
- Magnus XC, 2005. Energetics Degradation. phA Environmental Restoration, Inc. <http://pha-er.com/magnusXC.html>.
- McKelvie, J.R., S.K. Hirschorn, G. Lacrampe-Coulome, J. Lindstrom, J. Braddock, K. Finnerman, D. Trego and B.S. Lollar, 2007. Evaluation of TCE and MTBE *In Situ* Biodegradation: Integrating Stable Isotope, Metabolic Intermediate, and Microbial Lines of Evidence. *Ground Water Monit. Rev.* 27 (4), 63 -73, Fall 2007)
- MDE (Maryland Department of the Environment), 2008. Cleanup Standards for Soil and Groundwater, Type I and II Aquifers, Interim Final Guidance (Update No. 2.1), June 2008.

- Newell, C.J., H.S. Rifai, J.T. Wilson, J.A. Connor, J.A. Aziz and M.P. Suarez, 2002. Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies. United States Environmental Protection Agency, National Risk Management Research Laboratory, Cincinnati, OH, EPA/540/S-02/500, November 2002.
- Newell, C.J., J.A. Conner and D.L. Rowen, 2003. Groundwater Remediation Strategies Tool. Prepared for American Petroleum Institute, Regulatory Analysis and Scientific Affairs Department, Publication No. 4730, December 2003.
- Nowicki, B.L., E. Requentina, D. Van Kueren and J. Portnoy, 1999. The Role of Sediment Denitrification. I. Reducing Groundwater-Derived Nitrate Inputs to Nauset March Estuary, Cape Cod, Massachusetts. *Estuaries* 22 (2A): 245-259.
- NRC, 2005. Health Implications of Perchlorate Ingestion. National Academies Press, Washington, DC, USA, 276p.
- Nzengung, V.A., M.T. Lieberman, H.F. Stroo and P.J. Evans, 2008. Chapter 11, Emerging Technologies for Perchlorate Bioremediation. *In*: Stroo, H.F. and C.H. Ward (Eds). *In Situ* Bioremediation of Perchlorate in Groundwater. doi: 10.1007/978-0-387-84921-8\_11. Springer Science + Business Media, LLC.
- Portnoy, J.W., B.L. Nowicki, C.T. Roman and D.W. Urish, 1998. The Discharge of Nitrate-Contaminated Groundwater from Developed Shoreline to Marsh-Fringed Estuary. *Water Resources Res.* 34 (11): 3095-3104.
- Rectanus, H.V., M.A. Widdowson, F.H. Chapelle, C.A. Kelly and J.T. Novak, 2007. Investigation of Reductive Dechlorination Supported by Natural Organic Carbon. *Ground Water Monit. & Remed.* 27, no.4, Fall 2007, pp 53-62.
- Rikken, G.B., A.G.M. Kroon and C.G. van Ginkel, 1996. Transformation of (Per)chlorate into Chloride by a Newly Isolated Bacterium: Reduction and Dismutation. *Appl. Microbiol. Biotechnol.* 45: 420-426.
- Robertson, W.D., C.J. Ptacek and S.J. Brown, 2007. Geochemical and Hydrogeological Impacts of a Wood Particle Barrier Treating Nitrate and Perchlorate in Ground Water. *Ground Water Monit. & Remed.* 27 (2): 85-95, Spring 2007.
- Robinson, M., D. Gallagher and W. Reay, 1998. Field Observations of Tidal and Seasonal Variations in Groundwater Discharge to Tidal Estuarine Surface Water. *Ground Water Monit. Rev.* Winter 1998: 83-92.
- Solutions-IES, 2006. Evaluation of Potential for Monitored Natural Attenuation of Perchlorate in Groundwater, Technology Demonstration Plan for Building 1419 Site, Naval Surface Warfare Center, Indian Head, MD. Prepared for Environmental Security Technology Certification Program (ESTCP), Arlington, VA., May 2006.

- Stroo, H.F., R.C. Loehr, and C.H. Ward, 2009. Chapter 1, *In Situ* Bioremediation of Perchlorate in Groundwater: An Overview. *In*: Stroo, H.F and Ward, C.H. (eds). *In Situ Bioremediation of Perchlorate in Groundwater*. Doi:10.1007/978-0-387-84921-8\_1, Springer Science + Business Media, LLC, pp. 1-13.
- Stroo, H.F. and R.D. Norris, 2009. Chapter 5, Alternatives for *In Situ* Bioremediation of Perchlorate. *In*: Stroo, H.F and Ward, C.H. (eds). *In Situ Bioremediation of Perchlorate in Groundwater*. Doi:10.1007/978-0-387-84921-8\_1, Springer Science + Business Media, LLC, pp. 79-90.
- Sturchio, N.C., P.B. Hatzinger, M.D. Arkins, C. Suh and L.J. Heraty, 2003. Chlorine Isotope Fractionation during Microbial Reduction of Perchlorate. *Environ. Sci. Technol.* 37 (17): 3859-3863.
- Tan, K., T.A. Anderson and W.A. Jackson, 2004a. Degradation Kinetics of Perchlorate in Sediments and Soils. *Water, Air and Soil Pollut.* 151: 245 – 259.
- Tan, K., W.A. Jackson, T.A. Anderson and J.H. Perdue. 2004(b). Fate of Perchlorate-Contaminated Water in Upflow Wetlands. *Water Res.* 38: 4173-4185.
- Tan, K., T.A. Anderson and W.A. Jackson. 2005. Temporal and Spatial Variation of Perchlorate in Streambed Sediments: Results from *In-Situ* Dialysis Samplers. *Environ. Pollut.* 136: 283–291.
- Tetra Tech NUS, Inc., 2000. Remedial Investigation Report for IR Site 57, Former Drum Disposal Area, Building 292, Indian Head Division Naval Surface Warfare Center, Indian Head, Maryland. Prepared for the Engineering Field Activity Chesapeake Naval Facilities Engineering Command. Contract No. N62472-90-D-1298, July 2000
- Tobias, C.R., S.A.Macko, I.C. Anderson, E.A Canuel and J.W. Harvey, 2001. Tracking the Fate of a High Concentration Groundwater Nitrate Plume through a Fringing Marsh: A Combined Groundwater Tracer and *In Situ* Isotope Enrichment Study. *Limnol. Oceanogr.* 46(8): 1977-1989.
- Uchiyama, Y., 1999. Coastal Groundwater Flow and Associated Nutrient Transport into the Sea. Presented at: 2<sup>nd</sup> UJNR/CEST Panel, Charleston, Maryland, Sponsored by NOAA NOS, October 1999.
- USEPA, 1997. Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. OSWER Directive 9200.4-17, Interim Final, November 1997.
- USEPA, 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water. EPA/600/R-98/128. Washington, DC: ORD.

- USEPA, 1999. Final Directive: Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. OSWER Directive 9200.4-17P. <http://www.epa.gov/swerust1/directiv/d9200417.htm>.
- US EPA, 2005. Perchlorate Treatment Technology Update: Federal Facilities Forum Issue Paper. EPA No. 542-R05-015. InfoNational Service Center for Environmental Protection, Cincinnati, OH. (<http://yosemite.epa.gov/ncep/hom/nsCatalog.nsf/fe334be39822543485256fbf005fe5ec/84308272e16c68dc852570dd0056d0d5!openDocument>)
- US EPA, 2006. Assessment Guidance for Perchlorate. Memorandum from S.P. Bodine, Asst. Administrator, to Regional Administrators. January 26, 2006.
- USFDA (U.S. Food and Drug Administration), 2007. 2004-2005 Exploratory Survey Data on Perchlorate in Food. Posted May 2007. <http://www.cfscan.fds.gov/~dms/clo4data.html>.
- Westbrook, S.J., J.L. Rayner, G.B. Davis, T.P. Clemment, P.L. Bjerg and S.J. Fisher, 2005. Interaction Between Shallow Groundwater, Saline Surface Water and Contaminant Discharge at a Seasonally and Tidally Forced Estuarine Boundary. *J. Hydrol.* 302: 255-269.
- Wiedemeier, T.H., J.T. Wilson, D.H. Kampbell, R.N. Miller and J.E. Hansen, 1995. Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater, Volume II. Air Force Center for Environmental Excellence, Brooks Air Force Base, TX. November 1995.
- Wiedemeier, T.H., M.A. Swanson, D.E. Moutoux, E.K. Gordon, J.T. Wilson, B.H. Wilson, D.H. Kampbell, P.E. Haas, R.N. Miller, J.E. Hansen and F.H. Chapelle, 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater. EPA 600-R-98-128.
- Wilson, J.T. Jong S. Cho, Frank P. Beck, 1997. Field Estimation of Hydraulic Conductivity for Assessments of Natural Attenuation. Volume 2 of the Fourth International *In Situ* and On Site Bioremediation Symposium New Orleans, April 28 – May 1, 1997. Battelle Press, Columbus OH. pp 309 - 314

## **Appendix A**

### **Monitoring Well/Piezometer Construction Details & Select Boring Logs**

# Log of Soil Boring SGP-2D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Boring Date: 11/15/05

State:

Water Level From TOC: 7.64 feet

Water Level BGS: 7.16 feet

Installed By:

Logged By: DH

Checked By: DH

Depth of Well: 16.62 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						250	500	750		
						OVA Field Screen				
						250	500	750		
0		Ground Surface								
0-1	SW	Brown, silty fine sand with organic material								
1-2	SW	Brown, silty fine sand with gravel fill material		MC	100					
2-3	SW	Tan, silty fine sand								
3-4	SC	Wet, tan, clayey fine- sand								
4-5	SW	Tan, silty fine sand		MC	100					
5-6	SW	Tan, silty fine sand								
6-7	SW	Tan, silty fine sand								
7-8	SW	Tan, silty fine sand								
8-9	SW	Tan, silty fine sand								
9-10	SW	Tan, silty fine sand		MC	100					
10-11	SW	Tan, silty fine sand								
11-12	SW	Tan, silty fine sand with <1/2 inch dia. gravel								
12-13	CL	Tan, plastic and dense clay		MC	100					
13-14	SW	Tan, silty fine sand.								
14-15	SW	Tan, silty fine sand with slightly more clay.								
15-16	SW	Tan, silty fine sand with slightly more clay.								
16-17	SW	Tan, silty fine sand with slightly more clay.								
17-18	GC	Tan, clayey fine- sand		MC	100					
18-19	GC	Tan, clayey fine- sand								
19-20	GC	Tan, clayey fine- sand								

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-2D

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Initial Water Level: **6 feet**

Sampler Type: **Macro-Core**

County: **Charles**

Stabalized Water Level: **N/A**

Boring Date: **11/15/05**

Cave In Depth: **N/A**

Logged By: **DH**

Checked By: **DH**

Total Depth of Boring: **16.62 feet**

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	250	500	750		
21	CL	Bluish, grey sandy clay		MC	100	•	•	•		
22						ppm	ppm	ppm		
23	7					■	■	■		
24						ppm	ppm	ppm		
25		Boring terminated at 24 feet bgs				250	500	750		
26	8									
27										
28										
29	9									
30										
31										
32										
33	10									
34										
35										
36	11									
37										
38										
39	12									
40										

**Solutions-IES, Inc.**  
**1101 Nowell Road**  
**Raleigh, NC 27607**  
**(919) 873-1060**

# Log of Soil Boring SGP-4D

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Sampler Type: **Macro-Core**

County: **Charles**

Boring Date: **11/15/05**

State: **Maryland**

Water Level From TOC: **7.08 feet**

Water Level BGS: **5.86 feet**

Installed By: **Vironex**

Logged By: **DH**

Checked By: **DH**

Depth of Well: **16 feet bgs**

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						OVA Field Screen				
						ppm				
						250	500	750		
						250	500	750		
0		Ground Surface								
0	<b>SM</b>	Brown silty fine sand with organic matter								
1	<b>SM</b>	Tan, orange, silty fine sand with approx. 3% asphalt (fill material)		MC	100					
2	<b>SM</b>	Tan, orange, silty fine sand								
3	<b>SM</b>	Tan, orange, silty fine sand								
4	<b>SM</b>	Tan, orange, silty fine sand								
5	<b>SM</b>	Tan, orange, silty fine sand								
6	<b>SM</b>	Tan, orange, silty fine sand		MC	100					
7	<b>SM</b>	Tan, orange, silty fine sand								
8	<b>SM</b>	Tan, orange, silty fine sand								
9	<b>SM</b>	Tan, orange, silty fine sand								
10	<b>SM</b>	Tan, orange, silty fine sand								
11	<b>SM</b>	Tan, orange, silty fine sand								
12	<b>SM</b>	Tan, orange, silty fine sand								
13		No recovery								
14		No recovery			0					
15	<b>GM</b>	Orange, silty coarse sand with gravel (< 1/4 inch)		MC	37					
16	<b>GM</b>	Orange, silty coarse sand with gravel (< 1/4 inch)								
17	<b>CL</b>	Light grey, plastic and dense clay								
18	<b>CL</b>	Light grey, plastic and dense clay								
19	<b>CL</b>	Light grey, plastic and dense clay								
20	<b>CL</b>	Light grey, plastic and dense clay								

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-6D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Water Level From TOC: 7.04 feet

Boring Date: 11/15/05

State: Maryland

Water Level BGS: 5.99 feet

Installed By: Vironex

Logged By: DH

Checked By: DH

Depth of Well: 16 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						250	500	750		
						OVA Field Screen				
						ppm				
						250	500	750		
0		Ground Surface								
0	SM	Brown, silty fine sand with organic material and gravel								
1	SW	Red, fine sand with gravel		MC	100					
2	SM	Tan, orange, silty fine sand (dry)								
3	SM	Tan, silty fine sand (wet). Low strength zone from 14 to 16 feet. 50% recovery from 12 to 16 feet due to 1 inch sized gravel blocking Geoprobe sleeve		MC	100					
4	GM	Silty gravel, inferred.		MC	50					
5	CL	Light tan, plastic and dense clay		MC	100					
6		Boring terminated at 17 feet bgs								

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-6D

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Initial Water Level: **7 feet**

Sampler Type: **Macro-Core**

County: **Charles**

Stabalized Water Level: **N/A**

Boring Date: **11/15/05**

Cave In Depth: **N/A**

Logged By: **DH**

Checked By: **DH**

Total Depth of Boring: **17 feet**

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	250	500	750		
21		21 ft								
22										
23	7									
24										
25										
26	8									
27										
28										
29	9									
30										
31										
32										
33	10									
34										
35										
36	11									
37										
38										
39	12									
40										

**Solutions-IES, Inc.**  
**1101 Nowell Road**  
**Raleigh, NC 27607**  
**(919) 873-1060**

# Log of Soil Boring SGP-8D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Boring Date: 11/15/05

State: Maryland

Water Level From TOC: 19.48 feet

Water Level BGS: 17.21 feet

Installed By: Vironex

Logged By: DH

Checked By: DH

Depth of Well: 23 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						250	500	750		
						OVA Field Screen				
						ppm				
						250	500	750		
ft 0	m 0	Ground Surface								
1		<b>SM</b> Brown, silty fine sand with organic material								
2		<b>SM</b> Brown, silty fine sand with gravel fill material		MC	100					
3	1	<b>SM</b> Tan, silty fine sand								
4		<b>SM</b> Tan, silty fine sand								
5		<b>SC</b> Tan, clayey fine sand (wet)		MC	100					
6	2	<b>SM</b> Tan, silty fine sand								
7		<b>SM</b> Tan, silty fine sand								
8		<b>SM</b> Tan, silty fine sand								
9		<b>SM</b> Tan, silty fine sand								
10	3	<b>GM</b> Tan, silty fine sand with <1/2 inch dia. gravel								
11		<b>CL</b> Tan, plastic and dense clay		MC	100					
12	4	<b>SM</b> Tan, silty fine sand								
13		<b>SM</b> Tan, silty fine sand with slightly more clay								
14		<b>SM</b> Tan, silty fine sand								
15	5	<b>SC</b> Tan, clayey fine sand								
16		<b>CL</b> Bluish grey sandy clay		MC	100					
17										
18										
19										
20	6									
21										
22										
23	7									
24										
25		24 ft								

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-15

Project: **Perchlorate MNA**

Solutions-IES Project No.: **3030.04A2.ESTC**

Client: **ESTCP**

Drilling Method: **Geoprobe**

City: **Indian Head**

Sampler Type: **Macro-Core**

County: **Charles**

Water Level From TOC: **N/A**

Boring Date: **06/07/06**

State: **Maryland**

Water Level BGS: **N/A**

Installed By: **Vironex**

Logged By: **SK**

Checked By: **JM**

Depth of Well: **9.49 feet bgs**

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						250	500	750		
						OVA Field Screen				
						ppm				
						250	500	750		
0		Ground Surface								
1		No recovery		MC	0					
2										
3				MC	0					
4	CL	Grey, silty clay		MC	100					
5										
6		No recovery		MC	0					
7										
8	CL	Grey clay with some silt		MC	100					
9										
10		No recovery		MC	0					
11										
12		12 ft								
13										
14										
15										

**Solutions-IES, Inc.**  
**1101 Nowell Road**  
**Raleigh, NC 27607**  
**(919) 873-1060**

# Log of Soil Boring SGP-20

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Client: ESTCP

Drilling Method: Geoprobe

City: Indian Head

Sampler Type: Macro-Core

County: Charles

Water Level From TOC: N/A

Boring Date: 06/08/06

State: Maryland

Water Level BGS: N/A

Installed By: Vironex

Logged By: SK

Checked By: JM

Depth of Well: 6.22 feet bgs

SUBSURFACE PROFILE			SAMPLE			PID Field Screen			Lab Sample Depth	Well Data
Depth	USCS Symbol	Description	Sample Interval	Type	% Recovery	ppm				
						250	500	750		
						OVA Field Screen				
						250	500	750		
0		Ground Surface								
0	OL	Grey to black organic clay with fine sand and silt, odor		MC	100					
1										
2	SC	Grey, fine-grained clayey sand		MC	100					
3										
4	SC	Green, fine-grained sand with some clay		MC	100					
5										
6		No recovery								
7				MC	0					
8										
9	SC	Green, fine- to medium-grained sand with some clay		MC	100					
10										
11		10 ft								
12										
13										
14										
15										

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060

# Log of Soil Boring SGP-22D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Boring Number: SGP-22D

Client: ESTCP

Page: 1 of 1

Project Location: Naval Surface Warfare Center City: Indian Head, MD

County:

Site or Site Area: Channel Well

Drilling Method: Push

Date Started: 09/26/06

Date Finished: 09/26/06

Sample Type: Hand Samples

Initial Water Level:

Final Water Level:

Logged By: JD

Checked By:

Total Depth of Boring: 10

Total Depth of Well: 8.5 feet bgs

SUBSURFACE PROFILE				SAMPLE					PID Field Screen ▲ ppm ▲ 5 15 25 35 45 FID Field Screen ● ppm ● 5 15 25 35 45	Lab Sample	Well Data
Elevation	Depth in Feet	Symbol	Description	Number	Sample Interval	Type	Blows per Foot (N)	Recovery			
	0		Ground Surface								
	1	[Symbol]	OL Dark Brown to black clayey SILT, high organic content	1		HS		100			
	2										
	3	[Symbol]	ML Dark brown clayey SILT, with some fine sand	2		HS		100			
	4	[Symbol]	CL Brown, sandy CLAY								
	5	[Symbol]	SM Dark brown, fine to medium silty SAND	3		HS		100			
	6										
	7	[Symbol]	CL Brown, silty sandy CLAY	4		HS		100			
	8										
	9	[Symbol]	SP Brown medium to fine SAND	5		HS		0			
	10		10 ft								
	11										
	12										
	13										
	14										
	15										

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



# Log of Soil Boring SGP-23D

Project: Perchlorate MNA

Solutions-IES Project No.: 3030.04A2.ESTC

Boring Number: SGP-23D

Client: ESTCP

Page: 1 of 1

Project Location: Naval Surface Warfare Center City: Indian Head, MD

County:

Site or Site Area: Channel Well

Drilling Method: Push

Date Started: 09/27/06

Date Finished: 09/27/06

Sample Type: Hand Samples

Initial Water Level:

Final Water Level:

Logged By: JD

Checked By:

Total Depth of Boring: 10

Total Depth of Well: 8.5 feet bgs

SUBSURFACE PROFILE				SAMPLE					PID Field Screen ▲ ppm ▲ 5 15 25 35 45 FID Field Screen ● ppm ● 5 15 25 35 45	Lab Sample	Well Data
Elevation	Depth in Feet	Symbol	Description	Number	Sample Interval	Type	Blows per Foot (N)	Recovery			
	0		Ground Surface								
	1		OL Black clayey SILT, high organic content	1		HS		100			
	2		SP Black medium to fine SAND								
	3		ML Dark brown, clayey SILT with little fine sand	2		HS		100			
	4										
	5		SM Dark brown, fine silty SAND	3		HS		100			
	6		SP Green, glauconitic, medium to fine SAND								
	7			4		HS		100			
	8										
	9			5		HS		0			
	10		10 ft								
	11										
	12										
	13										
	14										
	15										

**Solutions-IES, Inc.**  
 1101 Nowell Road  
 Raleigh, NC 27607  
 (919) 873-1060



**APPENDIX A  
Monitor Well and Piezometer Construction Details**

Well ID	Diameter (in)	Location		Top of Casing (ft above Land Surf.)	Depth from TOC to Bottom	Screen Length (ft)	Depth		Elevations			
		Easting	Northing				Screen Top (bgs)	Screen Bottom (bgs)	Land Surface (ft MSL)	Top of Casing (ft MSL)	Top of Screen (ft MSL)	Bottom of Screen (ft MSL)
<b>MONITOR WELLS AND PIEZOMETERS ON LAND</b>												
MW-1	2	1265478.00	334658.98	2.50	17.72	10	5.22	15.22	9.05	11.55	3.83	-6.17
MW-2	2	1265504.81	334546.78	2.55	18.67	10	6.12	16.12	8.13	10.68	2.01	-7.99
MW-3	2	1265601.59	334593.57	2.73	17.55	UN	UN	UN	9.65	12.38	4.38	-5.17
MW-4	2	1265524.71	334600.28	0.84	17.85	10	7.01	17.01	8.65	9.49	1.64	-8.36
MW-5	2	1265531.18	334591.91	2.63	19.48	10	6.85	16.85	8.60	11.23	1.75	-8.25
SGP-1S	1	1265596.49	334405.67	3.46	15.86	5	7.40	12.40	4.70	8.16	-2.70	-7.70
SGP-1D	1	1265597.45	334404.40	1.23	16.87	2	13.64	15.64	4.76	5.99	-8.88	-10.88
SGP-2S	1	1265702.87	334447.42	1.60	14.91	5	8.31	13.31	7.23	8.83	-1.08	-6.08
SGP-2D	1	1265704.69	334449.16	0.57	17.10	2	14.53	16.53	7.34	7.91	-7.19	-9.19
SGP-3S	1	1265786.14	334522.64	3.20	14.97	5	6.77	11.77	6.04	9.24	-0.73	-5.73
SGP-3D	1	1265785.30	334526.57	1.90	17.25	2	13.35	15.35	5.93	7.83	-7.42	-9.42
SGP-4S	1	1265558.48	334470.88	3.57	14.55	5	5.98	10.98	6.27	9.84	0.29	-4.71
SGP-4D	1	1265555.75	334471.61	1.64	17.05	2	13.41	15.41	6.27	7.91	-7.14	-9.14
SGP-5S	1	1265695.72	334581.28	3.85	15.00	5	6.15	11.15	8.78	12.63	2.63	-2.37
SGP-5D	1	1265695.13	334578.79	2.81	17.00	2	12.19	14.19	8.68	11.49	-3.51	-5.51
SGP-6S	1	1265534.10	334558.22	2.46	15.98	5	8.52	13.52	8.78	11.24	0.26	-4.74
SGP-6D	1	1265533.48	334560.86	1.30	17.09	2	13.79	15.79	8.70	10.00	-5.09	-7.09
SGP-7S	1	1265637.41	334609.37	3.69	14.93	5	6.24	11.24	9.96	13.65	3.72	-1.28
SGP-7D	1	1265634.83	334610.02	2.68	17.13	2	12.45	14.45	9.99	12.67	-2.46	-4.46
SGP-8S	1	1265472.57	334600.47	3.43	14.97	5	6.54	11.54	7.85	11.28	1.31	-3.69
SGP-8D	1	1265474.56	334597.69	2.61	25.08	5	17.47	22.47	7.90	10.51	-9.57	-14.57
TP-5	1	NM	NM	1.00	11.00	5	5.00	10.00	4.02	5.02	-0.98	-5.98
TP-8	1	NM	NM	1.00	11.00	5	5.00	10.00	5.60	6.60	0.60	-4.40
<b>MONITOR WELLS AND PIEZOMETERS IN THE LITTORAL ZONE</b>												
SGP-9	3/4	1265857.10	334467.39	4.31	12.43	2	6.12	8.12	-0.98	3.33	-7.10	-9.10
SGP-19	3/4	1265701.76	334369.94	3.24	11.98	2	6.74	8.74	-0.47	2.77	-7.21	-9.21
SGP-20	3/4	1265591.09	334313.63	3.98	10.20	2	4.22	6.22	-1.08	2.90	-5.30	-7.30
SGP-21	1	1265480.63	334249.70	4.80	12.56	5	2.76	7.76	-1.09	3.71	-3.85	-8.85
TP-1	1	1265705.7	334357.2	2.45	5.45	1	2.00	3.00	-0.68	1.77	-2.68	-3.68
TP-2	1	1265705.7	334357.2	2.45	7.45	1	4.00	5.00	-0.68	1.77	-4.68	-5.68
TP-3	1	1265705.7	334357.2	2.45	9.12	1	5.67	6.67	-0.68	1.77	-6.35	-7.35
DP-1	1	1265781.7	334428.8	NM	NM	2	8.35	9.35	NM	1.75		
TP-4	1	1265596.9	334300.2	3.02	6.02	1	2.00	3.00	-0.67	NM	-2.67	-3.67
TP-6	1	1265596.9	334300.2	3.02	8.02	1	4.00	5.00	-0.67	NM	-4.67	-5.67
TP-7	1	1265596.9	334300.2	3.02	9.69	1	5.50	6.50	-0.67	NM	-6.17	-7.17
DP-2	1	1265596.9	334300.2	3.02	12.02	1	8.00	9.00	-0.67	NM	-8.67	-9.67
DP-3	1	1265535.6	334283.8	NM	NM	1	6.00	7.00	NM	2.74		
ISC-1	1	NM	NM									
ISC-2	1	NM	NM									
ISC-3	1	NM	NM									
ISC-4	1	NM	NM									
<b>MONITOR WELLS AND PIEZOMETERS IN THE SUBTIDAL CHANNEL</b>												
SGP-22S	1	1265608.75	334272.75	5.03	7.84	1	1.81	2.81	-1.65	3.38	-3.46	-4.46
SGP-22D	1	1265608.08	334272.58	4.27	8.50	1	3.23	4.23	-1.65	2.62	-4.88 (est)	-5.88
SGP-22SW	1	1265609.85	334273.21	4.30	NA	1	1.0	0.00	-1.65	2.65	NA	NA
SGP-23S	1	1265715.67	334333.75	4.30	8.38	1	3.08	4.08	-2.11	2.19	-5.19	-6.19
SGP-23D	1	1265715.13	334333.54	5.36	13.75	1	7.39	8.39	-2.11	3.25	-9.50	-10.50
SGP-23SW	1	1265715.26	334333.17	4.39	NM	1	1.00	0.00	-2.11	2.28	NM	NM
SGP-24S	1	1265865.89	334419.54	4.70	8.55	1	2.85	3.85	-1.46	3.24	-4.31	-5.31
SGP-24D	1	1265865.32	334418.81	2.83	11.40	1	7.57	8.57	-1.46	1.37	-9.03	-10.03
SGP-24SW	1	1265866.02	334418.83	3.47	NM	1	1.00	0.00	-1.46	2.01	NM	NM
<b>MONITOR WELLS AND PIEZOMETERS IN THE SUBTIDAL SHALLOWS</b>												
SGP-10	2	1265846.42	334370.28	4.43	14.83	2	8.40	10.40	-2.02	2.41	-10.42	-12.42
SGP-11	2	1265718.39	334316.09	4.80	14.84	2	8.04	10.04	-2.07	2.73	-10.11	-12.11
SGP-12	2	1265628.97	334215.13	4.57	14.82	2	8.25	10.25	-1.59	2.98	-9.84	-11.84
SGP-13	2	1265645.90	334038.29	5.62	17.15	2	9.53	11.53	-1.97	3.65	-11.50	-13.50
SGP-14	2	1265728.37	334142.48	5.42	14.84	2	7.42	9.42	-2.13	3.29	-9.55	-11.55
SGP-15	2	1265799.09	334219.15	5.46	14.95	2	7.49	9.49	-2.03	3.43	-9.52	-11.52
SGP-16	2	1265902.09	334267.02	4.43	14.90	2	8.47	10.47	-2.43	2.00	-10.90	-12.90
SGP-17	2	1265851.57	333901.79	5.98	14.21	2	6.23	8.23	-3.00	2.98	-9.23	-11.23
SGP-18	2	1265687.35	333733.42	5.09	14.87	2	7.78	9.78	-1.89	3.20	-9.67	-11.67

Survey Data provided by KCI, Inc.

Elevations are based on the NAVD 88 vertical datum

Piezometer and *In situ* Column locations and elevations were measured from nearby monitor wells.

Piezometer and *In Situ* Column coordinates are estimated from locations plotted on the basemap

NM = Not Measured

UN- Unknown

## **Appendix B**

### **Historical Water Level Measurements**

**APPENDIX B**  
**Groundwater Elevation Data**

Well ID	Date	Depth to Water (ft)	Top of Casing Elevation (ft msl)	Groundwater Elevation (ft msl)
<b>LAND MONITORING WELLS</b>				
MW-1	11/15/2005	6.02	11.55	5.53
	9/25/2006	5.80		5.75
	4/15/2008	5.76		5.79
MW-2	11/15/2005	7.78	10.68	2.90
	9/25/2006	7.42		3.26
	11/15/2005	9.97		2.41
MW-3	9/25/2006	9.49	12.38	2.89
	4/15/2008	8.92		3.46
	11/15/2005	6.24		3.25
MW-4	9/25/2006	5.79	9.49	3.70
	4/15/2008	5.24		4.25
	11/15/2005	8.08		3.15
CPMW-5	9/28/2006	7.75	11.23	3.48
	4/15/2008	7.04		4.19
	11/16/2005	7.89		0.27
SGP-1S	9/26/2006	7.91	8.16	0.25
	8/9/2007	6.74		1.42
	4/15/2008	7.00		1.16
	11/16/2005	5.38		0.61
SGP-1D	9/26/2006	5.76	5.99	0.23
	8/9/2007	8.97		-2.98
	4/15/2008	4.83		1.16
	11/16/2005	8.49		0.34
SGP-2S	9/26/2006	8.68	8.83	0.15
	2/8/2007	8.52		0.31
	8/9/2007	9.36		-0.53
	4/15/2008	8.01		0.82
SGP-2D	11/16/2005	7.64	7.91	0.27
	9/26/2006	7.76		0.15
	2/8/2007	7.64		0.27
	8/9/2007	8.44		-0.53
SGP-3S	4/15/2008	7.13	8.83	0.78
	11/16/2005	8.46		0.37
	9/26/2006	8.98		-0.15
	8/9/2007	9.68		-0.85
SGP-3D	4/15/2008	8.37	7.83	0.46
	11/16/2005	7.55		0.28
	9/25/2006	7.64		0.19
	8/9/2007	8.25		-0.42
SGP-4S	4/15/2008	6.97	9.84	0.86
	11/17/2005	8.67		1.17
	9/26/2006	8.83		1.01
	4/15/2008	7.70		2.14
SGP-4D	11/17/2005	7.08	7.91	0.83
	9/26/2006	7.27		0.64
	4/15/2008	6.27		1.64
SGP-5S	11/17/2005	11.96	12.63	0.67
	9/26/2006	11.75		0.88
	4/15/2008	10.96		1.67
SGP-5D	11/16/2005	10.98	11.49	0.51
	9/26/2006	10.85		0.64
	4/15/2008	10.17		1.32
SGP-6S	11/17/2005	8.11	11.24	3.13
	9/25/2006	7.92		3.32
	4/15/2008	7.18		4.06
SGP-6D	11/17/2005	7.04	10	2.96
	9/25/2006	6.58		3.42
	4/15/2008	5.90		4.10
SGP-7S	11/16/2005	12.07	13.65	1.58
	9/25/2006	11.67		1.98
	4/15/2008	10.88		2.77
SGP-7D	11/16/2005	11.25	12.67	1.42
	9/25/2006	10.87		1.80
	4/15/2008	10.12		2.55
SGP-8S	11/17/2005	7.33	11.28	3.95
	9/25/2006	7.24		4.04
	4/15/2008	6.71		4.57
SGP-8D	11/17/2005	19.48	10.51	-8.97
	9/25/2006	6.09		4.42
	3/29/2007	6.09		4.42
	4/15/2008	6.03		4.48

Well ID	Date	Depth to Water (ft)	Top of Casing Elevation (ft msl)	Groundwater Elevation (ft msl)
<b>SUBTIDAL CHANNEL MONITORING WELLS</b>				
SGP-9	6/8/2006	2.45	3.33	0.88
	9/25/2006	3.36		-0.03
	3/28/2007	2.54		0.79
	8/8/2007	3.59		-0.26
	4/15/2008	2.65		0.68
SGP-19	6/8/2006	1.94	2.77	0.83
	9/25/2006	2.64		0.13
	3/28/2007	1.80		0.97
	8/8/2007	3.30		-0.53
	4/15/2008	1.84		0.93
SGP-20	6/8/2006	1.70	2.90	1.20
	9/25/2006	3.16		-0.26
	3/28/2007	2.48		0.42
	4/15/2008	2.77		0.13
SGP-21	9/27/2006	3.29	3.71	0.42
	3/28/2007	3.42		0.29
	8/8/2007	3.46		0.25
	4/15/2008	3.78		-0.07
<b>CHANNEL MONITORING WELLS</b>				
SGP-22S	9/27/2006	3.04	3.38	0.34
	3/28/2007	3.11		0.27
	8/8/2007	3.04		0.34
	4/15/2008	2.80		0.58
SGP-22D	9/27/2006	2.83	2.62	-0.21
	3/28/2007	2.38		0.24
	8/8/2007	2.25		0.37
	4/15/2008	2.05		0.57
SGP-22SW				
SGP-23S*	9/27/2006	1.93	2.19	0.26
	4/15/2008	1.32		0.87
SGP-23D	9/27/2006	3.61	3.25	-0.36
	8/8/2007	3.05		0.20
	4/15/2008	3.11		0.14
SGP-23SW				
SGP-24S	9/27/2006	3.00	3.24	0.24
	8/8/2007	3.51		-0.27
	4/15/2008	2.49		0.75
SGP-24D	9/27/2006	3.25	1.37	-0.01
	8/8/2007	1.98		1.26
	4/15/2008	0.69		0.68
SGP-24SW		2.46		
<b>MUDFLATS MONITORING WELLS</b>				
SGP-10	6/8/2006	1.34	2.41	1.07
	9/25/2006	3.31		-0.90
SGP-11	6/8/2006	1.61	2.73	0.80
	9/25/2006	3.61		-0.88
SGP-12	6/8/2006	1.79	2.98	0.62
	9/25/2006	3.73		-0.75
SGP-13	6/8/2006	2.51	3.65	-0.10
	9/25/2006	4.54		-0.89
SGP-14	6/8/2006	1.97	3.29	0.44
	9/25/2006	4.28		-0.99
SGP-15	6/8/2006	2.19	3.43	0.22
	9/25/2006	4.54		-1.11
SGP-16	6/8/2006	1.01	2.00	1.40
	9/25/2006	2.97		-0.97
SGP-17	6/8/2006	2.04	2.98	0.37
	9/25/2006	4.01		-1.03
SGP-18	6/8/2006	2.27	3.20	0.14
	9/25/2006	4.09		-0.89

\* The pipe on SGP-23S is slanted  
NS-Well not surveyed  
Survey data provided by KCI, Inc.  
Elevations referenced to NADV88  
ft msl = feet above mean sea level

## **Appendix C**

### **Performance Monitoring Data**

**APPENDIX C - TABLE C1**  
**Summary Pre-Demonstration Analytical Results**  
**Samples Collected June 6, 7, 8, 2006**

Relative Location	units	Littoral Zone	Littoral Zone	Littoral Zone	Average	Subtidal Shallows	Subtidal Shallows	Subtidal Shallows	Subtidal Shallows	Subtidal Shallows	Subtidal Shallows	Subtidal Shallows	Subtidal Shallows	Subtidal Shallows	Average	Surface Water	Surface Water
		SGP-9	SGP-19	SGP-20		SGP-10	SGP-11	SGP-12	SGP-13	SGP-14	SGP-15	SGP-16	SGP-17	SGP-18			
Perchlorate	µg/L	200	4,400/4,300 <sup>(1)</sup>	13,000	<b>5,900</b>	ND	ND/ND <sup>(2)</sup>	ND	ND	ND	ND	ND	ND	ND	<b>ND</b>		
Methane	µg/L	ND	ND	120	<b>40</b>	6300	9.9	1,300	8,400	6,200	4,300	12,000	12,000	13,000	<b>7,100</b>		
TOC-soil	mg/kg	7,500 (2-4ft)	16,000 (0-2ft)	5,900 (2-4ft)	<b>9,800</b>	21,000 (4-6ft)	48,000 (0-2ft)	50,000 (0.25 ft)/ 34,000 (1.5 ft)	21,000 (1.5ft)	18,000 (4-6 ft)	29,000 (4-6ft)	24,000 (4-6ft)	34,000 (0-2ft)	28,000 (4-6ft)	<b>30,700</b>		
TOC-soil	mg/kg	1,800 (11.5 ft)	2,500 (6-8ft)	2,800 (4-6ft)	<b>2,400</b>	21,000 (10-12ft)	13,000 (8-10ft)	86,000 (6-8ft)	56,000 (8-10ft)	20,000 (6-8ft)	44,000 (8-10ft)	31,000 (10-12ft)	15,000 (11.5ft)	24,000 (6-8ft)	<b>34,000</b>		
TOC-Groundwater	mg/L	1.0	1.4	1.4	<b>1.3</b>	6.5	9.3	14	14	15	12	10	22	25	<b>14</b>		
Chloride	mg/L	21/21 <sup>(1)</sup>	8.3/8.3 <sup>(1)</sup>	17	<b>15</b>	100	120	170	190	210	210	140	130	120	<b>150</b>		
Nitrate	mg/L	1.8/1.8 <sup>(1)</sup>	2.4/2.4 <sup>(1)</sup>	1.7	<b>2.0</b>	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5			
Sulfate	mg/L	130/130 <sup>(1)</sup>	120/120 <sup>(1)</sup>	240	<b>163</b>	0.7	1,200	430	4.4	2.3	1.6	4.7	0.9	<0.5	<b>180</b>		
Bromide	mg/L	21/21 <sup>(1)</sup>	<0.5/<0.5 <sup>(1)</sup>	<0.5	<b>7.0</b>	0.5	0.6	0.8	0.9	0.8	0.9	0.6	0.9	1.0	<b>0.8</b>		
pH	SU	5.04	4.76	4.05	<b>4.6</b>	6.09	5.93	6.17	6.38	6.27	6.35	6.42	6.42	6.39	<b>6.27</b>	7.24 (near 15)	8.80 (near 12)
DO	mg/L	0.2	0.3	0.1	<b>0.2</b>	2.0	1.3	0.5	3.0	0.2	4.0	1.5	0.1	0.0	<b>1.4</b>	NT	NT
Conductivity	µS/cm	360	300	550	<b>400</b>	880	3,000	2,700	1,400	1,400	1,300	1,100	2,300	3,300	<b>1,900</b>	220	220
Temp	Celsius	17.4	16.2	16.9	<b>17</b>	17.1	16.8	15.8	18.1	18.3	17.3	17.6	17.0	16.5	<b>17.2</b>	25.2	25.6
ORP	mV	1.3	148	254	<b>130</b>	-168	-81	-235	-82	-90	-56	-132	-190	-206	<b>-138</b>	-55	55

ND-Not Detected

(1)-Duplicate

(2)-Confirmation by IC/MS/MS

NT-Not Tested

Perchlorate, Methane, TOC, Chloride, Nitrate, Sulfate, Bromide, DO, & Conductivity rounded to 2 significant figures.

**APPENDIX C - TABLE C2**

**Summary of Laboratory Analytical Results**

Well ID	Sample Date	Perchlorate		Chlorate (mg/L)	Chlorite (mg/L)	Chloride (mg/L)	Bromide (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Sulfate (mg/L)	TOC (mg/L)	Phosphate (mg/L)	Methane (µg/L)
		Method 314 (µg/L)	Method 332 (µg/L)										
<b>MONITOR WELLS AND PIEZOMETERS ON LAND</b>													
MW-1	2/5/02	85,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2/15/05	93,000	NA	NA	NA	16	NA	NA	113.0	38	NA	<1	NA
	11/17/05	24,000	NA	NA	NA	16	<1	140	<0.5	41	2.2	<1	<10
	9/28/06	15,000	NA	<0.5	<0.5	30	<0.5	40	<0.5	39	3.0	<0.5	7.0
	4/17/08	18,000	23,000	<0.5	<0.5	29	<0.5	26	<0.5	35	1.7	NA	7.0
MW-2	2/5/02	1,900	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2/15/05	3.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	11/17/05	16	NA	NA	NA	1.8	<1	3.4	<0.5	63	5.2	<1	<10
	9/28/06	6.0	NA	<0.5	<0.5	2.1	<0.5	1.3	<0.5	44	5.1	<0.5	11
MW-3	2/5/02	1,600	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	11/17/05	9,200	NA	NA	NA	4.7	<1	0.8	<0.5	57	2.4	<1	<10
	9/28/06	11,000	NA	<0.5	<0.5	12	<0.5	2.2	<0.5	110	2.3	<0.5	<4
	8/9/07	11,000	NA	<0.5	<0.5	14	<0.5	2.3	<0.5	83	1.3	NA	<4
	4/17/08	4,100	NA	<0.5	<0.5	5.1	<0.5	2.1	<0.5	110	2.2	NA	<4
MW-4	2/5/02	180,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2/15/05	36,000	NA	NA	NA	11	NA	NA	8.7	120	NA	NA	NA
	11/17/05	26,000	NA	NA	NA	2.1	<1	1.6	<0.5	57	2.8	<1	42
	9/28/06	18,000	NA	<0.5	<0.5	8.1	<0.5	1.2	<0.5	110	4.7	<0.5	27
	4/17/08	9,600	NA	<0.5	<0.5	9.4	<0.5	3.5	<0.5	51	2.5	NA	92
MW-5	2/5/02	83,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	11/17/05	17,000	NA	NA	NA	2.3	<1	2.4	<0.5	96	3.5	<1	27
	9/28/06	2,300	NA	<0.5	<0.5	5.5	<0.5	<0.5	<0.5	110	7.4	<0.5	34
	4/17/08	8,800	8,600/9,000	<0.5	<0.5	5.3	<0.5	6.5	<0.5	72	2.7	NA	6.0
MW-6	2/5/02	142,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SGP-1S	11/17/05	2,600	NA	NA	NA	2.6	<1	<0.5	<0.5	57	1.6	<1	<10
	9/27/06	2,400	2,800	<0.5	<0.5	5.5	<0.5	0.8	<0.5	90	1.8	<0.5	5.0
	8/9/07	1,600	NA	<0.5	<0.5	5.8	<0.5	<0.5	<0.5	90	2.1	NA	<4
	4/15/08	3,300	NA	<0.5	<0.5	3.6	<0.5	0.8	<0.5	63	1.2	NA	8.0
SGP-1D	11/17/05	2,700	NA	NA	NA	5.2	<1	0.9	<0.5	80	1.8	<1	<10
	9/27/06	2,200	NA	<0.5	<0.5	11	<0.5	0.6	<0.5	82	1.6	<0.5	<4
	8/9/07	750	NA	<0.5	<0.5	37	<0.5	0.6	<0.5	21	2.1	NA	<4
	4/15/08	4,000	NA	<0.5	<0.5	7.5	<0.5	0.6	<0.5	80	1.2	NA	7.0
SGP-2S	11/17/05	13,000	NA	NA	NA	11	<1	0.8	<0.5	130	1.2	<1	59
	9/26/06	16,000	NA	<0.5	<0.5	12	<0.5	1.9	<0.5	150	1.6	<0.5	21
	8/9/07	13,000	NA	<0.5	<0.5	14	<0.5	2.4	<0.5	170	1.5	NA	<4
	4/15/08	11,000	NA	<0.5	<0.5	17	<0.5	1.6	<0.5	97	1.1	NA	10
SGP-2D	11/17/05	12,000	NA	NA	NA	9.7	<1	<0.5	<0.5	78	8.0	<1	23
	9/26/06	33,000	NA	<0.5	<0.5	18	<0.5	3.7	<0.5	140	1.5	<0.5	7.0
	3/28/07	4,500	NA	<0.5	<0.5	6.9	<0.5	3.9	<0.5	130	NA	<0.5	NA
	8/9/07	15,000	NA	<0.5	<0.5	19	<0.5	1.9	<0.5	97	1.4	NA	80
	4/15/08	10,000	NA	<0.5	<0.5	13	<0.5	2.9	<0.5	130	1.2	NA	9.0
SGP-3S	11/17/05	23	NA	NA	NA	4.8	<1	<0.5	<0.5	55	1.3	<1	<10
	9/26/06	46	NA	<0.5	<0.5	12	<0.5	1.1	<0.5	89	1.4	<0.5	17
	8/9/07	19	NA	<0.5	<0.5	10	<0.5	<0.5	<0.5	68	6.2	NA	<4
	4/15/08	11	NA	<0.5	<0.5	16	<0.5	<0.5	<0.5	71	1.8	NA	<4
SGP-3D	11/17/05	80	NA	NA	NA	2.3	<1	<0.5	<0.5	60	<1	<1	<10
	9/26/06	89	NA	<0.5	<0.5	13	<0.5	1.9	<0.5	160	1.6	<0.5	7.0
	8/9/07	48	NA	<0.5	<0.5	3.9	<0.5	<0.5	<0.5	57	2.2	NA	<4
	4/15/08	210	NA	<0.5	<0.5	8.7	<0.5	1.00	<0.5	84	1.0	NA	6.0
SGP-4S	11/17/05	346	NA	NA	NA	6.4	<1	6.0	<0.5	16	15	<1	<10
	9/27/06	317	NA	<0.5	<0.5	2.6	<0.5	2.0	<0.5	31	3.0	<0.5	36
	4/17/08	56	NA	<0.5	<0.5	1.2	<0.5	2.1	<0.5	25	2.9	NA	48
SGP-4D	11/17/05	5,700	NA	NA	NA	2.6	<1	1.4	<0.5	47	2.2	<1	<10
	9/27/06	5,800	NA	<0.5	<0.5	5.7	<0.5	13	<0.5	68	2.0	<0.5	31
	4/17/08	2,400	NA	<0.5	<0.5	4.1	<0.5	9.9	<0.5	61	1.8	NA	7.0

**APPENDIX C - TABLE C2**

**Summary of Laboratory Analytical Results**

Well ID	Sample Date	Perchlorate		Chlorate (mg/L)	Chlorite (mg/L)	Chloride (mg/L)	Bromide (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Sulfate (mg/L)	TOC (mg/L)	Phosphate (mg/L)	Methane (µg/L)
		Method 314 (µg/L)	Method 332 (µg/L)										
SGP-5S	11/17/05	230	NA	NA	NA	5.3	<1	1.1	<0.5	100	2.6	<1	<10
	9/28/06	15	NA	<0.5	<0.5	7.3	<0.5	2.8	<0.5	150	2.4	<0.5	<4
	4/17/08	48	NA	<0.5	<0.5	4.9	<0.5	3.5	<0.5	120	1.1	NA	<4
SGP-5D	11/17/05	320	NA	NA	NA	11	<1	2.0	<0.5	170	1.5	<1	<10
	9/28/06	480	NA	<0.5	<0.5	25	<0.5	8.0	<0.5	310	1.2	<0.5	<4
	4/17/08	210	NA	<0.5	<0.5	11	<0.5	0.8	<0.5	150	1.2	NA	18
SGP-6S	11/17/05	18,000	NA	NA	NA	11	<1	2.8	<0.5	110	3.1	<1	83
	9/28/06	10,000	NA	<0.5	<0.5	22	<0.5	0.6	<0.5	150	<1	<0.5	46
	4/17/08	4,500	NA	<0.5	<0.5	17	<0.5	<0.5	<0.5	110	1.6	NA	16
SGP-6D	11/17/05	17,000	NA	NA	NA	11	<1	<0.5	<0.5	77	29	<1	1,100
	9/28/06	<1	NA	<0.5	<0.5	25	<0.5	<0.5	<0.5	<0.5	32	<0.5	7,100
	3/29/07	<1	NA	<0.5	<0.5	26	<0.5	<0.5	<0.5	9	NA	<50	NA
	4/17/08	<1	NA	<0.5	<0.5	26	<0.5	<0.5	<0.5	6	24	NA	1,100
SGP-7S	11/17/05	40	NA	NA	NA	3.8	<1	2.6	<0.5	62	3.5	<1	<10
	9/28/06	59	NA	<0.5	<0.5	7.3	<0.5	1.6	<0.5	72	2.9	<0.5	<4
	4/17/08	520	NA	<0.5	<0.5	2.4	<0.5	2.1	<0.5	63	3.2	NA	<4
SGP-7D	11/17/05	41	NA	NA	NA	4.4	<1	<0.5	<0.5	80	9.2	<1	<10
	9/28/06	150	NA	<0.5	<0.5	7.8	<0.5	1.9	<0.5	98	1.7	<0.5	14
	4/17/08	390	NA	<0.5	<0.5	2.8	<0.5	3.1	<0.5	98	1.7	NA	17
SGP-8S	11/17/05	28,000	NA	NA	NA	15	<1	7.7	<0.5	78	2.1	<1	11
	9/28/06	14,000	NA	<0.5	<0.5	29	<0.5	22	<0.5	75	<1	<0.5	21
	4/17/08	12,000	NA	<0.5	<0.5	32	<0.5	22	<0.5	55	2.0	NA	250
SGP-8D	11/17/05	27,000	NA	NA	NA	10	<1	4.9	<0.5	63	3.4	<1	<10
	9/28/06	<1	NA	<0.5	<0.5	12	<0.5	<0.5	<0.5	18	5.2	<0.5	301
	3/29/07	<1	NA	<0.5	<0.5	16	<0.5	<0.5	<0.5	30	NA	<50	NA
	4/17/08	11	NA	<0.5	<0.5	22	<0.5	<0.5	<0.5	29	4.5	NA	<4
TP-5	3/29/07	1,800	NA	<0.5	<0.5	33	<0.5	0.6	<0.5	120	NA	<50	NA
	8/8/07	1,300	NA	<0.5	<0.5	102	<0.5	<0.5	<0.5	80	2.9	NA	13
	4/16/08	1,300	NA	<0.5	<0.5	126	<0.5	<0.5	<0.5	83	2.5	NA	150
TP-8	3/30/07	34,000	NA	<0.5	<0.5	32	<0.5	<0.5	<0.5	450	NA	<50	NA
	4/16/08	22,000	NA	<0.5	<0.5	28	<0.5	<0.5	<0.5	330	2.4	NA	130
<b>MONITOR WELLS AND PIEZOMETERS IN THE LITTORAL ZONE</b>													
SGP-9	6/7/06	200	NA	<0.5	<0.5	21	<0.5	1.8	<0.5	130	<1	<10	<4
	9/27/06	61	75	<0.5	<0.5	24	<0.5	0.5	<0.5	100	1.1	<0.5	78
	8/9/07	<1	NA	<0.5	<0.5	23	<0.5	<0.5	<0.5	48	2.8	NA	240
	4/16/08	130	NA	<0.5	<0.5	18	<0.5	1.0	<0.5	110	0.9	NA	20
SGP-19	6/7/06	4,400	NA	<0.5	<0.5	8.3	<0.5	2.4	<0.5	120	1.4	<10	<4
	9/27/06	4,200	NA	<0.5	<0.5	8.2	<0.5	2.0	<0.5	120	1.6	<0.5	<4
	3/29/07	3,400	NA	<0.5	<0.5	5.5	<0.5	2.9	<0.5	130	NA	<50	NA
	8/8/07	4,200	NA	<0.5	<0.5	7.4	<0.5	2.3	<0.5	110	1.1	NA	<4
	4/16/08	4,700	NA	<0.5	<0.5	6.2	<0.5	2.7	<0.5	110	1.2	NA	<4
SGP-20	6/7/06	13,000	NA	<0.5	<0.5	17	<0.5	1.7	<0.5	240	1.4	<10	115
	9/27/06	11,000	NA	<0.5	<0.5	13	<0.5	<0.5	<0.5	280	1.6	<0.5	136
	3/30/07	10,000	NA	<0.5	<0.5	14	<0.5	<0.5	<0.5	270	NA	<50	NA
	8/9/07	1,700	NA	<0.5	<0.5	17	<0.5	<0.5	<0.5	300	2.1	NA	73
	4/16/08	10,000	NA	<0.5	<0.5	14	<0.5	<0.5	<0.5	250	1.6	NA	120
SGP-21	9/27/06	<1	NA	<0.5	<0.5	110	<0.5	<0.5	<0.5	33	7.7	<0.5	4,400
	3/29/07	<1	NA	<0.5	<0.5	100	<0.5	<0.5	<0.5	75	NA	<50	NA
	8/9/07	<1	<1	<0.5	<0.5	48	<0.5	<0.5	<0.5	35	2.7	NA	71
	4/17/08	<1	NA	<0.5	<0.5	95	<0.5	<0.5	<0.5	57	8.0	NA	120
DP-1	3/30/07	3,500	NA	<0.5	<0.5	9.0	<0.5	<0.5	<0.5	57	NA	<50	NA
DP-3	3/29/07	21,000	NA	<0.5	<0.5	42	<0.5	<0.5	<0.5	530	NA	<50	NA

**APPENDIX C - TABLE C2**

**Summary of Laboratory Analytical Results**

Well ID	Sample Date	Perchlorate Method 314 (µg/L)	Perchlorate Method 332 (µg/L)	Chlorate (mg/L)	Chlorite (mg/L)	Chloride (mg/L)	Bromide (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Sulfate (mg/L)	TOC (mg/L)	Phosphate (mg/L)	Methane (µg/L)
<b>LITTORAL ZONE PIEZOMETER GROUP 1</b>													
A TP-1 shallow	3/29/07	<1	NA	<0.5	<0.5	95	<0.5	<0.5	<0.5	2.1	NA	<50	NA
	8/9/07	<1	0.1	<0.5	<0.5	93	<0.5	<0.5	<0.5	<0.5	5.3	NA	810
	4/16/08	<4	<0.02	<0.5	<0.5	64	<0.5	<0.5	<0.5	<0.5	4.9	NA	2,000
B TP-2 intermediate	3/29/07	5.9	NA	<0.5	<0.5	42	<0.5	<0.5	<0.5	42	NA	<50	NA
	8/9/07	<1	NA	<0.5	<0.5	49	<0.5	<0.5	<0.5	9.3	0.2	NA	360
	4/16/08	<1	NA	<0.5	<0.5	44	<0.5	<0.5	<0.5	13	4.3	NA	640
C TP-3 deep	3/29/07	2,700	NA	<0.5	<0.5	16	<0.5	0.5	<0.5	110	NA	<50	NA
	8/9/07	2,400	NA	<0.5	<0.5	6.4	<0.5	<0.5	<0.5	68	1.0	NA	53
	4/16/08	3,200	NA	<0.5	<0.5	12	<0.5	0.5	<0.5	110	1.0	NA	150
Column 3 (IC-3)	8/8/07	<1	0.06	<0.5	<0.5	290	0.9	<0.5	<0.5	55	6.2	NA	1,600
	12/18/07	<1	NA	<0.5	<0.5	450	1.4	<0.5	<0.5	81	NA	NA	NA
	4/15/08	<1	NA	<0.5	<0.5	220	0.8	<0.5	<0.5	39	6.8	NA	<4
Column 4 (IC-4)	8/8/07	<1	NA	<0.5	<0.5	200	0.6	<0.5	<0.5	39	6.5	NA	<4
	12/18/07	<1	NA	<0.5	<0.5	560	1.7	1.1	<0.5	110	NA	NA	NA
	4/16/08	<4	NA	<0.5	<0.5	30	<0.5	1.1	<0.5	15	4.7	NA	<4
<b>LITTORAL ZONE PIEZOMETER GROUP 2</b>													
A TP-4 shallow	3/30/07	6.7	NA	<0.5	<0.5	55	<0.5	<0.5	<0.5	27	NA	<50	NA
	8/9/07	<1	NA	<0.5	<0.5	62	<0.5	0.6	<0.5	1.4	3.9	NA	450
	4/16/08	<1	0.61	<0.5	<0.5	56	<0.5	<0.5	<0.5	2.2	5.9	NA	400
B TP-6 intermediate	3/30/07	3.4	NA	<0.5	<0.5	35	<0.5	<0.5	<0.5	150	NA	<50	NA
	8/9/07	<1	NA	<0.5	<0.5	29	<0.5	<0.5	<0.5	96	1.5	NA	230
	4/16/08	<1	NA	<0.5	<0.5	36	<0.5	<0.5	<0.5	84	2.4	NA	400
C TP-7 deep	3/30/07	3,200	NA	<0.5	<0.5	27	<0.5	<0.5	<0.5	210	NA	<50	NA
	8/9/07	640	NA	<0.5	<0.5	29	<0.5	<0.5	<0.5	220	2.5	NA	17
	4/16/08	3,300	NA	<0.5	<0.5	24	<0.5	<0.5	<0.5	210	1.6	NA	25
D DP-2	3/30/07	3,700	NA	<0.5	<0.5	6.2	<0.5	<0.5	<0.5	75	NA	<50	NA
Column 1 (IC-1)	8/9/07	<1	NA	<0.5	<0.5	360	1.0	<0.5	<0.5	54	6.6	NA	91
	12/18/07	<1	NA	<0.5	<0.5	560	1.9	2.3	<0.5	110	NA	NA	NA
	4/15/08	<4	NA	<0.5	<0.5	33	<0.5	1.1	<0.5	18	5.9	NA	<4
Column 2 (IC-2)	8/9/07	<1	NA	<0.5	<0.5	360	1.2	<0.5	<0.5	70	6.8	NA	110
	12/18/07	<1	NA	<0.5	<0.5	630	2.4	2.7	<0.5	110	NA	NA	NA
	4/16/08	<1	NA	<0.5	<0.5	62	<0.5	0.6	<0.5	18	4.8	NA	2,700
<b>MONITOR WELLS AND PIEZOMETERS IN THE SUBTIDAL CHANNEL</b>													
SGP-22S	9/27/06	<1	0.08	<0.5	<0.5	120	0.6	<0.5	<0.5	89	12	<0.5	6,300
	8/8/07	<1	NA	<0.5	<0.5	110	<0.5	0.6	<0.5	100	1.1	NA	2,900
	4/16/08	<1	NA	<0.5	<0.5	110	0.6	0.6	<0.5	100	11	NA	4,500
SGP-22D	9/27/06	<1	0.05	<0.5	<0.5	98	0.5	<0.5	<0.5	1,700	6.6	<0.5	49
	8/8/07	<1	NA	<0.5	<0.5	77	<0.5	<0.5	<0.5	2,000	0.1	NA	12
	4/16/08	<1	NA	<0.5	<0.5	97	0.5	<0.5	<0.5	1,900	4.9	NA	25
SGP-22SW	9/27/06	<1	NA	<0.5	<0.5	130	<0.5	0.5	<0.5	36	5.1	<0.5	<4
	8/8/07	<4	NA	<0.5	<0.5	360	1.5	<0.5	<0.5	72	8.4	NA	<4
	4/16/08	61	NA	<0.5	<0.5	30	<0.5	1.3	<0.5	22	4.7	NA	5.0
SGP-23S	9/27/06	<1	NA	<0.5	<0.5	130	0.5	<0.5	<0.5	41	9.8	<0.5	4,000
	4/16/08	<1	NA	<0.5	<0.5	100	0.5	<0.5	<0.5	<0.5	12	NA	9,400
SGP-23D	9/27/06	<1	NA	<0.5	<0.5	110	<0.5	<0.5	<0.5	15	4.4	<0.5	1,100
	8/8/07	<1	NA	<0.5	<0.5	84	<0.5	<0.5	<0.5	2.0	4.3	NA	1,200
	4/16/08	<1	NA	<0.5	<0.5	100	<0.5	<0.5	<0.5	<0.5	4.4	NA	630
SGP-23SW	9/27/06	<1	NA	<0.5	<0.5	130	<0.5	0.7	<0.5	35	4.7	<0.5	<4
SGP-24S	9/27/06	<1	NA	<0.5	<0.5	99	<0.5	<0.5	<0.5	9.7	10	<0.5	13,000
	8/8/07	<1	NA	<0.5	<0.5	100	<0.5	<0.5	<0.5	<0.5	6.5	NA	6,500
	4/16/08	<1	NA	<0.5	<0.5	130	0.60	<0.5	<0.5	0.5	12	NA	19,000
SGP-24D	9/27/06	<1	NA	<0.5	<0.5	100	<0.5	<0.5	<0.5	9.5	9.6	<0.5	12,000
	8/8/07	<1	NA	<0.5	<0.5	32	<0.5	<0.5	<0.5	<0.5	3.9	NA	4,400
	4/16/08	<1	NA	<0.5	<0.5	100	0.50	<0.5	<0.5	<0.5	4.7	NA	12,000/11,000
SGP-24SW	9/27/06	<1	NA	<0.5	<0.5	130	<0.5	1.20	<0.5	36	4.5	<0.5	<4

**APPENDIX C - TABLE C2**

**Summary of Laboratory Analytical Results**

Well ID	Sample Date	Perchlorate Method 314 (µg/L)	Perchlorate Method 332 (µg/L)	Chlorate (mg/L)	Chlorite (mg/L)	Chloride (mg/L)	Bromide (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Sulfate (mg/L)	TOC (mg/L)	Phosphate (mg/L)	Methane (µg/L)
<b>MONITOR WELLS AND PIEZOMETERS IN THE SUBTIDAL SHALLOWS</b>													
SGP-10	6/7/06	<1	NA	<0.5	<0.5	100	0.5	<0.5	<0.5	0.7	6.5	<10	6,300
	9/26/06	<1	NA	<0.5	<0.5	140	0.6	<0.5	<0.5	<0.5	7.4	<0.5	13,000
SGP-11	6/7/06	<1	NA	<0.5	<0.5	120	0.6	<0.5	<0.5	1,200	9.3	<10	10
	9/26/06	<1	NA	<0.5	<0.5	62	<0.5	<0.5	<0.5	720	10	<0.5	38
SGP-12	6/7/06	<1	NA	<0.5	<0.5	170	0.8	<0.5	<0.5	430	14	<10	1,300
	9/26/06	<1	NA	<0.5	<0.5	190	1.0	<0.5	<0.5	470	14	2.40	2,900
SGP-13	6/7/06	<1	NA	<0.5	<0.5	190	0.9	<0.5	<0.5	4.4	14	<10	8,400
	9/26/06	<1	NA	<0.5	<0.5	230	1.1	2.20	0.90	2.5	14	<0.5	16,000
SGP-14	6/7/06	<1	NA	<0.5	<0.5	210	0.8	<0.5	<0.5	2.3	15	<10	6,200
	9/26/06	<1	NA	<0.5	<0.5	260	1.1	1.30	<0.5	4.9	16	<0.5	14,000
SGP-15	6/7/06	<1	NA	<0.5	<0.5	210	0.9	<0.5	<0.5	1.6	12	<10	4,300
	9/26/06	<1	NA	<0.5	<0.5	240	1.1	<0.5	<0.5	12	13	<0.5	9,700
SGP-16	6/7/06	<1	NA	<0.5	<0.5	140	0.6	<0.5	<0.5	4.7	10	<10	12,000
	9/26/06	<1	NA	<0.5	<0.5	190	0.9	<0.5	<0.5	<0.5	13	<0.5	16,000
SGP-17	6/7/06	<1	NA	<0.5	<0.5	130	0.9	<0.5	<0.5	0.9	22	<10	12,000
	9/26/06	<1	NA	<0.5	<0.5	180	1.5	<0.5	<0.5	<0.5	32	<0.5	19,000
SGP-18	6/7/06	<1	NA	<0.5	<0.5	120	1.0	<0.5	<0.5	<0.5	25	<10	13,000
	9/26/06	<1	NA	<0.5	<0.5	150	1.2	<0.5	<0.5	<0.5	35	<0.5	12,000
<b>SURFACE WATER SAMPLES</b>													
SW-1	3/29/07	<4	NA	<0.5	<0.5	32	<0.5	<0.5	<0.5	56	NA	<50	NA
	12/18/07	<1	NA	<0.5	<0.5	380	1.3	<0.5	<0.5	65	NA	NA	NA
SW-2	3/29/07	<1	NA	<0.5	<0.5	37	<0.5	<0.5	<0.5	15	NA	<50	NA
	12/18/07	8.7	NA	<0.5	<0.5	340	1.3	<0.5	<0.5	64	NA	NA	NA
SW-3	3/29/07	<1	NA	<0.5	<0.5	32	<0.5	<0.5	<0.5	16	NA	<50	NA
SW-4	3/29/07	<1	NA	<0.5	<0.5	27	<0.5	1.1	<0.5	18	NA	<50	NA
SEEP-1	3/29/07	<1	NA	<0.5	<0.5	43	<0.5	<0.5	<0.5	2.0	NA	<50	NA

Notes:

Data rounded to 2 significant figures.

NA denotes not analyzed.

February 2002 data taken from Cramer & Yates, 2004

**APPENDIX C - TABLE C3**

**Summary of Natural Attenuation Parameters**

Well ID	Sample Date	pH SU	DO (mg/L)	Conductivity (µS/cm)	Temp. °C	ORP mv <sup>(1)</sup>	Turbidity NTU	Manganese (mg/L)	Iron (mg/L)
<b>MONITOR WELLS AND PIEZOMETERS ON LAND</b>									
MW-1	11/15/05	5.46	0.2	498	19.1	NR	NS	NS	NS
	9/28/06	5.74	1.0	374	22.8	62	7	0	0
	4/17/08	6.12	0.5	295	14.1	127	NS	0	0
MW-2	11/15/05	7.14	0.5	540	17.0	NR	NS	NS	NS
	9/28/06	6.73	1.0	528	20.2	22	15	0	0
	4/17/08	NS	NS	NS	NS	NS	NS	NS	NS
MW-3	11/15/05	3.81	2-3	322	17.7	NR	NS	NS	NS
	9/28/06	4.42	0.5	317	19.7	26	37	0	0
	8/9/07	4.72	NS	256	26.6	193	NS	NS	NS
	4/17/08	5.19	0.5	392	12.0	89	NS	0	0
MW-4	11/15/05	4.96	0.1	382	18.4	NR	NS	NS	NS
	9/28/06	5.66	1.0	416	20.8	40	16	0	0
	4/17/08	5.95	0.4	294	12.8	101	NS	0	0
CPMW-5	11/15/05	3.79	0.1	458	18.5	NR	NS	NS	NS
	9/28/06	6.30	1.0	456	21.6	26	18	0	0
	4/17/08	6.46	0.4	361	13.8	48	NS	0	0
SGP-1S	11/16/05	4.92	2-3	281	16.2	NR	NS	NS	NS
	9/27/06	4.76	1.5	268	18.3	-58	9	0	0
	8/9/07	5.02	NS	211	20.6	183	NS	NS	NS
	4/16/08	4.88	0.4	222	11.9	84	NS	0	0
SGP-1D	11/16/05	5.39	4.0	320	16.2	NR	NS	NS	NS
	9/27/06	4.44	2.0	216	17.9	-66	72	0	0
	8/9/07	4.55	NS	166	19.2	187	NS	NS	NS
	4/16/08	4.88	1.0	169	12.5	86	NS	0	5
SGP-2S	11/16/05	4.65	1.0	448	16.8	NR	NS	NS	NS
	9/26/06	4.56	3.5	389	17.5	251	178	0	0
	8/9/07	4.29	NS	368	20.0	192	NS	NS	NS
	4/16/08	4.39	0.3	355	12.6	102	NS	0	0
SGP-2D	11/16/05	4.81	NS	392	16.4	NR	NS	NS	NS
	9/26/06	4.91	7.0	423	16.7	204	94	0	4
	3/28/07	5.32	NS	364	15.9	NS	NS	NS	NS
	8/9/07	4.96	NS	347	20.4	173	NS	NS	NS
	4/16/08	5.05	0.8	375	12.8	91	NS	0	0
SGP-3S	11/17/05	5.46	5 - 6	264	17.4	NR	NS	NS	NS
	9/26/06	5.23	2.0	269	18.0	129	28	0	0
	8/9/07	4.90	NS	198	20.0	175	NS	NS	NS
	4/15/08	4.96	1.0	254	12.4	53	NS	0	2
SGP-3D	11/16/05	4.30	5 - 6	359	16.5	NR	NS	NS	NS
	9/26/06	3.91	2.5	400	16.9	320	14	0	0
	8/9/07	4.12	NS	214	21.2	184	NS	NS	NS
	4/16/08	4.01	1.0	350	11.5	104	NS	0.5	0
SGP-4S	11/17/05	10.75	7.0	1150	14.4	NR	NS	NS	NS
	9/27/06	6.24	2.5	424	18.6	-74	868	0	38.0
	4/17/08	6.79	1.0	376	11.2	17	NS	0	0
SGP-4D	11/17/05	7.78	8 - 10	410	14.8	NR	NS	NS	NS
	9/27/06	5.47	1.0	298	17.1	-80	12	0	0
	4/17/08	5.47	1.0	234	11.8	78	NS	0	5
SGP-5S	11/17/05	5.43	7.0	406	14.6	NR	NS	NS	NS
	9/28/06	4.41	1.0	336	16.9	12	61	0	0
	4/17/08	4.44	0.8	311	10.0	110	NS	0	0
SGP-5D	11/16/05	3.71	2.0	584	16.4	NR	NS	NS	NS
	9/28/06	3.66	1.5	589	16.1	23	12	0	9
	4/17/08	4.46	0.5	368	11.3	98	NS	0.3	5

**APPENDIX C - TABLE C3**

**Summary of Natural Attenuation Parameters**

Well ID	Sample Date	pH SU	DO (mg/L)	Conductivity (µS/cm)	Temp. °C	ORP mv <sup>(1)</sup>	Turbidity NTU	Manganese (mg/L)	Iron (mg/L)
SGP-6S	11/17/05	6.62	5.0	687	16.5	NR	NS	NS	NS
	9/28/06	4.75	1.0	417	21.3	13	84	0	0
	4/17/08	5.23	1.0	413	13.6	89	NS	0	0
SGP-6D	11/17/05	6.35	2-3	642	16.9	NR	NS	NS	NS
	9/28/06	6.37	0.5	697	20.9	-77	NS	0	54
	3/29/07	6.47	NS	447	15.6	43	NS	NS	NS
	4/17/08	6.35	7.0	528	12.3	18	NS	0	30
SGP-7S	11/16/05	5.49	4 - 5	342	18.2	NR	NS	NS	NS
	9/28/06	5.66	1.0	329	19.3	11	NS	0	0
	4/17/08	6.27	1.0	382	12.5	44	NS	0	5
SGP-7D	11/16/05	3.96	3-4	374	18.4	NR	NS	NS	NS
	9/28/06	4.03	2.5	257	19.2	26	>1000	0	4.0
	4/17/08	4.74	1.5	221	15.4	152	NS	0	0
SGP-8S	11/17/05	4.69	2-3	366	17.3	NR	NS	NS	NS
	9/28/06	4.01	1.5	337	21.7	113	65	0	0
	4/17/08	4.41	4.0	376	12.9	163	NS	0	5
SGP-8D	11/17/05	6.28	2.0	386	16.7	NR	NS	NS	NS
	9/28/06	6.11	2.0	281	19.9	-10	521	0	2
	3/29/07	6.75	NS	283	15.5	45	NS	NS	NS
	4/17/08	6.24	4.0	277	13.5	50	NS	0	30
<b>MONITOR WELLS IN THE LITTORAL ZONE</b>									
SGP-9	6/7/06	5.04	0.2	357	17.3	1	NS	NS	NS
	9/27/06	5.12	1.5	364	22.3	59	5	0	0
	8/9/2007	5.37	NS	257	24.3	84	NS	NS	NS
	4/16/08	4.90	0.6	364	13.3	48	NS	0.6	5
SGP-19	6/7/06	4.76	0.3	303	16.2	148	NS		
	9/27/06	4.50	3.5	326	20.7	60	9	0	0
	8/8/07	4.86	NS	315	33.8	117	NS	NS	NS
	4/16/08	4.89	0.2	298	13.8	13	NS	0.3	5
SGP-20	6/7/06	4.05	0.1	545	16.9	254	NS		
	9/27/06	3.86	1.5	599	20.9	109	16	0	0
	8/9/07	4.28	NS	521	23.8	173	NS	NS	NS
	4/16/08	4.25	0.3	558	13.1	48	NS	0	5
SGP-21	9/27/06	6.14	1.5	776	21.5	-85	83	0	60
	8/9/07	6.09	NS	746	22.3	-48	NS	NS	NS
	4/17/08	6.22	0.1	794	13.1	1	NS	0.00	90
TP-1	8/9/07	6.06	NS	420	28.2	50	NS	NS	NS
	4/16/08	6.50	2.0	389	16.3	-59	NS	0.30	5
TP-2	8/9/07	5.93	NS	327	25.6	37	NS	NS	NS
	4/16/08	6.39	1.0	306	15.8	-24	NS	0.00	15
TP-3	8/9/07	5.04	NS	293	25.9	151	NS	NS	NS
	4/16/08	4.62	1.0	288	16.7	45	NS	0.00	8
TP-4	8/9/07	6.11	NS	409	24.9	-8	NS	NS	NS
	4/16/08	6.68	1.0	403	16.5	-9	NS	0.00	8
TP-5	8/8/07	5.24	NS	524	27.3	96	NS	NS	NS
	4/16/08	5.98	1.0	742	14.4	-31	NS	0.00	20
TP-6	8/9/07	5.78	NS	482	23.8	22	NS	NS	NS
	4/16/08	6.24	1.0	434	15.3	1	NS	0.30	5
TP-7	8/9/07	5.38	NS	532	25.5	111	NS	NS	NS
	4/16/08	4.84	0.8	527	15.5	52	NS	0.60	15
TP-8	4/16/08	3.98	0.6	898	12.6	132	NS	0.3	30
Column 1 (IC-1)	8/9/07	6.87	NS	1,280	29.5	-45	NS	NS	NS
	4/15/08	7.27	7.0	250	19.4	-45	NS	0	0
Column 2 (IC-2)	8/9/07	6.75	NS	1,250	28.9	-42	NS	NS	NS
	4/16/08	6.68	1.0	235	18.4	12	NS	0	0
Column 3 (IC-3)	8/8/07	6.30	NS	926	35.4	-30	NS	NS	NS
	4/16/08	6.53	NS	1,078	15.3	-49	NS	NS	NS
Column 4 (IC-4)	8/8/07	6.68	NS	1,097	34.1	-52	NS	NS	NS
	04/16/08	6.43	2.0	247	17.2	-34	NS	0	5

**APPENDIX C - TABLE C3**

**Summary of Natural Attenuation Parameters**

Well ID	Sample Date	pH SU	DO (mg/L)	Conductivity (µS/cm)	Temp. °C	ORP mv <sup>(1)</sup>	Turbidity NTU	Manganese (mg/L)	Iron (mg/L)
<b>SUBTIDAL CHANNEL MONITOR WELLS</b>									
SGP-22S	9/27/06	5.93	1.5	1,460	22.4	-56	7	0	30
	8/8/07	6.02	1.5	1,410	26.3	-36	NS	0	25
	4/16/08	6.25	0.5	1,510	12.6	-4	NS	0	45
SGP-22D	9/27/06	5.51	4.5	3,280	20.9	6	6	0	390
	8/8/07	5.59	1.5	2,780	23.8	12	NS	0	> 300
	4/16/08	3.41	1.0	2,930	13.8	383	NS	0.8	175
SGP-22SW (sws-1)	9/27/06	9.03	11.0	607	26.5	-29	14	0	0
	8/8/07	6.50	8.0	1,380	28.9	-3	NS	0	0
	4/16/08	7.29	5.0	251	19.7	54	NS	0	5
SGP-23S	9/27/06	6.69	4.5	943	23.8	-12	NS	0	23
	4/16/08	6.66	0.8	891	15.9	-77	NS	0	90
SGP-23D	9/27/06	5.95	5.0	633	21.0	6	NS	0	30
	8/8/07	6.30	3.5	680	23.8	-83	NS	0	> 300
	4/16/08	6.70	0.8	542	14.3	-29	NS	0.6	45
SGP-23SW (sws-2)	9/27/06	8.41	11.0	618	25.4	-44	NS	0	23
	4/16/08	NS	NS	NS	NS	NS	NS	NS	NS
SGP-24S	9/27/06	6.34	1.0	932	22.6	-107	18	0	45
	8/8/07	6.45	2.5	866	29.5	-115	NS	0	> 300
	4/16/08	6.54	1.5	1,020	13.5	-76	NS	1	45
SGP-24D	9/27/06	6.28	2.5	903	21.3	-89	18	0	10
	8/8/07	6.28	2.0	646	24.8	-8	NS	0	300
	4/16/08	6.36	0.8	705	13.7	-80	NS	0.6	5
SGP-24SW (sws-3)	9/27/06	6.34	6.5	932	22.6	-57	8	0	45
	4/16/08	NS	NS	NS	NS	NS	NS	NS	NS
<b>SUBTIDAL SHALLOWS MONITOR WELLS</b>									
SGP-10	6/7/06	6.09	2.0	883	17.1	-168	NS		
	9/26/06	6.05	2.0	794	20.5	-57	61	0	9
SGP-11	6/7/06	5.93	1.3	2,990	16.8	-81	NS		
	9/26/06	5.94	5.0	2,190	21.8	-83	43	0	120
SGP-12	6/7/06	6.17	0.5	2,730	15.8	-234	NS		
	9/26/06	6.22	1.5	1,480	18.6	-226	4	0	0
SGP-13	6/7/06	6.38	3.0	1,420	18.1	-82	NS		
	9/26/06	6.40	1.5	1,030	19.2	-130	116	0	12
SGP-14	6/7/06	6.27	0.2	1,390	18.3	-90	NS		
	9/26/06	6.30	2.5	1,120	20.2	-151	351	0	60
SGP-15	6/7/06	6.35	4.0	1,310	17.3	-56	NS		
	9/26/06	6.34	1.5	1,080	20.3	-96	NS	0	15
SGP-16	6/7/06	6.42	1.5	1,130	17.6	-132	NS		
	9/26/06	6.42	2.5	1,140	20.7	-119	72	0	30
SGP-17	6/7/06	6.42	0.1	2,330	17.0	-190	NS		
	9/26/06	6.46	1.5	2,390	20.3	-139	26	0	60
SGP-18	6/7/06	6.39	0.0	3,260	16.5	-206	NS		
	9/26/06	6.47	1.0	3,460	20.6	-147	32	0	60

NR = Not Reported because ORP meter was not working correctly during Nov 05.

NA denotes not analyzed.

## **Appendix D**

### **Natural Attenuation Rate Calculations**

**APPENDIX D**

**Attenuation Rates & Associated Statistics**

Monitoring Well	Estimated Rate and Time (1st Order)		Estimated Rate and Time (90%CI 1st order)		F Statistic (F<0.1)	Estimated Rate and Time (zero-order linear)			Estimated Rate and Time (90%CI Linear)		F Statistic (F<0.1)
	Rate (per day)	R squared	Rate	Time* (Years)		Rate (µg/L/day)	R squared	Time* (Years)	Rate	Time* (Years)	
<b>Land Wells</b>											
MW-1	-8.7E-04	0.63	-3.6E-04	67	<b>0.06</b>	-3.7E+01	0.60	7	-1.4E+01	25	<b>0.06</b>
MW-2	-3.5E-03	0.79	-1.1E-03		0.11	-1.2E+00	0.89	4	-6.5E-01	7	<b>0.05</b>
MW-3	7.2E-04	0.50	1.3E-03		0.12	3.1E+00	0.34		6.5E+00		0.22
MW-4	-1.4E-03	0.91	-1.1E-03	23	<b>0.00</b>	-8.0E+01	0.84	5.5	-5.3E+01	10	<b>0.01</b>
SGP-1S	7.5E-05	0.01	1.1E-03		0.90	3.8E-01	0.04		2.8E+00		0.90
SGP-1D	-5.7E-05	0.00	2.4E-03		0.97	6.5E-01	0.03		5.2E+00		0.81
SGP-2S	6.6E-04	0.30	1.3E-03		0.45	-3.0E+00	0.26		3.6E+00		0.48
SGP-2D	-5.3E-04	0.06	1.4E-03		0.69	-8.8E+00	0.07		2.1E+01		0.65
SGP-3S	-1.0E-03	0.42	5.6E-03		0.35	-2.0E-02	0.27		2.4E-02		0.48
SGP-3D	7.1E-04	0.19	2.7E-03		0.56	1.1E-01	0.35		3.2E-01		0.40
SGP-4S	-2.2E-03	0.90	5.3E-05		0.21	-3.3E-01	0.93		-5.3E-02		0.17
SGP-4D	-1.0E-03	0.87	2.1E-04		0.23	-4.0E+00	0.86		-8.8E-01		0.24
SGP-5S	-1.3E-03	0.19	7.2E-03		0.70	-1.8E-01	0.46		4.2E-01		0.53
SGP-5D	-5.8E-04	0.40	1.6E-03		0.56	-1.6E-01	0.29		6.2E-01		0.63
SGP-6S	-1.6E-03	0.99	-1.2E-03	14	<b>0.04</b>	-1.4E+01	0.93		-2.6E+00		0.16
SGP-6D	4.5E-03	0.90	9.2E-03			NO Slope					
SGP-7S	3.0E-03	0.95	5.1E-03		0.14	5.8E-01	0.89		1.2E+00		0.21
SGP-7D	2.4E-03	0.94	4.4E-03		0.16	4.0E-01	1.00	-1	4.6E-01	-1	<b>0.03</b>
SGP-8S	-8.3E-04	0.70	8.4E-04		0.37	-1.6E+01	0.67		1.9E+01		0.39
SGP-8D	4.5E-03	0.90	9.2E-03		0.20	-1.8E-01	0.90		4.2E-01		0.20
TP-5	-6.6E-04	0.49	1.4E-03		0.50	-1.0E+00	0.51		2.1E+00		0.49
<b>Littoral Zone</b>											
SGP-9	-2.1E-03	0.07	0.00805		0.73	-9.0E-02	0.10		2.7E-01		0.68
SGP-19	1.0E-04	0.05	0.00051		0.71	4.5E-01	0.07		2.0E+00		0.68
SGP-20	-1.1E-03	0.11	0.00178		0.58	-6.8E+00	0.17		7.2E+00		0.48
SGP-21	NO DETECTIONS					NO DETECTIONS					
TP-1	3.9E-03	0.88	0.00817		0.22	8.4E-03	0.88		1.8E-02		0.22
TP-2	-4.0E-03	0.58	0.00639		0.44	-1.1E-02	0.58		1.8E-02		0.44
TP-3	5.0E-04	0.51	0.00199		0.49	1.5E+00	0.55		5.4E+00		0.46
TP-4	-4.3E-03	0.58	0.00689		0.44	-1.3E-02	0.58		2.1E-02		0.44
TP-6	-2.8E-03	0.58	0.00444		0.45	-5.4E-03	0.58		8.7E-03		0.44
TP-7	9.0E-04	0.03	0.01543		0.88	1.5E+00	0.04		2.5E+01		0.87
<b>Subtidal Channel</b>											
SGP-22S	NO DETECTIONS					NO DETECTIONS					
SGP-22D	NO DETECTIONS					NO DETECTIONS					
SGP-22SW	7.1E-03	0.94	0.01274		0.15	1.0E-01	0.73		2.9E-01		0.34
SGP-23S	NO DETECTIONS					NO DETECTIONS					
SGP-23D	NO DETECTIONS					NO DETECTIONS					
SGP-23SW	NO DETECTIONS					NO DETECTIONS					
SGP-24S	NO DETECTIONS					NO DETECTIONS					
SGP-24D	NO DETECTIONS					NO DETECTIONS					
SGP-24SW	NO DETECTIONS					NO DETECTIONS					

## **Appendix E**

### **Mass Flux Calculations**

# Input Data and Grid

## Data Input Instructions

- Enter value directly.
- Value calculated by model (Don't enter any data)

Site Location and I.D.: Indian head NSWC Flux Evaluation #5  
 Description: Perchlorate MNA Study

### 4. CHOOSE TRANSECT

Transect 1

### 5. CHOOSE TIME PERIOD

1

### 6. ENTER TRANSECT DATA

6.1 Distance of Transect 1 from Source  (ft)

6.2  Darcy Velocity  Hydraulic Conductivity

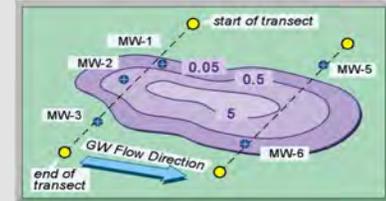
6.6  Sampling Interval  Mid Point of Sampling Interval

6.3 Hydraulic Conductivity Units

6.4 Uniform Hydraulic Conductivity?

6.5 Uniform Hydraulic Gradient?

Hydraulic Conductivity  (ft/d)  
 Hydraulic Gradient  (ft/ft)



Monitoring Point	Distance of Monitoring Point from Start of Transect (ft)	Sampling Interval (ft MSL)		Plume Top (ft MSL)	Plume Bottom (ft MSL)	Concentration (mg/L)	
		Top	Bottom			Constituent A	Constituent B
						Perchlorate	
1 Start of Transect	0					0	0
2 End of Transect	120					0	0
3 SGP-19	10	-7.2	-9.2	-0.5	-12	4.658	
4 SGP-20	110	-5.3	-7.3	-0.5	-12	10.412	
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

### 7. CHOOSE GRID (OPTIONAL)

Current Grid  
 Number of rows   
 Number of columns

Refine Grid By  Refined Grid

### 8. SELECT CONSTITUENT FOR CALCULATIONS

Perchlorate  Constituent B

Next Step: Continue Data Input

# Input Data and Grid

**Data Input Instructions**

- Enter value directly.
- Value calculated by model (Don't enter any data)

Site Location and I.D.: **Indian head NSWC Flux Evaluation #5**  
 Description: **Perchlorate MNA Study**

4. CHOOSE TRANSECT Transect 2 5. CHOOSE TIME PERIOD 1

**6. ENTER TRANSECT DATA**

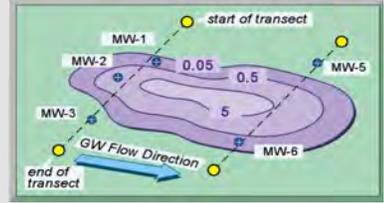
6.1 Distance of Transect 2 from Source 40 (ft)

6.2  Darcy Velocity  Hydraulic Conductivity 6.6  Sampling Interval  Mid Point of Sampling Interval

6.3 Hydraulic Conductivity Units ft/d

6.4 Uniform Hydraulic Conductivity? Yes Hydraulic Conductivity 4.00E-01 (ft/d)

6.5 Uniform Hydraulic Gradient? Yes Hydraulic Gradient 2.60E-02 (ft/ft)



Monitoring Point	Distance of Monitoring Point from Start of Transect (ft)	Sampling Interval (ft MSL)		Plume Top (ft MSL)	Plume Bottom (ft MSL)	Concentration (mg/L)	
		Top	Bottom			Constituent A	Constituent B
						Perchlorate	
1 Start of Transect	0					0	0
2 End of Transect	120					0	0
3 TP-3	10	-6.4	-7.4	-5.5	-7.5	3.169	
4 TP-7	110	-6.2	-7.2	-5.5	-7.5	3.259	
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

7. CHOOSE GRID (OPTIONAL) Current Grid 10 Refine Grid By 1 Refined Grid 10

Number of rows 4 Number of columns 4

8. SELECT CONSTITUENT FOR CALCULATIONS  Perchlorate  Constituent B

**Next Step: Continue Data Input**

[Back to Transect Calculator Screen](#)
[Import MW Data](#)
[Export MW Data](#)
[See Conc/Flux Grids](#)

[Clear Screen](#)
[Paste Example](#)
[Restore Table Formatting](#)
[Print](#)
[HELP](#)

# Mass Flux Result

**TOTAL MASS FLUX**    **2.08E-01** (g/day)    **7.60E-02** (kg/yr)

[Next Step: Mass Flux Summary](#)    
 [Run/View Uncertainty Analysis \(Optional\)](#)    
 [View Final Concentration Grid](#)  
[Back to Data Grid](#)    [Print](#)    [HELP](#)

**Data Representation**

1. Bold values represent calculations based on given values.
2. Values in italics represent calculations based on interpolation.
3. Black shaded cells represent the top and bottom of the plume.

SELECT TRANSECT TO VIEW       
 SELECT TIME PERIOD TO VIEW   

## Perchlorate Mass Flux (g/day)

Distance from Edge of Transect (ft)

	Start of Transect <i>0.0</i>	TP-3 <i>10.0</i>	TP-7 <i>110.0</i>	End of Transect <i>120.0</i>
6.5	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
6.7	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
6.9	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
7.1	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
7.3	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
7.5	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
7.7	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
7.9	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
8.1	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
8.3	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>
8.5	<b>0.00E+00</b>	<i>1.03E-02</i>	<i>1.06E-02</i>	<b>0.00E+00</b>

**NOTES:**

This Transect lies between Piezometer Groups 1 and 2

The gradient is calculated to be 0.026 using an estimated hydraulic conductivity and equivalent groundwater discharge

The hydraulic conductivity is estimated to be 0.4 ft/day since the orientation of groundwater flow is closer to Kz

Kz is estimated to be Kx/10

The calculated flux is for a 2 foot slice 100 ft long.

# Input Data and Grid

**Data Input Instructions**

- Enter value directly.
- Value calculated by model (Don't enter any data)

Site Location and I.D.: Indian head NSWC Flux Evaluation #5  
 Description: Perchlorate MNA Study

4. CHOOSE TRANSECT Transect 3 5. CHOOSE TIME PERIOD 1

**6. ENTER TRANSECT DATA**

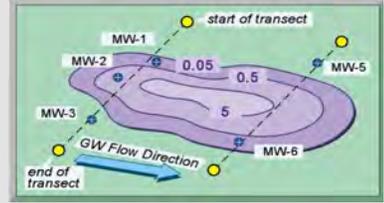
6.1 Distance of Transect 3 from Source 45 (ft)

6.2  Darcy Velocity  Hydraulic Conductivity 6.6  Sampling Interval  Mid Point of Sampling Interval

6.3 Hydraulic Conductivity Units ft/d

6.4 Uniform Hydraulic Conductivity? Yes Hydraulic Conductivity 3.00E-01 (ft/d)

6.5 Uniform Hydraulic Gradient? Yes Hydraulic Gradient 3.70E-02 (ft/ft)



Monitoring Point	Distance of Monitoring Point from Start of Transect (ft)	Sampling Interval (ft MSL)		Plume Top (ft MSL)	Plume Bottom (ft MSL)	Concentration (mg/L)	
		Top	Bottom			Constituent A	Constituent B
						Perchlorate	
1 Start of Transect	0					0	0
2 End of Transect	120					0	0
3 TP-2	10	-4.7	-5.7	-4	-6	0.0005	
4 TP-6	110	-4.7	-5.7	-4	-6	0.0005	
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

7. CHOOSE GRID (OPTIONAL) Current Grid 10 Refine Grid By 1 Refined Grid 10

Number of rows 4 Number of columns 4

8. SELECT CONSTITUENT FOR CALCULATIONS  Perchlorate  Constituent B

**Next Step: Continue Data Input**

Back to Transect Calculator Screen
Import MW Data
Export MW Data
See Conc/Flux Grids

Clear Screen
Paste Example
Restore Table Formatting
Print
HELP

# Mass Flux Result

**TOTAL MASS FLUX**    **3.46E-05** (g/day)    **1.26E-05** (kg/yr)

[Next Step: Mass Flux Summary](#)    
 [Run/View Uncertainty Analysis \(Optional\)](#)    
 [View Final Concentration Grid](#)  
[Back to Data Grid](#)    [Print](#)    [HELP](#)

**Data Representation**

1. Bold values represent calculations based on given values.
2. Values in italics represent calculations based on interpolation.
3. Black shaded cells represent the top and bottom of the plume.

SELECT TRANSECT TO VIEW       
 SELECT TIME PERIOD TO VIEW   

## Perchlorate Mass Flux (g/day)

Distance from Edge of Transect (ft)

	Start of Transect 0.0	TP-2 10.0	TP-6 110.0	End of Transect 120.0
5.0	0.00E+00	1.73E-06	1.73E-06	0.00E+00
5.2	0.00E+00	1.73E-06	1.73E-06	0.00E+00
5.4	0.00E+00	1.73E-06	1.73E-06	0.00E+00
5.6	0.00E+00	1.73E-06	1.73E-06	0.00E+00
5.8	0.00E+00	1.73E-06	1.73E-06	0.00E+00
6.0	0.00E+00	1.73E-06	1.73E-06	0.00E+00
6.2	0.00E+00	1.73E-06	1.73E-06	0.00E+00
6.4	0.00E+00	1.73E-06	1.73E-06	0.00E+00
6.6	0.00E+00	1.73E-06	1.73E-06	0.00E+00
6.8	0.00E+00	1.73E-06	1.73E-06	0.00E+00
7.0	0.00E+00	1.73E-06	1.73E-06	0.00E+00

Depth in ft-bgs

**NOTES:**

Transect 3 is approximately 100 feet long and is located between piezometers TP-2 and TP-6

The hydraulic conductivity is estimated to be 0.3 ft/day as groundwater flow is nearly vertical (close to Kz)

The gradient is estimated to be 0.37 ft/ft

The flux shown is for a 2 ft by 100 ft section of the aquifer

# Mass Flux Result

**TOTAL MASS FLUX**    **1.24E+01** (g/day)    **4.53E+00** (kg/yr)

[Next Step: Mass Flux Summary](#)

[Run/View Uncertainty Analysis \(Optional\)](#)

[View Final Concentration Grid](#)

[Back to Data Grid](#)

[Print](#)

[HELP](#)

### Data Representation

1. Bold values represent calculations based on given values.
2. Values in italics represent calculations based on interpolation.
3. Black shaded cells represent the top and bottom of the plume.

SELECT TRANSECT TO VIEW

Transect 1 ▼

SELECT TIME PERIOD TO VIEW

1 ▼

## Perchlorate Mass Flux (g/day)

Distance from Edge of Transect (ft)

Start of Transect                      SGP-19                      SGP-20                      End of Transect  
 0.0                                      10.0                                      110.0                                      120.0

Depth in ft-bgs	0.0	10.0	110.0	120.0
0.6	0.00E+00	<i>3.84E-01</i>	<i>8.58E-01</i>	0.00E+00
1.8	0.00E+00	<i>3.84E-01</i>	<i>8.58E-01</i>	0.00E+00
2.9	0.00E+00	<i>3.84E-01</i>	<i>8.58E-01</i>	0.00E+00
4.1	0.00E+00	<i>3.84E-01</i>	<i>8.58E-01</i>	0.00E+00
5.2	0.00E+00	<i>3.84E-01</i>	<i>8.58E-01</i>	0.00E+00
6.4	0.00E+00	<i>3.84E-01</i>	<i>8.58E-01</i>	0.00E+00
7.5	0.00E+00	<b>3.84E-01</b>	<i>8.58E-01</i>	0.00E+00
8.7	0.00E+00	<b>3.84E-01</b>	<i>8.58E-01</i>	0.00E+00
9.8	0.00E+00	<i>3.84E-01</i>	<i>8.58E-01</i>	0.00E+00
11.0	0.00E+00	<i>3.84E-01</i>	<i>8.58E-01</i>	0.00E+00
12.1				

**NOTES:**

Mass flux determined for a slice of the aquifer lying between two flow lines spaced approximately 100 feet apart.

The aquifer thickness is approximately 12 feet

Hydraulic conductivity is estimated at 2.3 ft/day

The gradient used is the site average of 0.02 ft/ft.

## **Appendix F**

### **Macrocsm Study Results**

<b>Appendix F</b>								
<b>Macrocosm Study Data</b>								
<b>Macrocosm ID</b>	<b>Day</b>	<b>Perchlorate (mg/L)</b>	<b>Chlorate (mg/L)</b>	<b>Chlorite (mg/L)</b>	<b>Chloride (mg/L)</b>	<b>Nitrate (mg/L)</b>	<b>Nitrite (mg/L)</b>	<b>Sulfate (mg/L)</b>
SGP-2D	0	4.3	<0.5	<0.5	6.9	3.8	<0.5	130
#1	0	3.9	<0.5	<0.5	8.7	3.8	<0.5	123
	5	3.4	<0.5	<0.5	9.0	<0.5	<0.5	117
	7	2.3	<0.5	<0.5	12	0.6	<0.5	106
#2	0	3.9	<0.5	<0.5	8.9	3.9	<0.5	123
	5	3.8	<0.5	<0.5	8.8	1.4	<0.5	117
	12	2.3	<0.5	<0.5	12	1.0	<0.5	108
	19	1.3	<0.5	<0.5	NS	NS	<0.5	NS
	20	0.2	<0.5	<0.5	NS	NS	<0.5	NS
#3	0	3.8	<0.5	<0.5	9.3	3.7	<0.5	121
	5	3.3	<0.5	<0.5	9.0	1.7	<0.5	112
	12	<0.5	<0.5	<0.5	12	<0.5	<0.5	109
	13	0.1	<0.5	<0.5	NS	NS	<0.5	NS
#4	0	3.7	<0.5	<0.5	9.5	3.7	<0.5	120
	5	3.3	<0.5	<0.5	9.3	1.6	<0.5	114
	12	2.0	<0.5	<0.5	12	0.9	<0.5	107
	19	1.3	<0.5	<0.5	NS	NS	<0.5	NS
	22	0.2	<0.5	<0.5	NS	NS	<0.5	NS
#5	0	3.8	<0.5	<0.5	9.4	3.8	<0.5	121
	5	3.4	<0.5	<0.5	9.3	0.8	<0.5	115
	12	2.3	<0.5	<0.5	12	1.1	<0.5	107
	19	1.5	<0.5	<0.5	NS	NS	<0.5	NS
	22	0.3	<0.5	<0.5	NS	NS	<0.5	NS

- 1) Analysis performed at the Laboratory of Environmental Engineering in the Department of Civil, Construction and Environmental Engineering at North Carolina State University, Raleigh, NC.
- 2) Incubations and analyses performed between March 28, 2007 (Day 0) and April 19, 2007 (Day 22)

## **Appendix G**

### **Points of Contact**

## Appendix G Points of Contact

<b>Point Of Contact Name</b>	<b>Organization Name and Address</b>	<b>Phone/Fax/email</b>	<b>Role in Project</b>
Dr. Robert C. Borden, P.E.	Solutions-IES 1101 Nowell Road Raleigh, NC 276159	919-873-1060 919-873-1074 (fax) rcborden@eos.ncsu.edu	Principal Investigator
M. Tony Lieberman, R.S.M.	Solutions-IES 1101 Nowell Road Raleigh, NC 276159	919-873-1060 919-873-1074 (fax) tliberman@solutions-ies.com	Co-Principal Investigator; Project Manager
Mark B. Yeaton.	Naval Support Facility, Indian Head Environmental Program Office 3942 Ward Road, Suite 101 Indian Head, MD 20640-5157	(301) 744-2272 mark.b.yeaton@navy.mil	Indian Head Site Contact

## **Appendix B**

### **Field SOPs**



<b>STANDARD OPERATING PROCEDURES</b>	Number CT-04	Page 1 of 6
	Effective Date 02/04	Revision 0
	Applicability	
	Prepared	
Subject SAMPLE NOMENCLATURE	Approved	

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY .....	2
4.0 RESPONSIBILITIES .....	2
5.0 PROCEDURES .....	2
5.1 INTRODUCTION .....	2
5.2 SAMPLE IDENTIFICATION FIELD REQUIREMENTS .....	3
5.3 EXAMPLE SAMPLE FIELD DESIGNATIONS .....	4
5.4 EXAMPLES OF SAMPLE NOMENCLATURE .....	5
5.5 FIELD QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) SAMPLE NOMENCLATURE .....	6
5.6 EXAMPLES OF FIELD QA/QC SAMPLE NOMENCLATURE .....	6
6.0 DEVIATIONS .....	6

Subject  SAMPLE NOMENCLATURE	Number CT-04	Page 2 of 6
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

The purpose of this document is to specify a consistent sample nomenclature system that will facilitate subsequent data management in a cost-effective manner. The sample nomenclature system has been devised such that the following objectives can be attained:

- Sorting of data by matrix.
- Sorting of data by depth.
- Maintenance of consistency (field, laboratory, and data base sample numbers).
- Accommodation of all project-specific requirements.
- Accommodation of laboratory sample number length constraints (maximum of 20 characters).

## 2.0 SCOPE

The methods described in this procedure shall be used consistently for all projects requiring electronic data.

## 3.0 GLOSSARY

None.

## 4.0 RESPONSIBILITIES

**Program Manager** - It shall be the responsibility of the Program Manager (or designee) to inform contract-specific Project Managers of the existence and requirements of this Standard Operating Procedure.

**Project Manager** - It shall be the responsibility of the Project Manager to determine the applicability of this Standard Operating Procedure based on: (1) program-specific requirements, and (2) project size and objectives. It shall be the responsibility of the Project Manager (or designee) to ensure that the sample nomenclature is thoroughly specified in the relevant project planning document (e.g., sampling and analysis plan) and is consistent with this Standard Operating Procedure if relevant. It shall be the responsibility of the project manager to ensure that the Field Operations Leader is familiar with the sample nomenclature system.

**Field Operations Leader** - It shall be the responsibility of the Field Operations Leader to ensure that all field technicians or sampling personnel are thoroughly familiar with this Standard Operating Procedure and the project-specific sample nomenclature system. It shall be the responsibility of the Field Operations Leader to ensure that the sample nomenclature system is used during all project-specific sampling efforts.

## 5.0 PROCEDURES

### 5.1 Introduction

The sample identification (ID) system can consist of as few as 8 but not more than 20 distinct alphanumeric characters. The sample ID will be provided to the laboratory on the sample labels and chain-of-custody forms. The basic sample ID provided to the lab has three segments and shall be as follows where "A" indicates "alpha," and "N" indicates "numeric":

A or N 3- or 4-Characters	AAA 2- or 3-Characters	A or N 3- to 6-Characters
Site Identifier	Sample Type	Sample Location

Subject  SAMPLE NOMENCLATURE	Number CT-04	Page 3 of 6
	Revision 0	Effective Date 02/04

Additional segments may be added as needed. For example:

See Sample Details Table on Worksheet 8 for specified sample IDs for this project.

(1) Soil and Sediment Sample ID

<b>A or N</b> 3- or 4-Characters	<b>AAA</b> 2- or 3-Characters	<b>A or N</b> 3- to 6-Characters	<b>NNNN</b> 4-Characters
Site Identifier	Sample Type	Sample Location	Sample Depth

(2) Aqueous (groundwater or surface water) Sample ID

NNNNNN  
Sample Date

<b>A or N</b> 3- or 4-Characters	<b>AAA</b> 2- or 3-Characters	<b>A or N</b> 3- to 6-Characters	<del><b>NN</b> 2-Characters</del>	<del><b>-A</b></del>
Site Identifier	Sample type	Sample Location	Round Number	Filtered Sample only

~~(3) Biota Sample ID~~

<del><b>A or N</b> 3- or 4-Characters</del>	<del><b>AAA</b> 2- or 3-Characters</del>	<del><b>A or N</b> 3- to 6-Characters</del>	<del><b>AA</b> 2-Characters</del>	<del><b>NNN</b> 3-Characters</del>
<del>Site Identifier</del>	<del>Sample Type</del>	<del>Sample Location</del>	<del>Species Identifier</del>	<del>Sample Group Number</del>

## 5.2 Sample Identification Field Requirements

The various fields in the sample ID will include but are not limited to the following:

- Site Identifier
- Sample Type
- Sample Location
- Sample Depth
- Sampling Round Number
- Filtered
- Species Identifier
- Sample Group Number

The site identifier must be a three- or four-character field (numeric characters, alpha characters, or a mixture of alpha and numeric characters may be used). A site number is necessary since many facilities/sites have multiple individual sites, SWMUs, operable units, etc. Several examples are presented in Section 5.3 of this SOP.

The sample type must be a two- or three-character alpha field. Suggested codes are provided in Section 5.3 of this SOP.

The sample location must be at least a three-character field but may have up to six-characters (alpha, numeric, or a mixture). The six-characters may be useful in identifying a monitoring well to be sampled or describing a grid location.

The sample depth field is used to note the depth below ground surface (bgs) at which a soil or sediment sample is collected. The first two numbers of the four-number code specify the top interval, and the third and fourth specify the bottom interval in feet bgs of the sample. If the sample depth is equal to or greater than 100, then only the top interval would be represented and the sampling depth would be truncated to

Subject  SAMPLE NOMENCLATURE	Number CT-04	Page 4 of 6
	Revision 0	Effective Date 02/04

three-characters. The depths will be noted in whole numbers only; further detail, if needed, will be recorded on the sample log sheet, boring log, logbook, etc.

A two-digit round number identifies the aqueous sample location. For example, 01, the second 02, etc. for different locations.

Date in MMDDYY format distinguishes 'sample rounds.'

taken from a particular location. The round identifier is used for wells and surface water

Aqueous samples that are filtered. No entry in the

Filtered samples have same sample ID as parent sample.

" in the last field

The species identifier must be a two-character alpha field. Several suggested codes are provided in Section 5.3 of this SOP.

The three digit sample group number will be used to track the number of biota sample groups (a particular group size may be determined by sample technique, media type, the number of individual caught, weight issues, time, etc.) by species and location. The first sample group of a particular species collected from a given location will be assigned the sample group number 001 and the second sample group of the same species collected from the same location will be assigned the sample group number 002.

### 5.3 Example Sample Field Designations

Examples of each of the fields are as follows:

Site Identifier - Examples of site numbers/designations are as follows:

- A01 - Area of Concern Number 1
- 125 - Solid Waste Management Unit Number 125
- 000 - Base or Facility Wide Sample (e.g., upgradient well)
- BBG - Base Background

The examples cited are only suggestions. Each Project Manager (or designee) must designate appropriate (and consistent) site designations for their individual project.

Sample Type - Examples of sample types are as follows:

- AH - Ash Sample
- AS - Air Sample
- BM - Building Material Sample
- BSB - Biota Sample Full Body
- BSF - Biota Sample Fillet
- CP - Composite Sample
- CS - Chip Sample
- DS - Drum Sample
- DU - Dust Sample
- FP - Free Product
- IDW - Investigation Derived Waste Sample
- LT - Leachate Sample
- MW - Monitoring Well Groundwater Sample
- OF - Outfall Sample
- RW - Residential Well Sample
- SB - Soil Boring Sample
- SD - Sediment Sample
- SC - Scrape Sample

Subject  SAMPLE NOMENCLATURE	Number CT-04	Page 5 of 6
	Revision 0	Effective Date 02/04

SG - Soil Gas Sample  
 SL - Sludge Sample  
 SP - Seep Sample  
 SS - Surface Soil Sample  
 ST - Storm Sewer Water Sample  
 SW - Surface Water Sample  
 TP - Test Pit Sample  
 TW - Temporary Well Sample  
 WC - Well Construction Material Sample  
 WP - Wipe Sample  
 WS - Waste/Solid Sample  
 WW - Wastewater Sample

Sample Location - Examples of the location field are as follows:

001 - Monitoring Well 1  
 N32E92 - Grid location 32 North and 92 East  
 D096 - Investigation derived waste drum number 96

Species Identifier - Examples of species identifier are as follows:

BC - Blue Crab  
 GB - Blue Gill  
 CO - Corn  
 SB - Soybean

#### 5.4 Examples of Sample Nomenclature

The first round monitoring well groundwater sample collected from existing monitoring well 001 at SWMU 16 for a filtered sample would be designated as 016MW00101-F.

The second round monitoring well groundwater sample collected from existing monitoring well C20P2 at Site 23 for an unfiltered sample would be designated as 023MWC20P202.

The second surface water sample collected from point 01 at SWMU 130 for an unfiltered sample would be designated as 130SW00102.

A surface soil sample collected from grid location 32 North and 92 East at Site 32 at the 0- to 2-foot interval would be designated as 032SSN32E920002.

A subsurface soil sample from soil boring 03 at SWMU 32 at an interval of 4 to 5 feet bgs would be designated as 032SB0030405.

A sediment sample collected at SWMU 19 from 0 to 6 inches at location 14 would be designated as 019SD0140001. The sample data sheet would reflect the precise depth at which this sample was collected.

During biota sampling for full body analysis the first time a minnow trap was checked at grid location A25 of SWMU 1415 three small blue gills were captured, collected and designated with the sample ID of 1415BSBA25BG001. The second time blue gill were collected at the same location (grid location A25 at SWMU 1415) the sample ID designation given was 1415BSBA25BG002.

Note: No dash (-) or spacing is used between the segments with the exception of the filtered segment. The "F" used for a filtered aqueous sample is preceded by a dash "-F".

Subject  SAMPLE NOMENCLATURE	Number CT-04	Page 6 of 6
	Revision 0	Effective Date 02/04

### 5.5 Field Quality Assurance/Quality Control (QA/QC) Sample Nomenclature

Field QA/QC will be designated using a different coding system. The QC code will consist of a three- to four-segment alpha-numeric code that identifies the sample QC type, the date the sample was collected, and the number of this type of QC sample collected on that date.

A or N Site Identifier	AA	NNNNNN	NN	-F
	QC Type	Date	Sequence Number (per day)	Filtered (aqueous only, if needed)

The QC types are identified as:

- TB = Trip Blank
- ~~EB~~ RB = Rinsate Blank (Equipment Blank)
- ~~FD = Field Duplicate~~
- AB = Ambient Conditions Blank
- WB = Source Water Blank

Add "P" after sample location in sample ID to indicate field duplicate at that location

The sampling time recorded on the Chain-of-Custody Form, labels, and tags for duplicate samples will be 0000 so that the samples are "blind" to the laboratory. Notes detailing the sample number, time, date, and type will be recorded on the routine sample log sheets and will document the location of the duplicate sample (sample log sheets are not provided to the laboratory). Documentation for all other QC types (TB, ~~EB~~ RB, AB, and WB) will be recorded on the QC Sample Log sheet (see SOP on Field Documentation).

### 5.6 Examples of Field QA/QC Sample Nomenclature

~~The first duplicate of the day for a filtered ground water sample collected from well MW01 on November 17, 2001 would be designated as FD06030001-F.~~

Duplicate of groundwater sample collected from well MW01 on November 17, 2001, would be designated as S67-MW01P-111701

~~The third duplicate of the day taken of a subsurface sample collected from well MW01 on November 17, 2001 would be designated as FD11170303.~~

~~The first trip blank associated with samples collected from well MW01 on November 17, 2001 would be designated as TB10120001.~~

The <sup>first</sup> only rinsate blank collected on November 17, 2001 would be designated as ~~RB11170101.~~  
S67-EB01-111701

### 6.0 **DEVIATIONS**

Any deviation from this SOP must be addressed in detail in the site specific planning documents.

<b>STANDARD OPERATING PROCEDURES</b>	Number GH-1.1	Page 1 of 7
	Effective Date 02/04	Revision 0
	Applicability	
	Prepared	
Subject SITE RECONNAISSANCE	Approved	

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY .....	2
4.0 RESPONSIBILITIES .....	2
5.0 PROCEDURES .....	4
5.1 EQUIPMENT ITEMS/NEEDED .....	4
5.2 OBSERVATIONS .....	4
6.0 RECORDS .....	5
 <b><u>ATTACHMENTS</u></b>	
A SITE RECONNAISSANCE CHECKLIST .....	6

Subject  SITE RECONNAISSANCE	Number GH-1.1	Page 2 of 7
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

The purpose of a site reconnaissance is to collect both general and technical information which will support the scoping, scheduling, implementing project activities, and writing reports for an environmental investigation. This procedure is not intended as a guide for Phase I investigations or for Environmental Baseline Survey activities.

## 2.0 SCOPE

This procedure is applicable to the performance of a site reconnaissance for initial site characterization. The steps necessary to develop and carry out a site reconnaissance are presented here. These steps include a list of equipment and items which may be needed, areas of special interest during field observations, and methods by which the field observation team can ensure that necessary and appropriate observations have been made.

## 3.0 GLOSSARY

Site reconnaissance. An onsite inspection program used to identify site-specific conditions that control scheduling, manpower, and affect costs. A site reconnaissance usually consists of visual observations and, often, the use of field monitoring instruments to identify potential health and safety threats and potential sampling locations for site evaluation during subsequent field investigations.

## 4.0 RESPONSIBILITIES

Field Operations Leader (FOL) is responsible for ensuring that the survey is carried out in sufficient detail. To accomplish this, the FOL must assign the proper personnel and equipment to characterize the site adequately, in accordance with the requirements defined in this procedure and best engineering practices. Other disciplines which may be applicable (but are not limited to): Geology/Hydrogeology; Health and Safety; Ecological Specialists; and/or Engineering. In addition, the FOL is responsible for supervising equipment preparation, including necessary calibrations, and supervising field data collection and documentation in accordance with the methods described in all referenced standard operation procedures.

Project Manager is responsible for the following:

- Supervising the retrieval and examination of available, applicable information regarding the site.
- Obtaining appropriate program approvals and ensuring the preparation of a site Health and Safety plan for the site reconnaissance.
- Coordinating the field activities with facility personnel and other Navy and regulatory personnel, as applicable.

Field Personnel are primarily responsible for observing and documenting, either through written documentation or photographic evidence, the site reconnaissance. Field personnel will take direction from the FOL.

Subject  SITE RECONNAISSANCE	Number GH-1.1	Page 3 of 7
	Revision 0	Effective Date 02/04

## 5.0 PROCEDURES

### 5.1 Equipment Items/Needed

Below is a list of items that may be useful when conducting a site reconnaissance. All, or a portion of these items may be required, depending upon the objective of the site reconnaissance.

- Health and Safety equipment and information as required by the Site Safety Officer.
- Maps (U.S.G.S. quadrangle, geologic maps, street and highway maps, and client facility maps).
- Geologic tools (compass, tape measure, hand level, digital camera, etc.).
- Physical monitoring equipment, if applicable (PID, Immunoassay Test Kits, etc.)
- Regional publications (U.S.G.S reports, water well surveys, U.S.D.A. soil conservation surveys, etc.).
- Site-specific publications by previous investigators (EPA aerial photographic analyses, remedial investigation reports, data on waste disposal practices, boring logs, etc.).
- Marking items (ink markers, surveyor's flagging, spray paint, pin flags, wooden stakes).
- Field notebooks.
- Local telephone book with yellow pages (for obtaining utilities, site trailer, living accommodations, etc.).

Sufficient time will be required in order to obtain some of the aforementioned material. In general, most publications can be obtained in time to be used in the site reconnaissance if ordered approximately 2 weeks before the actual site visit takes place.

### 5.2 Observations

A site reconnaissance usually requires one to two days, however, additional time may be needed depending upon the objective, site size, etc. The following observations, when applicable, should be documented either on a site map, field notebook, or photographed.

- General Site Access. It should be noted whether site roads provide access to all proposed work locations, or if it will be necessary to prepare access roads with either a backhoe, dozer, chain saws, etc., in order to get drill rigs, excavators, or other work vehicles to specific locations. If temporary driveways must be constructed from existing public roads, regulatory permits may be required. Military facilities may have specific security requirements which require detailed clearance procedures.
- Location of the Command Post or Site Trailer and Sanitary Facilities. The ideal location for the site trailer and sanitary facilities is a level area, within an uncontaminated zone, and centralized in order to provide easy access to work areas on the site. However, certain utility companies may require that the site trailer be placed within a specified radius (usually 100 feet), of the nearest utility pole. Contact the necessary utility companies and inquire about the requirements regarding service before conducting the site reconnaissance. Information that may be required by the utility companies is: type of electric service needed (inquire with trailer vendor for this information); and utility pole number of interest (pole numbers are usually stamped on a brass plate on the pole).

Subject  SITE RECONNAISSANCE	Number GH-1.1	Page 4 of 7
	Revision 0	Effective Date 02/04

- Potable Water Sources. Local fire departments may allow access to fire hydrants. Private water delivery companies may also be available in the area.
- Sources of Possible Contamination. Drums, tanks, sludge areas, areas of stressed vegetation, fill areas, and leachate seeps may indicate where sources of contamination exist. Filler pipes protruding from the ground surface may indicate the presence of underground storage tanks. Areas where the original ground surface has been reworked may be contaminated fill areas that have since been buried and covered with natural material. Previous environmental investigations may also identify source areas.
- Location of Decon Areas and Storage/Disposal Areas for Equipment and Wastes Generated by Field Activities.
- Locations of Surface Water Bodies. The locations of surface water bodies, both man-made and natural, and their relation to topographic highs may give an indication of the groundwater flow direction in the area (groundwater flow typically follows topography with the topographic highs serving as groundwater recharge areas, and the surface waters at topographic lows serve as groundwater discharge areas). Visible signs of contamination, the existence of aquatic life, flow rates, and approximate levels should also be observed and noted. Check if the surface water bodies could potentially be impacted by field activities. If so, appropriate sedimentation and erosion controls will be required.
- Existing Wells. Existing monitoring wells, or domestic wells within the site and off site, should be noted on a map, and access checked to see if the wells can be used for data collection.
- Outcrops. Outcrops can be useful in providing hydrogeologic data (lithologic description, strike and dip information, fracture and joint system analysis, identification of moist zones, etc.) Outcrops may occur naturally or be a part of a man-made feature such as a road-cut.
- Lineaments. A lineament is a straight lengthy feature on the earth's surface which is expressed topographically as a line of depression. Stream beds, vegetation patterns or soil characteristics may be aligned or controlled by this feature. Lineaments are due in some cases to the presence of intense jointing or faults beneath the ground surface. Groundwater in the bedrock may follow lineaments. Lineaments should be noted on site maps and described in the field notebooks.
- Bench or Property Markers. Benchmarks or property markers should be marked with paint or surveyor's flagging if encountered during a site reconnaissance. Surveyors may need to use these markers as a reference point when surveying. Benchmarks are typically a brass plate secured in concrete in the ground with numbering on the top. Property markers can range from a stake driven into the ground to a rock protruding from the ground surface. Facility contacts may also be aware of local benchmarks used during the course of other environmental or public work projects.
- Metal Cultural Effects. Overhead power lines, railroad tracks, junk automobiles, fences, etc. will greatly affect certain geophysical surveys. These features should be noted while conducting a site reconnaissance.

## 6.0 RECORDS

The data collected during a site reconnaissance will be compiled into a trip report when returning from the field. This trip report can then be distributed to the project team. A site reconnaissance checklist is located in Attachment A which can be copied and used while conducting the site reconnaissance.

Subject  SITE RECONNAISSANCE	Number GH-1.1	Page 5 of 7
	Revision 0	Effective Date 02/04

**ATTACHMENT A**  
**SITE RECONNAISSANCE CHECKLIST**

**SITE SKETCH**

Include the following as appropriate:

- Site name
- Site location
- Site boundaries
- Entrance locations
- Access roads and security requirements
- Disposal locations
- Storage areas
- Office areas
- Well locations
- Treatment facility locations
- Surface drainage, outcrops, general topography descriptions
- Cultural interferences
- Fences
- Aboveground utilities

**CHEMICAL STORAGE FACILITIES DESCRIPTION**

- Storage tanks - numbers, volumes, condition, contents, etc.
- Drums - number, conditions, labeling, etc.
- Lagoons and surface pits - number, size, use of liner, contents, etc.

**TREATMENT SYSTEMS**

Note the presence of any treatment systems. These can be difficult to evaluate visually. One should appraise general appearance, maintenance and visual integrity; ask operators for any monitoring records; note presence of odors; and visually characterize any effluents or residues. Describe type of wastes and volumes treated.

- Incinerators
- Flocculation/filtration
- Chemical/physical treatment
- Biological treatment
- Volume reduction
- Waste recycling
- Compositing
- Other

Subject  SITE RECONNAISSANCE	Number GH-1.1	Page 6 of 7
	Revision 0	Effective Date 02/04

**ATTACHMENT A  
SITE RECONNAISSANCE CHECKLIST  
PAGE TWO**

**DISPOSAL FACILITIES**

Note the presence and use of any of the following operations. Include a description of the size, use of liners, soil type, and the presence of leachate. Provide a description of management practices. Interview site workers if possible. Describe waste types.

- Landfills
- Land forms
- Open dump
- Surface impoundment
- Underground injection
- Incineration

Also, records for disposal of concentrated/containerized waste should be reviewed.

**HAZARDOUS SUBSTANCE CHARACTERISTICS**

Ask facility contacts for manifests, inventories, or monitoring reports. Note markings on containers.

- Chemical identities
- Quantities
- Hazard characteristics (toxic, explosive, flammable, etc.)
- Container markings
- Monitoring data, other analytical data
- Physical state (liquid, solid, gas, sludge)

**CHEMICAL PROCESS INFORMATION**

- Manufacturing processes and chemicals
- Off-specification or by-product disposal processes
- Housekeeping practices
- Locations of plant operations

Subject  SITE RECONNAISSANCE	Number GH-1.1	Page 7 of 7
	Revision 0	Effective Date 02/04

**ATTACHMENT A  
SITE RECONNAISSANCE CHECKLIST  
PAGE THREE**

**HYDROGEOLOGIC ASSESSMENT**

Look for situations that promote hazardous substance migration, i.e., porous soils, fractured bedrock formations, shallow water table and karst features.

- Soil type
- Surface water features
- Surface drainage pattern
- Outcrop studies
- Water wells (use, water depth, and construction details)
- Erosion potential
- Flooding potential
- Climatology

**IDENTIFICATION OF SENSITIVE RECEPTORS**

- Number and locations of private homes
- Public buildings including tenant usage
- Areas of dead or dying vegetation or animals
- Presence of sensitive ecosystems (wetlands, tidal marshes, etc.)
- Other public use areas (roads, parks, etc.)
- Natural areas

<b>STANDARD OPERATING PROCEDURES</b>	Number GH-1.2	Page 1 of 9
	Effective Date 02/04	Revision 0
	Applicability	
	Prepared	
Subject EVALUATION OF EXISTING MONITORING WELLS AND WATER LEVEL MEASUREMENT	Approved	

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY .....	2
4.0 RESPONSIBILITIES .....	2
5.0 PROCEDURES .....	2
5.1 PRELIMINARY EVALUATION .....	3
5.2 FIELD INSPECTION .....	3
5.3 WATER LEVEL (HYDRAULIC HEAD) MEASUREMENTS .....	4
5.3.1 General .....	4
5.3.2 Water Level Measuring Techniques .....	5
5.3.3 Methods .....	5
5.3.4 Water Level Measuring Devices .....	6
5.3.5 Data Recording .....	6
5.3.6 Specific Quality Control Procedures for Water Level Measuring Devices .....	7
5.4 EQUIPMENT DECONTAMINATION .....	7
5.5 HEALTH AND SAFETY CONSIDERATIONS .....	7
6.0 RECORDS .....	7

**ATTACHMENTS**

A MONITORING WELL INSPECTON SHEET .....	8
B GROUNDWATER LEVEL MEASUREMENT SHEET .....	9

Subject EVALUATION OF EXISTING MONITORING WELLS AND WATER LEVEL MEASUREMENT	Number GH-1.2	Page 2 of 9
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

The purpose of this procedure is to provide reference information regarding the proper methods for evaluating the physical condition and project utility of existing monitoring wells and determining water levels.

## 2.0 SCOPE

The procedures described herein are applicable to all existing monitoring wells and, for the most part, are independent of construction materials and methods.

## 3.0 GLOSSARY

Hydraulic Head - The height to which water will rise in a well.

Water Table - A surface in an unconfined aquifer where groundwater pressure is equal to atmospheric pressure (i.e., the pressure head is zero).

## 4.0 RESPONSIBILITIES

Site Geologist/Hydrogeologist - Has overall responsibility for the evaluation of existing wells, obtaining water level measurements and developing groundwater contour maps. The site geologist/hydrogeologist (in concurrence with the Project Manager) shall specify the reference point from which water levels are measured (usually a specific point on the upper edge of the inner well casing), the number and location of data points which shall be used for constructing a contour map, and how many complete sets of water levels are required to adequately define groundwater flow directions (e.g., if there are seasonal variations).

Field Personnel - Must have a basic familiarity with the equipment and procedures involved in obtaining water levels and must be aware of any project-specific requirements or objectives.

## 5.0 PROCEDURES

Accurate, valid and useful groundwater monitoring requires that four important conditions be met:

- Proper characterization of site hydrogeology.
- Proper design of the groundwater monitoring program, including adequate numbers of wells installed at appropriate locations and depths.
- Satisfactory methods of groundwater sampling and analysis to meet the project data quality objectives (DQOs).
- The assurance that specific monitoring well samples are representative of water quality conditions in the monitored interval.

To insure that these conditions are met, adequate descriptions of subsurface geology, well construction methods and well testing results must be available. The following steps will help to insure that the required data are available to permit an evaluation of the utility of existing monitoring wells for collecting additional samples.

Subject EVALUATION OF EXISTING MONITORING WELLS AND WATER LEVEL MEASUREMENT	Number GH-1.2	Page 3 of 9
	Revision 0	Effective Date 02/04

## 5.1 Preliminary Evaluation

A necessary first step in evaluating existing monitoring well data is the study and review of the original work plan for monitoring well installation (if available). This helps to familiarize the site geologist/hydrogeologist with site-specific condition, and will promote an understanding of the original purpose of the monitoring wells.

The next step of the evaluation should involve a review of all available information concerning borehole drilling and well construction. This will allow interpretation of groundwater flow conditions and area geology, and will help to establish consistency between hydraulic properties of the well and physical features of the well or formation. The physical features which should be identified and detailed, if available, include:

- The well identification number, permit number and location by referenced coordinates, the distance from prominent site features, or the location of the well on a map.
- The installation dates, drilling methods, well development methods, past sampling dates, and drilling contractors.
- The depth to bedrock -- where rock cores were not taken, auger refusal, drive casing refusal or penetration test results (blow counts for split-barrel sampling) may be used to estimate bedrock interface.
- The soil profile and stratigraphy.
- The borehole depth and diameter.
- The elevation of the top of the protective casing, the top of the well riser, and the ground surface.
- The total depth of the well.
- The type of well materials, screen type, slot size, and length, and the elevation/depths of the screen, interval, and/or monitored interval.
- The elevation/depths of the tops and bottom of the filter pack and well seals and the type and size.

## 5.2 Field Inspection

During the onsite inspection of existing monitoring wells, features to be noted include:

- The condition of the protective casing, cap and lock.
- The condition of the cement seal surrounding the protective casing.
- The presence of depressions or standing water around the casing.
- The presence of and condition of dedicated sampling equipment.
- The presence of a survey mark (e.g., a notch) on the inner well casing.

If the protective casing, cap and lock have been damaged or the cement collar appears deteriorated, or if there are any depressions around the well casing capable of holding water, surface water may have infiltrated into the well. This may invalidate previous sampling results unless the time when leakage started can be precisely determined.

The routine physical inspection must be followed by a more detailed investigation to identify other potential routes of contamination or sampling equipment malfunction. Any of these occurrences may invalidate

Subject EVALUATION OF EXISTING MONITORING WELLS AND WATER LEVEL MEASUREMENT	Number GH-1.2	Page 4 of 9
	Revision 0	Effective Date 02/04

previously-collected water quality data. If the monitoring well is to be used in the future, considerations shown in the steps described above should be rectified to rehabilitate the well.

After disconnecting any wires, cables or electrical sources, remove the lock and open the cap. Check for the presence of organic vapors with a photoionization detector (PID) or flame-ionization detector (FID) to determine the appropriate worker safety level. The following information should be noted:

- Cap function.
- Physical characteristics and composition of the inner casing or riser, including inner diameter and annular space.
- Presence of grout between the riser and outer protective casing and the existence of drain holes in the protective casing.
- Presence of a riser cap, method of attachment to casing, and venting of the riser.
- Presence of dedicated sampling equipment; if possible, remove such equipment and inspect size, materials of construction and condition.

The final step of the field inspection is to confirm previous hydraulic or physical property data and to obtain data not previously available. This includes the determination of static water levels, total well depth and well obstruction. This may be accomplished using a weighted tape measure which can also be used to check for sediment (the weight will advance slowly if sediment is present, and the presence of sediment on the weight upon removal should be noted). If sediment is present and/or the well has not been sampled in 12 or more months, it should be redeveloped before sampling.

Lastly, as a final step, the location, condition and expected water quality of the wells should be reviewed in light of their usefulness for the intended purpose of the investigation.

See Attachment A, Monitoring Well Inspection Sheet.

### 5.3 Water Level (Hydraulic Head) Measurements

#### 5.3.1 General

Groundwater level measurements can be made in monitoring wells, private or public water wells, piezometers, open boreholes, or test pits (after stabilization). Groundwater measurements should generally not be made in boreholes with drilling rods or auger flights present. If groundwater sampling activities are to occur, groundwater level measurements shall take place prior to well purging or sampling.

All groundwater level measurements shall be made to the nearest 0.01 foot, and recorded in the site geologist/hydrogeologist's field notebook or on the Groundwater Level Measurement Sheet (Attachment B), along with the date and time of the reading. The total depth of the well shall be measured and recorded, if not already known. Weather changes that occur over the period of time during which water levels are being taken, such as precipitation and barometric pressure changes, should be noted.

In measuring groundwater levels, there shall be a clearly-established reference point of known elevation, which is normally identified by a mark (e.g., a notch) on the upper edge of the inner well casing. To be useful, the reference point should be tied in with an established USGS benchmark or other properly surveyed elevation datum. An arbitrary datum could be used for an isolated group of wells, if necessary.

Subject EVALUATION OF EXISTING MONITORING WELLS AND WATER LEVEL MEASUREMENT	Number GH-1.2	Page 5 of 9
	Revision 0	Effective Date 02/04

Cascading water within a borehole or steel well casings can cause false readings with some types of sounding devices (chalked line, electrical). Oil layers may also cause problems in determining the true water level in a well. Special devices (interface probes) are available for measuring the thickness of oil layers and true depth to groundwater, if required.

Water level readings shall be taken regularly, as required by the site geologist/hydrogeologist. Monitoring wells or open-cased boreholes that are subject to tidal fluctuations should be read in conjunction with a tidal chart (or preferably in conjunction with readings of a tide staff or tide level recorder installed in the adjacent water body); the frequency of such readings shall be established by the site hydrogeologist. All water level measurements at a site used to develop a groundwater contour map shall be made in the shortest practical time to minimize affects due to weather changes.

### 5.3.2 Water Level Measuring Techniques

There are several methods for determining standing or changing water levels in boreholes and monitoring wells. Certain methods have particular advantages and disadvantages depending upon well conditions. A general description of these methods is presented, along with a listing of various advantages and disadvantages of each technique. An effective technique shall be selected for the particular site conditions by the site geologist/hydrogeologist.

In most instances, preparation of accurate potentiometric surface maps requires that static water level measurements be obtained to a precision of 0.01 feet. To obtain such measurements in individual accessible wells, electrical water level indicator methods have been found to be best, and thus should be utilized whenever possible when precision is required (e.g., synoptic water level measurements for defining potentiometric surfaces). Other, less precise methods, such as the popper or bell sound, or bailer line methods, should be avoided when precision is required, but may be suitable when used to establish approximate water depths for purging and sampling purposes. When a large number of (or continuous) readings are required, time-consuming individual readings are not usually feasible. In such cases, it is best to use a pressure transducer.

### 5.3.3 Methods

Water levels can be measured by several different techniques, but the same steps shall be followed in each case. The proper sequence is as follows:

1. Check operation of recording equipment above ground. Prior to opening the well, don personal protective equipment, as required. Never remove an air-tight lock (such as a J-plug) with your face over the well. Pressure changes within the well may explosively force the cap off once loosened.
2. Record all information specified below in the geologist/hydrogeologist's field notebook or on the Groundwater Level Measurement Sheet (Attachment B):
  - Well number.
  - Water level (to the nearest 0.01 foot). Water levels shall be taken from the surveyed reference mark (e.g., notch) on the top edge of the inner well casing. If the J-plug was on the well very tightly, it may take several minutes for the water level to stabilize.
  - Time and day of the measurement.
  - Thickness of free product if present.

Water level measuring devices with permanently marked intervals shall be used. The devices shall be free of kinks or folds which will affect the ability of the equipment to hang straight in the well pipe.

Subject EVALUATION OF EXISTING MONITORING WELLS AND WATER LEVEL MEASUREMENT	Number GH-1.2	Page 6 of 9
	Revision 0	Effective Date 02/04

### 5.3.4 Water Level Measuring Devices

#### Electric Water Level Indicators

These are the most commonly used devices and consist of a spool of small-diameter cable and a weighted probe attached to the end. When the probe comes in contact with the water, an electrical circuit is closed and a meter, light, and/or buzzer attached to the spool will signal the contact.

There are a number of commercial electric sounders available, none of which is entirely reliable under all conditions likely to occur in a contaminated monitoring well. In conditions where there is oil on the water, groundwater with high specific conductance, water cascading into the well, steel well casing, or a turbulent water surface in the well, measuring with an electric sounder may be difficult.

For accurate readings, the probe shall be lowered slowly into the well adjacent to the survey mark on the inner well casing. The electric tape is read (to the nearest 0.01 ft.) at the measuring point and recorded where contact with the water surface was indicated.

#### ~~Popper or Bell Sounder~~

~~A bell- or cup-shaped weight that is hollow on the bottom is attached to a measuring tape and lowered into the well. A "plopping" or "popping" sound is made when the weight strikes the surface of the water. An accurate reading can be determined by lifting and lowering the weight in short strokes, and reading the tape when the weight strikes the water. This method is not sufficiently accurate to obtain water levels to 0.01 feet, and thus is more appropriate for obtaining only approximate water levels quickly.~~

#### ~~Pressure Transducer~~

~~Pressure transducers can be lowered into a well or borehole to measure the pressure of water and therefore the water elevation above the transducer. The transducer is wired into a recorder at the surface to record changes in water level with time. The recorder digitizes the information and can provide a printout or transfer the information to a computer for evaluation (using a well drawdown/recovery model). The pressure transducer should be initially calibrated with another water level measurement technique to ensure accuracy. This technique is very useful for hydraulic conductivity testing in highly permeable material where repeated, accurate water level measurements are required in a very short period of time. A sensitive transducer element is required to measure water levels to 0.01 foot accuracy.~~

#### Borehole Geophysics

Approximate water levels can be determined during geophysical logging of the borehole (although this is not the primary purpose for geophysical logging and such logging is not cost effective if used only for this purpose). Several logging techniques will indicate water level. Commonly-used logs which will indicate saturated/unsaturated conditions include the spontaneous potential (SP) log and the neutron log.

### 5.3.5 Data Recording

Water level measurements, time, data, and weather conditions shall be recorded in the geologist/hydrogeologist's field notebook or on the Groundwater Level Measurement Sheet. All water level measurements shall be measured from a known reference point. The reference point is generally a marked point on the upper edge of the inner well casing that has been surveyed for an elevation. The exact reference point shall be marked with permanent ink on the casing since the top of the casing may not be entirely level. It is important to note changes in weather conditions because changes in the barometric pressure may affect the water level within the well.

Subject EVALUATION OF EXISTING MONITORING WELLS AND WATER LEVEL MEASUREMENT	Number GH-1.2	Page 7 of 9
	Revision 0	Effective Date 02/04

### 5.3.6 **Specific Quality Control Procedures for Water Level Measuring Devices**

All groundwater level measurement devices must be cleaned before and after each use to prevent cross contamination of wells. See Section 5.4 regarding decontamination of water level measuring equipment. Some devices used to measure groundwater levels may need to be calibrated. These devices shall be calibrated to 0.01 foot accuracy and any adjustments/corrections shall be recorded in the field logbook/notebook. After the corrections/adjustments are made to the measuring device and entered in the field logbook/notebook, the corrected readings shall be entered onto the Groundwater Level Measurement Sheet (Attachment B). Elevations will be entered on the sheet when they become available.

### 5.4 **Equipment Decontamination**

All portions of a device which projects down the well casing must be decontaminated prior to advancing to the next well. Manufacturer's instructions for equipment decontamination should be followed. Variations from the manufacturer's requirements may be implemented based on the project objectives, but they must be defined prior to conducting any field activities. Consult the project planning documents and SA-7.1 Decontamination of Field Equipment.

### 5.5 **Health and Safety Considerations**

Groundwater contaminated by volatile organic compounds may release toxic vapors into the air space inside the well pipe. The release of this air when the well is initially opened is a health/safety hazard which must be considered. Initial monitoring of the well headspace and breathing zone concentrations using a PID or FID shall be performed to determine required levels of protection. Under certain conditions, air-tight well caps may explosively fly off the well when the pressure is relieved. Never stand directly over a well when uncapping it.

## 6.0 **RECORDS**

A record of all field procedures, tests and observations must be recorded in the site logbook or designated field notebook. Entries in the log/notebook should include the individuals participating in the field effort, and the date and time. The use of annotated sketches may help to supplement the evaluation.

Subject EVALUATION OF EXISTING MONITORING WELLS AND WATER LEVEL MEASUREMENT	Number GH-1.2	Page 8 of 9
	Revision 0	Effective Date 02/04

**ATTACHMENT A  
MONITORING WELL INSPECTION SHEET**

**Monitoring Well Inspection Sheet**

Project Name: \_\_\_\_\_ Date: \_\_\_\_\_  
 Location: \_\_\_\_\_ Time: \_\_\_\_\_  
 Tidally Influenced: Y / N Personnel: \_\_\_\_\_

Field Measurements				
Well ID	PID Reading PPM	Depth to Water *	Total Depth *	Flush Mt./ Stick-up

Well Construction Details (Taken from construction logs)		
Total Depth *	Ground Elev.	Top/Btm Screen *

**Check List:**

Riser Pipe Material:
Riser Notched for Surveyors:
Well ID Tag In-place:
Well security:
Photo taken:

**Condition of Well:**

Protective Case:
Riser:
Well Pad:
Other:

**Presence/Evidence of:**

Standing Water Around Well:
Existing Sampling Equipment:
Sediment build-up in Well Btm:

<b>Comments:</b>          
--

\* = Measurements are from the top of the inner case to the nearest 0.01'



# STANDARD OPERATING PROCEDURES

Number GH-1.3	Page 1 of 20
Effective Date 02/04	Revision 0
Applicability	
Prepared	
Approved	

Subject  
SOIL AND ROCK DRILLING METHODS

## TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY .....	2
4.0 RESPONSIBILITIES .....	2
5.0 PROCEDURES .....	3
5.1 GENERAL .....	3
5.2 DRILLING METHODS .....	3
5.2.1 Hollow-Stem Auger Drilling .....	3
5.2.2 Drill-through Casing Driver .....	5
5.2.3 Jet Drilling (Washing) .....	6
5.2.4 Drilling with a Hand Auger .....	6
5.2.5 Rock Drilling and Coring .....	7
5.2.6 Drilling & Support Vehicles .....	8
5.2.7 Equipment Sizes .....	9
5.2.8 Estimated Drilling Progress .....	9
5.3 PREVENTION OF CROSS-CONTAMINATION .....	10
5.4 CLEANOUT OF CASING PRIOR TO SAMPLING .....	11
5.5 MATERIALS OF CONSTRUCTION .....	12
5.6 SUBSURFACE SOIL SAMPLES .....	12
5.7 ROCK SAMPLING (CORING) (ASTM D2113-83) .....	13
5.7.1 Diamond Core Drilling .....	16
5.7.2 Rock Sample Preparation and Documentation .....	16
6.0 REFERENCES .....	17

### ATTACHMENT

A	DRILLING EQUIPMENT SIZES .....	19
---	--------------------------------	----

### FIGURE

<u>NUMBER</u>	<u>PAGE</u>
1	STANDARD SIZES OF CORE BARRELS AND CASING ..... 15

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 2 of 20
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

The purpose of this procedure is to describe the methods and equipment necessary to perform soil and rock borings and identify the equipment, sequence of events, and appropriate methods necessary to obtain soil, both surface and subsurface, and rock samples during field sampling activities.

## 2.0 SCOPE

This guideline addresses most of the accepted and standard drilling techniques, their benefits, and drawbacks. It should be used generally to determine what type of drilling techniques would be most successful depending on site-specific geologic conditions and the type of sampling required.

The sampling methods described within this procedure are applicable to collecting surface and subsurface soil samples, and obtaining rock core samples for lithologic and hydrogeologic evaluation, excavation/foundation design, remedial alternative design and related civil engineering purposes.

## 3.0 GLOSSARY

~~Rock Coring - A method in which a continuous solid cylindrical sample of rock or compact rock-like soil is obtained by the use of a double tube core barrel that is equipped with an appropriate diamond-studded drill bit which is advanced with a hydraulic rotary drilling machine.~~

~~Wire-Line Coring - As an alternative to conventional coring, this technique is valuable in deep hole drilling, since this method eliminates trips in and out of the hole with the coring equipment. With this technique, the core barrel becomes an integral part of the drill rod string. The drill rod serves as both a coring device and casing.~~

## 4.0 RESPONSIBILITIES

Project Manager - In consultation with the project geologist, the Project Manager is responsible for evaluating the drilling requirements for the site and specifying drilling techniques that will be successful given the study objectives and the known or suspected geologic conditions at the site. The Project Manager also determines the disposal methods for products generated by drilling, such as drill cuttings and well development water, as well as any specialized supplies or logistical support required for the drilling operations.

Field Operations Leader (FOL) - The FOL is responsible for the overall supervision and scheduling of drilling activities, and is strongly supported by the project geologist.

Project Geologist - The project geologist is responsible for ensuring that standard and approved drilling procedures are followed. The geologist will generate a detailed boring log for each test hole. This log shall include a description of materials, samples, method of sampling, blow counts, and other pertinent drilling and testing information that may be obtained during drilling (see SOPs SA-6.3 and GH-1.5). Often this position for inspecting the drilling operations may be filled by other geotechnical personnel, such as soils and foundation engineers, civil engineers, etc.

Determination of the exact location for borings is the responsibility of the site geologist. The final location for drilling must be properly documented on the boring log. The general area in which the borings are to be located will be shown on a site map included in the Work Plan and/or Sampling and Analysis Plan.

Drilling Subcontractor - Operates under the supervision of the FOL. Responsible for obtaining all drilling permits and clearances, and supplying all services (including labor), equipment and material required to

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 3 of 20
	Revision 0	Effective Date 02/04

perform the drilling, testing, and well installation program, as well as maintenance and quality control of such required equipment except as stated in signed and approved subcontracts.

The driller must report any major technical or analytical problems encountered in the field to the FOL within 24 hours of determination, and must provide advance written notification of any changes in field procedures, describing and justifying such changes. No such changes shall be made unless requested and authorized in writing by the FOL (with the concurrence of the Project Manager). Depending on the subcontract, the Project Manager may need to obtain written authorization from appropriate administrative personnel before approving any changes.

The drilling subcontractor is responsible for following decontamination procedures specified in the project plan documents. Upon completion of the work, the driller is responsible for demobilizing all equipment, cleaning up any materials deposited on site during drilling operations, and properly backfilling any open borings.

## 5.0 PROCEDURES

### 5.1 General

The purpose of drilling boreholes is:

- To determine the type, thickness, and certain physical and chemical properties of the soil, water and rock strata which underlie the site.
- To install monitoring wells or piezometers.

All drilling and sampling equipment will be cleaned between samples and borings using appropriate decontamination procedures as outlined in SOP SA-7.1. Unless otherwise specified, it is generally advisable to drill borings at "clean" locations first, and at the most contaminated locations last, to reduce the risk of spreading contamination between locations. All borings must be logged by the site geologist as they proceed (see SOPs SA-6.3 and GH-1.5). Situations where logging would not be required would include installation of multiple well points within a small area, or a "second attempt" boring adjacent to a boring that could not be continued through resistant material. In the latter case, the boring log can be resumed 5 feet above the depth at which the initial boring was abandoned, although the site geologist should still confirm that the stratigraphy at the redrilled location conforms essentially with that encountered at the original location. If significant differences are seen, each hole should be logged separately.

### 5.2 Drilling Methods

The selected drilling methods described below apply to drilling in subsurface materials, including, but not limited to, sand, gravel, clay, silt, cobbles, boulders, rock and man-made fill. Drilling methods should be selected after studying the site geology and terrain, the waste conditions at the site, and reviewing the purpose of drilling and the overall subsurface investigation program proposed for the site. The full range of different drilling methods applicable to the proposed program should be identified with final selection based on relative cost, availability, time constraints, and how well each method meets the sampling and testing requirements of the individual drilling program.

#### 5.2.1 Hollow-Stem Auger Drilling

This method of drilling consists of rotating augers with a hollow stem into the ground. Cuttings are brought to the surface by the rotating action of the auger. This method is relatively quick and inexpensive. Advantages of this type of drilling include:

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 4 of 20
	Revision 0	Effective Date 02/04

- Samples can be obtained without pulling the augers out of the hole. However, this is a poor method for obtaining grab samples from thin, discrete formations because of mixing of soils which occurs as the material is brought to the surface. Sampling of such formations requires the use of split-barrel or thin-wall tube samplers advanced through the hollow core of the auger.
- No drilling fluids are required.
- A well can be installed inside the auger stem and backfilled as the augers are withdrawn.

Disadvantages and limitations of this method of drilling include:

- Augering can only be done in unconsolidated materials.
- The inside diameter of hollow stem augers used for well installation should be at least 4 inches greater than the well casing. Use of such large-diameter hollow-stem augers is more expensive than the use of small-diameter augers in boreholes not used for well installation. Furthermore, the density of unconsolidated materials and depths become more of a limiting factor. More friction is produced with the larger diameter auger and subsequently greater torque is needed to advance the boring.
- The maximum effective depth for drilling is 150 feet or less, depending on site conditions and the size of augers used.
- In augering through clean sand formations below the water table, the sand will tend to flow into the hollow stem when the plug is removed for soil sampling or well installation. If the condition of "running" or "flowing" sands is persistent at a site, an alternative method of drilling is recommended, in particular for wells or boreholes deeper than 25 feet.

Hollow-stem auger drilling is the preferred method of drilling. Most alternative methods require the introduction of water or mud downhole (air rotary is the exception) to maintain the open borehole. With these other methods, great care must be taken to ensure that the method does not interfere with the collection of a representative sample (which may be the prime objective of the borehole construction). With this in mind, the preferred order of choice of drilling method after hollow-stem augering (HSA) is:

- Drill-through casing drive
- Jet drilling
- Hand auger

However, the use of any method will also depend on efficiency and cost-effectiveness. In many cases, mud rotary is the only feasible alternative to hollow-stem augering. Thus, mud rotary drilling is generally acceptable as a first substitute for HSA.

The procedures for sampling soils through holes drilled by hollow-stem auger shall conform with the applicable ASTM Standards: D1587-83 and D1586-84. The guidelines established in SOP SA-1.3 shall also be followed. The hollow-stem auger may be advanced by any power-operated drilling machine having sufficient torque and ram range to rotate and force the auger to the desired depth. The machine must, however, be equipped with the accessory equipment needed to perform required sampling, or rock coring.

The hollow-stem auger may be used without the plug when boring for geotechnical examination or for well installation. However, when drilling below the water table, specially designed plugs which allow passage of formation water but not solid material shall be used (see Reference 1 of this guideline). This drilling configuration method also prevents blow back and plugging of the auger when the plug is removed for sampling.

Alternately, it may be necessary to keep the hollow stem full of water, at least to the level of the water table, to prevent blowback and plugging of the auger. If water is added to the hole, it must be sampled

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 5 of 20
	Revision 0	Effective Date 02/04

and analyzed to determine if it is free from contaminants prior to use. In addition, the amount of water introduced, the amount recovered upon attainment of depth, and the amount of water extracted during well development must be carefully logged in order to ensure that a representative sample of the formation water can be obtained. Well development should occur as soon after well completion as practicable (see SOP GH-2.8 for well development procedures). If gravelly or hard material is encountered which prevents advancing the auger to the desired depth, augering should be halted and either driven casing or hydraulic rotary methods should be attempted. If the depth to the bedrock/soil interface and bedrock lithology must be determined, then a 5-foot confirmatory core run should be conducted (see Section 5.2.9).

At the option of the Field Operations Leader (in communication with the Project Manager), when resistant materials prevent the advancement of the auger, a new boring can be attempted. The original boring must be properly backfilled and the new boring started a short distance away at a location determined by the site geologist. If multiple water bearing strata were encountered, the original boring must be grouted. In some formations, it may be prudent to also grout borings which penetrate only the water table aquifer, since loose soil backfill in the boring may still provide a preferred pathway for surface liquids to reach the water table. Backfilling requirements may also be driven by state or local regulations.

### **5.2.2 Drill-through Casing Driver**

The driven-casing method consists of alternately driving casing (fitted with a sharp, hardened casing shoe) into the ground using a hammer lifted and dropped by the drill rig (or an air-hammer) and cleaning out the casing using a rotary chopping bit and air or water to flush out the materials. The casing is driven down in stages (usually 5 feet per stage); a continuous record is kept of the blows per foot in driving the casing (see SOP GH-1.5). The casing is normally advanced by a 300-pound hammer falling freely through a height of 30 inches. Simultaneous washing and driving of the casing is not recommended. If this procedure is used, the elevations within which wash water is used and in which the casing is driven must be clearly recorded.

The driven casing method is used in unconsolidated formations only. When the boring is to be used for later well installation, the driven casing used should be at least 4 inches larger in diameter than the well casing to be installed. Advantages to this method of drilling include:

- Split-barrel (split-spoon) sampling can be conducted while drilling.
- Well installation is easily accomplished.
- Drill rigs used are relatively small and mobile.
- The use of casing minimizes flow into the hole from upper water-bearing layers; therefore, multiple aquifers can be penetrated and sampled for rough field determinations of some water quality parameters.

Some of the disadvantages include:

- This method can only be used in unconsolidated formations.
- The method is slower than other methods (average drilling progress is 30 to 50 feet per day).
- Maximum depth of the borehole varies with the size of the drill rig and casing diameter used, and the nature of the formations drilled.
- The cost per hour or per foot of drilling may be substantially higher than other drilling methods.

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 6 of 20
	Revision 0	Effective Date 02/04

- It is difficult and time consuming to pull back the casing if it has been driven very deep (deeper than 50 feet in many formations).

### 5.2.3 Jet Drilling (Washing)

Jet drilling, which should be used only for piezometer or vadose zone sampler installation, consists of pumping water or drilling mud down through a small diameter (1/2- to 2-inch) standard pipe (steel or PVC). The pipe may be fitted with a chisel bit or a special jetting screen. Formation materials dislodged by the bit and jetting action of the water are brought to the surface through the annulus around the pipe. As the pipe is jetted deeper, additional lengths of pipe may be added at the surface.

Jet percussion is a variation of the jetting method, in which the casing is driven with a drive weight. Normally, this method is used to place 2-inch-diameter casing in shallow, unconsolidated sand formations, but this method has also been used to install 3- to 4-inch-diameter casings to a depth of 200 feet.

Jetting is acceptable in very soft formations, usually for shallow sampling, and when introduction of drilling water to the formation is acceptable. Such conditions would occur during rough stratigraphic investigation or installation of piezometers for water level measurement. Advantages of this method include:

- Jetting is fast and inexpensive.
- Because of the small amount of equipment required, jetting can be accomplished in locations where access by a normal drilling rig would be very difficult. For example, it would be possible to jet down a well point in the center of a lagoon at a fraction of the cost of using a drill rig.
- Jetting numerous well points just into a shallow water table is an inexpensive method for determining the water table contours, hence flow direction.

Disadvantages include the following:

- A large amount of foreign water or drilling mud is introduced above and into the formation to be sampled.
- Jetting is usually done in very soft formations which are subject to caving. Because of this caving, it is often not possible to place a grout seal above the screen to assure that water in the well is only from the screened interval.
- The diameter of the casing is usually limited to 2 inches.
- Jetting is only possible in very soft formations that do not contain boulders or coarse gravel, and the depth limitation is shallow (about 30 feet without jet percussion equipment).
- Large quantities of water are often needed.

### 5.2.4 Drilling with a Hand Auger

This method is applicable wherever the formation, total depth of sampling, and the site and groundwater conditions are such as to allow hand auger drilling. Hand augering can also be considered at locations where drill rig access is not possible. All hand auger borings will be performed according to ASTM D1452-80.

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 7 of 20
	Revision 0	Effective Date 02/04

Samples should be taken continuously unless otherwise specified by the project plan documents. Any required sampling is performed by rotation, pressing, or driving in accordance with the standard or approved method governing use of the particular sampling tool. Typical equipment used for sampling and advancing shallow "hand auger" holes are Iwan samplers (which are rotated) or post hole diggers (which are operated like tongs). These techniques are slow but effective where larger pieces of equipment do not have access, and where very shallow holes are desired (less than 15 feet). Surficial soils must be composed of relatively soft and non-cemented formations to allow penetration by the auger.

### **5.2.5 Rock Drilling and Coring**

When soil borings cannot be continued using augers or rotary methods due to the hardness of the soil or when rock or large boulders are encountered, drilling and sampling can be performed using a diamond bit corer in accordance with ASTM D2113.

Drilling is done by rotating and applying downward pressure to the drill rods and drill bit. The drill bit is a circular, hollow, diamond-studded bit attached to the outer core barrel in a double-tube core barrel. The use of single-tube core barrels is not recommended, as the rotation of the barrel erodes the sample and limits its use for detailed geological evaluation. Water or air is circulated down through the drill rods and annular space between the core barrel tubes to cool the bit and remove the cuttings. The bit cuts a core out of the rock which rises into an inner barrel mounted inside the outer barrel. The inner core barrel and rock core are removed by lowering a wire line with a coupling into the drill rods, latching onto the inner barrel and withdrawing the inner barrel. A less efficient variation of this method utilizes a core barrel that cannot be removed without pulling all of the drill rods. This variation is practical only if less than 50 feet of core is required.

Core borings are made through the casing used for the soil borings. The casing must be driven and sealed into the rock formation to prevent seepage from the overburden into the hole to be cored (see Section 5.3 of this guideline). A double-tube core barrel with a diamond bit and reaming shell or equivalent should be used to recover rock cores of a size specified in the project plans. The most common core barrel diameters are listed in Attachment A.

Soft or decomposed rock should be sampled with a driven split-barrel whenever possible or cored with a Denison or Pitcher sampler.

When coring rock, including shale and claystone, the speed of the drill and the drilling pressure, amount and pressure of water, and length of run can be varied to give the maximum recovery from the rock being drilled. Should any rock formation be so soft or broken that the pieces continually fall into the hole causing unsatisfactory coring, the hole should be reamed and a flush-joint casing installed to a point below the broken formation. The size of the flush-joint casing must permit securing the core size specified. When soft or broken rock is anticipated, the length of core runs should be reduced to less than 5 feet to avoid core loss and minimize core disturbance.

Advantages of core drilling include:

- Undisturbed rock cores can be recovered for examination and/or testing.
- In formations in which the cored hole will remain open without casing, water from the rock fractures may be recovered from the well without the installation of a well screen and gravel pack.
- Formation logging is extremely accurate.
- Drill rigs are relatively small and mobile.

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 8 of 20
	Revision 0	Effective Date 02/04

~~Disadvantages include:~~

- ~~• Water or air is needed for drilling.~~
- ~~• Coring is slower than rotary drilling (and more expensive).~~
- ~~• Depth to water cannot accurately be determined if water is used for drilling.~~
- ~~• The size of the borehole is limited.~~

~~This drilling method is useful if accurate determinations of rock lithology are desired or if open wells are to be installed into bedrock. To install larger diameter wells in coreholes, the hole must be reamed out to the proper size after boring, using air or mud rotary drilling methods.~~

### **5.2.6 Drilling & Support Vehicles**

In addition to the drilling method required to accomplish the objectives of the field program, the type of vehicle carrying the drill rig and/or support equipment and its suitability for the site terrain, will often be an additional deciding factor in planning the drilling program. The types of vehicles available are extensive, and depend upon the particular drilling subcontractor's fleet. Most large drilling subcontractors will have a wide variety of vehicle and drill types suited for most drilling assignments in their particular region, while smaller drilling subcontractors will usually have a fleet of much more limited diversity. The weight, size, and means of locomotion (tires, tracks, etc.) of the drill rig must be selected to be compatible with the site terrain to assure adequate mobility between borehole locations. Such considerations also apply to necessary support vehicles used to transport water and/or drilling materials to the drill rigs at the borehole locations. When the drill rigs or support vehicles do not have adequate mobility to easily traverse the site, provisions must be made for assisting equipment, such as bulldozers, winches, timber planking, etc., to maintain adequate progress during the drilling program.

Some of the typical vehicles which are usually available for drill rigs and support equipment are:

- Totally portable drilling/sampling equipment, where all necessary components (tripods, samplers, hammers, catheads, etc.) may be hand carried to the borehole site. Drilling/sampling methods used with such equipment include:
  - Hand augers and lightweight motorized augers.
  - Retractable plug samplers--driven by hand (hammer).
  - Motorized cathead - a lightweight aluminum tripod with a small gas-engine cathead mounted on one leg, used to install small-diameter cased borings. This rig is sometimes called a "monkey on a stick."
- Skid-mounted drilling equipment containing a rotary drill or engine-driven cathead (to lift hammers and drill string), a pump, and a dismantled tripod. The skid is pushed, dragged, or winched (using the cathead drum) between boring locations.
- Small truck-mounted drilling equipment using a Jeep, stake body or other light truck (4 to 6 wheels), upon which are mounted the drill and/or a cathead, a pump, and a tripod or small drilling derrick. On some rigs, the drill and/or a cathead are driven by a power take-off from the truck, instead of by a separate engine.
- Track-mounted drilling equipment is similar to truck-mounted rigs, except that the vehicle used has wide bulldozer tracks for traversing soft ground. Sometimes a continuous-track "all terrain vehicle" is also modified for this purpose. Some types of tracked drill rigs are called "bombardier" or "weasel" rigs.

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 9 of 20
	Revision 0	Effective Date 02/04

- Heavy truck-mounted drilling equipment is mounted on tandem or dual tandem trucks to transport the drill, derrick, winches, and pumps or compressors. The drill may be provided with a separate engine or may use a power take-off from the truck engine. Large augers, hydraulic rotary and reverse circulation rotary drilling equipment are usually mounted on such heavy duty trucks. For soft-ground sites, the drilling equipment is sometimes mounted on vehicles having low pressure, very wide diameter tires and capable of floating; these vehicles are called "swamp buggy" rigs.
- ~~Marine drilling equipment is mounted on various floating equipment for drilling borings in lakes, estuaries and other bodies of water. The floating equipment varies, and is often manufactured or customized by the drilling subcontractor to suit specific drilling requirements. Typically, the range of flotation vehicles include:~~
  - ~~Barrel-float rigs - a drill rig mounted on a timber platform buoyed by empty 55-gallon drums or similar flotation units.~~
  - ~~Barge-mounted drill rigs.~~
  - ~~Jack-up platforms - drilling equipment mounted on a floating platform having retractable legs to support the unit on the sea or lake bed when the platform is jacked up out of the water.~~
  - ~~Drill ships - for deep ocean drilling.~~

In addition to the mobility for the drilling equipment, similar consideration must be given for equipment to support the drilling operations. Such vehicles or floating equipment are needed to transport drill water, drilling supplies and equipment, samples, drilling personnel, etc. to and/or from various boring locations.

### 5.2.7 Equipment Sizes

In planning subsurface exploration programs, care must be taken in specifying the various drilling components, so that they will fit properly in the boring or well.

For drilling open boreholes using rotary drilling equipment, tri-cone drill bits are employed with air, water or drilling mud to remove cuttings and cool the bit. Tri-cone bits are slightly smaller than the holes they drill (i.e., 5-7/8-inch or 7-7/8-inch bits will nominally drill 6-inch and 8-inch holes, respectively).

For obtaining split-barrel samples of a formation, samplers are commonly manufactured in sizes ranging from 2 inches to 3-1/2 inches in outside diameter. However, the most commonly used size is the 2-inch O.D., 1-3/8-inch I.D. split-barrel sampler. When this sampler is used and driven by a 140-pound ( $\pm$  2-pound) hammer dropping 30 inches ( $\pm$  1 inch), the procedure is called a Standard Penetration Test, and the blows per foot required to advance the sampler into the formation can be correlated to the formation's density or strength.

In planning the drilling of boreholes using hollow-stem augers or casing, in which thin-wall tube samples or diamond core drilling will be performed, refer to the various sizes and clearances provided in Attachment A of this guideline. Sizes selected must be stated in the project plan documents.

### 5.2.8 Estimated Drilling Progress

To estimate the anticipated rates of drilling progress for a site, the following must be considered:

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 10 of 20
	Revision 0	Effective Date 02/04

- The speed of the drilling method employed.
- Applicable site conditions (e.g., terrain, mobility between borings, difficult drilling conditions in bouldery soils, rubble fill or broken rock, etc.).
- Project-imposed restrictions (e.g., drilling while wearing personal protective equipment, decontamination of drilling equipment, etc.).

Based on recent experience in drilling average soil conditions (no boulders) and taking samples at 5-foot intervals, for moderate depth (30 feet to 50 feet) boreholes (not including installation or development of wells), the following daily rates of total drilling progress may be anticipated for the following drilling methods:

Drilling Method	Average Daily Progress (linear feet)
Hollow-stem augers	75'
<del>Solid-stem augers</del>	<del>50'</del>
<del>Mud Rotary Drilling</del>	<del>100' (cuttings samples)</del>
<del>Rotosonic Drilling</del>	<del>100'-160' (continuous core)</del>
<del>Reverse-Circulation Rotary</del>	<del>100' (cuttings samples)</del>
<del>Skid-Rig with driven casing</del>	<del>30'</del>
<del>Rotary with driven casing</del>	<del>50'</del>
<del>Cable Tool</del>	<del>30'</del>
Hand Auger	Varies
<del>Continuous Rock Coring</del>	<del>50'</del>

### 5.3 Prevention of Cross-Contamination

A telescoping or multiple casing technique minimizes the potential for the migration of contaminated groundwater to lower strata below a confining layer. The telescoping technique consists of drilling to a confining layer utilizing a spun casing method with a diamond cutting or augering shoe (a method similar to the rock coring method described in Section 5.2.10, except that larger casing is used) or by using a driven-casing method (see Section 5.2.6 of this guideline) and installing a specified diameter steel well casing. The operation consists of three separate steps. Initially, a drilling casing (usually of 8-inch diameter) is installed followed by installation of the well casing (6-inch-diameter is common for 2-inch wells). This well casing is driven into the confining layer to ensure a tight seal at the bottom of the hole. The well casing is sealed at the bottom with a bentonite-cement slurry. The remaining depth of the boring is drilled utilizing a narrower diameter spun or driven casing technique within the outer well casing. A smaller diameter well casing with an appropriate length of slotted screen on the lower end, is installed to the surface.

Clean sand is placed in the annulus around and to a point of about 2 feet above the screen prior to withdrawal of the drilling casing. The annular space above the screen and to a point 2 feet above the bottom of the outer well casing is sealed with a tremied cement-bentonite slurry which is pressure-grouted or displacement-grouted into the hole. The remaining casing annulus is backfilled with clean material and grouted at the surface, or it is grouted all the way to the surface.

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 11 of 20
	Revision 0	Effective Date 02/04

#### 5.4 Cleanout of Casing Prior to Sampling

The boring hole must be completely cleaned of disturbed soil, segregated coarse material and clay adhering to the inside walls of the casing. The cleaning must extend to the bottom edge of the casing and, if possible, a short distance further (1 or 2 inches) to bypass disturbed soil resulting from the advancement of the casing. Loss of wash water during cleaning should be recorded.

For disturbed samples both above and below the water table and where introduction of relatively large volumes of wash water is permissible, the cleaning operation is usually performed by washing the material out of the casing with water; however, the cleaning should never be accomplished with a strong, downward-directed jet which will disturb the underlying soil. When clean out has reached the bottom of the casing or slightly below (as specified above), the string of tools should be lifted one foot off the bottom with the water still flowing, until the wash water coming out of the casing is clear of granular soil particles. In formations where the cuttings contain gravel and other larger particles, it is often useful to repeatedly raise and lower the drill rods and wash bit while washing out the hole, to surge these large particles upward out of the hole. As a time saver, the drilling contractor may be permitted to use a split-barrel (split-spoon) sampler with the ball check valve removed as the clean-out tool, provided the material below the spoon is not disturbed and the shoe of the spoon is not damaged. However, because the ball check valve has been removed, in some formations it may be necessary to install a flap valve or spring sample retainer in the split-spoon bit, to prevent the sample from falling out as the sampler is withdrawn from the hole. The use of jet-type chopping bits is discouraged except where large boulders and cobbles or hard-cemented soils are encountered. If water markedly softens the soils above the water table, clean out should be performed dry with an auger.

For undisturbed samples below the water table, or where wash water must be minimized, clean out is usually accomplished with an appropriate diameter clean out auger. This auger has cutting blades at the bottom to carry loose material up into the auger, and up-turned water jets just above the cutting blades to carry the removed soil to the surface. In this manner, there is a minimum of disturbance at the top of the material to be sampled. If any gravel material washes down into the casing and cannot be removed by the clean out auger, a split-barrel sample can be taken to remove it; bailers and sandpumps should not be used. For undisturbed samples above the groundwater table, all operations must be performed in a dry manner.

If all of the cuttings created by drilling through the overlying formations are not cleaned from the borehole prior to sampling, some of the problems which may be encountered during sampling include:

- When sampling is attempted through the cuttings remaining in the borehole, all or part of the sampler may become filled with the cuttings. This limits the amount of sample from the underlying formation which can enter and be retained in the sampler, and also raises questions as to the validity of the sample.
- If the cuttings remaining in the borehole contain coarse gravel and/or other large particles, these may block the bit of the sampler and prevent any materials from the underlying formation from entering the sampler when the sampler is advanced.
- In cased borings, should sampling be attempted through cuttings which remain in the lower portion of the casing, these cuttings could cause the sampler to become bound into the casing, such that it becomes very difficult to either advance or retract the sampler.
- When sampler blow counts are used to estimate the density or strength of the formation being sampled, the presence of cuttings in the borehole will usually give erroneously high sample blow counts.

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 12 of 20
	Revision 0	Effective Date 02/04

To confirm that all cuttings have been removed from the borehole prior to attempting sampling, it is important that the site geologist measure the "stickup" of the drill string. This is accomplished by measuring the assembled length of all drill rods and bits or samplers (the drill string) as they are lowered to the bottom of the hole, below some convenient reference point of the drill string, then measuring the height of this reference point above the ground surface. The difference of these measurements is the depth of the drill string (lower end of the bit or sampler) below the ground surface, which must then be compared with the depth of sampling required (installed depth of casing or depth of borehole drilled). If the length of drill string below grade is more than the drilled or casing depth, the borehole has been cleaned too deeply, and this deeper depth of sampling must be recorded on the log. If the length of drill string below grade is less than the drilled or casing depth, the difference represents the thickness of cuttings which remain in the borehole. In most cases, an inch or two of cuttings may be left in the borehole with little or no problem. However, if more than a few inches of cuttings are encountered, the borehole must be recleaned prior to attempting sampling.

### **5.5 Materials of Construction**

The effects of monitoring well construction materials on specific chemical analytical parameters are described and/or referenced in SOP GH-2.8. However, there are several materials used during drilling, particularly drilling fluids and lubricants, which must be used with care to avoid compromising the representativeness of soil and ground water samples.

The use of synthetic or organic polymer slurries is not permitted at any location where soil samples for chemical analysis are to be collected. These slurry materials could be used for installation of long-term monitoring wells, but the early time data in time series collection of ground water data may then be suspect. If synthetic or organic polymer muds are proposed for use at a given site, a complete written justification including methods and procedures for their use must be provided by the site geologist and approved by the Project Manager. The specific slurry composition and the concentration of suspected contaminants for each site must be known.

For many drilling operations, potable water is an adequate lubricant for drill stem and drilling tool connections. However, there are instances, such as drilling in tight clayey formations or in loose gravels, when threaded couplings must be lubricated to avoid binding. In these instances, to be determined in the field by the judgment of the site geologist and noted in the site logbook, and only after approval by the Project Manager, a vegetable oil or silicone-based lubricant should be used. Petroleum based greases, etc. will not be permitted. Samples of lubricants used must be provided and analyzed for chemical parameters appropriate to the given site.

### **5.6 Subsurface Soil Samples**

Subsurface soil samples are used to characterize subsurface stratigraphy. This characterization can indicate the potential for migration of chemical contaminants in the subsurface. In addition, definition of the actual migration of contaminants can be obtained through chemical analysis of the soil samples. Where the remedial activities may include in-situ treatment or excavation and removal of the contaminated soil, the depth and areal extent of contamination must be known as accurately as possible.

Engineering and physical properties of soil may also be of interest should site construction activities be planned. Soil types, grain size distribution, shear strength, compressibility, permeability, plasticity, unit weight, and moisture content are some of the physical characteristics that may be determined for soil samples.

Penetration tests are also described in this procedure. The tests can be used to estimate various physical and engineering parameters such as relative density, unconfined compressive strength, and consolidation characteristics of soils.

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 13 of 20
	Revision 0	Effective Date 02/04

Surface protocols for various soil sampling techniques are discussed in SOP SA-1.3. Continuous-core soil sampling and rock coring are discussed below. The procedures described here are representative of a larger number of possible drilling and sampling techniques. The choice of techniques is based on a large number of variables such as cost, local geology, etc. The final choice of methods must be made with the assistance of drilling subcontractors familiar with the local geologic conditions. Alternative techniques must be based upon the underlying principles of quality assurance implicit in the following procedures.

The CME continuous sample tube system provides a method of sampling soil continuously during hollow-stem augering. The 5-foot sample barrel fits within the lead auger of a hollow-auger column. The sampling system can be used with a wide range of I.D. hollow-stem augers (from 3-1/4-inch to 8-1/4-inch I.D.). This method has been used to sample many different materials such as glacial drift, hard clays and shales, mine tailings, etc. This method is particularly used when SPT samples are not required and a large volume of material is needed. Also, this method is useful when a visual description of the subsurface lithology is required. Rotasonic drilling methods also provide a continuous soil sample.

#### **5.7 Rock Sampling (Coring) (ASTM D2113-83)**

Rock coring enables a detailed assessment of borehole conditions to be made, showing precisely all lithologic changes and characteristics. Because coring is an expensive drilling method, it is commonly used for shallow studies of 500 feet or less, or for specific intervals in the drill hole that require detailed logging and/or analyzing. Rock coring can, however, proceed for thousands of feet continuously, depending on the size of the drill rig, and yields better quality data than air-rotary drilling, although at a substantially reduced drilling rate. Rate of drilling varies widely, depending on the characteristics of lithologies encountered, drilling methods, depth of drilling, and condition of drilling equipment. Average output in a 10-hour day ranges from 40 to over 200 feet. Down hole geophysical logging or television camera monitoring is sometimes used to complement the data generated by coring.

Borehole diameter can be drilled to various sizes, depending on the information needed. Standard sizes of core barrels (showing core diameter) and casing are shown in Figure 1.

Core drilling is used when formations are too hard to be sampled by soil sampling methods and a continuous solid sample is desired. Usually, soil samples are used for overburden, and coring begins in sound bedrock. Casing is set into bedrock before coring begins to prevent loose material from entering the borehole, to prevent loss of drilling fluid, and to prevent cross-contamination of aquifers.

Drilling through bedrock is initiated by using a diamond-tipped core bit threaded to a drill rod (outer core barrel) with a rate of drilling determined by the downward pressure, rotation speed of drill rods, drilling fluid pressure in the borehole, and the characteristics of the rock (mineralogy, cementation, weathering).

**FIGURE 1**  
**STANDARD SIZES OF CORE BARRELS AND CASING**

Coring Bit Size	Nominal*		Set Size*	
	O.D.	I.D.	O.D.	I.D.
RWT	1 5/32	3/4	1.160	0.735
EWT	1 1/2	29/32	1.470	0.905
EX, EXL, EWG, EWM	1 1/2	13/16	1.470	0.845
AWT	1 7/8	1 9/32	1.875	1.281
AX, AXL, AWG, AWM	1 7/8	1 3/16	1.875	1.185
BWT	2 3/8	1 3/4	2.345	1.750
BX, BXL, BWG, BWM	2 3/8	1 5/8	2.345	1.655
NWT	3	2 5/16	2.965	2.313
NX, NXL, NWG, NWM	3	2 1/8	2.965	2.155
HWT	3 29/32	3 3/16	3.889	3.187
HWG	3 29/32	3	3.889	3.000
2 3/4 x 3 7/8	3 7/8	2 3/4	3.840	2.690
4 x 5 1/2	5 1/2	4	5.435	3.970
6 x 7 3/4	7 3/4	6	7.655	5.970
AX Wire line <u>  </u> / <u>  </u>	1 7/8	1	1.875	1.000
BX Wire line <u>  </u> / <u>  </u>	2 3/8	1 7/16	2.345	1.437
NX Wire line <u>  </u> / <u>  </u>	3	1 15/16	2.965	1.937

\* All dimensions are in inches; to convert to millimeters, multiply by 25.4.  
  /   Wire line dimensions and designations may vary according to manufacturer.

**FIGURE 1  
STANDARD SIZES OF CORE BARRELS AND CASING  
PAGE TWO**

Size Designations		Casing O.D., Inches	Casing Coupling		Casing bit O.D., Inches	Core barrel bit O.D., Inches*	Drill rod O.D., Inches	Approximate Core Diameter	
Casing; Casing coupling; Casing bits; Core barrel bits	Rod; rod couplings		O.D., Inches	I.D., Inches				Normal, Inches	Thinwall, Inches
RX	RW	1.437	1.437	1.188	1.485	1.160	1.094	---	0.735
EX	E	1.812	1.812	1.500	1.875	1.470	1.313	0.845	0.905
AX	A	2.250	2.250	1.906	2.345	1.875	1.625	1.185	1.281
BX	B	2.875	2.875	2.375	2.965	2.345	1.906	1.655	1.750
NX	N	3.500	3.500	3.000	3.615	2.965	2.375	2.155	2.313
HX	HW	4.500	4.500	3.938	4.625	3.890	3.500	3.000	3.187
RW	RW	1.437	Flush Joint	No Coupling	1.485	1.160	1.094	---	0.735
EW	EW	1.812			1.875	1.470	1.375	0.845	0.905
AW	AW	2.250			2.345	1.875	1.750	1.185	1.281
BW	BW	2.875			2.965	2.345	2.125	1.655	1.750
NW	NW	3.500			3.615	2.965	2.625	2.155	2.313
HW	HW	4.500			4.625	3.890	3.500	3.000	3.187
PW	---	5.500			5.650	---	---	---	---
SW	---	6.625			6.790	---	---	---	---
UW	---	7.625			7.800	---	---	---	---
ZW	---	8.625			8.810	---	---	---	---
---	AX <u>  </u> \	---	---	---	---	1.875	1.750	1.000	---
---	BX <u>  </u> \	---	---	---	---	2.345	2.250	1.437	---
---	NX <u>  </u> \	---	---	---	---	2.965	2.813	1.937	---

\* All dimensions are in inches; to convert to millimeters, multiply by 25.4.

   / Wire line dimensions and designations may vary according to manufacturer.

**NOMINAL DIMENSIONS FOR DRILL CASINGS AND ACCESSORIES.  
(DIAMOND CORE DRILL MANUFACTURERS ASSOCIATION). 288-  
D-2889**

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 16 of 20
	Revision 0	Effective Date 02/04

### 5.7.1 Diamond Core Drilling

A penetration of typically less than 6 inches per 50 blows using a 140-lb. hammer dropping 30 inches with a 2-inch split-barrel sampler shall be considered an indication that soil sampling methods may not be applicable and that coring may be necessary to obtain samples.

When formations are encountered that are too hard to be sampled by soil sampling methods, the following diamond core drilling procedure may be used:

- Firmly seat a casing into the bedrock or the hard material to prevent loose materials from entering the hole and to prevent the loss of drilling fluid return. Level the surface of the rock or hard material when necessary by the use of a fishtail or other bits. If the drill hole can be retained open without the casing and if cross-contamination of aquifers in the unconsolidated materials is unlikely, leveling may be omitted.
- Begin the core drilling using a double-tube swivel-core barrel of the desired size. After drilling no more than 10 feet (3 m), remove the core barrel from the hole and take out the core. If the core blocks the flow of the drilling fluid during drilling, remove the core barrel immediately. In soft materials, a large starting size may be specified for the coring tools; where local experience indicates satisfactory core recovery or where hard, sound materials are anticipated, a smaller size or the single-tube type may be specified and longer runs may be drilled. NX/NW size coring equipment is the most commonly used size.
- When soft materials are encountered that produce less than 50 percent recovery, stop the core drilling. If soil samples are desired, secure such samples in accordance with the procedures described in ASTM Method D 1586 (Split-barrel Sampling) or in Method D 1587 (Thin-Walled Tube Sampling); sample soils per SOP SA-1.3. Resume diamond core drilling when refusal materials are again encountered.
- Since rock structures and the occurrence of seams, fissures, cavities, and broken areas are among the most important items to be detected and described, take special care to obtain and record these features. If such broken zones or cavities prevent further advance of the boring, one of the following three steps shall be taken: (1) cement the hole; (2) ream and case; or (3) case and advance with the next smaller size core barrel, as conditions warrant.
- In soft, seamy, or otherwise unsound rock, where core recovery may be difficult, M-design core barrels may be used. In hard, sound rock where a high percentage of core recovery is anticipated, the single-tube core barrel may be employed.

### 5.7.2 Rock Sample Preparation and Documentation

Once the rock coring has been completed and the core recovered, the rock core shall be carefully removed from the barrel, placed in a core tray (previously labeled "top" and "bottom" to avoid confusion), classified, and measured for percentage of recovery as well as the rock quality designation (RQD). Each core shall be described, classified, and logged using a uniform system as presented in SOP GH-1.5. If moisture content will be determined or if it is desirable to prevent drying (e.g., to prevent shrinkage of clay formations) or oxidation of the core, the core shall be wrapped in plastic sleeves immediately after logging. Each plastic sleeve shall be labeled with indelible ink. The boring number, run number, and the footage represented in each sleeve shall be included, as well as designating the top and bottom of the core run.

After sampling, rock cores shall be placed in the sequence of recovery in well-constructed wooden boxes provided by the drilling contractor. Rock cores from two different borings shall not be placed in the same core box unless accepted by the Project Geologist. The core boxes shall be constructed to accommodate

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 17 of 20
	Revision 0	Effective Date 02/04

at least 20 linear feet of core in rows of approximately 5 feet each and shall be constructed with hinged tops secured with screws, and a latch (usually a hook and eye) to keep the top securely fastened down. Wood partitions shall be placed at the end of each core run and between rows.

The depth from the surface of the boring to the top and bottom of the drill run and run number shall be marked on the wooden partitions with indelible ink. A wooden partition (wooden block) shall be placed at the end of each run with the depth of the bottom of the run written on the block. These blocks will serve to separate successive core runs and indicate depth intervals for each run. The order of placing cores shall be the same in all core boxes. Rock core shall be placed in the box so that, when the box is open, with the inside of the lid facing the observer, the top of the cored interval contained within the box is in the upper left corner of the box, and the bottom of the cored interval is in the lower right corner of the box. The top and bottom of each core obtained and its true depth shall be clearly and permanently marked on each box. The width of each row must be compatible with the core diameter to prevent lateral movement of the core in the box. Similarly, an empty space in a row shall be filled with an appropriate filler material or spacers to prevent longitudinal movement of the core in the box.

The inside and outside of the core-box lid shall be marked by indelible ink to show all pertinent data on the box's contents. At a minimum, the following information shall be included:

- Project name.
- Project number.
- Boring number.
- Run numbers.
- Footage (depths).
- Recovery.
- RQD (%).
- Box number and total number of boxes for that boring (Example: Box 5 of 7).

For easy retrieval when core boxes are stacked, the sides and ends of the box shall also be labeled and include project number, boring number, top and bottom depths of core and box number.

Prior to final closing of the core box, a photograph of the recovered core and the labeling on the inside cover shall be taken. If moisture content is not critical, the core shall be wetted and wiped clean for the photograph. (This will help to show true colors and bedding features in the cores).

## 6.0 REFERENCES

Acker Drill Co., 1958. Basic Procedures of Soil Sampling. Acker Drill Co., Scranton, Pennsylvania.

American Institute of Steel Construction, 1978. Manual of Steel Construction, 7th Edition. American Institute of Steel Construction, New York, New York.

American Society for Testing and Materials, 1987. ASTM Standards D1587-83, D1586-84, and D1452-80. ASTM Annual Book of Standards, ASTM, Philadelphia, Pennsylvania, Vol. 4.08.

American Society for Testing and Materials, 1989. Standard Practice for Diamond Core Drilling for Site Investigation. ASTM Method D2113-83 (reapproved 1987), Annual Book of Standards, ASTM, Philadelphia, Pennsylvania.

Barcelona, M. J., J. P. Gibb and R. A. Miller, 1983. A Guide to the Selection of Material for Monitoring Well Construction and Ground Water Sampling. ISWS Contract Report 327, Illinois State Water Survey, Champaign, Illinois.

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 18 of 20
	Revision 0	Effective Date 02/04

BOART Longyear Co., Sonic Drilling. Environmental Drilling Division, Andova, Minnesota.

Central Mine Equipment Company, Drilling Equipment, St. Louis, Missouri.

Dept. of the Navy, Naval Facilities Engineering Command, 1982. Soil Mechanics Design Manual 7.1.

Driscoll, Fletcher G., 1986. Groundwater and Wells, 2nd Edition. Johnson Division, St. Paul, Minnesota.

Procedure GH-1.5 - Borehole and Sample Logging.

Scaif, M. R., J. F. McNabb, W. J. Dunlap, R. L. Crosby and J. Fryberger, 1981. Manual of Ground-Water Sampling Procedures. NWWA/EPA Series. Kerr Environmental Research Laboratory, Office of Research and Development, U.S. EPA, Ada, Oklahoma.

U.S. Department of the Interior, 1974, Earth Manual, A Water Resources Technical Publication, 810 pages.

U.S. EPA, 1980. Procedure Manual for Ground Water Monitoring at Solid Waste Disposal Facilities. SW-611. Office of Solid Waste, U.S. EPA, Cincinnati, Ohio.

W. L. Acker III, 1974. Basic Procedures for Soil Sampling and Core Drilling. Acker Drill Co., Inc., Scranton, Pennsylvania.

## ATTACHMENT A

## DRILLING EQUIPMENT SIZES

Drilling Component	Designation or Hole Size (Inches)	O.D. (Inches)	I.D. (Inches)	Coupling I.D. (Inches)
Hollow-stem augers (Ref. 7)	6 1/4	5	2 1/4	
	6 3/4	5 3/4	2 3/4	---
	7 1/4	6 1/4	3 1/4	---
	13 1/4	12	6	---
Thin Wall Tube Samplers (Ref. 7)	---	2	1 7/8	---
	---	2 1/2	2 3/8	---
	---	3	2 7/8	---
	---	3 1/2	3 3/8	---
	---	4 1/2	4 3/8	---
	---	5	4 3/4	---
Drill Rods (Ref. 7)	RW	1 3/32	23/32	13/32
	EW	1 3/8	15/16	7/16
	AW	1 3/4	1 1/4	5/8
	BW	2 1/8	1 3/4	3/4
	NW	2 5/8	2 1/4	1 3/8
	HW	3 1/2	3 1/16	2 3/8
	E	1 5/16	7/8	7/16
	A	1 5/8	1 1/8	9/16
	B	1 7/8	1 1/4	5/8
	N	2 3/8	2	1
				Wall Thickness (Inches)
Driven External Coupled Extra Strong Steel* Casing (Ref. 8)	2 1/2	2.875	2.323	0.276
	3	3.5	2.9	0.300
	3 1/2	4.0	3.364	0.318
	4	4.5	3.826	0.337
	5	5.63	4.813	0.375
	6	6.625	5.761	0.432
	8	8.625	7.625	0.500
	10	10.750	9.750	0.500
	12	12.750	11.750	0.500

\* Add twice the casing wall thickness to casing O.D. to obtain the approximate O.D. of the external pipe couplings.

Subject SOIL AND ROCK DRILLING METHODS	Number GH-1.3	Page 20 of 20
	Revision 0	Effective Date 02/04

**ATTACHMENT A  
DRILLING EQUIPMENT SIZES  
PAGE TWO**

Drilling Component	Designation or Hole Size (Inches)	O.D. (Inches)	I.D. (Inches)	Coupling I.D. (Inches)
Flush Coupled Casing (Ref. 7)	RX	1 7/16	1 3/16	1 3/16
	EX	1 13/16	1 5/8	1 1/2
	AX	2 1/4	2	1 29/32
	BX	2 7/8	2 9/16	2 3/8
	NX	3 1/2	3 3/16	3
	HX	4 1/2	4 1/8	3 15/16
Flush Joint Casing (Ref. 7)	RW	1 7/16	1 3/16	
	EW	1 13/16	1 1/2	
	AW	2 1/4	1 29/32	
	BW	2 7/8	2 3/8	
	NW	3 1/2	3	
	HW	4 1/2	4	
	PW	5 1/2	5	
	SW	6 5/8	6	
	UW	7 5/8	7	
	ZW	8 5/8	8	
Diamond Core Barrels (Ref. 7)	EWM	1 1/2	7/8**	
	AWM	1 7/8	1 1/8**	
	BWM	2 3/8	1 5/8**	
	NWM	3	2 1/8	
	HWG	3 7/8	3	
	2 3/4 x 3 7/8	3 7/8	2 11/16	
	4 x 5 1/2	5 1/2	3 15/16	
	6 x 7 3/4	7 3/4	5 15/16	
	AQ (wireline)	1 57/64	1 1/16**	
	BQ (wireline)	2 23/64	1 7/16**	
	NQ (wireline)	2 63/64	1 7/8	
	HQ (wireline)	3 25/32	2 1/2	

\*\* Because of the fragile nature of the core and the difficulty to identify rock details, use of small-diameter core (1 3/8") is not recommended.

<b>STANDARD OPERATING PROCEDURES</b>	Number GH-1.5	Page 1 of 20
	Effective Date 02/04	Revision 0
	Applicability	
	Prepared	
Subject BOREHOLE AND SAMPLE LOGGING	Approved	

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
<b>1.0 PURPOSE .....</b>	<b>3</b>
<b>2.0 SCOPE .....</b>	<b>3</b>
<b>3.0 GLOSSARY .....</b>	<b>3</b>
<b>4.0 RESPONSIBILITIES .....</b>	<b>3</b>
<b>5.0 PROCEDURES .....</b>	<b>3</b>
5.1 MATERIALS NEEDED .....	3
5.2 CLASSIFICATION OF SOILS .....	3
5.2.1 USCS Classification.....	6
5.2.2 Color .....	6
5.2.3 Relative Density and Consistency .....	6
5.2.4 Weight Percentages .....	7
5.2.5 Moisture .....	10
5.2.6 Stratification .....	10
5.2.7 Texture/Fabric/Bedding .....	10
5.2.8 Summary of Soil Classification .....	10
5.3 CLASSIFICATION OF ROCKS .....	13
5.3.1 Rock Type.....	13
5.3.2 Color .....	16
5.3.3 Bedding Thickness .....	16
5.3.4 Hardness .....	16
5.3.5 Fracturing.....	16
5.3.6 Weathering .....	17
5.3.7 Other Characteristics.....	17
5.3.8 Additional Terms Used in the Description of Rock .....	18
5.4 ABBREVIATIONS.....	19
5.5 BORING LOGS AND DOCUMENTATION .....	19
5.5.1 Soil Classification.....	19
5.5.2 Rock Classification .....	23
5.5.3 Classification of Soil and Rock from Drill Cuttings .....	24
5.6 REVIEW .....	24
<b>6.0 REFERENCES .....</b>	<b>24</b>
<b>7.0 RECORDS .....</b>	<b>25</b>

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 2 of 20
	Revision 0	Effective Date 02/04

**TABLE OF CONTENTS (Continued)**

**FIGURES**

<u>NUMBERS</u>		<u>PAGE</u>
1	BORING LOG (EXAMPLE) .....	4
2	CONSISTENCY FOR COHESIVE SOILS .....	8
3	BEDDING THICKNESS CLASSIFICATION .....	10
4	GRAIN SIZE CLASSIFICATION FOR ROCKS .....	12
5	COMPLETED BORING LOG (EXAMPLE) .....	17

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 3 of 20
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

The purpose of this document is to establish standard procedures and technical guidance on borehole and sample logging.

## 2.0 SCOPE

These procedures provide descriptions of the standard techniques for borehole and sample logging. These techniques shall be used for each boring logged to provide consistent descriptions of subsurface lithology. While experience is the only method to develop confidence and accuracy in the description of soil and rock, the field geologist/engineer can do a good job of classification by careful, thoughtful observation and by being consistent throughout the classification procedure.

## 3.0 GLOSSARY

None.

## 4.0 RESPONSIBILITIES

Site Geologist. Responsible for supervising all boring activities and assuring that each borehole is completely logged. If more than one rig is being used on site, the Site Geologist must make sure that each field geologist is properly trained in logging procedures. A brief review or training session may be necessary prior to the start up of the field program and/or upon completion of the first boring.

## 5.0 PROCEDURES

The classification of soil and rocks is one of the most important jobs of the field geologist/engineer. To maintain a consistent flow of information, it is imperative that the field geologist/engineer understand and accurately use the field classification system described in this SOP. This identification is based on visual examination and manual tests.

### 5.1 Materials Needed

When logging soil and rock samples, the geologist or engineer may be equipped with the following:

- Rock hammer
- Knife
- Camera
- Dilute hydrochloric acid (HCl)
- Ruler (marked in tenths and hundredths of feet)
- Hand Lens

### 5.2 Classification of Soils

All data shall be written directly on the boring log (Figure 1) or in a field notebook if more space is needed. Details on filling out the boring log are discussed in Section 5.5.



FIGURE 1 (CONTINUED)

SOIL TERMS

UNIFIED SOIL CLASSIFICATION (USCS)

COARSE-GRAINED SOILS More Than Half of Material is LARGER Than No. 200 Sieve Size				FINE-GRAINED SOILS More Than Half of Material is SMALLER Than					
FIELD IDENTIFICATION PROCEDURES (Excluding Particles Larger Than 3 Inches and Basing Fracture on Estimated Weights)		GROUP SYMBOL	TYPICAL NAMES	FIELD IDENTIFICATION PROCEDURES (Excluding Particles Larger Than 3 Inches and Basing Fracture on Estimated Weights)					
				Identification Procedures on Fraction Smaller than No. 40 Sieve Size					
				DAY STRENGTH (Crushing Characteristics)	DILATANCY (Reaction to Shaking)	TOUGHNESS (Consistency Near Plastic Limit)			
GRAVELS (50% > 1/4" Ø)	CLEAN GRAVELS (Low % Fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well graded gravels, gravel-sand mixtures, little or no fines.	SILTS AND CLAYS Liquid Limit < 50	None to Slight	Quick to Slow	None	
		Primarily one size or a range of sizes with some intermediate sizes missing.	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.		Medium to High	None to Very Slow	Medium	
		Non-plastic fines (for identification procedures, see ML)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures.		Slight to Medium	Slow	Slight	
		Plastic fines (for identification procedures, see CL)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.		Slight to Medium	Slow to None	Slight to Medium	
SANDS (50% > 1/4" Ø)	CLEAN SANDS (Low % Fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes.	SW	Well graded sand, gravelly sands, little or no fines.	SILTS AND CLAYS Liquid Limit < 50	High to Very High	None	High	
		Primarily one size or a range of sizes with some intermediate sizes missing.	SP	Poorly graded sands, gravelly sands, little or no fines.		Medium to High	None to Very Slow	Slight to Medium	
		Non-plastic fines (for identification procedures, see ML)	SM	Silty sands, poorly graded sand-silt mixtures.		HIGHLY ORGANIC SOILS Readily identified by color, odor, spongy feel and frequently by fibrous texture.			
		Plastic fines (for identification procedures, see CL)	SC	Clayey sands, poorly graded sand-clay mixtures.					

Boundary classifications: Soil possessing characteristics of two groups are designated by combining group symbols. For example, GW-GC, well graded gravel-sand mixture with clay binder.  
All sieve sizes on this chart are U.S. Standard.

DESIGNATION	STANDARD PENETRATION RESISTANCE - BLOWS/FOOT
Very Loose	0-4
Loose	5-10
Medium Loose	11-30
Dense	31-50
Very Dense	Over 50

CONSISTENCY	UNC COMPRESSION STRENGTH (TONS/SQ. FT.)	STANDARD PENETRATION RESISTANCE - BLOWS/FOOT	
Very Soft	Less than 0.25	0 to 2	Easily penetr.
Soft	0.25 to 0.50	2 to 4	Easily penetr.
Medium Soft	0.50 to 1.0	4 to 8	Can be penetr.
Stiff	1.0 to 2.0	8 to 15	Readily indented
Very Stiff	2.0 to 4.0	15 to 30	Readily indented
Hard	More than 4.0	Over 30	Indented with

ROCK TERMS

ROCK HARDNESS (FROM CORE SAMPLES)			ROCK BROKENNESS		
Descriptive Terms	Screwdriver or Knife Effects	Hammer Effects	Descriptive Terms	Abbreviation	Splicing
Soft	Easily Gouged	Crushes when pressed with hammer	Very Broken	(V. Br.)	0-2'
Medium Soft	Can be Gouged	Breaks (one blow); crumbly edges	Broken	(Br.)	2'-1'
Medium Hard	Can be scratched	Breaks (one blow); sharp edges	Blocky	(Bl.)	1'-3'
Hard	Cannot be scratched	Breaks conclusively (several blows); sharp edges	Massive	(M.)	3'-10'

LEGEND:

SOIL SAMPLES - TYPES

5" Split-Barrel Sample

3" O.D. Undisturbed Sample

0 - Other Samples, Specify in Remarks

ROCK SAMPLES - TYPES

X-NX (Conventional) Core (-2.10" O.D.)

Q-NQ (Wireline) Core (-1.75" O.D.)

Z - Other Core Sizes, Specify in Remarks

WATER LEVELS

12.0' Initial Level  
w/Date & Depth

12.0' Stabilized Level  
w/Date & Depth

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 6 of 20
	Revision 0	Effective Date 02/04

### 5.2.1 USCS Classification

Soils are to be classified according to the Unified Soil Classification System (USCS). This method of classification is detailed in Figure 1 (Continued).

This method of classification identifies soil types on the basis of grain size and cohesiveness.

Fine-grained soils, or fines, are smaller than the No. 200 sieve and are of two types: silt (M) and clay (C). Some classification systems define size ranges for these soil particles, but for field classification purposes, they are identified by their respective behaviors. Organic material (O) is a common component of soil but has no size range; it is recognized by its composition. The careful study of the USCS will aid in developing the competence and consistency necessary for the classification of soils.

Coarse-grained soils shall be divided into rock fragments, sand, or gravel. The terms sand and gravel not only refer to the size of the soil particles but also to their depositional history. To insure accuracy in description, the term rock fragments shall be used to indicate angular granular materials resulting from the breakup of rock. The sharp edges typically observed indicate little or no transport from their source area, and therefore the term provides additional information in reconstructing the depositional environment of the soils encountered. When the term "rock fragments" is used it shall be followed by a size designation such as "(1/4 inch $\Phi$ -1/2 inch $\Phi$ )" or "coarse-sand size" either immediately after the entry or in the remarks column. The USCS classification would not be affected by this variation in terms.

### 5.2.2 Color

Soil colors shall be described utilizing a single color descriptor preceded, when necessary, by a modifier to denote variations in shade or color mixtures. A soil could therefore be referred to as "gray" or "light gray" or "blue-gray." Since color can be utilized in correlating units between sampling locations, it is important for color descriptions to be consistent from one boring to another.

Colors must be described while the sample is still moist. Soil samples shall be broken or split vertically to describe colors. Samplers tend to smear the sample surface creating color variations between the sample interior and exterior.

The term "mottled" shall be used to indicate soils irregularly marked with spots of different colors. Mottling in soils usually indicates poor aeration and lack of good drainage.

Soil Color Charts shall not be used unless specified by the project manager.

### 5.2.3 Relative Density and Consistency

To classify the relative density and/or consistency of a soil, the geologist is to first identify the soil type. Granular soils contain predominantly sands and gravels. They are noncohesive (particles do not adhere well when compressed). Finer-grained soils (silts and clays) are cohesive (particles will adhere together when compressed).

The density of noncohesive, granular soils is classified according to standard penetration resistances obtained from split-barrel sampling performed according to the methods detailed in Standard Operating Procedures GH-1.3 and SA-1.3. Those designations are:

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 7 of 20
	Revision 0	Effective Date 02/04

Designation	Standard Penetration Resistance (Blows per Foot)
Very loose	0 to 4
Loose	5 to 10
Medium dense	11 to 30
Dense	31 to 50
Very dense	Over 50

Standard penetration resistance is the number of blows required to drive a split-barrel sampler with a 2-inch outside diameter 12 inches into the material using a 140-pound hammer falling freely through 30 inches. The sampler is driven through an 18-inch sample interval, and the number of blows is recorded for each 6-inch increment. The density designation of granular soils is obtained by adding the number of blows required to penetrate the last 12 inches of each sample interval. It is important to note that if gravel or rock fragments are broken by the sampler or if rock fragments are lodged in the tip, the resulting blow count will be erroneously high, reflecting a higher density than actually exists. This shall be noted on the log and referenced to the sample number. Granular soils are given the USCS classifications GW, GP, GM, SW, SP, SM, GC, or SC (see Figure 1).

The consistency of cohesive soils is determined by performing field tests and identifying the consistency as shown in Figure 2.

Cohesive soils are given the USCS classifications ML, MH, CL, CH, OL, or OH (see Figure 1).

The consistency of cohesive soils is determined either by blow counts, a pocket penetrometer (values listed in the table as Unconfined Compressive Strength), or by hand by determining the resistance to penetration by the thumb. The pocket penetrometer and thumb determination methods are conducted on a selected sample of the soil, preferably the lowest 0.5 foot of the sample in the split-barrel sampler. The sample shall be broken in half and the thumb or penetrometer pushed into the end of the sample to determine the consistency. Do not determine consistency by attempting to penetrate a rock fragment. If the sample is decomposed rock, it is classified as a soft decomposed rock rather than a hard soil. Consistency shall not be determined solely by blow counts. One of the other methods shall be used in conjunction with it. The designations used to describe the consistency of cohesive soils are shown in Figure 2.

#### 5.2.4 Weight Percentages

In nature, soils are comprised of particles of varying size and shape, and are combinations of the various grain types. The following terms are useful in the description of soil:

Terms of Identifying Proportion of the Component	Defining Range of Percentages by Weight
Trace	0 - 10 percent
Some	11 - 30 percent
Adjective form of the soil type (e.g., "sandy")	31 - 50 percent

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 8 of 20
	Revision 0	Effective Date 02/04

**FIGURE 2**

**CONSISTENCY FOR COHESIVE SOILS**

<b>Consistency</b>	<b>Standard Penetration Resistance (Blows per Foot)</b>	<b>Unconfined Compressive Strength (Tons/Sq. Foot by pocket penetration)</b>	<b>Field Identification</b>
Very soft	0 to 2	Less than 0.25	Easily penetrated several inches by fist
Soft	2 to 4	0.25 to 0.50	Easily penetrated several inches by thumb
Medium stiff	4 to 8	0.50 to 1.0	Can be penetrated several inches by thumb with moderate effort
Stiff	8 to 15	1.0 to 2.0	Readily indented by thumb but penetrated only with great effort
Very stiff	15 to 30	2.0 to 4.0	Readily indented by thumbnail
Hard	Over 30	More than 4.0	Indented with difficulty by thumbnail

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 9 of 20
	Revision 0	Effective Date 02/04

Examples:

- Silty fine sand: 50 to 69 percent fine sand, 31 to 50 percent silt.
- Medium to coarse sand, some silt: 70 to 80 percent medium to coarse sand, 11 to 30 percent silt.
- Fine sandy silt, trace clay: 50 to 68 percent silt, 31 to 49 percent fine sand, 1 to 10 percent clay.
- Clayey silt, some coarse sand: 70 to 89 percent clayey silt, 11 to 30 percent coarse sand.

**5.2.5 Moisture**

Moisture content is estimated in the field according to four categories: dry, moist, wet, and saturated. In dry soil, there appears to be little or no water. Saturated samples obviously have all the water they can hold. Moist and wet classifications are somewhat subjective and often are determined by the individual's judgment. A suggested parameter for this would be calling a soil wet if rolling it in the hand or on a porous surface liberates water, i.e., dirties or muddies the surface. Whatever method is adopted for describing moisture, it is important that the method used by an individual remains consistent throughout an entire drilling job.

Laboratory tests for water content shall be performed if the natural water content is important.

**5.2.6 Stratification**

Stratification can only be determined after the sample barrel is opened. The stratification or bedding thickness for soil and rock is depending on grain size and composition. The classification to be used for stratification description is shown in Figure 3.

**5.2.7 Texture/Fabric/Bedding**

The texture/fabric/bedding of the soil shall be described. Texture is described as the relative angularity of the particles: rounded, subrounded, subangular, and angular. Fabric shall be noted as to whether the particles are flat or bulky and whether there is a particular relation between particles (i.e., all the flat particles are parallel or there is some cementation). The bedding or structure shall also be noted (e.g., stratified, lensed, nonstratified, heterogeneous varved).

**5.2.8 Summary of Soil Classification**

In summary, soils shall be classified in a similar manner by each geologist/engineer at a project site. The hierarchy of classification is as follows:

- Density and/or consistency
- Color
- Plasticity (Optional)
- Soil types
- Moisture content
- Stratification
- Texture, fabric, bedding
- Other distinguishing features

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 10 of 20
	Revision 0	Effective Date 02/04

**FIGURE 3**

**BEDDING THICKNESS CLASSIFICATION**

<b>Thickness (metric)</b>	<b>Thickness (Approximate English Equivalent)</b>	<b>Classification</b>
> 1.0 meter	> 3.3'	Massive
30 cm - 1 meter	1.0' - 3.3'	Thick Bedded
10 cm - 30 cm	4" - 1.0'	Medium Bedded
3 cm - 10 cm	1" - 4"	Thin Bedded
1 cm - 3 cm	2/5" - 1"	Very Thin Bedded
3 mm - 1 cm	1/8" - 2/5"	Laminated
1 mm - 3 mm	1/32" - 1/8"	Thinly Laminated
< 1 mm	<1/32"	Micro Laminated

(Weir, 1973 and Ingram, 1954)

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 11 of 20
	Revision 0	Effective Date 02/04

### 5.3 Classification of Rocks

Rocks are grouped into three main divisions: sedimentary, igneous and metamorphic. Sedimentary rocks are by far the predominant type exposed at the earth's surface. The following basic names are applied to the types of rocks found in sedimentary sequences:

- Sandstone - Made up predominantly of granular materials ranging between 1/16 to 2 mm in diameter.
- Siltstone - Made up of granular materials less than 1/16 to 1/256 mm in diameter. Fractures irregularly. Medium thick to thick bedded.
- Claystone - Very fine-grained rock made up of clay and silt-size materials. Fractures irregularly. Very smooth to touch. Generally has irregularly spaced pitting on surface of drilled cores.
- Shale - A fissile very fine-grained rock. Fractures along bedding planes.
- Limestone - Rock made up predominantly of calcite (CaCO<sub>3</sub>). Effervesces strongly upon the application of dilute hydrochloric acid.
- Coal - Rock consisting mainly of organic remains.
- Others - Numerous other sedimentary rock types are present in lesser amounts in the stratigraphic record. The local abundance of any of these rock types is dependent upon the depositional history of the area. Conglomerate, halite, gypsum, dolomite, anhydrite, lignite, etc. are some of the rock types found in lesser amounts.

In classifying a sedimentary rock the following hierarchy shall be noted:

- Rock type
- Color
- Bedding thickness
- Hardness
- Fracturing
- Weathering
- Other characteristics

#### 5.3.1 Rock Type

As described above, there are numerous types of sedimentary rocks. In most cases, a rock will be a combination of several grain types, therefore, a modifier such as a sandy siltstone, or a silty sandstone can be used. The modifier indicates that a significant portion of the rock type is composed of the modifier. Other modifiers can include carbonaceous, calcareous, siliceous, etc.

Grain size is the basis for the classification of clastic sedimentary rocks. Figure 4 is the Udden-Wentworth classification that will be assigned to sedimentary rocks. The individual boundaries are slightly different than the USCS subdivision for soil classification. For field determination of grain sizes, a scale can be used for the coarse grained rocks. For example, the division between siltstone and claystone may not be measurable in the field. The boundary shall be determined by use of a hand lens. If the grains cannot be seen with the naked eye but are distinguishable with a hand lens, the rock is a siltstone. If the grains are not distinguishable with a hand lens, the rock is a claystone.

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 12 of 20
	Revision 0	Effective Date 02/04

**FIGURE 4**

**GRAIN SIZE CLASSIFICATION FOR ROCKS**

<b>Particle Name</b>	<b>Grain Size Diameter</b>
Cobbles	> 64 mm
Pebbles	4 - 64 mm
Granules	2 - 4 mm
Very Coarse Sand	1 - 2 mm
Coarse Sand	0.5 - 1 mm
Medium Sand	0.25 - 0.5 mm
Fine Sand	0.125 - 0.25 mm
Very Fine Sand	0.0625 - 0.125 mm
Silt	0.0039 - 0.0625 mm

After Wentworth, 1922

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 13 of 20
	Revision 0	Effective Date 02/04

### 5.3.2 Color

The color of a rock can be determined in a similar manner as for soil samples. Rock core samples shall be classified while wet, when possible, and air cored samples shall be scraped clean of cuttings prior to color classifications.

Rock color charts shall not be used unless specified by the Project Manager.

### 5.3.3 Bedding Thickness

The bedding thickness designations applied to soil classification (see Figure 3) will also be used for rock classification.

### 5.3.4 Hardness

The hardness of a rock is a function of the compaction, cementation, and mineralogical composition of the rock. A relative scale for sedimentary rock hardness is as follows:

- Soft - Weathered, considerable erosion of core, easily gouged by screwdriver, scratched by fingernail. Soft rock crushes or deforms under pressure of a pressed hammer. This term is always used for the hardness of the saprolite (decomposed rock which occupies the zone between the lowest soil horizon and firm bedrock).
- Medium soft - Slight erosion of core, slightly gouged by screwdriver, or breaks with crumbly edges from single hammer blow.
- Medium hard - No core erosion, easily scratched by screwdriver, or breaks with sharp edges from single hammer blow.
- Hard - Requires several hammer blows to break and has sharp conchoidal breaks. Cannot be scratched with screwdriver.

Note the difference in usage here of the words "scratch" and "gouge." A scratch shall be considered a slight depression in the rock (do not mistake the scraping off of rock flour from drilling with a scratch in the rock itself), while a gouge is much deeper.

### 5.3.5 Fracturing

The degree of fracturing or brokenness of a rock is described by measuring the fractures or joint spacing. After eliminating drilling breaks, the average spacing is calculated and the fracturing is described by the following terms:

- Very broken (V. BR.) - Less than 2-inch spacing between fractures
- Broken (BR.) - 2-inch to 1-foot spacing between fractures
- Blocky (BL.) - 1- to 3-foot spacing between fractures
- Massive (M.) - 3 to 10-foot spacing between fractures

The structural integrity of the rock can be approximated by calculating the Rock Quality Designation (RQD) of cores recovered. The RQD is determined by adding the total lengths of all pieces exceeding 4 inches and dividing by the total length of the coring run, to obtain a percentage.

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 14 of 20
	Revision 0	Effective Date 02/04

Method of Calculating RQD  
(After Deere, 1964)

$$RQD \% = r/l \times 100$$

$r =$  Total length of all pieces of the lithologic unit being measured, which are greater than 4 inches length, and have resulted from natural breaks. Natural breaks include slickensides, joints, compaction slicks, bedding plane partings (not caused by drilling), friable zones, etc.

$l =$  Total length of the coring run.

### 5.3.6 Weathering

The degree of weathering is a significant parameter that is important in determining weathering profiles and is also useful in engineering designs. The following terms can be applied to distinguish the degree of weathering:

- Fresh - Rock shows little or no weathering effect. Fractures or joints have little or no staining and rock has a bright appearance.
- Slight - Rock has some staining which may penetrate several centimeters into the rock. Clay filling of joints may occur. Feldspar grains may show some alteration.
- Moderate - Most of the rock, with exception of quartz grains, is stained. Rock is weakened due to weathering and can be easily broken with hammer.
- Severe - All rock including quartz grains is stained. Some of the rock is weathered to the extent of becoming a soil. Rock is very weak.

### 5.3.7 Other Characteristics

The following items shall be included in the rock description:

- Description of contact between two rock units. These can be sharp or gradational.
- Stratification (parallel, cross stratified).
- Description of any filled cavities or vugs.
- Cementation (calcareous, siliceous, hematitic).
- Description of any joints or open fractures.
- Observation of the presence of fossils.
- Notation of joints with depth, approximate angle to horizontal, any mineral filling or coating, and degree of weathering.

All information shown on the boring logs shall be neat to the point where it can be reproduced on a copy machine for report presentation. The data shall be kept current to provide control of the drilling program and to indicate various areas requiring special consideration and sampling.

### 5.3.8 Additional Terms Used in the Description of Rock

The following terms are used to further identify rocks:

- Seam - Thin (12 inches or less), probably continuous layer.

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 15 of 20
	Revision 0	Effective Date 02/04

- Some - Indicates significant (15 to 40 percent) amounts of the accessory material. For example, rock composed of seams of sandstone (70 percent) and shale (30 percent) would be "sandstone -- some shale seams."
- Few - Indicates insignificant (0 to 15 percent) amounts of the accessory material. For example, rock composed of seam of sandstone (90 percent) and shale (10 percent) would be "sandstone -- few shale seams."
- Interbedded - Used to indicate thin or very thin alternating seams of material occurring in approximately equal amounts. For example, rock composed of thin alternating seams of sandstone (50 percent) and shale (50 percent) would be "interbedded sandstone and shale."
- Interlayered - Used to indicate thick alternating seams of material occurring in approximately equal amounts.

The preceding sections describe the classification of sedimentary rocks. The following are some basic names that are applied to igneous rocks:

- Basalt - A fine-grained extrusive rock composed primarily of calcic plagioclase and pyroxene.
- Rhyolite - A fine-grained volcanic rock containing abundant quartz and orthoclase. The fine-grained equivalent of a granite.
- Granite - A coarse-grained plutonic rock consisting essentially of alkali feldspar and quartz.
- Diorite - A coarse-grained plutonic rock consisting essentially of sodic plagioclase and hornblende.
- Gabbro - A coarse-grained plutonic rock consisting of calcic plagioclase and clinopyroxene. Loosely used for any coarse-grained dark igneous rock.

The following are some basic names that are applied to metamorphic rocks:

- Slate - A very fine-grained foliated rock possessing a well developed slaty cleavage. Contains predominantly chlorite, mica, quartz, and sericite.
- Phyllite - A fine-grained foliated rock that splits into thin flaky sheets with a silky sheen on cleavage surface.
- Schist - A medium to coarse-grained foliated rock with subparallel arrangement of the micaceous minerals which dominate its composition.
- Gneiss - A coarse-grained foliated rock with bands rich in granular and platy minerals.
- Quartzite - A fine- to coarse-grained nonfoliated rock breaking across grains, consisting essentially of quartz sand with silica cement.

#### 5.4 Abbreviations

Abbreviations may be used in the description of a rock or soil. However, they shall be kept at a minimum. Following are some of the abbreviations that may be used:

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 16 of 20
	Revision 0	Effective Date 02/04

C - Coarse	Lt - Light	Yl - Yellow
Med - Medium	BR - Broken	Or - Orange
F - Fine	BL - Blocky	SS - Sandstone
V - Very	M - Massive	Sh - Shale
Sl - Slight	Br - Brown	LS - Limestone
Occ - Occasional	Bl - Black	Fgr - Fine-grained
Tr - Trace		

## 5.5 Boring Logs and Documentation

This section describes in more detail the procedures to be used in completing boring logs in the field. Information obtained from the preceding sections shall be used to complete the logs. A sample boring log has been provided as Figure 5.

The field geologist/engineer shall use this example as a guide in completing each boring log. Each boring log shall be fully described by the geologist/engineer as the boring is being drilled. Every sheet contains space for 25 feet of log. Information regarding classification details is provided either on the back of the boring log or on a separate sheet, for field use.

### 5.5.1 Soil Classification

- Identify site name, boring number, job number, etc. Elevations and water level data to be entered when surveyed data is available.
- Enter sample number (from SPT) under appropriate column. Enter depth sample was taken from (1 block = 1 foot). Fractional footages, i.e., change of lithology at 13.7 feet, shall be lined off at the proportional location between the 13- and 14-foot marks. Enter blow counts (Standard Penetration Resistance) diagonally (as shown). Standard penetration resistance is covered in Section 5.2.3.
- Determine sample recovery/sample length as shown. Measure the total length of sample recovered from the split-spoon sampler, including material in the drive shoe. Do not include cuttings or wash material that may be in the upper portion of the sample tube.
- Indicate any change in lithology by drawing a line at the appropriate depth. For example, if clayey silt was encountered from 0 to 5.5 feet and shale from 5.5 to 6.0 feet, a line shall be drawn at this increment. This information is helpful in the construction of cross-sections. As an alternative, symbols may be used to identify each change in lithology.
- The density of granular soils is obtained by adding the number of blows for the last two increments. Refer to Density of Granular Soils Chart on back of log sheet. For consistency of cohesive soils refer also to the back of log sheet - Consistency of Cohesive Soils. Enter this information under the appropriate column. Refer to Section 5.2.3.

Subject:

BOREHOLE AND SAMPLE LOGGING

Number

GH-1.5

Page

17 of 20

Revision

0

Effective Date

02/04

FIGURE 5  
COMPLETED BORING LOG (EXAMPLE)



**BORING LOG**

Page 1 of 1

PROJECT NAME: NSB- SITE BORING NUMBER: SB/MW 1  
 PROJECT NUMBER: 9594 DATE: 3/8/96  
 DRILLING COMPANY: SOILTEST CO. GEOLOGIST: SJ CONTI  
 DRILLING RIG: CME-55 DRILLER: R. ROCK

Sample No. and Type or RQD	Depth (Ft.) or Run No.	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	MATERIAL DESCRIPTION			USCS	Remarks	PID/FID Reading (ppm)			
					Soil Density/Consistency or Rock Hardness	Color	Material Classification			Sample	Sampler BZ	Borehole	Driller BZ
S-1 C 0800	0.0 2.0	7 9	1.5/2.0 2.0		M DENSE	BRN TO BLK	SILTY SAND - SOME ROCK FR. - TR BRICKS (FILL)	SM	MOIST SL. ORG. ODOR FILL TO 4'±	5	0	0	0
	4.0			4.0									
S-2 e 0810	6.0	5 9	2.0/2.0 2.0		M DENSE	BRN	SILTY SAND - TR FINE GRAVEL	SM	MOIST - W ODOR NAT. MATL. TOOK SAMPLE SB01-0406 FOR ANALYSIS	10	0	-	-
	8.0			7.0 ± 8.0									
S-3 e 0820	10.0	6 17	1.9/2.0 1.6		DENSE	TAN BRN	FINE TO COARSE SAND TR.F. GRAVEL	SW	WET HIT WATER: 7'±	0	0	0	0
	12.0			12.0									
S-4 e 0830	14.0	7 5	1.6/2.0 1.6		STIFF	GRAY	SILTY CLAY	CL	MOIST → WET AUGER REF 15'	0	.5	-	-
	15.0			15.0									
	16.0			16.0	M HARD	BRN	SILTSTONE	VER	WEATHERED LO X JNTS @ 15.5 WATER STAINS @ 16.5, 17.1, 17.5	0	0	0	0
	19.0			19.0					LOSING SOME				
	20.0			20.0	HARD	GRAY	SANDSTONE - SOME SILTSTONE	BR	DRILL H2O @ 17'± SET TEMP 6" CAS TO 15.5				
	25.0			25.0					SET 2"Ø PVC SCREEN 16-25 SAND 14-25 PELLETS 12-14	0	0	0	0

\* When rock coring, enter rock brokenness.

\*\* Include monitor reading in 6 foot intervals @ borehole. Increase reading frequency if elevated response read.

Remarks: CME-55 RIG, 4 1/4" ID HSA - 9" OD ± • 1-20Z Drilling Area  
2" SPLIT SPOONS - 140 LB HAMMER - 30" DROP 1-80Z Background (ppm): 0  
NIX CORE IN BEDROCK RUN (1) = 25 min, RUN (2) = 15 min

Converted to Well: Yes  No  Well I.D. #: MW-1

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 18 of 20
	Revision 0	Effective Date 02/04

- Enter color of the material in the appropriate column.
- Describe material using the USCS. Limit this column for sample description only. The predominant material is described last. If the primary soil is silt but has fines (clay) - use clayey silt. Limit soil descriptors to the following:
  - Trace: 0 - 10 percent
  - Some: 11 - 30 percent
  - And/Or: 31 - 50 percent
- Also indicate under Material Classification if the material is fill or natural soils. Indicate roots, organic material, etc.
- Enter USCS symbol - use chart on back of boring log as a guide. If the soils fall into one of two basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example ML/CL or SM/SP.
- The following information shall be entered under the "Remarks" column and shall include, but is not limited by, the following:
  - Moisture - estimate moisture content using the following terms - dry, moist, wet and saturated. These terms are determined by the individual. Whatever method is used to determine moisture, be consistent throughout the log.
  - Angularity - describe angularity of coarse grained particles using the terms angular, subangular, subrounded, or rounded. Refer to ASTM D 2488 or Earth Manual for criteria for these terms.
  - Particle shape - flat, elongated, or flat and elongated.
  - Maximum particle size or dimension.
  - Water level observations.
  - Reaction with HCl - none, weak, or strong.
- Additional comments:
  - Indicate presence of mica, caving of hole, when water was encountered, difficulty in drilling, loss or gain of water.
  - Indicate odor and Photoionization Detector (PID) or Flame Ionization Detector (FID) reading if applicable.
  - Indicate any change in lithology by drawing a line through the lithology change column and indicate the depth. This will help when cross-sections are subsequently constructed.
  - At the bottom of the page indicate type of rig, drilling method, hammer size and drop, and any other useful information (i.e., borehole size, casing set, changes in drilling method).
  - Vertical lines shall be drawn (as shown in Figure 5) in columns 6 to 8 from the bottom of each sample to the top of the next sample to indicate consistency of material from sample to sample, if the material is consistent. Horizontal lines shall be drawn if there is a change in lithology, then vertical lines drawn to that point.

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 19 of 20
	Revision 0	Effective Date 02/04

- Indicate screened interval of well, as needed, in the lithology column. Show top and bottom of screen. Other details of well construction are provided on the well construction forms.

### 5.5.2 Rock Classification

- Indicate depth at which coring began by drawing a line at the appropriate depth. Indicate core run depths by drawing coring run lines (as shown) under the first and fourth columns on the log sheet. Indicate RQD, core run number, RQD percent, and core recovery under the appropriate columns.
- Indicate lithology change by drawing a line at the appropriate depth as explained in Section 5.5.1.
- Rock hardness is entered under designated column using terms as described on the back of the log or as explained earlier in this section.
- Enter color as determined while the core sample is wet; if the sample is cored by air, the core shall be scraped clean prior to describing color.
- Enter rock type based on sedimentary, igneous or metamorphic. For sedimentary rocks use terms as described in Section 5.3. Again, be consistent in classification. Use modifiers and additional terms as needed. For igneous and metamorphic rock types use terms as described in Sections 5.3.8.
- Enter brokenness of rock or degree of fracturing under the appropriate column using symbols VBR, BR, BL, or M as explained in Section 5.3.5 and as noted on the back of the Boring Log.
- The following information shall be entered under the remarks column. Items shall include but are not limited to the following:
  - Indicate depths of joints, fractures and breaks and also approximate to horizontal angle (such as high, low), i.e., 70° angle from horizontal, high angle.
  - Indicate calcareous zones, description of any cavities or vugs.
  - Indicate any loss or gain of drill water.
  - Indicate drop of drill tools or change in color of drill water.
- Remarks at the bottom of Boring Log shall include:
  - Type and size of core obtained.
  - Depth casing was set.
  - Type of rig used.
- As a final check the boring log shall include the following:
  - Vertical lines shall be drawn as explained for soil classification to indicate consistency of bedrock material.
  - If applicable, indicate screened interval in the lithology column. Show top and bottom of screen. Other details of well construction are provided on the well construction forms.

### 5.5.3 Classification of Soil and Rock from Drill Cuttings

The previous sections describe procedures for classifying soil and rock samples when cores are obtained. However, some drilling methods (air/mud rotary) may require classification and borehole logging based on

Subject  BOREHOLE AND SAMPLE LOGGING	Number GH-1.5	Page 20 of 20
	Revision 0	Effective Date 02/04

identifying drill cuttings removed from the borehole. Such cuttings provide only general information on subsurface lithology. Some procedures that shall be followed when logging cuttings are:

- Obtain cutting samples at approximately 5-foot intervals, sieve the cuttings (if mud rotary drilling) to obtain a cleaner sample, place the sample into a small sample bottle or "zip lock" bag for future reference, and label the jar or bag (i.e. hole number, depth, date, etc.). Cuttings shall be closely examined to determine general lithology.
- Note any change in color of drilling fluid or cuttings, to estimate changes in lithology.
- Note drop or chattering of drilling tools or a change in the rate of drilling, to determine fracture locations or lithologic changes.
- Observe loss or gain of drilling fluids or air (if air rotary methods are used), to identify potential fracture zones.
- Record this and any other useful information onto the boring log as provided in Figure 1.

This logging provides a general description of subsurface lithology and adequate information can be obtained through careful observation of the drilling process. It is recommended that split-barrel and rock core sampling methods be used at selected boring locations during the field investigation to provide detailed information to supplement the less detailed data generated through borings drilled using air/mud rotary methods.

#### 5.6 Review

Upon completion of the borings logs, copies shall be made and reviewed. Items to be reviewed include:

- Checking for consistency of all logs.
- Checking for conformance to the guideline.
- Checking to see that all information is entered in their respective columns and spaces.

#### 6.0 REFERENCES

Unified Soil Classification System (USCS).

ASTM D2488, 1985.

Earth Manual, U.S. Department of the Interior, 1974.

#### 7.0 RECORDS

Originals of the boring logs shall be retained in the project files.

# STANDARD OPERATING PROCEDURES

Number GH-2.8	Page 1 of 12
Effective Date 02/04	Revision 0
Applicability	
Prepared	
Approved	

Subject  
GROUNDWATER MONITORING WELL INSTALLATION

## TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY .....	2
4.0 RESPONSIBILITIES .....	2
5.0 PROCEDURES .....	3
5.1 EQUIPMENT/ITEMS NEEDED .....	3
5.2 WELL DESIGN .....	3
5.2.1 Well Depth, Diameter, and Monitored Interval .....	3
5.2.2 Riser Pipe and Screen Materials .....	5
5.2.3 Annular Materials .....	6
5.2.4 Protective Casing .....	6
5.3 MONITORING WELL INSTALLATION .....	7
5.3.1 Monitoring Wells in Unconsolidated Sediments .....	7
5.3.2 Confining Layer Monitoring Wells .....	7
5.3.3 Bedrock Monitoring Wells .....	8
5.3.4 Drive Points .....	8
5.3.5 Innovative Monitoring Well Installation Techniques .....	8
5.4 WELL DEVELOPMENT METHODS .....	8
5.4.1 Overpumping and Backwashing .....	8
5.4.2 Surging with a Surge Plunger .....	9
5.4.3 Compressed Air .....	9
5.4.4 High Velocity Jetting .....	9
6.0 RECORDS .....	9
7.0 REFERENCES .....	10
 <u>ATTACHMENTS</u>	
A RELATIVE COMPATIBILITY OF RIGID WELL-CASING MATERIAL (PERCENT) / RELATIVE COMPATIBILITY OF SEMI-RIGID OR ELASTOMERIC MATERIALS (PERCENT) .....	11
B COMPARISON OF STAINLESS STEEL AND PVC FOR MONITORING WELL CONSTRUCTION .....	12

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 2 of 12
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

This procedure provides general guidance and information pertaining to proper monitoring well design, installation, and development.

## 2.0 SCOPE

This procedure is applicable to the construction of monitoring wells. The methods described herein may be modified by project-specific requirements for monitoring well construction. In addition, many regulatory agencies have specific regulations pertaining to monitoring well construction and permitting. These requirements must be determined during the project planning phases of the investigation, and any required permits must be obtained before field work begins. Innovative monitoring well installation techniques, which typically are not used, will be discussed only generally in this procedure.

## 3.0 GLOSSARY

Monitoring Well - A well which is screened, cased, and sealed which is capable of providing a groundwater level and groundwater sample representative of the zone being monitored. Some monitoring wells may be constructed as open boreholes.

Piezometer - A pipe or tube inserted into the water bearing zone, typically open to water flow at the bottom and to the atmosphere at the top, and used to measure water level elevations. Piezometers may range in size from 1/2-inch-diameter plastic tubes to well points or monitoring wells.

Potentiometric Surface - The surface representative of the level to which water will rise in a well cased to the screened aquifer.

Well Point (Drive Point) - A screened or perforated tube (Typically 1-1/4 or 2 inches in diameter) with a solid, conical, hardened point at one end, which is attached to a riser pipe and driven into the ground with a sledge hammer, drop weight, or mechanical vibrator. Well points may be used for groundwater injection and recovery, as piezometers (i.e., to measure water levels) or to provide groundwater samples for water quality data.

## 4.0 RESPONSIBILITIES

Driller - The driller provides adequate and operable equipment, sufficient quantities of materials, and an experienced and efficient labor force capable of performing all phases of proper monitoring well installation and construction. The driller may also be responsible for obtaining, in advance, any required permits for monitoring well installation and construction.

Field Geologist - The field geologist supervises and documents well installation and construction performed by the driller, and insures that well construction is adequate to provide representative groundwater data from the monitored interval. Geotechnical engineers, field technicians, or other suitable trained personnel may also serve in this capacity.

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 3 of 12
	Revision 0	Effective Date 02/04

## 5.0 PROCEDURES

### 5.1 Equipment/Items Needed

Below is a list of items that may be needed when installing a monitoring well or piezometer:

- Health and safety equipment (hard hats, safety glasses, etc.) as required by the Site Safety Officer.
- Well drilling and installation equipment with associated materials (typically supplied by the driller).
- Hydrogeologic equipment (weighted engineer's tape, water level indicator, retractable engineers rule, electronic calculator, clipboard, mirror and flashlight - for observing downhole activities, paint and ink marker for marking monitoring wells, sample jars, well installation forms, and a field notebook).
- Drive point installation tools (sledge hammer, drop hammer, or mechanical vibrator; tripod, pipe wrenches, drive points, riser pipe, and end caps).

### 5.2 Well Design

The objectives and intended use for each monitoring well must be clearly defined before the monitoring system is designed. Within the monitoring system, different monitoring wells may serve different purposes and, therefore, require different types of construction. During all phases of the well design, attention must be given to clearly documenting the basis for design decisions, the details of well construction, and the materials used. The objectives for installing the monitoring wells may include:

- Determining groundwater flow directions and velocities.
- Sampling or monitoring for trace contaminants.
- Determining aquifer characteristics (e.g., hydraulic conductivity).

Siting of monitoring wells shall be performed after a preliminary estimation of the groundwater flow direction. In most cases, groundwater flow directions and potential well locations can be determined by an experienced hydrogeologist through the review of geologic data and the site terrain. In addition, data from production wells or other monitoring wells in the area may be used to determine the groundwater flow direction. If these methods cannot be used, piezometers, which are relatively inexpensive to install, may have to be installed in a preliminary investigative phase to determine groundwater flow direction.

#### 5.2.1 Well Depth, Diameter, and Monitored Interval

The well depth, diameter, and monitored interval must be tailored to the specific monitoring needs of each investigation. Specification of these items generally depends on the purpose of the monitoring system and the characteristics of the hydrogeologic system being monitored. Wells of different depth, diameter, and monitored interval can be employed in the same groundwater monitoring system. For instance, varying the monitored interval in several wells, at the same location (cluster wells) can help to determine the vertical gradient and the depths at which contaminants are present. Conversely, a fully penetrating well is usually not used to quantify or vertically locate a contaminant plume, since groundwater samples collected in wells that are screened over the full thickness of the water-bearing zone will be representative of average conditions across the entire monitored interval. However, fully penetrating wells can be used to establish the existence of contamination in the water-bearing zone. The well diameter desired depends upon the hydraulic characteristics of the water-bearing zone, sampling requirements, drilling method and cost.

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 4 of 12
	Revision 0	Effective Date 02/04

The decision concerning the monitored interval and well depth is based on the following (and possibly other) information:

- The vertical location of the contaminant source in relation to the water-bearing zone.
- The depth, thickness and uniformity of the water-bearing zone.
- The anticipated depth, thickness, and characteristics (e.g., density relative to water) of the contaminant plume.
- Fluctuation in groundwater levels (due to pumping, tidal influences, or natural recharge/discharge events).
- The presence and location of contaminants encountered during drilling.
- Whether the purpose of the installation is for determining existence or non-existence of contamination or if a particular stratigraphic zone is being investigated.
- The analysis of borehole geophysical logs.

In most situations where groundwater flow lines are horizontal, depending on the purpose of the well and the site conditions, monitored intervals are 20 feet or less. Shorter screen lengths (5 feet or less) are usually required where flow lines are not horizontal, (i.e., if the wells are to be used for accurate measurement of the potentiometric head at a specific point).

Many factors influence the diameter of a monitoring well. The diameter of the monitoring well depends on the application. In determining well diameter, the following needs must be considered:

- Adequate water volume for sampling.
- Drilling methodology.
- Type of sampling device to be used.
- Costs.

Standard monitoring well diameters are 2, 4, 6, or 8 inches. Drive points are typically 1-1/4 or 2 inches in diameter. For monitoring programs which require screened monitoring wells, either a 2-inch or 4-inch-diameter well is preferred. Typically, well diameters greater than 4 inches are used in monitoring programs in which open-hole bedrock monitoring wells are used. With smaller diameter wells, the volume of stagnant water in the well is minimized, and well construction costs are reduced; however, the sampling devices that can be used are limited.

In specifying well diameter, sampling requirements must be considered (up to a total of 4 gallons of water may be required for a single sample to account for full organic and inorganic analyses, and split samples), particularly if the monitored formation is known to be a low-yielding formation. The unit volume of water contained within a monitoring well is dependent on the well diameter as follows:

Casing Inside Diameter (Inch)	Standing Water Length to Obtain 1 Gallon Water (Feet)
2	6.13
4	1.53
6	0.68

If a well recharges quickly after purging, then well diameter may not be an important factor regarding sample volume requirements.

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 5 of 12
	Revision 0	Effective Date 02/04

Pumping tests for determining aquifer characteristics may require larger diameter wells (for installation of high capacity pumps); however, in small-diameter wells in-situ permeability tests can be performed during drilling or after well installation is completed.

### 5.2.2 Riser Pipe and Screen Materials

Well materials are specified by diameter, type of material, and thickness of pipe. Well screens require an additional specification of slot size. Thickness of pipe is referred to as "Schedule" for polyvinyl chloride (PVC) casing and is usually Schedule 40 (thinner wall) or 80 (thicker wall). Steel pipe thickness is often referred to as "Strength". Standard Strength is usually adequate for monitoring well purposes. With larger diameter pipe, the wall thickness must be greater to maintain adequate strength. The required thickness is also dependent on the method of installation; risers for drive points require greater strength than wells installed inside drilled borings.

The selection of well screen and riser materials depends on the method of drilling, the type of subsurface materials the well penetrates, the type of contamination expected, and natural water quality and depth. Cost and the level of accuracy required are also important. The materials generally available are Teflon, stainless steel, PVC galvanized steel, and carbon steel. Each has advantages and limitations (see Attachment A of this guideline for an extensive presentation on this topic). The two most commonly used materials are PVC and stainless steel. Properties of these two materials are compared in Attachment B. Stainless steel is a good choice where trace metals or organic sampling is required; however, costs are high. Teflon materials are extremely expensive, but are relatively inert and provide the least opportunity for water contamination due to well materials. PVC has many advantages, including low cost, excellent availability, light weight, ease of manipulation, and widespread acceptance. The crushing strength of PVC may limit the depth of installation, but the use of Schedule 80 materials may overcome some of the problems associated with depth. However, the smaller inside diameter of Schedule 80 pipe may be an important factor when considering the size of bailers or pumps required for sampling or testing. Due to this problem, the minimum well pipe size recommended for Schedule 80 wells is 4-inch I.D.

Screens and risers may have to be decontaminated before use because oil-based preservatives and oil used during thread cutting and screen manufacturing may contaminate samples. Metal pipe may corrode and release metal ions or chemically react with organic constituents, but this is considered a minor issue. Galvanized steel is not recommended where samples may be collected for metals analyses, as zinc and cadmium levels in groundwater samples may become elevated from leaching of the zinc coating.

Threaded, flush-joint casing is most often preferred for monitoring well applications. PVC, Teflon, and steel can all be obtained with threaded joints. Welded-joint steel casing is also acceptable. Glued PVC may release organic contaminants into the well, and therefore, should not be used if the well is to be sampled for organic constituents.

When the water-bearing zone is in consolidated bedrock, such as limestone or fractured granite, a well screen is often not necessary (the well is simply an open hole in bedrock). Unconsolidated materials, such as sands, clay, and silts require a screen. A screen slot size of 0.010 or 0.020 inch is generally used when a screen is necessary, and the annular borehole space around the screened interval is artificially packed with an appropriately sized sand, selected based on formation grain size. The slot size controls the quantity of water entering the well and prevents entry of natural materials or sand pack. The screen shall pass no more than 10 percent of the pack material, or in-situ aquifer material. The site geologist shall specify the combination of screen slot size and sand pack which will be compatible with the water-bearing zone, to maximize groundwater inflow and minimize head losses and movement of fines into the wells. For example, as a standard procedure, a Morie No. 1 or No. 10 to No. 20 U.S. Standard Sieve size filter pack is typically appropriate for a 0.020-inch slot screen; however, a No. 20 to No. 40 U.S. Standard Sieve size filter pack is typically appropriate for a 0.010-inch slot screen.

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 6 of 12
	Revision 0	Effective Date 02/04

### 5.2.3 Annular Materials

Materials placed in the annular space between the borehole and riser pipe and screen include a sand pack when necessary, a bentonite seal, and cement-bentonite grout. The sand pack is usually a medium-to coarse-grained poorly graded, silica sand and should relate to the grain size of the aquifer sediments. The quantity of sand placed in the annular space is dependent upon the length of the screened interval, but should always extend at least 1 foot above the top of the screen. At least 1 to 3 feet of bentonite pellets or equivalent shall be placed above the sand pack. Cement-bentonite grout (or equivalent) is then placed to extent from the top of the bentonite pellets to the ground surface.

On occasion, and with the concurrence of the involved regulatory agencies, monitoring wells may be packed naturally (i.e., no artificial sand pack installed). In this case, the natural formation material is allowed to collapse around the well screen after the well is installed. This method has been used where the formation material itself is a relatively uniform grain size, or when artificial sand packing is not possible due to borehole collapse.

Bentonite expands by absorbing water and provides a seal between the screened interval and the overlying portion of the annular space and formation. Cement-bentonite grout is placed on top of the bentonite pellets, extending to the surface. The grout effectively seals the remaining borehole annulus and eliminates the possibility for surface infiltration reaching the screened interval. Grouting also replaces material removed during drilling and prevents hole collapse and subsidence around the well. A tremie pipe should be used to introduce grout from the bottom upward, to prevent bridging, and to provide a better seal. In shallow boreholes that don't collapse, it may be more practical to pour the grout from the surface without a tremie pipe.

Grout is a general term which has several different connotations. For all practical purposes within the monitoring well installation industry, grout refers to the solidified material which is installed and occupies the annular space above the bentonite pellet seal. Grout, most of the time, is made up of one or two assemblages of material, (e.g., cement and/or bentonite). A cement-bentonite grout, which is the most common type of grout used in monitoring well completions, normally is a mixture of cement, bentonite, and water at a ratio of one 90-pound bag of Portland Type I cement, plus 3 to 5 pounds of granular or flake-type bentonite, and 6-7 gallons of water. A neat cement consists of one ninety-pound bag of Portland Type I cement and 6-7 gallons of water. A bentonite slurry (bentonite and water mixed to a thick but pumpable mixture) is sometimes used instead of grout for deep well installations where placement of bentonite pellets is difficult. Bentonite chips are also occasionally used for annular backfill in place of grout.

In certain cases, the borehole may be drilled to a depth greater than the anticipated well installation depth. For these cases, the well shall be backfilled to the desired depth with bentonite pellets/chips or sand. A short (1- to 2-foot) section of capped riser pipe sump is sometimes installed immediately below the screen, as a silt reservoir, when significant post-development silting is anticipated. This will ensure that the entire screen surface remains unobstructed.

### 5.2.4 Protective Casing

When the well is completed and grouted to the surface, a protective steel casing is typically placed over the top of the well. This casing generally has a hinged cap and can be locked to prevent vandalism. The protective casing has a larger diameter than the well and is set into the wet cement grout over the well upon completion. In addition, one hole is drilled just above the cement collar through the protective casing which acts as a weep hole for the flow of water which may enter the annulus during well development, purging, or sampling.

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 7 of 12
	Revision 0	Effective Date 02/04

A protective casing which is level with the ground surface (flush-mounted) is used in roadway or parking lot applications where the top of a monitoring well must be below the pavement. The top of the riser pipe is placed 4 to 5 inches below the pavement, and a locking protective casing is cemented in place to 3 inches below the pavement. A large diameter, manhole-type protective collar is set into the wet cement around the well with the top set level with or slightly above the pavement. An appropriately-sized id is placed over the protective sleeve. The cement should be slightly mounded to direct pooled water away from the well head.

### 5.3 Monitoring Well Installation

Pertinent data regarding monitoring well installation shall be recorded on log sheets as depicted and discussed in SOP SA-6.3. Attachments to this referenced SOP illustrate terms and physical construction of various types of monitoring wells.

#### 5.3.1 Monitoring Wells in Unconsolidated Sediments

After the borehole is drilled to the desired depth, well installation can begin. The procedure for well installation will partially be dictated by the stability of the formation in which the well is being placed. If the borehole collapses immediately after the drilling tools are withdrawn, then a temporary casing must be installed and well installation will proceed through the center of the temporary casing, and continue as the temporary casing is withdrawn from the borehole. In the case of hollow-stem auger drilling, the augers will act to stabilize the borehole during well installation.

Before the screen and riser pipe are lowered into the borehole, all pipe and screen sections should be measured with an engineer's rule to ensure proper placement. When measuring sections, the threads on one end of the pipe or screen must be excluded while measuring, since the pipe and screen sections are screwed flush together.

After the screen and riser pipe are lowered through the temporary casing, the sand pack can be installed. A weighted tape measure must be used during the installation procedure to carefully monitor installation progress. The sand is slowly poured into the annulus between the riser pipe and temporary casing, as the casing is withdrawn. Sand should always be kept within the temporary casing during withdrawal in order to ensure an adequate sand pack. However, if too much sand is within the temporary casing (greater than 1 foot above the bottom of the casing) bridging between the temporary casing and riser pipe may occur. Centralizers may be used at the geologist's discretion, one above and one below the screen, to assure enough annular space for sand pack placement.

After the sand pack is installed to the desired depth (at least 1 foot above the top of the screen), then the bentonite pellet seal (or equivalent), can be installed in the same manner as the sand pack. At least 1 to 3 feet of bentonite pellets should be installed above the sand pack. Pellets should be added slowly and their fall monitored closely to ensure that bridging does not occur.

The cement-bentonite grout is then mixed and tremied into the annulus as the temporary casing or augers are withdrawn. Finally, the protective casing can be installed as detailed in Section 5.2.4.

#### ~~5.3.2 Confining Layer Monitoring Wells~~

~~When drilling and installing a well in a confined aquifer, proper well installation techniques must be applied to avoid cross contamination between aquifers. Under most conditions, this can be accomplished by installing double-cased wells. This is accomplished by drilling a large-diameter boring through the upper aquifer, 1 to 5 feet into the underlying confining layer, and setting and pressure grouting or tremie grouting a large-diameter casing into the confining layer. The grout material must fill the space between the native material and the outer casing. A smaller diameter boring is then continued through the confining layer for~~

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 8 of 12
	Revision 0	Effective Date 02/04

~~installation of the monitoring well as detailed for overburden monitoring wells. Sufficient time (determined by the field geologist), must be allowed for setting of the grout prior to drilling through the confined layer.~~

### ~~5.3.3 Bedrock Monitoring Wells~~

~~When installing bedrock monitoring wells, a large diameter boring is drilled through the overburden and approximately 5 –10 feet into bedrock. A casing (typically steel) is installed and either pressure grouted or tremie grouted in place. After the grout has cured, a smaller diameter boring is continued into bedrock to the desired depth. If the boring does not collapse, the well can be left open, and a screen is not necessary. If the boring collapses, then a screen is required and can be installed as detailed for overburden monitoring wells. If a screen is to be used, then the casing which is installed through the overburden and into the bedrock does not require grouting and can be removed when the final well installation is completed.~~

### ~~5.3.4 Drive Points~~

~~Drive points can be installed with either a sledge hammer, drop hammer, or a mechanical vibrator. The screen section is threaded and tightened onto the riser pipe with pipe wrenches. The drive point is simply pounded into the subsurface to the desired depth. If a heavy drop hammer is used, then a tripod and pulley setup is required to lift the hammer. Drive points typically cannot be manually driven to depths exceeding 10 feet.~~

Direct push sampling/monitoring point installation methods, using a direct push rig or drilling rig, are described in SOP SA-2.5.

### ~~5.3.5 Innovative Monitoring Well Installation Techniques~~

~~Certain innovative sampling devices have proven advantageous. These devices are essentially screened samplers installed in a borehole with only small-diameter tubes extending to the surface. This reduces drilling costs, decreases the volume of stagnant water, and provides a sampling system that minimizes cross-contamination from sampling equipment. Four manufacturers of these samplers include Timco Manufacturing Company, Inc., of Prairie du Sac, Wisconsin, BARCAD Systems, Inc., of Concord, Massachusetts, Westbay Instruments Ltd. of Vancouver, British Columbia, Canada and the University of Waterloo at Waterloo, Ontario, Canada.. Each manufacturer offers various construction materials.~~

## 5.4 Well Development Methods

The purpose of well development is to stabilize and increase the permeability of the gravel pack around the well screen, and to restore the permeability of the formation which may have been reduced by drilling operations. Wells are typically developed until all fine material and drilling water is removed from the well. Sequential measurements of pH, conductivity, turbidity, and temperature taken during development may yield information (stabilized values) regarding whether sufficient development has been performed. The selection of the well development method shall be made by the field geologist and is based on the drilling methods, well construction and installation details, and the characteristics of the formation that the well is screened in. The primary methods of well development are summarized below. A more detailed discussion may be found in Driscoll (1986).

### ~~5.4.1 Overpumping and Backwashing~~

~~Wells may be developed by alternatively drawing the water level down at a high rate (by pumping or bailing) and then reversing the flow direction (backwashing) so that water is passing from the well into the formation. This back and forth movement of water through the well screen and gravel pack serves to~~

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 9 of 12
	Revision 0	Effective Date 02/04

~~remove fines from the formation immediately adjacent to the well, while preventing bridging (wedging) of sand grains. Backwashing can be accomplished by several methods, including pouring water into the well and then bailing, starting and stopping a pump intermittently to change water levels, or forcing water into the well under pressure through a water-tight fitting ("rawhiding"). Care should be taken when backwashing not to apply too much pressure, which could damage or destroy the well screen.~~

#### 5.4.2 Surging with a Surge Plunger

A surge plunger (also called a surge block) is approximately the same diameter as the well casing and is aggressively moved up and down within the well to agitate the water, causing it to move in and out of the screens. This movement of water pulls fine materials into the well, where they may be removed by any of several methods, and prevents bridging of sand particles in the gravel pack. There are two basic types of surge plungers; solid and valved surge plungers. In formations with low yields, a valved surge plunger may be preferred, as solid plungers tend to force water out of the well at a greater rate than it will flow back in. Valved plungers are designed to produce a greater inflow than outflow of water during surging.

#### ~~5.4.3 Compressed Air~~

~~Compressed air can be used to develop a well by either of two methods: backwashing or surging. Backwashing is done by forcing water out through the screens, using increasing air pressure inside a sealed well, then releasing the pressurized air to allow the water to flow back into the well. Care should be taken when using this method so that the water level does not drop below the top of the screen, thus introducing air into the formation and reducing well yield. Surging, or the "open well" method, consists of alternately releasing large volumes of air suddenly into an open well below the water level to produce a strong surge by virtue of the resistance of water head, friction, and inertia. Pumping of the well is subsequently done using the air lift method.~~

#### ~~5.4.4 High Velocity Jetting~~

~~In the high velocity jetting method, water is forced at high velocities from a plunger-type device and through the well screen to loosen fine particles from the sand pack and surrounding formation. The jetting tool is slowly rotated and raised and lowered along the length of the well screen to develop the entire screened area. Jetting using a hose lowered into the well may also be effective. The fines washed into the screen during this process can then be bailed or pumped from the well.~~

### 6.0 RECORDS

A critical part of monitoring well installation is recording of all significant details and events in the site logbook or field notebook. The geologist must record the exact depths of significant hydrogeological features, screen placement, gravel pack placement, and bentonite placement.

A Monitoring Well Sheet (see Attachments to SOP SA-6.3) shall be completed, ensuring the uniform recording of data for each installation and rapid identification of missing information. Well depth, length, materials of construction, length and openings of screen, length and type of riser, and depth and type of all backfill materials shall be recorded. Additional information shall include location, installation date, problems encountered, water levels before and after well installation, cross-reference to the geologic boring log, and methods used during the installation and development process. Documentation is very important to prevent problems involving questionable sample validity. Somewhat different information will need to be recorded, depending on whether the well is completed in overburden (single- or double-cased), as a cased well in bedrock, or as an open hole in bedrock.

The quantities of sand, bentonite, and grout placed in the well are also important. The geologist shall calculate the annular space volume and have an idea of the quantity of material needed to fill the annular

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 10 of 12
	Revision 0	Effective Date 02/04

space. Volumes of backfill significantly higher than the calculated volume may indicate a problem such as a large cavity, while a smaller backfill volume may indicate a cave-in or bridging of the backfill materials. Any problems with rig operation or down-time shall be recorded and may affect the driller's final fee.

## 7.0 REFERENCES

Scaif, M. R., J. F. McNabb, W. J. Dunlap, R. L. Cosby, and J. Fryberger, 1981: Manual of Groundwater Sampling Procedures. R. S. Kerr Environmental Research Laboratory, Office of Research and Development, U.S. EPA, Ada, Oklahoma.

Barcelona, M. J., P. P. Gibb and R. A. Miller, 1983. A Guide to the selection of Materials for Monitoring Well Construction and Groundwater Sampling. ISWS Contract Report 327, Illinois State Water Survey, Champaign, Illinois.

U.S. EPA, 1980. Procedures Manual for Groundwater Monitoring of Solid Waste Disposal Facilities. Publication SW-611, Office of Solid Waste, U.S. EPA, Washington, D.C.

Driscoll, Fletcher G., 1986. Groundwater and Wells. Johnson Division, St. Paul, Minnesota, 1989.

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 11 of 12
	Revision 0	Effective Date 02/04

**ATTACHMENT A**

**RELATIVE COMPATIBILITY OF RIGID WELL CASING MATERIAL (PERCENT)**

Potentially-Deteriorating Substance	Type of Casing Material						
	PVC 1	Galvanized Steel	Carbon Steel	Lo-carbon Steel	Stainless Steel 304	Stainless Steel 316	Teflon*
Buffered Weak Acid	100	56	51	59	97	100	100
Weak Acid	98	59	43	47	96	100	100
Mineral Acid/ High Solids Content	100	48	57	60	80	82	100
Aqueous/Organic Mixtures	64	69	73	73	98	100	100
Percent Overall Rating	91	58	56	59	93	96	100

Preliminary Ranking of Rigid Materials:

- |    |                     |   |                  |
|----|---------------------|---|------------------|
| 1  | Teflon <sup>®</sup> | 5 | Lo-Carbon Steel  |
| 2  | Stainless Steel 316 | 6 | Galvanized Steel |
| 3. | Stainless Steel 304 | 7 | Carbon Steel     |
| 4  | PVC 1               |   |                  |

\* Trademark of DuPont

**RELATIVE COMPATIBILITY OF SEMI-RIGID OR ELASTOMERIC MATERIALS (PERCENT)**

Potentially-Deteriorating Substance	Type of Casing Material								
	PVC Flexible	PP	PE Conv.	PE Linear	PMM	Viton <sup>®</sup> *	Silicone	Neoprene	Teflon <sup>®</sup> *
Buffered Weak Acid	97	97	100	97	90	92	87	85	100
Weak Acid	92	90	94	96	78	78	75	75	100
Mineral Acid/ High Solids Content	100	100	100	100	95	100	78	82	100
Aqueous/Organic Mixtures	62	71	40	60	49	78	49	44	100
Percent Overall Rating	88	90	84	88	78	87	72	72	100

Preliminary Ranking of Semi-Rigid or Elastomeric Materials:

- |    |                        |   |                        |
|----|------------------------|---|------------------------|
| 1  | Teflon <sup>®</sup>    | 5 | PE Conventional        |
| 2  | Polypropylene (PP)     | 6 | Plexiglas/Lucite (PMM) |
| 3. | PVC Flexible/PE Linear | 7 | Silicone/Neoprene      |
| 4  | Viton <sup>®</sup>     |   |                        |

\* Trademark of DuPont

Source: Barcelona et al., 1983

Subject GROUNDWATER MONITORING WELL INSTALLATION	Number GH-2.8	Page 12 of 12
	Revision 0	Effective Date 02/04

**ATTACHMENT B**

**COMPARISON OF STAINLESS STEEL AND PVC FOR MONITORING WELL CONSTRUCTION**

Characteristic	Stainless Steel	PVC
Strength	Use in deep wells to prevent compression and closing of screen/riser.	Use when shear and compressive strength are not critical.
Weight	Relatively heavier.	Light-weight; floats in water.
Cost	Relatively expensive.	Relatively inexpensive.
Corrosivity	Deteriorates more rapidly in corrosive water.	Non-corrosive -- may deteriorate in presence of ketones, aromatics, alkyl sulfides, or some chlorinated hydrocarbons.
Ease of Use	Difficult to adjust size or length in the field.	Easy to handle and work with in the field.
Preparation for Use	Should be steam cleaned if organics will be subsequently sampled.	Never use glue fittings -- pipes should be threaded or pressure fitted. Should be steam cleaned when used for monitoring wells.
Interaction with Contaminants*	May sorb organic or inorganic substances when oxidized.	May sorb or release organic substances.

\* See also Attachment A.

<b>STANDARD OPERATING PROCEDURES</b>	Number SA-1.6	Page 1 of 21
	Effective Date 03/08	Revision 0
	Applicability	
	Prepared	
Subject NATURAL ATTENUATION PARAMETER COLLECTION	Approved	

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
<b>1.0 PURPOSE .....</b>	<b>2</b>
<b>2.0 SCOPE .....</b>	<b>2</b>
<b>3.0 GLOSSARY .....</b>	<b>2</b>
<b>4.0 RESPONSIBILITIES .....</b>	<b>3</b>
<b>5.0 PROCEDURES .....</b>	<b>3</b>
5.1 GENERAL .....	3
5.2 PLANNING FOR NATURAL ATTENUATION SAMPLING .....	4
5.3 SELECTION OF NATURAL ATTENUATION PARAMETERS .....	5
5.4 SELECTION OF NATURAL ATTENUATION ANALYTICAL METHODS AND PROCEDURES .....	6
5.5 PROCEDURES FOR SAMPLE COLLECTION .....	6
5.6 PROCEDURES FOR FIELD SAMPLE ANALYSIS .....	7
5.7 PROCEDURES FOR QUALITY ASSURANCE AND QUALITY CONTROL FIELD SAMPLE ANALYSIS .....	8
5.8 DOCUMENTATION PROCEDURES FOR FIELD SAMPLE ANALYSIS .....	9
5.9 WASTE HANDLING AND DISPOSAL .....	9
5.10 UNDERSTANDING FIELD SAMPLE ANALYTICAL RESULTS .....	9
<b>6.0 REFERENCES .....</b>	<b>10</b>

**ATTACHMENTS**

A	HYPOTHETICAL LONG-TERM MONITORING STRATEGY .....	11
B	REDOX POTENTIALS FOR VARIOUS ELECTRON ACCEPTORS .....	12
<del>C</del>	<del>NATURAL ATTENUATION PARAMETERS FOR CHLORINATED VOLATILE ORGANIC COMPOUND PLUMES .....</del>	<del>13</del>
<del>D</del>	<del>NATURAL ATTENUATION PARAMETERS FOR PETROLEUM HYDROCARBON PLUMES .....</del>	<del>14</del>
E	GEOCHEMICAL SAMPLING PARAMETERS - METHODS, EQUIPMENT, VOLUMES, CONTAINERS, PRESERVATION, HOLDING TIMES, AND DETECTION RANGES .....	15
F	FIELD ANALYTICAL LOG SHEET, GEOCHEMICAL PARAMETERS .....	19

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 2 of 21
	Revision 0	Effective Date 03/08

## 1.0 PURPOSE

The purpose of this document is to provide general reference information regarding natural attenuation parameter and methodology selection, sample collection, and a general understanding of the sample results.

## 2.0 SCOPE

This document provides information on selection of appropriate groundwater natural attenuation parameters, selection of sampling methods for these parameters, techniques for onsite field analysis of select parameters, and some basic understanding of the field sample results. Review of the information contained herein will facilitate planning of the field sampling effort by describing standard sampling practices and techniques. To a limited extent, it shall also facilitate the understanding and interpretation of the sampling results. It addresses field procedures for collection of data at sites with organic groundwater contaminants (e.g., chlorinated and petroleum hydrocarbons) to the extent practical. The focus of this document is on natural attenuation, not enhanced bioremediation.

The techniques described shall be followed whenever applicable, noting that site-specific conditions, project-specific objectives, local, state, and federal guidelines may be used as a basis for modification of the procedures noted herein. The intent of this document is to supplement the local, state, and federal guidance documents and manufacturer's analytical methods referenced in Section 6.0. It is not intended for this document to supersede this guidance or information. Please note that natural attenuation is a relatively dynamic science with ongoing research in the science and engineering community. It is important that data collectors and interpreters use the most recent regulatory guidance, which may be updated on a periodic basis from that noted in Section 6.

## 3.0 GLOSSARY

**Aerobe:** Bacteria that use oxygen as an electron acceptor.

**Anaerobe:** Organisms that can use electron acceptors other than molecular oxygen to support their metabolism.

**Anoxic groundwater:** Groundwater that contains oxygen in concentrations less than about 0.5 mg/L. This term is synonymous with the term anaerobic.

**Anthropogenic:** Man-made.

**Cometabolism:** The process in which a compound is fortuitously degraded by an enzyme or cofactor produced during microbial metabolism of another compound.

**Daughter product:** A compound that results directly from the biotic or abiotic degradation of another. For example, *cis*-1,2-dichloroethene (*cis*-1,2-DCE) is a common daughter product of trichloroethene (TCE).

**Diffusion:** The process whereby molecules move from a region of higher concentration to a region of lower concentration as a result of Brownian motion.

**Dispersion:** The tendency for a solute to spread from the path that it would be expected to follow under advective transport.

**Electron acceptor:** A compound capable of accepting electrons during oxidation-reduction reactions. Microorganisms obtain energy by transferring electrons from an electron donor such as an organic compound (or sometimes a reduced inorganic compound such as sulfide) to an electron acceptor. Electron acceptors are compounds that are relatively oxidized and include oxygen, nitrate, iron(III), manganese(IV), sulfate, carbon dioxide, or in some cases chlorinated aliphatic hydrocarbons such as tetrachloroethene (PCE), TCE, DCE and vinyl chloride (VC).

**Electron donor:** A compound capable of supplying (giving up) electrons during oxidation-reduction reactions. Microorganisms obtain energy by transferring electrons from an electron donor such as an organic compound (or sometimes a reduced inorganic compound such as sulfide) to an

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 3 of 21
	Revision 0	Effective Date 03/08

electron acceptor. Electron donors are compounds that are relatively reduced and include fuel hydrocarbons and native organic carbon.

*Metabolic byproduct:* A product of the reaction between an electron donor and an electron acceptor. Metabolic byproducts include volatile fatty acids, daughter products of chlorinated aliphatic hydrocarbons, methane, and chloride.

*Oxic groundwater:* Groundwater that contains oxygen in concentrations greater than about 0.5 mg/L.

*Oxidation/reduction reaction:* A chemical or biological reaction wherein an electron is transferred from an electron donor (donor is oxidized) to an electron acceptor (acceptor is reduced).

*Predominant terminal electron-accepting process:* The electron-accepting process (oxygen reduction, nitrate reduction, iron(III) reduction, etc.) that sequesters the majority of the electron flow in a given system.

*Reductive dechlorination:* Reduction of a chlorine-containing organic compound via the replacement of chlorine with hydrogen.

*Respiration:* The process of coupling the oxidation of organic compounds with the reduction of inorganic compounds such as oxygen, nitrate, iron(III), manganese(IV), and sulfate.

*Seepage velocity:* The average velocity of groundwater in a porous medium.

*Substrate:* A compound used by microorganisms to obtain energy for growth. The term can refer to either an electron acceptor or an electron donor.

#### 4.0 RESPONSIBILITIES

Project Manager (PM) / Task Order Manager (TOM) - Responsible for ensuring that all field activities are conducted in accordance with this standard operating procedure (SOP).

Project Hydrogeologist or Geochemist - Responsible for selecting and detailing the specific groundwater sampling techniques, onsite water quality testing (type, frequency, and location), and equipment to be used, and providing detailed input in this regard to the project plan documents. The project hydrogeologist or geochemist is also responsible for properly briefing and overseeing the performance of the site sampling personnel.

Site Manager (SM) / Field Operations Leader (FOL) - Responsible for the onsite verification that all field activities are performed in compliance with approved SOPs or as otherwise directed by the approved project plan(s).

Project Geologist - is primarily responsible for the proper acquisition of the groundwater samples. He/she is also responsible for the actual analyses of onsite water quality samples, as well as instrument calibration, care, and maintenance. When appropriate, such responsibilities may be performed by other qualified personnel (e.g., field sampling technicians or site personnel).

#### 5.0 PROCEDURES

##### 5.1 General

Natural attenuation includes physical, chemical, and biochemical processes affecting the concentrations of dissolved contaminants in groundwater. These processes may include advection, dispersion, volatilization, dilution, sorption to aquifer solids, and/or precipitation or mineralization of compounds. Of greatest importance are those processes that lead to a reduction in contaminant mass (by degrading or destroying contaminants) such as biodegradation. These biochemical processes remove organic contaminants from the aquifer by destruction. Depending on the type of contaminant, particularly the organic contaminant (e.g., petroleum hydrocarbons or chlorinated organic solvents), the biochemical environment in the aquifer will vary. The biochemical environment within the aquifer influences and is influenced by the activities of aquifer microbiota. Specific types of microbiota, working singly or in complex consortia, may use organic contaminants as part of their normal cell functions. Natural

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 4 of 21
	Revision 0	Effective Date 03/08

attenuation monitoring is designed to measure indicators of the biochemical environment within the aquifer and, with direct and indirect lines of evidence and associated chemical concentration data, evaluate the likely fate (i.e., transformation, destruction, dilution, attenuation, etc.) of organic contaminants.

## 5.2 Planning for Natural Attenuation Sampling

The first step in preparing a natural attenuation investigation is to develop a site-specific conceptual model. The first step in development of this model is the analysis and review of available site-specific characterization data. The development and refinement of this model should be supplemented with additional data as needed. The data should include but is not limited to:

- Geologic and hydrogeologic information in three dimensions
- Nature, extent, and magnitude of contamination
- Location and presence of potential receptors to contamination

### **Lines of Evidence**

Several lines of evidence are used to determine whether natural attenuation is working. The most compelling, primary evidence is decreasing groundwater contaminant concentrations over time. Decreasing concentration trends can be demonstrated in several ways including:

- Isoconcentration maps of the dissolved plume over time wherein the extent of the plume is either stable or decreasing.
- Time series plots of contaminant concentrations within a well illustrating a clear downward trend.
- Contaminant concentration profiles in a series of monitoring wells along a groundwater flow path illustrating decreasing concentrations beyond that attributable to dilution and dispersion.

Secondary, or supporting, lines of evidence include:

- Analytical data showing production and subsequent destruction of primary contaminant breakdown products.
- Geochemical data indicating that the biochemical environment is favorable for the appropriate microbiota.
- Geochemical data that indicate the aquifer microbiota are active.

### **Monitoring Well Location and Sampling Frequency**

The number and locations of wells required to monitor natural attenuation will depend on the physical setting at each location. One possible array of monitoring wells is illustrated in Attachment A. In this scenario, one well is used to monitor conditions upgradient of the source, one well is located in the source area, and several wells are used to define and monitor the downgradient and lateral extent of the dissolved plume. At a minimum, there should be at least one upgradient well (ideally with no contamination present), one well in the source area, one well downgradient from the source area in the dissolved plume, and one downgradient well where contaminant concentrations are below regulatory criteria. Note that the number and locations of monitoring wells will vary depending on the site complexity and site objectives.

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 5 of 21
	Revision 0	Effective Date 03/08

Sampling frequency will be dictated by the ultimate use of the data and site-specific characteristics. Contaminant concentrations may be used to define statistically meaningful trends in contaminant concentrations. The sampling frequency may be defined by the hydrogeologic and/or geochemical conditions as well as the proposed statistical method for data analysis. For example, groundwater flow and contaminant characteristics (e.g., seepage velocity and contaminant loading) may dictate the sample frequency. Regardless of the factors, sampling frequency and duration will need to establish the range of natural chemical variability within the aquifer. After a sufficient amount of data has been collected and the geochemical conditions are understood, the frequency of sampling may be reduced. See Section 5.4 for additional information on sample collection and frequency.

### 5.3 Selection of Natural Attenuation Parameters

Natural attenuation via biodegradation depends on the nature of the organic contaminants and the oxidation-reduction (redox) environment within the aquifer. Simply stated, if the contaminants are fuels, biodegradation will be most effective if the redox conditions are aerobic or oxidizing. If the contaminants are chlorinated solvents, the biodegradation will be most effective (in the source and near source areas) if redox conditions in the aquifer are anaerobic or reducing.

Several parameters are needed to evaluate whether natural attenuation is taking place and, if so, the rate at which it may be occurring. The primary parameter providing direct evidence of natural attenuation is the aqueous concentrations of parent and daughter volatile organic compounds. More specifically, a decrease in parent products, an increase in daughter products, evidence that the plume is stable or shrinking in size, and overall decline in contaminant concentrations is direct evidence of natural attenuation. Natural attenuation or geochemical parameters that provide information about the redox conditions in the aquifer include:

- Dissolved oxygen
- Nitrate/nitrite
- Dissolved manganese
- Iron
- Sulfate/sulfide
- Methane
- Oxidation-reduction potential (ORP)

Secondary parameters that indicate biological activity in the aquifer and thereby support the natural attenuation evaluation include:

- Dissolved hydrogen
- Alkalinity
- Dissolved carbon dioxide

The concentrations of natural attenuation parameters are used to define the aquifer redox conditions. It is important to record and document the presence or absence (i.e., measurable or not measurable concentration) of certain natural attenuation parameters. The presence or absence of a certain substance may be sufficient to indicate the redox condition within the aquifer. By reference to Attachment B, which illustrates the typical sequence of biologically mediated redox reactions in natural systems, it is apparent that, for example, sulfate reduction (producing dissolved sulfide in groundwater) does not operate in an aerobic environment. Therefore, measurable sulfide should not be present if there is also dissolved oxygen at concentrations indicating an aerobic environment. Attachment B also illustrates the redox potential (measured in millivolts) associated with the redox reactions. ORP readings, also in millivolts, measured during well purging, may be compared with the range of values in Attachment B but with caution. Redox potentials measured with a platinum electrode in natural water samples may be misleading, especially when biologically mediated reactions are important, because many of the critical

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 6 of 21
	Revision 0	Effective Date 03/08

reactions in Attachment B do not generate a response in the electrode. Dissolved hydrogen concentration ranges associated with important redox reactions are also indicated in Attachment B. Because dissolved hydrogen is actually used by microbiota during redox reactions, its concentration may provide an additional indicator of the overall redox condition in the aquifer.

Attachments C and D tabulate the natural attenuation parameters for chlorinated volatile organic compound and petroleum hydrocarbon plumes, respectively. The parameters listed in these tables are organized in order of importance. Parameters selected for analysis shall be determined based on site conditions, project-specific plans, and/or other criteria established for the project. Based on these criteria, it is possible that all of the parameters may be selected.

#### **5.4 Selection of Natural Attenuation Analytical Methods and Procedures**

There are many analytical methods available to measure concentrations of the natural attenuation parameters discussed in the previous sections. Attachment E summarizes the sample methodologies, sampling equipment needed, sample volume, container, preservation, and holding time requirements. This table also summarizes the detection limits and the detection ranges for each method. A number of factors should be considered when selecting the appropriate sample analytical methodology including the required parameters, appropriate detection ranges for each compound, cost, and ease of use in the field. For example, when determining the correct methodology for measuring concentrations of total sulfide, the metabolic byproduct of sulfate reducing conditions, it is important to analyze for each of the forms of sulfide ( $H_2S$ ,  $S^{2-}$ , and  $HS^-$ ). Also, when the detection limit of the selected method is exceeded, another method may be considered, or the sampler may be able to dilute the sample (per manufacturer's instructions) to quantify it within the detected range. In terms of cost, some parameters are very time consuming when performed in the field. Without sacrificing sample integrity it may be more appropriate to select a methodology performed in a fixed-base laboratory. Finally, in terms of ease of use, certain field methods are generally easier compared to other methods. Using simpler methods may result in better quality sample results and increased sample repeatability without sacrificing sample integrity. For example, in some cases CHEMetrics Titret® Titration Ampule kits may be a good alternative to other hand digital titration methods.

The sample technicians should be aware that based on geochemical conditions recorded in the field, certain geochemical parameters may not have positive detections. For example, if dissolved oxygen concentrations indicate aerobic conditions then it is unlikely that dissolved hydrogen is present (see Section 5.10 for additional information). Another example is alkalinity. If the pH of the groundwater sample is less than 4.5, then it is unlikely that alkalinity will be measurable. Despite the potential for non-detect results, in cases such as those described above, all parameters should be collected in the field based upon project plans. The value in collecting the parameters in the future shall be determined by the project hydrogeologist and/or geochemist in accordance with the projects planning documents data quality objectives (DQO) and the items discussed in Section 5.2.

#### **5.5 Procedures for Sample Collection**

Groundwater sample collection for natural attenuation sampling should be performed using low flow purging and sampling techniques. These techniques are described in detail in SOP SA-1.1. Low flow purging and sampling procedures should be used to ensure the collection of a sample that is "representative" of the water present in the aquifer formation. Minimizing stress on the aquifer formation during low flow purging and sample collection ensures that there are minimal alternations to the water chemistry of the sample. The criteria used in the purging process should include minimization of drawdown in the well, stabilization of applicable indicator parameters, and evacuation of a sufficient amount of purge volume in accordance with SOP SA-1.1, project plans, and/or applicable regulatory guidance.

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 7 of 21
	Revision 0	Effective Date 03/08

Groundwater purging and sampling for natural attenuation should be performed using submersible pumps (e.g., bladder pumps) in accordance with SOP SA-1.1. However, in accordance with project plans and applicable regulatory guidance, peristaltic pumps may also be used for this purpose. Limitations of and factors associated with using these devices should be considered (see SOP SA-1.1 for more information). As a result of difficulties in collecting "representative" groundwater samples, bailers should not be used for the collection of natural attenuation samples.

It is critical that disturbance and aeration of samples monitored and collected at the well head are minimized. As a result, a flow-through sampling cell and a direct reading meter shall be used for the measurement of well stabilization indicator parameters (e.g., pH, conductivity, temperature, dissolved oxygen, turbidity, and ORP) at the well head. The pump effluent tubing should be placed at the bottom of the flow-through cell allowing effluent water from the cell to discharge at the top of the meter (above the detector probes) to minimize the agitation of water in the cell.

Documentation of the purging process shall be recorded during and at the completion of purging as discussed in Section 5.8. Immediately following the purging process and before sampling, all applicable indicator parameters must be measured and recorded on the appropriate sample log sheets as discussed in Section 5.8.

After all of the purging requirements have been met, groundwater sampling and natural attenuation data collection can begin. Monitoring wells will be sampled using the same pump and tubing used during well purging.

## **5.6 Procedures for Field Sample Analysis**

Each of the field and fixed-base laboratory sample parameters requires different sampling procedures and holding times. Attachment E presents parameter-specific requirements for sampling, analysis, and storage of all of the parameters and methods sampled as part of natural attenuation analysis.

Due to parameter procedure and holding times, it is important to consider the sequence of sample collection and analysis. Generally speaking, with the exception of volatile organic compounds, field parameters shall be analyzed first followed by fixed-base laboratory sample collection. All samples will be collected in a sequence and manner that minimizes volatilization, oxidation, and/or chemical transformation of compounds. As a result, the following sample and analysis order should be followed:

- |   |                                    |
|---|------------------------------------|
| 1. Volatile organic compounds                       | 8. Nitrate / Nitrite               |
| 2. Dissolved oxygen                                 | 9. Dissolved manganese             |
| 3. Alkalinity                                       | 10. Semivolatile organic compounds |
| 4. Dissolved carbon dioxide                         | 11. Other dissolved metals         |
| 5. Dissolved ferrous iron                           | 12. Total metals                   |
| 6. Dissolved sulfide (hydrogen sulfide and sulfide) | 13. All other constituents         |
| 7. Dissolved hydrogen, methane, ethene, and ethane  |                                    |

Field-analyzed parameters should be collected and immediately analyzed directly from the pump effluent per the requirements on Attachment E and manufacturer's recommendations. Care should be taken to minimize any unnecessary disturbance, aeration, or agitation of the sample prior to analysis. It is not acceptable to collect and store samples that are to be analyzed immediately at the well head in a temporary holding container (e.g., open topped pitcher) to be analyzed at a later time.

The manufacturer's procedure manual for each of the field-based analyses shall be maintained in the field during the entire sampling program. The procedures give a detailed explanation of how to perform each particular method and include information on sampling, storage, accuracy checks, interferences, reagents, and apparatus needed to perform each analysis.

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 8 of 21
	Revision 0	Effective Date 03/08

### 5.7 Procedures for Quality Assurance and Quality Control Field Sample Analysis

Accuracy and precision checks shall be performed to check the performance of the reagents, apparatus, and field analytical procedures per the manufacturer's recommendations. The accuracy checks should include the use of standard solutions (i.e., standard addition), as appropriate. The manufacturer's field test kit manual provides details on how to perform each of the accuracy checks for each parameter where applicable. Refer to Section 6.0 for manufacturer contact information.

Precision checks must include the performance of duplicate analysis. When using a colorimeter, precision checks may also include reagent blank corrections and standard curve adjustments as recommended by the manufacturer. Field duplicate results shall be performed and evaluated for relative percent difference (RPD) at a rate of 1 per 10 samples or as determined by the project plans. The RPD can be calculated as follows:

$$RPD = \left| \frac{\text{First result} - \text{Second result}}{\text{Mean arithmetic (average) of first and second result}} \right| \times 100$$

If the RPD exceeds 50 percent, it is required that the test be performed again to verify the result. The duplicate results shall be documented in the 'Notes' section for that specific parameter on the appropriate sample logsheet (see Section 5.8).

If a colorimeter (e.g., HACH DR-890 or equivalent) is used for parameter analysis, an instrument performance verification test using absorbance standards may also be performed to ensure the meter is providing accurate measurements.

The following table lists examples of the types and frequencies of accuracy checks required for each parameter. Refer to the manufacturer's instructions for information regarding other analyses.

Parameter	Method	Standard Solution	Field Duplicate	Reagent Blank Correction
Alkalinity	CHEMetrics K-9810, -15, -20	None	1 per 10	None
Carbon dioxide	CHEMetrics K-1910, -20, -25	None	1 per 10	None
Dissolved oxygen	CHEMetrics K-7501, -12	None	1 per 10	None
Ferrous iron	HACH DR-890	None	1 per 10	None
Nitrite	HACH DR-890	1 per round	1 per 10	1 per lot
Nitrate	HACH DR-890	1 per round	1 per 10	1 per lot
Sulfide	HACH DR-890	None	1 per 10	None
Hydrogen sulfide	HACH HS-C	None	1 per 10	None

Prior to analysis, the expiration dates of reagents shall be checked. If the reagents have exceeded their expiration date or shelf life, the reagents shall be replaced. If deviations from the applicable analytical procedure are identified, the deviations shall be corrected and the associated samples re-analyzed. If problems are identified with the reagents, apparatus, or procedures, data interferences may be present. Interferences may also be due to other factors (e.g., pH, presence or concentration of other ions, turbidity, temperature, etc.) that may interfere with the sample result. The manufacturer's procedures (e.g., Hach, 1999) should be reviewed prior to analysis to avoid or minimize such interferences. Associated problems

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 9 of 21
	Revision 0	Effective Date 03/08

or suspected interferences shall be documented in the 'Notes' section of the sample logsheet. Often, interferences cannot be avoided. In these cases, the sampler should be aware of these potential interferences and document them properly.

**5.8 Documentation Procedures for Field Sample Analysis**

Field results shall be properly documented in the field as noted in SOP SA-6.3. The sample log sheet titled "Field Analytical Log Sheet, Geochemical Parameters" shall be prepared for each sample collected and analyzed in the field. A copy of this form can be found as Attachment F of this SOP. Other field log sheets (e.g., low flow purge log sheet, groundwater sample logsheet, etc.) shall also be completed in accordance with SOP SA-6.3.

Specific information shall also be recorded in the project logbook. This information shall include, but is not limited to, the test kit name and model number, lot number and expiration date of the test kit and reagents used, serial number of the instrument (e.g., colorimeter) used for the analysis, and results of the quality assurance and quality control field sample analysis. Because environmental conditions and changes in those conditions may affect the field analytical results, it is important to document the site conditions (weather, temperature, etc.) at the time of sampling in the logbook in accordance with SOP SA-6.3.

**5.9 Waste Handling and Disposal**

Several of the test kits listed in Attachment E require the use of chemicals and materials that must be properly handled and disposed of in a proper and responsible manner. Refer to specific manufacturer's guidance for handling and disposal practices. See also Section 6.0 for more detailed and complete information. Handling and disposal of these items should be conducted in accordance with all local, state, and federal guidelines.

**5.10 Understanding Field Sample Analytical Results**

Natural attenuation data interpretation is complicated by the complex inter-relationships of various parameters. The complexity reflects the myriad of biochemical processes. Real-time evaluation of field analytical data can be misleading because a full interpretation often requires combining the field analytical results with fixed-base laboratory results. Regardless, some simple observations and data interpretations in the field may provide insights about the monitoring system or early warnings about sample collection and handling problems.

Data collected from the designated upgradient monitoring well is the baseline from which other interpretations are made. Field analytical data will indicate that the upgradient environment is either oxidizing or reducing. The redox condition within the upgradient area of the aquifer may be natural or impacted by other contaminant source areas (see Section 5.2 for upgradient well selection). Regardless, the redox condition of the upgradient groundwater will influence the source area. Changes in field analytical results from the upgradient well to the source area well will be reflected in samples from monitoring wells further downgradient.

The general characteristics of the two redox environments are summarized in the following table.

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 10 of 21
	Revision 0	Effective Date 03/08

Aerobic/Oxidizing	Anaerobic/Reducing
<ul style="list-style-type: none"> <li>• Measurable dissolved oxygen (&gt;1 to 2 ppm)</li> <li>• Measurable nitrate</li> <li>• No measurable dissolved manganese</li> <li>• No measurable dissolved ferrous iron</li> <li>• Measurable dissolved sulfate</li> <li>• No measurable dissolved sulfide</li> <li>• No measurable dissolved methane</li> <li>• No measurable dissolved hydrogen</li> </ul>	<ul style="list-style-type: none"> <li>• No measurable dissolved oxygen (&lt;1 ppm)</li> <li>• No measurable nitrate</li> <li>• Measurable dissolved manganese</li> <li>• Measurable dissolved ferrous iron</li> <li>• No measurable dissolved sulfate</li> <li>• Measurable dissolved sulfide</li> <li>• Measurable dissolved methane</li> <li>• Measurable dissolved hydrogen</li> </ul>

Transitional environments between these two extremes may have intermediate characteristics and are actually quite common. Because reactions are mediated by biological systems, equilibrium (the basis for the figure in Attachment B) conditions within the aquifer should not be expected. For example, sulfate reduction environments may occur in close proximity to methanogenic environments, and this natural attenuation data may be difficult to interpret. Carefully collected and analyzed field measurements and sample collections for fixed-base laboratory analyses are designed to characterize the aquifer environment along the continuum between strongly aerobic and strongly anaerobic. Because the land surface environment is generally more oxidizing than any groundwater environment, sample handling at the point of collection and analysis is extremely important in preserving the chemical integrity of the groundwater sample.

## 6.0 REFERENCES

American Society for Testing and Materials (ASTM), 1998. Standard Guide for Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites, Designation: E1943-98, West Conshohocken, Pennsylvania.

Chemetrics, 2002, <http://www.chemetrics.com>.

Department of the Navy, 1998. Technical Guidelines for Evaluating Monitored Natural Attenuation of Petroleum Hydrocarbons and Chlorinated Solvents in Ground Water at Naval and Marine Corps Facilities, Department of the Navy, September. Prepared by T. H. Weidemeier and F. H. Chappelle.

USEPA (United States Environmental Protection Agency), 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water, EPA/600/R-98/128, Office of Research and Development, Washington, D.C.

Hach Company, 1999. DR-890 Colorimeter Procedures Manual, Product Number 48470-22, Loveland Colorado.

Hach Company, 1999. Digital Titrator (manual), Model Number 16900, Catalog Number 16900-08. Loveland, Colorado.

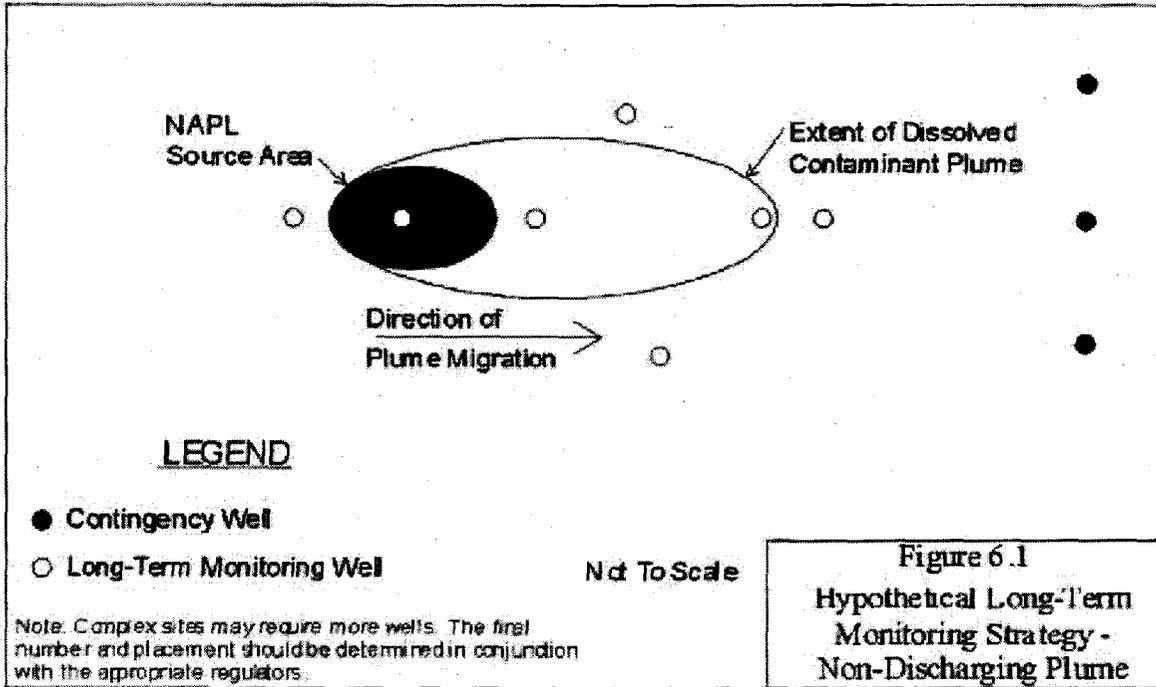
Hach Company, 2002, <http://www.hach.com/>.

USEPA, 1997. Draft EPA Region 4 Suggested Practices for Evaluation of a Site for Natural Attenuation (Biological Degradation) of Chlorinated Solvents; Version 3.0. November.

USEPA, 1999. Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, USEPA OSWER Directive 9200.4-17P, April 21, 1999

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 11 of 21
	Revision 0	Effective Date 03/08

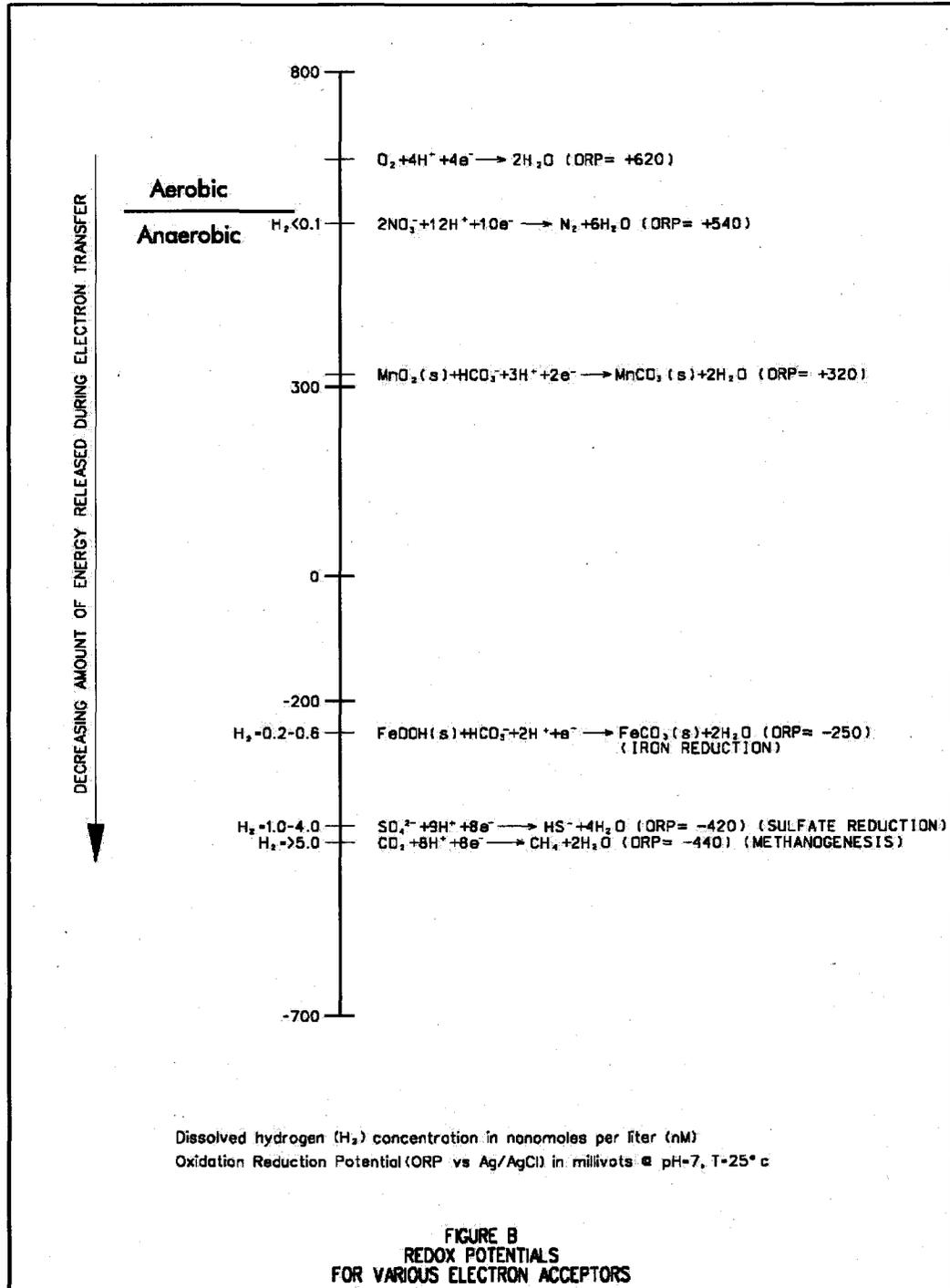
**ATTACHMENT A**  
**HYPOTHETICAL LONG-TERM MONITORING STRATEGY**



Taken from: Department of the Navy, 1998, Technical Guidelines for Evaluating Monitored Natural Attenuation of Petroleum Hydrocarbons and Chlorinated Solvents in Ground Water at Naval and Marine Corps Facilities, Prepared by Todd Weidemeier and Francis Chappelle.

## ATTACHMENT B

## REDOX POTENTIALS FOR VARIOUS ELECTRON ACCEPTORS



k:\dgn\envy\arlando\attee\ac2\ac2-033.dgn 9-19-02

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 13 of 21
	Revision 0	Effective Date 03/08

**ATTACHMENT C**

**NATURAL ATTENUATION PARAMETERS FOR  
CHLORINATED VOLATILE ORGANIC COMPOUND PLUMES  
SCREENING PROCESS SUMMARY FOR REDUCTIVE (ANAEROBIC) DECHLORINATION**

Potential Electron Donors	Electron Acceptors:	Reduced Species:	Related Dechlorination Pathway:
Native total organic carbon (TOC) Anthropogenic carbon (e.g., leachate) Fuel hydrocarbons (e.g., BTEX) Lightly chlorinated solvents (DCE/VC)	Dissolved Oxygen	⇒ Carbon Dioxide (CO <sub>2</sub> )	~ DCE → VC → CO <sub>2</sub>
	Manganese (Mn <sup>4+</sup> )	⇒ Manganese (Mn <sup>2+</sup> )	~ DCE → VC
	Nitrate (NO <sub>3</sub> )	⇒ Nitrite (NO <sub>2</sub> )	~ DCE → VC
	Ferric Iron (Fe <sup>3+</sup> )	⇒ Ferrous Iron (Fe <sup>2+</sup> )	~ DCE → VC → CO <sub>2</sub>
	Sulfate (SO <sub>4</sub> )	⇒ Sulfide (S <sup>2-</sup> , HS <sup>-</sup> , H <sub>2</sub> S)	~ TCE → DCE → VC → Ethene
	Carbon Dioxide (CO <sub>2</sub> )	⇒ Methane (CH <sub>4</sub> )	~ PCE → TCE → DCE → VC → Ethene

**Geochemical Parameter List:**

Parameter	Field or Lab	Rationale	Importance
Volatile organic compounds	L	Source products; daughter products; electron donors (e.g., benzene, toluene, ethylbenzene, and xylene; BTEX)	1
Dissolved oxygen	F	Primary electron acceptor (respiration); an/aerobic indicator	1
Nitrate (and nitrite), dissolved	F or L	Anaerobic electron acceptor (product of nitrate reduction)	1
Manganese, dissolved	F or L	Anaerobic electron acceptor	1
Ferrous Iron (Fe <sup>2+</sup> )	F	Product of iron reduction	1
Sulfate [and sulfide (S <sup>2-</sup> )]	F or L	Common anaerobic electron acceptor (product of sulfate reduction)	1
Sulfide (H <sub>2</sub> S)	F	Common product of sulfate reduction	1
Methane, ethane, ethene	L	Product of methanogenesis; daughter products of reductive dechlorination	1
Chloride	L	Ultimate daughter product of reductive dechlorination	1
TOC - upgradient groundwater	L	Electron donor	1
ORP, pH, specific conductance, temperature, turbidity	F	General water quality determination	1
Carbon dioxide (CO <sub>2</sub> )	F	Anaerobic electron acceptor (methanogenesis); biotic respiration indicator	2
Alkalinity/DIC	F	Buffering capacity; biotic respiration indicator	2
Hydrogen, dissolved	L	Fingerprint for characterizing electron acceptor pathway - indicator of what redox is occurring	2
TOC - upgradient soil	L	Input to analytical NA models; quantifies soil-water distribution coefficient and retardation factor	2
Volatile fatty acids	L	Determination of anthropogenic carbon used as an electron donor	3

Importance: 1=Most important; 3=Least important (depending on DQOs, all may be recommended).  
See Attachment E for details regarding analytical methods.

**ATTACHMENT D**

**NATURAL ATTENUATION PARAMETERS FOR  
PETROLEUM HYDROCARBON PLUMES  
SCREENING PROCESS SUMMARY FOR OXIDATIVE (AEROBIC) DEGRADATION**

Parameter	Field or Lab	Rationale	Importance
Volatile organic compounds	L	Source products; daughter products; electron donors (BTEX)	1
Dissolved oxygen	F	Primary electron acceptor (respiration); an/aerobic indicator	1
Nitrate (and nitrite), dissolved	F or L	Anaerobic electron acceptor (and product of nitrate reduction)	1
Manganese, dissolved	F or L	Anaerobic electron acceptor	1
Ferrous Iron (Fe <sup>2+</sup> )	F	Product of iron reduction	1
Sulfate [and Sulfide (S <sup>-2</sup> )]	F or L	Common anaerobic electron acceptor (product of sulfate reduction)	1
Sulfide (H <sub>2</sub> S)	F	Common product of sulfate reduction	1
TOC - upgradient groundwater	L	Electron donor	1
ORP, pH, specific conductance temperature, turbidity	F	General water quality determination	1
Dissolved methane (CH <sub>4</sub> )	L	Product of methanogenesis	1
Anions: chloride (Cl), nitrate (NO <sub>3</sub> ), nitrite (NO <sub>2</sub> ), phosphate (PO <sub>4</sub> ), sulfate (SO <sub>4</sub> )	L		1
TOC - Upgradient soil	L	Input to analytical NA models; quantifies soil-water distribution coefficient and retardation factor	2
Biological oxygen demand (BOD)	L	Understanding of aquifer oxygen demand	3
Chemical oxygen demand (COD)	L	Understanding of aquifer oxygen demand	3

Importance: 1=Most important; 3=Least important (depending on DQOs, all may be recommended).

See Attachment E for details regarding analytical methods.

Subject

NATURAL ATTENUATION  
PARAMETER COLLECTION

Number

SA-1.6

Page

15 of 21

Revision

0

Effective Date

03/08

**ATTACHMENT E**  
**GEOCHEMICAL SAMPLING PARAMETERS - METHODS, EQUIPMENT, VOLUMES, CONTAINERS,  
 PRESERVATION, HOLDING TIMES, AND DETECTION RANGES**  
 PAGE 1 OF 4

Parameter	Method / Reference	Equipment / Method Chemistry	Sample Volume, Container, Preservation, & Holding Time	Range (mg/L)	Precision (mg/L)	Estimated Detection Limit (mg/L)
Alkalinity	CHEMetrics K-9810, K-9815, K-9820 -ASTM D 1067-92 -EPA 310.1	Titret® Titration Ampules / Hydrochloric Acid, Phenolphthalein	Field. Follow test kit instructions. Avoid agitation and analyze at well head to determine total alkalinity. Filter if turbid (>10 NTU).	10-100 (K-9810) 50-500 (K-9815) 100-1000 (K-9820)	N/A	10 50 100-
Alkalinity	Fixed-base lab -EPA 310.1	N/A	100 to 250 mL in glass or plastic container. Cool to 4°C. Analyze within 14 days. Filter if turbid.	N/A	N/A	N/A
Alkalinity / Dissolved Inorganic Carbon	HACH AL-DT -HACH 8203 -SM 2320 / SM 403	Digital Titration / Hydrochloric Acid, Phenolphthalein (P) and Total (M)	Field. Follow test kit instructions. Avoid agitation and analyze at well head to determine carbonate, bicarbonate, and hydroxide ions. Filter if turbid as recommended by manufacture. May use a pH meter for colored samples.	10-4000	N/A	10
Arsenic	Fixed-base lab -SW-6010 B	N/A	1 liter glass or polyethylene container, HNO <sub>3</sub> to pH ≤ 2. 6 months.	N/A	N/A	N/A
Biochemical Oxygen Demand	Fixed-base lab -EPA 410.1	N/A	2 liter HDPE. Cool to 4°C. Analyze within 48 hours.	N/A	N/A	N/A
Carbon Dioxide, dissolved	CHEMetrics K-1910, K-1920, K-1925 -ASTM D 513.82 -SM 4500-CO <sub>2</sub> -C	Titret® Titration Ampules / Sodium Hydroxide, Phenolphthalein	Field. Follow test kit instructions. Avoid agitation and analyze at well head.	10-100 (K-1910) 100-1000 (K-1920) 250-2500 (K-1925)	N/A	10 100 250
Carbon Dioxide, dissolved	Fixed-base lab -VOA water sample (Vaportech)	GC-ECD/RGD/FID Detector	40 mL in VOA vial. 2 to 3 vials by (Vaportech).	N/A	N/A	N/A
Carbon Dioxide, dissolved	Fixed-base lab -Microseeps gas stripping cell	GC-ECD/RGD/FID Detector	Field bubble-strip sampling required. Ship in glass septum vial (Microseeps only).	N/A	N/A	N/A
Carbon Dioxide, dissolved	HACH CA-DT -HACH 8205 -Mod. SM 406	Digital Titration / Sodium Hydroxide, Phenolphthalein	Field. Follow test kit instructions. Do not aerate or agitate. Analyze at well head.	10-1000	N/A	10
Chemical Oxygen Demand	Fixed-base lab -EPA 410.1	N/A	125 mL HDPE. H <sub>2</sub> SO <sub>4</sub> to pH <2.0. Cool to 4°C. Analyze within 28 days.	N/A	N/A	N/A
Chloride (Cl)	Fixed-base lab -EPA 300	N/A	100 to 250 mL in glass or plastic container. Cool to 4°C. Analyze within 28 days.	N/A	N/A	N/A
Chlorine - Total (Cl <sub>2</sub> )	HACH DR-850 -HACH 8167 -SM 4500-Cl	Colorimeter / DPD Method	Field. Follow test kit instructions.	0.02-2.00	± 0.01 mg/L with a 1.00 mg/L chlorine solution.	1
Conductance, Specific	Field Meter -SW-9050 A	Direct Reading Meter	100 to 250 mL in glass or plastic container. Analyze immediately.	N/A	N/A	N/A
Ethane, dissolved	Fixed-base lab -VOA water sample, Vaportech -RSK SOP-147 & 175	GC-ECD/RGD/FID Detector	40 mL in VOA vial. 2 to 3 vials by (Vaportech).	N/A	N/A	N/A
Ethane, dissolved	Fixed-base lab -Microseeps gas stripping cell -RSK SOP-147 & 175	GC-ECD/RGD/FID Detector	Field bubble-strip sampling required. Ship in glass septum vial (Microseeps only).	N/A	N/A	N/A

Subject

NATURAL ATTENUATION  
PARAMETER COLLECTION

Number

SA-1.6

Page

16 of 21

Revision

0

Effective Date

03/08

## ATTACHMENT E

GEOCHEMICAL SAMPLING PARAMETERS - METHODS, EQUIPMENT, VOLUME, CONTAINER,  
PRESERVATION, HOLDING TIME, AND DETECTION RANGES  
PAGE 2 OF 4

Parameter	Method / Reference	Equipment / Method Chemistry	Sample Volume, Container, Preservation, & Holding Time	Range (mg/L)	Precision (mg/L)	Estimated Detection Limit (mg/L)
Ethene, dissolved	Fixed-base lab -VOA water sample, Vaportech -RSK SOP-147 & 175	GC-ECD/RGD/FID Detector	40 mL in VOA vial. 2 to 3 vials by (Vaportech).	N/A	N/A	N/A
Ethene, dissolved	Fixed-base lab -Microseeps gas stripping cell -RSK SOP-147 & 175	GC-ECD/RGD/FID Detector	Field bubble-strip sampling required. Ship in glass septum vial (Microseeps only).	N/A	N/A	N/A
Fraction Organic Carbon (foc) -Soil Upgradient Saturated Soil	Fixed-base lab -Walk-Black -SW-846 8060	N/A	200 gram glass jar. Cool to 4°C. Analyze within 14 days.	N/A	N/A	N/A
Hydrogen, dissolved	Fixed-base lab -Microseeps or Vapor Tech gas stripping cell -RSK SOP-147 & 175	GC-ECD/RGD/FID Detector	Field bubble-strip sampling required. Ship in glass septum vial.	N/A	N/A	N/A
Iron, ferrous (Fe <sup>2+</sup> )	HACH DR-850 HACH 8146 -Mod. SM 315 B	Colorimeter 1, 10 Phenanthroline	Field. Follow test kit instructions. Analyze immediately at well head. Filter if turbid (>10 NTU) as recommended by the manufacture.	0-3.00	±0.017 mg/L with a 2.00 mg/L Fe <sup>2+</sup> solution.	0.03
Iron, ferrous (Fe <sup>2+</sup> )	HACH IR-18C -Mod. SM 315 B	Color Disc 1, 10 Phenanthroline	Field. Follow test kit instructions. Analyze immediately at well head. Filter if turbid (>10 NTU) as recommended by the manufacture.	0-10	N/A	0.2
Iron, total dissolved (Filtered)	Fixed-base lab -SW-846 6010B	N/A	250 mL in plastic container. Field filter to 0.45 µ. HCl to pH <2. Cool to 4°C. Analyze within 6 months.	N/A	N/A	N/A
Manganese (Mn <sup>2+</sup> )	HACH DR-850 HACH 8034 -CFR 44(116) 34193	Colorimeter / Cold Periodate Oxidation	Field. Follow test kit instructions. Avoid agitation and analyze at well head. Filter if turbid as recommended by the manufacture.	0-20.0	± 0.18 mg/L with a 10.00 mg/L Mn solution.	0.12
Manganese (Mn <sup>2+</sup> )	HACH MN-5 -Mod. SM 319 B -CFR 44(116) 34193	Color Disc / Cold Periodate Oxidation	Field. Follow test kit instructions. Avoid agitation and analyze at well head. Filter if turbid as recommended by the manufacture.	0-3	N/A	0.1
Manganese, total dissolved (Filtered)	Fixed-base lab -SW-846 6010B	N/A	250 mL in plastic container. Field filter to 0.45 µ. HCl to pH <2. Cool to 4°C. Analyze within 6 months.	N/A	N/A	N/A
Methane, dissolved	Fixed-base lab -VOA water sample, Vaportech -RSK SOP-147 & 175	GC-ECD/RGD/FID Detector	40 mL in VOA vial. 2 to 3 vials by (Vaportech).	N/A	N/A	N/A
Methane, dissolved	Fixed-base lab -Microseeps gas stripping cell -RSK SOP-147 & 175	GC-ECD/RGD/FID Detector	Field bubble-strip sampling required. Ship in glass septum vial (Microseeps only).	N/A	N/A	N/A
Nitrate (NO <sub>3</sub> <sup>-</sup> )	Fixed-base lab -EPA 300	N/A	250 mL plastic container. Cool to 4°C. Analyze within 48 hours.	N/A	N/A	N/A
Nitrate (NO <sub>3</sub> <sup>-</sup> )	HACH DR-850 HACH 8192 -Mod. EPA 353.2	Colorimeter / Cadmium Reduction	Field. Follow test kit instructions. Avoid agitation and analyze at well head. Pretreatment required if nitrite is present.	0-0.50	± 0.03 mg/L with a 0.25 mg/L of nitrate nitrogen (NO <sub>3</sub> <sup>-</sup> N) solution.	0.01
Nitrite (NO <sub>2</sub> <sup>-</sup> )	Fixed-base lab -EPA 300	N/A	250 mL plastic container. Cool to 4°C. Analyze within 48 hours. Filter if turbid as recommended by the manufacture.	N/A	N/A	N/A

NATURAL ATTENUATION  
PARAMETER COLLECTION

## ATTACHMENT E

GEOCHEMICAL SAMPLING PARAMETERS - METHODS, EQUIPMENT, VOLUME, CONTAINER,  
PRESERVATION, HOLDING TIME, AND DETECTION RANGES  
PAGE 3 OF 4

Parameter	Method / Reference	Equipment / Method Chemistry	Sample Volume, Container, Preservation, & Holding Time	Range (mg/L)	Precision (mg/L)	Estimated Detection Limit (mg/L)
Nitrite (NO <sub>2</sub> )	HACH DR-850 HACH 8507 Mod. EPA 354.1 Mod. SM 419 CFR 44(85) 25585	Colorimeter / Diazotization	Field. Follow test kit instructions. Avoid agitation and analyze at well head. Filter if turbid as recommended by the manufacture.	0-0.350	± 0.001 mg/L with a 0.250 mg/L nitrite nitrogen solution.	0.005
Nitrogen, dissolved	Fixed-base lab -Microseeps gas stripping cell -Vaportech VOA water sample	GC-ECD/RGD/FID Detector	Field bubble-strip sampling required for Microseeps. Ship in glass septum vial (Microseeps) or VOA vial (Vaportech).	N/A	N/A	N/A
Nitrogen, Total Kjeldahl	Fixed-base lab EPA 351.2	N/A	500 mL plastic/glass container. Cool to 4°C. H <sub>2</sub> SO <sub>4</sub> to pH ≤ 2. Analyze within 28 days.	N/A	N/A	N/A
Oxidation Reduction Potential	Field Meter - ASTM D-1498	Direct Reading Meter	Field. Do not aerate. Gently agitate probe using flow over or flow-through method. Analyze immediately at well head.	N/A	N/A	N/A
Oxygen, dissolved	CHEMetrics K-7501, K-7512 -ASTM D 5543-84 -ASTM D 887-92	CHEMetrics® Vacuum Vials / Rhodazine D and Indigo Carmine	Field. Follow test kit instructions. Avoid agitation and analyze immediately at well head.	0-1 (K-7501) 1-12 (K-7512)	N/A	0.025 1
Oxygen, dissolved	Fixed-base lab -VOA water sample, Vaportech -RSK SOP-147 & 175	GC-ECD/RGD/FID Detector	40 mL in VOA vial. 2 to 3 vials by (Vaportech).	N/A	N/A	N/A
Oxygen, dissolved	Fixed-base lab -Microseeps gas stripping cell -RSK SOP-147 & 175	GC-ECD/RGD/FID Detector	Field bubble-strip sampling required. Ship in glass septum vial (Microseeps only).	N/A	N/A	N/A
Oxygen, dissolved	HACH OX-DT HACH 8215 -SM 4500-O-G	Digital Titration / Azide Modification of Winkler Digital Titration Method	Field. Follow test kit instructions. Avoid agitation and analyze immediately at well head.	1-10	N/A	1
Oxygen, dissolved	HACH DR-850 (AccuVac Ampules) LR HRDO Method	-Indigo Carmine Method -Rhodazine D Method	Field. Follow test kit instructions. Avoid agitation and analyze immediately at well head.	0-0.8 ppm 0-10 ppm	0.01 ppm 0.1 ppm	N/A
Oxygen, dissolved	Field Meter	Direct Reading Meter	Analyze immediately at well head. Avoid agitation and analyze immediately at well head. Used for well stabilization measurement parameter only.	N/A	N/A	N/A
pH	Field Meter -SW 9040B	Direct Reading Meter	Analyze immediately at well head.	N/A	N/A	N/A
Phosphate (ortho)	Fixed-base lab EPA 300	Ion Chromatography	250 mL plastic container. Cool to 4°C. Analyze within 48 hours. Filter if turbid as recommended by the manufacture.	N/A	N/A	N/A
Phosphate, potassium	Fixed-base lab -SW-846 8010B	Inductively Coupled Plasma	250 mL plastic container. Cool to 4°C. Analyze within 48 hours. Filter if turbid as recommended by the manufacture.	N/A	N/A	N/A
Salinity	Field Meter	Direct Reading Meter	Analyze immediately.	N/A	N/A	N/A
Sulfate (SO <sub>4</sub> <sup>2-</sup> )	Fixed-base lab	N/A	250 mL plastic container. Cool to 4°C. Analyze within 48 hours. Filter if turbid as recommended by the manufacture.	N/A	N/A	N/A
Sulfate (SO <sub>4</sub> <sup>2-</sup> )	HACH DR-850 HACH 8051 EPA 375.4	Colorimeter / Turbimetric Sulfa Ver 4	Field. Follow test kit instructions. Filter if turbid as recommended by the manufacture.	0-70	± 0.5 mg/L with a 50 mg/L sulfate solution.	4.9
Sulfide (Hydrogen Sulfide, H <sub>2</sub> S)	HACH HS-C -HACH Proprietary -Mod. SM 428 C	Color Chart / Effervescence of H <sub>2</sub> S through sulfide reactive paper.	Field. Follow test kit instructions. Avoid agitation and analyze immediately at well head.	0-5	N/A	0.1
Sulfide (S <sup>2-</sup> )	CHEMetrics K-9510 -SM 4500-S <sup>2-</sup>	CHEMetrics® Vacuum Vials / Methylene Blue	Field. Follow test kit instructions. Avoid agitation and analyze immediately at well head.	0-1 1-10	N/A	0.1 1

Subject

NATURAL ATTENUATION  
PARAMETER COLLECTION

Number

SA-1.6

Page

18 of 21

Revision

0

Effective Date

03/08

ATTACHMENT E

GEOCHEMICAL SAMPLING PARAMETERS - METHODS, EQUIPMENT, VOLUME, CONTAINER,  
PRESERVATION, HOLDING TIME, AND DETECTION RANGES  
PAGE 4 OF 4

Parameter	Method / Reference	Equipment / Method Chemistry	Sample Volume, Container, Preservation, & Holding Time	Range (mg/L)	Precision (mg/L)	Estimated Detection Limit (mg/L)
Sulfide (S <sup>2-</sup> )	Fixed-base lab -EPA 376.1/376.2	N/A	1 liter in plastic container, no headspace. NaOH to pH >9. Cool to 4°C. Avoid agitation and analyze within 7 days.	N/A	N/A	N/A
Sulfide (S <sup>2-</sup> )	HACH DR-850 -HACH 8131 -SM 4500-S <sup>2</sup>	Colorimeter / Methylene Blue	Field. Follow test kit instructions. Avoid agitation and analyze immediately at well head. Pretreatment required for turbid samples as recommended by the manufacture.	0-0.70	± 0.02 mg/L with a 0.73 mg/L sulfide solution.	0.01
Sulfide (S <sup>2-</sup> )	HACH HS-WR -SM 4500-S <sup>2</sup>	Color Disc / Methylene Blue	Field. Follow test kit instructions. Avoid agitation and analyze immediately at well head. Pretreatment required for turbid samples as recommended by the manufacture.	0-11.25	N/A	0.1-2.5
Temperature	Field Meter / Thermometer -E170.1	Direct Reading Meter / Thermometer	Analyze immediately.	N/A	N/A	N/A
Total Organic Carbon (TOC)-Groundwater	Fixed-base lab -E 415.1	N/A	125 mL HDPE. H <sub>2</sub> SO <sub>4</sub> to pH < 2.0. Cool to 4°C. Analyze within 28 days.	N/A	N/A	N/A
Turbidity	Field Meter -E 180.1	Direct Reading Meter	Analyze immediately.	N/A	N/A	N/A

N/A = Not applicable.

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6  Revision 0	Page 19 of 21  Effective Date 03/08
--	---------------------------------------	---

**ATTACHMENT F**

**FIELD ANALYTICAL LOG SHEET, GEOCHEMICAL PARAMETERS  
PAGE 1 OF 3**

Note: Analyte, method, and/or equipment may be deleted from form if not being performed.



**FIELD ANALYTICAL LOG SHEET  
GEOCHEMICAL PARAMETERS**

Tetra Tech NUS, Inc.

Page      of     

Project Site Name: _____				Sample ID No.: _____				
Project No.: _____				Sample Location: _____				
Sampled By: _____				Duplicate: <input type="checkbox"/>				
Field Analyst: _____				Blank: <input type="checkbox"/>				
Field Form Checked as per QA/QC Checklist (initials): _____								
<b>SAMPLING DATA:</b>								
Date: _____	Color (Visual)	pH (S.U.)	S.C. (mS/cm)	Temp. (°C)	Turbidity (NTU)	DO (mg/l)	Salinity (‰)	ORP (Eh) (+/- mv)
Time: _____								
Method: _____								
<b>SAMPLE COLLECTION/ANALYSIS INFORMATION:</b>								
<b>ORP (Eh) (+/- mv)</b>				Electrode Make & Model: _____				
				Reference Electrode (circle one): Silver-Silver Chloride / Calomel / Hydrogen				
<b>Dissolved Oxygen:</b>								
Equipment: Chemetrics Test Kit				Concentration: _____ ppm				
Range Used:	Range	Method	Concentration ppm					
<input type="checkbox"/>	0 to 1 ppm	K-7510		Analysis Time: _____				
<input type="checkbox"/>	1 to 12 ppm	K-7512						
Equipment: HACH Digital Titrator OX-DT				Analysis Time: _____				
Range Used:	Range	Sample Vol.	Cartridge	Multiplier	Titration Count	Multiplier	Concentration	
<input type="checkbox"/>	1-5 mg/L	200 ml	0.200 N	0.01		x 0.01	= mg/L	
<input type="checkbox"/>	2-10 mg/L	100 ml	0.200 N	0.02		x 0.02	= mg/L	
Notes: _____								
<b>Carbon Dioxide:</b>								
Equipment: Chemetrics Test Kit				Concentration: _____ ppm				
Range Used:	Range	Method	Concentration ppm					
<input type="checkbox"/>	10 to 100 ppm	K-1910		Analysis Time: _____				
<input type="checkbox"/>	100 to 1000 ppm	K-1920						
<input type="checkbox"/>	250 to 2500 ppm	K-1925						
Equipment: HACH Digital Titrator CA-DT								
Range Used:	Range	Sample Vol.	Cartridge	Multiplier	Titration Count		Concentration	
<input type="checkbox"/>	10-50 mg/L	200 ml	0.3636 N	0.1		x 0.1	= mg/L	
<input type="checkbox"/>	20-100 mg/L	100 ml	0.3636 N	0.2		x 0.2	= mg/L	
<input type="checkbox"/>	100-400 mg/L	200 ml	3.636 N	1.0		x 1.0	= mg/L	
<input type="checkbox"/>	200-1000 mg/L	100 ml	3.636 N	2.0		x 2.0	= mg/L	
Standard Additions: <input type="checkbox"/> Titrant Molarity: _____				Digits Required: 1st.: _____ 2nd.: _____ 3rd.: _____				
Notes: _____								
<b>Hydrogen, dissolved</b>								
Equipment: Bubble strip sampling field method								
Start stripper at _____ (time)								
End stripper at _____ (time)								
Total stripper time _____								
Pump rate _____ milliliters/minute								

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 20 of 21
	Revision 0	Effective Date 03/08

**ATTACHMENT F**

**FIELD ANALYTICAL LOG SHEET, GEOCHEMICAL PARAMETERS  
PAGE 2 OF 3**

Note: Analyte, method, and/or equipment may be deleted from form if not being performed.



**FIELD ANALYTICAL LOG SHEET  
GEOCHEMICAL PARAMETERS**

Tetra Tech NUS, Inc.

Page      of     

Project Site Name: _____		Sample ID No.: _____					
Project No.: _____		Sample Location: _____					
Sampled By: _____		Duplicate: <input type="checkbox"/>					
Field Analyst: _____		Blank: <input type="checkbox"/>					
<b>Alkalinity:</b>							
Equipment: Chemetrics Test Kit		Concentration: _____ ppm					
Range Used:	Range	Method	Concentration ppm				
<input type="checkbox"/>	10 to 100 ppm	K-9810					
<input type="checkbox"/>	50 to 500 ppm	K-9815					
<input type="checkbox"/>	100 to 1000 ppm	K-9820					
		Analysis Time: _____					
Filtered: <input type="checkbox"/>							
Equipment: HACH Digital Titrator AL-DT							
Range Used:	Range	Sample Vol.	Cartridge	Multiplier	Titration Count	Multiplier	Concentration
<input type="checkbox"/>	10-40 mg/L	100 ml	0.1600 N	0.1	&	x 0.1	= mg/L
<input type="checkbox"/>	40-160 mg/L	25 ml	0.1600 N	0.4	&	x 0.4	= mg/L
<input type="checkbox"/>	100-400 mg/L	100 ml	1.600 N	1.0	&	x 1.0	= mg/L
<input type="checkbox"/>	200-800 mg/L	50 ml	1.600 N	2.0	&	x 2.0	= mg/L
<input type="checkbox"/>	500-2000 mg/L	20 ml	1.600 N	5.0	&	x 5.0	= mg/L
<input type="checkbox"/>	1000-4000 mg/L	10 ml	1.600 N	10.0	&	x 10.0	= mg/L
Parameter:		Hydroxide	Carbonate	Bicarbonate			
Relationship:							
Standard Additions: <input type="checkbox"/>		Titrant Molarity: _____		Digits Required: 1st.: _____ 2nd.: _____ 3rd.: _____			
Notes:							
<b>Ferrous Iron (Fe<sup>2+</sup>):</b>							
Equipment: DR-850		DR-8 __		Range: 0 - 3.00 mg/L		Concentration: _____ ppm	
Program/Module: 500nm		33				Analysis Time: _____	
Equipment: IR-18C Color Wheel				Range: 0 - 10 mg/L			
Notes:							
Filtered: <input type="checkbox"/>							
<b>Hydrogen Sulfide (H<sub>2</sub>S):</b>							
Equipment: HS-C		Other: _____		Range: 0 - 5 mg/L		Concentration: _____ ppm	
Exceeded 5.0 mg/L range on color chart		<input type="checkbox"/>				Analysis Time: _____	
Notes:							
<b>Sulfide (S<sup>2-</sup>):</b>							
Equipment: Chemetrics Test Kit		Range: 0 - 10 mg/L				Concentration: _____ ppm	
Range Used:	Range	Method	Concentration ppm				
<input type="checkbox"/>	0 to 1 ppm	K-9510					
<input type="checkbox"/>	1 to 10 ppm	K-9510					
				Analysis Time: _____			
Filtered: <input type="checkbox"/>							
Equipment: DR-850		DR-8 __		Range: 0 - 0.70 mg/L			
Program/Module: 610nm		93					
Notes:							

Subject  NATURAL ATTENUATION PARAMETER COLLECTION	Number SA-1.6	Page 21 of 21
	Revision 0	Effective Date 03/08

**ATTACHMENT F**

**FIELD ANALYTICAL LOG SHEET, GEOCHEMICAL PARAMETERS  
PAGE 3 OF 3**

Note: Analyte, method, and/or equipment may be deleted from form if not being performed.



**FIELD ANALYTICAL LOG SHEET  
GEOCHEMICAL PARAMETERS**

Tetra Tech NUS, Inc.

Page      of     

<b>Project Site Name:</b> _____		<b>Sample ID No.:</b> _____	
<b>Project No.:</b> _____		<b>Sample Location:</b> _____	
<b>Sampled By:</b> _____		Duplicate: <input type="checkbox"/>	
<b>Field Analyst:</b> _____		Blank: <input type="checkbox"/>	
<b>Sulfate (SO<sub>4</sub><sup>2-</sup>):</b>			
Equipment:	DR-850	DR-8 __	Range: 0 - 70 mg/L
Program/Module:	_____ 91		Concentration: _____ ppm
			Analysis Time: _____
Standard Solution:	<input type="checkbox"/>	Results: _____	Filtered: <input type="checkbox"/>
Standard Additions:	<input type="checkbox"/>	Digits Required: 0.1ml: _____ 0.2ml: _____ 0.3ml: _____	
Notes:			
<b>Nitrate (NO<sub>3</sub>-N):</b>			
Equipment:	DR-850	DR-8 __	Range: 0 - 0.50 mg/L <sup>(1)</sup>
Program/Module:	_____ 55		Concentration: _____ ppm
			Analysis Time: _____
Standard Solution:	<input type="checkbox"/>	Results: _____	Nitrite Interference Treatment: <input type="checkbox"/>
Standard Additions:	<input type="checkbox"/>	Digits Required: 0.1ml: _____ 0.2ml: _____ 0.3ml: _____	Reagent Blank Correction: <input type="checkbox"/>
Alternate forms: NO <sub>2</sub> _____ NaNO <sub>2</sub> _____ mg/L			
Notes (1): If results are over limit use dilution method at step 3, 5ml sample 10ml DI result X3, range upto 1.5mg/L			
Notes:			
<b>Nitrite (NO<sub>2</sub>-N):</b>			
Equipment:	DR-850	DR-8 __	Range: 0 - 0.350 mg/L
Program/Module:	_____ 62		Concentration: _____ ppm
			Analysis Time: _____
Standard Solution:	<input type="checkbox"/>	Results: _____	Filtered: <input type="checkbox"/>
			Reagent Blank Correction: <input type="checkbox"/>
Notes:			
<b>Manganese (Mn<sup>2+</sup>):</b>			
Equipment:	DR-850	DR-8 __	Range: 0 - 20.0 mg/L
Program/Module:	525nm	_____ 41	Concentration: _____ ppm
			Analysis Time: _____
Standard Solution:	<input type="checkbox"/>	Results: _____	Digestion: <input type="checkbox"/>
Standard Additions:	<input type="checkbox"/>	Digits Required: 0.1ml: _____ 0.2ml: _____ 0.3ml: _____	Reagent Blank Correction: <input type="checkbox"/>
Equipment:	HACH MN-5		Range: 0 - 3 mg/L
Notes:			
<b>QA/QC Checklist:</b>			
All data fields have been completed as necessary: <input type="checkbox"/>			
Correct measurement units are cited in the SAMPLING DATA block: <input type="checkbox"/>			
Values cited in the SAMPLING DATA block are consistent with the Groundwater Sample Log Sheet: <input type="checkbox"/>			
Multiplication is correct for each Multiplier table: <input type="checkbox"/>			
Final calculated concentration is within the appropriate Range Used block: <input type="checkbox"/>			
Alkalinity Relationship is determined appropriately as per manufacturer (HACH) instructions: <input type="checkbox"/>			
QA/QC sample (e.g., Std. Additions, etc.) frequency is appropriate as per the project planning documents: <input type="checkbox"/>			
Nitrite Interference treatment was used for Nitrate test if Nitrite was detected: <input type="checkbox"/>			
Title block on each page of form is initialized by person who performed this QA/QC Checklist: <input type="checkbox"/>			

<b>STANDARD OPERATING PROCEDURES</b>	Number SA-1.1	Page 1 of 33
	Effective Date 03/08	Revision 1
	Applicability	
	Prepared	
Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Approved	

### TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
<b>1.0 PURPOSE</b> .....	<b>2</b>
<b>2.0 SCOPE</b> .....	<b>2</b>
<b>3.0 GLOSSARY</b> .....	<b>2</b>
<b>4.0 RESPONSIBILITIES AND PERSONNEL QUALIFICATIONS</b> .....	<b>3</b>
<b>5.0 HEALTH AND SAFETY</b> .....	<b>4</b>
<b>6.0 PROCEDURES</b> .....	<b>5</b>
6.1 General .....	5
6.2 Sampling, Monitoring, and Evacuation Equipment .....	6
6.3 Calculations of Well Volume .....	7
6.4 Evacuation of Static Water – Purging .....	8
6.4.1 General .....	8
6.4.2 Evacuation Devices .....	9
6.5 Onsite Water Quality Testing .....	12
6.5.1 Measurement of pH .....	12
6.5.2 Measurement of Specific Conductance .....	14
6.5.3 Measurement of Temperature .....	16
6.5.4 Measurement of Dissolved Oxygen .....	16
6.5.5 Measurement of Oxidation-Reduction Potential .....	18
6.5.6 Measurement of Salinity .....	19
6.5.7 Measurement of Turbidity .....	20
6.6 Sampling .....	21
6.6.1 Sampling Plan .....	21
6.6.2 Sampling Methods as Related to Low-Flow Sampling .....	22
6.7 Low-Flow Purging and Sampling .....	24
6.7.1 Scope and Application .....	24
6.7.2 Equipment .....	24
6.7.3 Purging and Sampling Procedure .....	25
<b>7.0 REFERENCES</b> .....	<b>27</b>
 <b><u>ATTACHMENTS</u></b>	
A PURGING EQUIPMENT SELECTION .....	28
B GROUNDWATER SAMPLE LOG SHEET .....	31
C EQUIPMENT CALIBRATION LOG .....	32
D LOW FLOW PURGE DATA SHEET .....	34

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 2 of 33
	Revision 1	Effective Date 03/08

## 1.0 PURPOSE

This Standard Operating Procedure (SOP) describes the process to be used for purging groundwater monitoring wells prior to sampling, for collecting groundwater samples, and for measuring groundwater quality parameters.

## 2.0 SCOPE

This document provides information on proper sampling equipment, onsite water quality testing, safety measures to ensure the safety of the field technician(s), and techniques for groundwater sampling. All personnel are encouraged to review the information contained herein to facilitate planning of the field sampling effort. The techniques described shall be followed whenever applicable, noting that site-specific conditions or project-specific plans may require modifications to methodology.

## 3.0 GLOSSARY

Conductivity – Conductivity is a numerical expression of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions and their total concentration, mobility, valence, and relative concentrations and on temperature. Conductivity is highly dependent on temperature and should be reported at a particular temperature, i.e., 20.2 microSiemens per centimeter (mS/cm) at 14°C.

Dissolved Oxygen (DO) – DO levels in natural and wastewater depend on the physical, chemical, and biochemical activities in the water sample.

Groundwater Sample – A quantity of water removed from the ground, usually via a monitoring well that may or may not be lined with a well casing.

Oxidation-Reduction Potential (ORP) - A measure of the activity ratio of oxidizing and reducing species as determined by the electromotive force developed by a noble metal electrode immersed in water, as referenced against a reference electrode. A reference electrode commonly used in the field is the silver/silver chloride electrode, which has a voltage offset of about 210 mV from the standard hydrogen electrode (SHE). To convert field ORP measurements to equivalent SHE values, approximately 210 mV must be added to the ORP values obtained using the silver/silver chloride electrode. The actual offset depends on the concentration of the potassium chloride (KCl) in the field reference electrode and the temperature. Offsets typically range from 199 (saturated KCl) to 205 (3.5 Molar KCl) to 222 mV (1 Molar KCl) at 25°C and are greater at lower temperatures.

pH - The negative logarithm (base 10) of the hydrogen ion activity. The hydrogen ion activity is related to the hydrogen ion concentration, and, in a relatively weak solution, the two are nearly equal. Thus, for all practical purposes, pH is a measure of the hydrogen ion concentration.

~~pH Paper - Indicator paper that turns different colors depending on the pH of the solution to which it is exposed. Comparison with color standards supplied by the manufacturer will then give an indication of the solution's pH.~~

Representativeness – A qualitative description of the degree to which an individual sample accurately reflects population characteristics or parameter variations at a sampling point. It is therefore an important characteristic not only of assessment and quantification of environmental threats posed by the site, but also for providing information for engineering design and construction. Proper sample location selection and proper sample collection methods are important to ensure that a truly representative sample has been collected.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 3 of 33
	Revision 1	Effective Date 03/08

~~Salinity – The measurement of dissolved salts in a given mass of solution. Note: most field meters determined salinity automatically from conductivity and temperature. The value will be displayed in either parts per thousand (ppt) or percent (e.g., 35 ppt equals 3.5 percent). The parts per thousand symbol (<sup>0</sup>/<sub>00</sub>) is not the same as the percent symbol (%).~~

Turbidity – Turbidity in water is caused by suspended matter such as clay, silt, and fine organic and inorganic matter. Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in a straight line through the sample.

#### 4.0 RESPONSIBILITIES AND PERSONNEL QUALIFICATIONS

Project Manager - The Project Manager is responsible for determining the sampling objectives, initial sampling locations, and field procedures used in the collection of groundwater samples. Additionally, in consultation with other project personnel (geologist, hydrogeologist, etc.), the Project Manager identifies sampling locations.

Site Safety Officer (SSO) - The SSO (or a qualified designee) is responsible for providing the technical support necessary to implement the project Health and Safety Plan (HASP). This includes but is not limited to performing air quality monitoring during sampling, boring and excavation activities, and ensuring that workers and offsite (downwind) individuals are not exposed to hazardous levels of airborne contaminants. The SSO or SSO designee may also be required to advise the FOL on other safety-related matters regarding sampling, such as mitigative measures to address potential hazards from hazardous objects or conditions.

Project Geologist/Sampler - The project geologist/sampler is responsible for the proper acquisition of samples in accordance with this SOP or other project-specific documents. In addition, this individual is responsible for the completion of all required paperwork (e.g., sample log sheets, field notebook, boring logs, container labels, custody seals, and chain-of-custody forms) associated with the collection of those samples.

Project Hydrogeologist – This individual is responsible for selecting and detailing the specific groundwater sampling techniques, onsite water quality testing (type, frequency, and location), equipment to be used, and providing detailed input in this regard to the project planning documents. The project hydrogeologist is also responsible for properly briefing and overseeing the performance of site sampling personnel.

Field Operations Leader (FOL) – This individual is primarily responsible for the execution of the planning document containing the Sampling and Analysis Plan (SAP). This is accomplished through management of a field sampling team for the proper acquisition of samples. He or she is responsible for the supervision of onsite analyses; ensuring proper instrument calibration, care, and maintenance; sample collection and handling; the completion and accuracy of all field documentation; and making sure that custody of all samples obtained is maintained according to proper procedures. When appropriate and as directed by the FOL, such responsibilities may be performed by other qualified personnel (e.g., field technicians) where credentials and time permit. The FOL is ultimately responsible for adherence to Occupational Safety and Health Administration (OSHA) regulations during these operations through self acquisition or through the management of a field team of samplers.

General personnel qualifications for groundwater sample collection and onsite water quality testing include the following:

- Occupational Safety and Health Administration (OSHA) 40-hour and applicable refresher training.
- Capability of performing field work under the expected physical and environmental (i.e., weather) conditions.
- Familiarity with appropriate procedures for sample documentation, handling, packaging, and shipping.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 4 of 33
	Revision 1	Effective Date 03/08

## 5.0 HEALTH AND SAFETY

Specific safety and health precautions are identified throughout this SOP. In addition to those precautions, the following general hazards may be incurred during sampling activities:

- Knee injuries from kneeling on hard surfaces
- Slips, trips, and falls
- Cuts and lacerations
- Traffic hazards associated with sampling in parking areas and roadways and along highways.

Methods of avoiding these hazards are provided below.

**Knee injuries** – Many monitoring wells are installed as flush mounts. Personnel are required to kneel to open these wells and to take groundwater level measurements, etc. This could result in knee injuries from kneeling on stones/foreign objects and general damage due to stress on the joints. To combat this hazard:

- Clear any foreign objects from the work area.
- Wear hard-sided knee pads.

**Slips, Trips, and Falls** – These hazards exist while traversing varying terrains carrying equipment to sample wells. To minimize these hazards:

- Pre-survey well locations. Eliminate, barricade, or otherwise mark physical hazards leading to the locations.
- Carry small loads that do not restrict the field of vision.
- Travel the safest and clearest route (not necessarily the shortest).

**Cuts and Lacerations** - To prevent cuts and lacerations associated with groundwater sampling, the following provisions are required:

- Always cut away from yourself and others when cutting tubing or rope. This will prevent injury to yourself and others if the knife slips.
- Do not place items to be cut in your hand or on your knee.
- Change blades as necessary to maintain a sharp cutting edge. Many accidents result from struggling with dull cutting attachments.
- Whenever practical, wear cut-resistant gloves (e.g., leather or heavy cotton work gloves) at least on the hand not using the knife.
- Keep cutting surfaces clean and smooth.
- Secure items to be cut -- do not hold them against the opposing hand, a leg, or other body part.
- When transporting glassware, keep it in a hard-sided container such as a cooler so that if there is a fall, you will be less likely to get cut by broken glass.
- DO NOT throw broken glass or glass ampoules into garbage bags. Place broken glass and glass ampoules in hard-sided containers such as a cardboard box or directly into a dumpster. DO NOT reach into garbage bags to retrieve any item accidentally thrown away. Empty the contents onto a flat surface to avoid punctures and lacerations from reaching where you cannot see.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 5 of 33
	Revision 1	Effective Date 03/08

**Vehicular and Foot Traffic Hazards** – When sampling along the roadway or near traffic patterns, follow the following precautions:

- Motorists may be distracted by onsite activities – ASSUME THEY DO NOT SEE YOU OR MEMBERS OF YOUR FIELD CREW.
- DO NOT place obstructions (such as vehicles) along the sides of the road that may cause site personnel to move into the flow of traffic to avoid your activities or equipment or that will create a blind spot.
- **Provide a required free space of travel.** Maintain at least 6 feet of space between you and moving traffic. Where this is not possible, use flaggers and/or signs to warn oncoming traffic of activities near or within the travel lanes.
- **Face Traffic.** Whenever feasible, if you must move within the 6 feet of the required free space or into traffic, attempt to face moving traffic at all times. Always leave yourself an escape route.
- Wear high-visibility vests to increase visual recognition by motorists.
- Do not rely on the vehicle operator's visibility, judgment, or ability. Make eye contact with the driver. Carefully and deliberately use hand signals so they will not startle or confuse motorists or be mistaken for a flagger's direction before moving into traffic.
- Your movements may startle a motorist and cause an accident, so move deliberately. Do not make sudden movements that might confuse a motorist.

## 6.0 PROCEDURES

### 6.1 General

For information derived from a groundwater sample to be useful and accurate, the sample must be representative of the particular zone being sampled. The physical, chemical, and bacteriological integrity of the sample must be maintained from the time of sampling to the time of analysis to keep any changes in water quality parameters to a minimum.

#### **CAUTION**

A closed well may generate and accumulate gases due to biological degradation, evolution of volatile chemicals from groundwater into the air, or other chemical actions. These gases may also be artificially generated, such as in the case of air sparging or extraction wells, which may take several days to depressurize. See Section 6.6.2 for safety measures to be employed to protect sampling personnel.

Methods for withdrawing samples from completed wells include the use of pumps, compressed air or nitrogen, bailers, and various types of samplers. The primary considerations in obtaining a representative sample of groundwater are to avoid collection of stagnant (standing) water in the well and to avoid physical or chemical alteration of the water sample due to external influences of the sampling technique(s). In a non-pumping well, there will be little or no vertical mixing of water in the well pipe or casing, and stratification will occur. The well water in the screened section will mix with groundwater due to normal flow patterns, but the well water above the screened section will remain isolated and become stagnant. Concentration gradients resulting from mixing and dispersion processes, layers of variable geologic permeability, and the presence of separate-phase product (e.g., floating hydrocarbons) may cause stratification. Excessive pumping or improper sampling methods can dilute or increase

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 6 of 33
	Revision 1	Effective Date 03/08

contaminant concentrations in the collected sample compared to what is representative of the integrated water column as it naturally occurs at that point, resulting in the collection of a non-representative sample. To safeguard against collecting non-representative samples, the following approach shall be followed prior to sample acquisition:

**CAUTION**

Mechanical agitation of well water may cause off-gas generation of volatile contaminants, creating an inhalation exposure to the sampler(s). Where avoiding an inhalation exposure is not possible and mechanical agitation is possible, pump into closed-top containers to control potential air emissions.

1. If possible, position yourself (and the sampling equipment) upwind of the well head.
2. Purge the monitoring well to be sampled prior to obtaining any samples from it. Evacuation of three to five well volumes is recommended prior to sampling, unless low-flow purging and sampling methods are utilized as described in Section 6.7 (Consult the site-specific SAP for exact purging parameters). In a high-yielding groundwater formation and where there is no stagnant water in the well above the screened section, extensive evacuation prior to sample withdrawal is not as critical as it is in a low-yielding well or in wells containing stagnant water.
3. For wells with low yields that are purged dry during sampling, evacuate the well and allow it to recover to 75 percent of full capacity prior to sample acquisition. If the recovery rate is fairly rapid (generally 300 mL per minute or greater), attempt to continue evacuation until the number of well volumes specified in the SAP is achieved. If this cannot be accomplished, allow recovery to 75 percent of capacity and begin sampling.

**CAUTION**

For moderate to high-yielding monitoring wells, an evacuation rate that does not cause excessive turbulence in the well should be selected. There is no absolute safeguard against contaminating the sample with stagnant water; hence, special techniques are required for purging to minimize the potential for sample contamination (see below).

4. For moderate to high-yielding monitoring wells, use one of the following purge techniques:
  - Place a submersible pump or the intake line of a surface pump or bailer just below the water surface when removing the stagnant water.
  - While purging and as the water level decreases, lower the pump or intake line as the water level drops in the well. Three to five volumes of water shall be removed to provide reasonable assurance that all stagnant water has been evacuated. After this is accomplished, a bailer or other approved device may be used to collect the sample for analysis.
  - Unless otherwise directed, place the intake line of the sampling pump (or the submersible pump itself) near the center of the screened section, and pump approximately one casing volume of water from the well at a low purge rate equal to the well's recovery rate (low-flow sampling).

**6.2 Sampling, Monitoring, and Evacuation Equipment**

Sample containers shall conform to the guidelines in SOP SA-6.1.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 7 of 33
	Revision 1	Effective Date 03/08

The following equipment shall be on hand when sampling groundwater wells (reference SOPs SA-6.1 and SA-7.1):

- Sample packaging and shipping equipment – Coolers for sample shipping and cooling, chemical preservatives, appropriate sampling containers and filler materials, ice, labels, and chain-of-custody documents.
- Field tools and instrumentation
  - Multi-parameter water quality meter with an in-line sample chamber capable of measuring ORP, pH, temperature, DO, specific conductance, turbidity, and salinity, or individual meters (as applicable)
  - pH Paper
  - Camera and film (if appropriate)
  - Appropriate keys (for locked wells)
  - Water level indicator and/or oil-water interface probe if separate-phase product is expected
- Pumps
  - Shallow-well pumps: Centrifugal, bladder, suction, or peristaltic pumps with drop lines and air-lift apparatus (compressor and tubing) where applicable.
  - Deep-well pumps: Submersible pump and electrical power-generating unit, or bladder pumps where applicable.
- Other sampling equipment – Bailers, graduated cylinder, stopwatch, and inert line with tripod-pulley assembly (if necessary).
- Pails – Plastic, graduated.
- Clean paper or cotton towels for cleaning equipment.
- Buckets with lids for collecting purge water.
- Decontamination solutions – Deionized water, potable water, phosphate-free laboratory-grade detergent, and analytical-grade solvent (e.g., pesticide-grade isopropanol), as required.

Ideally, sample withdrawal equipment shall be completely inert, economical, easily cleaned, cleaned prior to use, reusable, able to operate at remote sites in the absence of power sources, and capable of delivering variable rates for well purging and sample collection.

### 6.3 Calculations of Well Volume

To ensure that the proper volume of water has been removed from the well prior to sampling, it is first necessary to know the volume of standing water in the well pipe (including well screen where applicable). This volume can be easily calculated by the following method. Calculations shall be entered in the site logbook or field notebook or on a sample log sheet form or equivalent electronic form(s) (see SOP SA-6.3):

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 8 of 33
	Revision 1	Effective Date 03/08

1. Obtain all available information on well construction (location, casing, screen, etc.).
2. Determine well or inner casing diameter.
3. Measure and record static water level (depth below ground level or top of casing reference point).
4. Determine depth of well by sounding using a clean, decontaminated, weighted tape measure or water level indicator.
5. Calculate number of linear feet of static water (total depth or length of well pipe minus the depth to static water level).
6. Calculate one static well volume in gallons  $V = (0.163)(T)(r^2)$

where: V = Static volume of well in gallons.  
T = Linear feet of water in the well.  
r = Inside radius of well casing in inches.  
0.163 = Conversion factor (compensates for conversion of casing radius from inches to feet and cubic feet to gallons and pi.

7. Per evacuation volumes discussed above, determine the minimum amount to be evacuated before sampling.

Measuring devices may become contaminated when gathering the above information if they are submerged in contaminated water. Decontamination of the tape or water level indicator must be conducted between measurements in different wells as follows:

1. Saturate a paper towel or clean cotton towel with deionized water.
2. As the measuring device is extracted, wipe the tape, changing the cleaning surface frequently.
3. After it is extracted, rinse the probe or tape using a spray bottle of deionized water over a bucket or similar collection container.

Based on the contaminant (oily, etc), it may be necessary to use a soap and water wash and rinse to remove contaminants. Isopropanol can be used on the probe/tape. However, it is recommended that the use of solvents on the tape be minimized because they could degrade the protective covering or possibly remove the scale designations. If isopropanol (or some other solvent) is used, assure that the manufacturer/supplier Material Safety Data Sheet (MSDS) is obtained, kept on site at a readily available location with other MSDSs, and reviewed by personnel prior to the first usage of the solvent. Also, add the substance to the site-specific Hazardous Chemical Inventory list (see Section 5 of the TtNUS Health and Safety Guidance Manual [HSGM], Hazard Communication Program and OSHA Standard 29 CFR 1910.1200).

#### 6.4 Evacuation of Static Water – Purging

##### 6.4.1 General

The amount to be purged from each well will be determined prior to sample collection. This amount will depend on the intent of the monitoring program and the hydrogeologic conditions. Programs to determine overall quality of water resources may require long pumping periods to obtain a sample that is representative of a large volume of the aquifer. The pumped volume may be specified prior to sampling so that the sample can be a composite of a known volume of the aquifer. Alternately, the well can be pumped until parameters such as temperature, specific conductance, pH, and turbidity (as applicable)

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 9 of 33
	Revision 1	Effective Date 03/08

have stabilized. Onsite measurements of these parameters shall be recorded in the site logbook or field notebook or on standardized data sheets or an equivalent electronic form(s).

#### 6.4.2 Evacuation Devices

The following discussion is limited to those devices commonly used at hazardous waste sites. Attachment A provides guidance on the proper evacuation device to use for given sampling situations. All of these techniques involve equipment that is portable and readily available.

##### Bailers

Bailers are the simplest evacuation devices used and have many advantages. They generally consist of a length of tubing equipped with a base plate and ball check-valve at the bottom. Bailers are comprised of stainless steel and plastic. They come in a variety of sizes, but the two most often used are 2 inches and 4 inches in diameter. An inert non-absorbent line such as polyethylene rope is used to lower and then raise the bailer to retrieve the sample. As the bailer is lowered into the water column, the ball is pushed up allowing the tube to be filled. When the bailer is pulled upward, the ball seats in the base plate preventing water from escaping.

Advantages of bailers include the following:

- There are few limitations on size and materials used.
- No external power source is needed.
- Bailers are inexpensive and can be dedicated and hung in a well to reduce the chances of cross-contamination.
- Bailers are relatively easy to decontaminate.

Limitations on the use of bailers include the following:

- It is time consuming to remove stagnant water using a bailer.
- Splashing the bailer into the water or transfer of sample may cause aeration.
- The use of a bailer does not permit constant in-line monitoring of groundwater parameters.
- Use of bailers is physically demanding, especially in warm temperatures at personal protection equipment (PPE) levels above Level D.

Safety concerns using a bailer include the following:

- Muscle stress and strain, especially when using 4-inch bailers and when pulling from excessively deep wells.
- Entanglement, possible hand/finger injuries, and rope burns during a sudden release of the bailer back down the well.
- Direct contact with contaminants of concern and sample preservatives when discharging the bailer contents because there is not a high level of control during a direct pour, and splashing and indirect contact with contaminants/preservatives could occur.

Control measures for these hazards are provided in Section 6.6.2.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 10 of 33
	Revision 1	Effective Date 03/08

### Suction Pumps

There are many different types of inexpensive suction pumps including centrifugal, diaphragm, and peristaltic pumps. Centrifugal and diaphragm pumps can be used for well evacuation at a fast pumping rate and for sampling at a low pumping rate. The peristaltic pump is a low-volume pump that uses rollers to squeeze flexible tubing to create suction. This tubing can be dedicated to a well to prevent cross-contamination from well to well. Suction pumps are all portable, inexpensive, and readily available. However, because they are based on suction, their use is restricted to areas with water levels within 20 to 25 feet of the ground surface. A significant limitation is that the vacuum created by these pumps can cause loss of dissolved gases and volatile organics. Another limitation of these pumps is that they require a secondary energy source to drive them. Electrically driven pumps may require portable generators as energy sources. Air diaphragm pumps require air compressors and/or compressed gas cylinders to drive them. The advantage of the peristaltic pump is that it will operate from a portable battery source. Safety measures associated with these pumps are provided below.

### Air-Lift and Gas-Lift Samplers

This group of pump samplers uses gas pressure either in the annulus of the well or in a venturi to force groundwater up a sampling tube. These pumps are also relatively inexpensive. Air- or gas-lift samplers are more suitable for well development than for sampling because the samples may be aerated as a result of pump action. Aeration can cause pH changes and subsequent trace metal precipitation or loss of volatile organics.

### Submersible Pumps

Submersible pumps take in water and push the sample up a sample tube to the surface. The power sources for these samplers may be compressed gas or electricity. Operation principles vary, and displacement of the sample can be by an inflatable bladder, sliding piston, gas bubble, or impeller. Pumps are available for 2-inch-diameter wells and larger. These pumps can lift water from considerable depths (several hundred feet).

Limitations of this class of pumps include the following:

- They may have low delivery rates.
- Many models are expensive.
- Compressed gas or electric power is needed.
- Sediment in water may cause clogging of the valves or eroding of the impellers with some of these pumps.
- Decontamination of internal components can be difficult and time consuming.

### Compressed Gases

Safety concerns using compressed gases as an energy source in these pumps are numerous. The nitrogen gas or compressed air is provided in a compressed gas cylinder at a pressure of approximately 2,000 psi. If damaged, these cylinders can become dangerous projectiles. Additionally, a sudden release of a cylinder's contents can involve considerable force that could cause significant damage to the eyes and/or skin. Protective measures include the following.

- Always wear safety impact glasses when handling compressed gases.
- Always administer compressed gases through an appropriate pressure-reducing regulator.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 11 of 33
	Revision 1	Effective Date 03/08

- When clearing the cylinder connection port, open the cylinder valve only enough to clear foreign debris. During this process, always position the cylinder valve so that it faces away from you and others.
- If the cylinder is designed to accept a valve protection cap, always keep that protection cap in place, except the cylinder is connected for use.
- When using the cylinder, lay the cylinder on its side to avoid the potential of it falling and knocking the valve off (and becoming a missile).
- DO NOT use the compressed nitrogen or air to clean clothing or to spray off the skin. Small cuts in the protective layer of the skin may permit the gas to enter into the bloodstream, presenting the potential danger of an embolism.

See the project-specific HASP for additional direction concerning cylinder safe handling procedures pertaining to the safe handling, transportation, and storage of compressed gas cylinders.

#### Electrical Shock

Even in situations where portable batteries are used, the potential for electrical shock exists. This potential risk is increased in groundwater sampling activities because of the presence of groundwater near the batteries. This potential is also increased in (prohibited) situations where jury-rigging of electrical connections is performed. Other potential hazards occur when field samplers open the hood of a running car to access the battery as a power source. To control these hazards:

- If you are unfamiliar with electrical devices, do not experiment, get help, and get the proper equipment necessary to power your device.
- Use the proper portable power inverters for cigarette lighter connections to minimize the need to access the battery under the hood of your vehicle.
- Use of electrical generators may pose a number of hazards including noise, those associated with fueling, and indirect sample influence.

To minimize or eliminate electrical generator hazards:

- Inspect the generator before use. Ensure that the generator and any extension cords are rated for the intended operation and have a Ground Fault Circuit Interrupter (GFCI) in line to control potential electrical shock.
- Fuel the generator before purging and sampling to avoid loss of power during sampling.
- Fuel engines only when they are turned OFF and have cooled sufficiently to prevent a fire hazard.
- Place the generator and any fuel source at least 50 feet from the well to be sampled to avoid indirect influence to the sample from fuel vapors or emission gases.

#### Lifting Hazards

This hazard may be experienced when moving containers of purge water, equipment, cylinders, etc. To control these potential hazards:

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 12 of 33
	Revision 1	Effective Date 03/08

- Do not fill purge buckets to more than 80 percent of their capacity.
- Obtain a gas cylinder of sufficient size to complete the designated task but not too large to handle. K-size cylinders weigh approximately 135 pounds and are difficult to handle. M-size cylinders weigh approximately 50 pounds and are easier to handle and move.
- When necessary, get help lifting and moving gas cylinders and other heavy objects. Minimize twisting and turning while lifting. If it is necessary to move these cylinders or generators over significant distance, use mechanical means (carts, etc.).
- Use proper lifting techniques as described in Section 4.4 of the HSGM.

## 6.5 Onsite Water Quality Testing

This section describes the procedures and equipment required to measure the following parameters of an aqueous sample in the field:

- pH
- Specific conductance
- Temperature
- DO
- ORP
- Turbidity
- Salinity

This section is applicable for use in an onsite groundwater quality monitoring program to be conducted at a hazardous or nonhazardous waste site. The procedures and equipment described are applicable to groundwater samples and are not, in general, subject to solution interferences from color, turbidity, or colloidal material or other suspended matter.

This section provides general information for measuring the parameters listed above with instruments and techniques in common use. Because instruments from different manufacturers may vary, review of the manufacturer's literature pertaining to the use of a specific instrument is required before use. Most meters used to measure field parameters require calibration on a daily basis. Refer to SOP SA-6.3 for an example equipment calibration log.

### 6.5.1 Measurement of pH

#### 6.5.1.1 General

Measurement of pH is one of the most important and frequently used tests in water chemistry. Practically every phase of water supply and wastewater treatment such as acid-base neutralization, water softening, and corrosion control is pH dependent. Likewise, the pH of leachate can be correlated with other chemical analyses to determine the probable source of contamination. It is therefore important that reasonably accurate pH measurements be taken and recorded on the groundwater sample log sheet (Attachment B) or equivalent electronic form.

Two methods are given for pH measurement: the pH meter and ~~pH indicator paper~~. Indicator paper is used when only an approximation of the pH is required or when pH meter readings need to be verified, and the pH meter is used when a more accurate measurement is needed. The response of a pH meter can be affected by high levels of colloidal or suspended solids, but the effect is generally of little significance. Consequently, specific methods to overcome this interference are not described. The

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 13 of 33
	Revision 1	Effective Date 03/08

response of pH paper is unaffected by solution interferences from color, turbidity, or colloidal or suspended materials unless extremely high levels capable of coating or masking the paper are encountered. In such cases, use of a pH meter is recommended.

#### 6.5.1.2 Principles of Equipment Operation

Use of pH papers for pH measurement relies on a chemical reaction caused by the acidity or alkalinity of the solution created by the addition of the water sample reacting with the indicator compound on the paper. Various types of pH papers are available, including litmus (for general acidity or alkalinity determination) and specific, or narrower range, pH range paper.

Use of a pH meter relies on the same principle as other ion-specific electrodes. Measurement relies on establishment of a potential difference across a glass or other type of membrane in response to (in this instance, hydrogen) ion activity (which is usually similar to concentration) across that membrane. The membrane is conductive to ionic species and, in combination with a standard or reference electrode, a potential difference proportional to the ion concentration is generated and measured.

#### 6.5.1.3 Equipment

The following equipment is to be used for obtaining pH measurements:

- A stand-alone portable pH meter or combination meter equipped with an in-line sample chamber (e.g., YSI 600 series and Horiba U-22).
- Combination electrode with polymer body to fit the above meter. Alternately, a pH electrode and a reference electrode can be used if the pH meter is equipped with suitable electrode inputs.
- Buffer solutions, as specified by the manufacturer. If the buffer solutions are considered hazardous per 29 Code of Federal Regulations (CFR) 1910.1200 (Hazard Communication) or the volumes used are greater than consumer commodity levels, the SSO shall obtain MSDSs from the manufacturer for the specific buffer solutions (see Section 4 of the HSGM regarding the Hazard Communication Program)
- pH indicator paper to cover the pH range 2 through 12.
- Manufacturer's operation manual. All personnel must be familiar with the equipment operation to ensure that the integrity of samples is preserved and that the equipment is operated safely.

#### 6.5.1.4 Measurement Techniques for Field Determination of pH

##### pH Meter

The following procedure shall be used for measuring pH with a pH meter (meter standardization is according to manufacturer's instructions):

1. Inspect the instrument and batteries prior to initiation of the field effort.
2. Check the integrity of the buffer solutions used for field calibration. Buffer solutions need to be changed often as a result of degradation upon exposure to the atmosphere.
3. If applicable, make sure all electrolyte solutions within the electrode(s) are at their proper levels and that no air bubbles are present within the electrode(s).

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 14 of 33
	Revision 1	Effective Date 03/08

4. Calibrate the meter and electrode(s) on a daily use basis (or as recommended by manufacturer) following manufacturer's instructions. Record calibration data on a water quality meter calibration log sheet (Attachment C) or equivalent electronic form.
5. Immerse the electrode(s) in the sample. Stabilization may take several seconds to minutes. If the pH continues to drift, the sample temperature may not be stable, a physical reaction (e.g., degassing) may be taking place in the sample, or the meter or electrode may be malfunctioning. The failure of the measurements to stabilize must be clearly noted in the logbook or equivalent electronic form.
6. Read and record the pH of the sample. pH shall be recorded to the nearest 0.01 pH standard unit. Also record the sample temperature (unless otherwise specified in the SAP, record temperatures to the nearest whole degree Fahrenheit or 0.5 degree Celsius).
7. Rinse the electrode(s) with deionized water.
8. Store the electrode(s) in an accordance with manufacturer's instructions when not in use.

Any visual observation of conditions that may interfere with pH measurement, such as oily materials or turbidity, shall be noted and avoided as much as possible.

#### pH Paper

Use of pH paper is very simple and requires no sample preparation, standardization, etc. pH paper is available in several ranges, including wide-range (indicating approximately pH 1 to 12), mid-range (approximately pH 0 to 6, 6 to 9, 8 to 14) and narrow-range (many available, with ranges as narrow as 1.5 pH units). The appropriate range of pH paper shall be selected. If the pH is unknown the investigation shall start with wide-range paper and proceed with successively narrower range paper until the sample pH is determined. To measure the pH with pH paper:

1. Collect a small portion of sample into a clean container.
2. Dip the pH paper into this small portion of sample.
3. Compare the color of the paper to the color chart that is provided with the pH paper and read the corresponding pH from the chart.
4. Record the pH value from the chart on the sampling log sheet.
5. Discard the used pH paper as trash.
6. Discard the small volume of sample that was used for the pH measurement with the other investigative derived waste.

### 6.5.2 Measurement of Specific Conductance

#### 6.5.2.1 General

Conductance provides a measure of dissolved ionic species in water and can be used to identify the direction and extent of migration of contaminants in groundwater or surface water. It can also be used as a measure of subsurface biodegradation or to indicate alternate sources of groundwater contamination.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 15 of 33
	Revision 1	Effective Date 03/08

Conductivity is a numerical expression of the ability of a water sample to carry an electric current. This value depends on the total concentration of ionized substances dissolved in the water and the temperature at which the measurement is made. The mobility of each of the various dissolved ions, their valences, and their actual and relative concentrations affect conductivity.

It is important to obtain a specific conductance measurement soon after taking a sample because temperature changes, precipitation reactions, and absorption of carbon dioxide from the air all affect specific conductance. Most conductivity meters in use today display specific conductance in units of mS/cm, which is the conductivity normalized to a temperature of 25°C. These are the required units to be recorded on the groundwater sample log field form or equivalent electronic form.

#### 6.5.2.2 Principles of Equipment Operation

An aqueous system containing ions will conduct an electric current. In a direct-current field, the positive ions migrate toward the negative electrode, and the negatively charged ions migrate toward the positive electrode. Most inorganic acids, bases, and salts such as hydrochloric acid, sodium carbonate, and sodium chloride, respectively, are relatively good conductors. Conversely, organic compounds such as sucrose or benzene, which do not dissociate in aqueous solution, conduct a current very poorly if at all.

A conductance cell and a Wheatstone Bridge (for the measurement of potential difference) may be used for measurement of electrical resistance. The ratio of current applied to voltage across the cell may also be used as a measure of conductance. The core element of the apparatus is the conductivity cell containing the solution of interest. Depending on the ionic strength of the aqueous solution to be tested, a potential difference is developed across the cell, which can be converted directly or indirectly (depending on instrument type) to a measurement of specific conductance.

#### 6.5.2.3 Equipment

The following equipment is needed for taking specific conductance measurements:

- Stand-alone portable conductivity meter or combination meter equipped with an in-line sample chamber (e.g., YSI 600 series and Horiba U-22).
- Calibration solution, as specified by the manufacturer.
- Manufacturer's operation manual.

A variety of conductivity meters are available that may also be used to monitor salinity and temperature. Probe types and cable lengths vary, so equipment must be obtained to meet the specific requirements of the sampling program.

#### 6.5.2.4 Measurement Techniques for Specific Conductance

The steps involved in taking specific conductance measurements are as follows (calibration shall be conducted according to manufacturer's instructions):

1. Check batteries and calibrate instrument before going into the field.
2. Calibrate on a daily use basis (or as recommended by manufacturer), according to the manufacturer's instructions and record all pertinent information on a water quality meter calibration log sheet or equivalent electronic form. Potassium chloride solutions with a specific conductance closest to the values expected in the field shall be used for calibration.
3. Rinse the cell with one or more portions of the sample to be tested or with deionized water and shake excess water from the cell.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 16 of 33
	Revision 1	Effective Date 03/08

4. Immerse the electrode in the sample and measure the conductivity.
5. Read and record the results in a field logbook or on a sample log sheet or equivalent electronic form.
6. Rinse the electrode with deionized water.

If the specific conductance measurements become erratic, recalibrate the instrument and see the manufacturer's instructions for troubleshooting assistance.

### **6.5.3 Measurement of Temperature**

#### **6.5.3.1 General**

In combination with other parameters, temperature can be a useful indicator of the likelihood of biological action in a water sample. It can also be used to trace the flow direction of contaminated groundwater. Temperature measurements shall be taken in situ, or as quickly as possible in the field because collected water samples may rapidly equilibrate with the temperature of their surroundings.

#### **6.5.3.2 Equipment**

Temperature measurements may be taken with alcohol-toluene, mercury-filled, dial-type thermometers or combination meters equipped with an in-line sample chamber (e.g., YSI 600 series and Horiba U-22). In addition, various meters such as specific conductance or DO meters that have temperature measurement capabilities may also be used. Using such instrumentation along with suitable probes and cables, in-situ measurements of temperature at great depths can be performed.

#### **6.5.3.3 Measurement Techniques for Water Temperature**

If a thermometer is used to determine the temperature for a water sample, use the following procedure:

1. Immerse the thermometer in the sample until temperature equilibrium is obtained (1 to 3 minutes). To avoid the possibility of cross-contamination, the thermometer shall not be inserted into samples that will undergo subsequent chemical analysis.
2. Record values in a field logbook or on a sample log sheet or equivalent electronic form.

If a temperature meter or probe is used:

1. Calibrate the instrument according to manufacturer's recommendations prior to use.
2. Immerse the meter/probe in the sample until temperature equilibrium is obtained (1 to 3 minutes). To avoid the possibility of cross-contamination, the meter/probe shall not be inserted into samples that will undergo subsequent chemical analysis.
3. Record values in a field logbook or on a sample log sheet or equivalent electronic form.

### **6.5.4 Measurement of Dissolved Oxygen**

#### **6.5.4.1 General**

DO levels in natural water and wastewater depend on the physical, chemical and biochemical activities in the water body. In addition, the growth of many aquatic organisms and the rate of corrosivity are dependent on DO concentrations. Thus, analysis for DO is a key test in water pollution and waste

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 17 of 33
	Revision 1	Effective Date 03/08

treatment process control. If at all possible, DO measurements shall be taken in situ because concentrations may show a large change in a short time if the sample is not adequately preserved.

The monitoring method discussed herein is limited to the use of DO meters. Chemical methods of analysis (i.e., Winkler methods) are available but require more equipment and greater sample manipulation. Furthermore, DO meters using a membrane electrode are suitable for highly polluted waters because the probe is completely submersible and is not susceptible to interference caused by color, turbidity, or colloidal material or suspended matter.

#### 6.5.4.2 Principles of Equipment Operation

DO probes are normally electrochemical cells that have two solid metal electrodes of different nobility immersed in an electrolyte. The electrolyte is retained by an oxygen-permeable membrane. The metal of highest nobility (the cathode) is positioned at the membrane. When a suitable potential exists between the two metals, reduction of oxygen to hydroxide ion (OH<sup>-</sup>) occurs at the cathode surface. An electrical current is developed that is directly proportional to the rate of arrival of oxygen molecules at the cathode. This rate is proportional to the oxygen concentration in the water being measured.

Because the current produced in the probe is directly proportional to the rate of arrival of oxygen at the cathode, it is important that a fresh supply of sample always be in contact with the membrane. Otherwise, the oxygen in the aqueous layer along the membrane is quickly depleted and false low readings are obtained. It is therefore necessary to stir the sample (or the probe) constantly to maintain fresh solution near the membrane interface. Stirring, however, shall not be so vigorous that additional oxygen is introduced through the air-water interface at the sample surface. To avoid this possibility, some probes are equipped with stirrers to agitate the solution near the probe, leaving the surface of the solution undisturbed.

DO probes are relatively unaffected by interferences. Interferences that can occur are reactions with oxidizing gases such as chlorine or with gases such as hydrogen sulfide that are not easily depolarized from the indicating electrode. If a gaseous interference is suspected, it shall be noted in the field logbook and checked if possible. Temperature variations can also cause interference because probes exhibit temperature sensitivity. Automatic temperature compensation is normally provided by the manufacturer. This compensation can counteract some of the temperature effects but not all of them.

#### 6.5.4.3 Equipment

The following equipment is needed to measure DO concentrations:

- A stand-alone portable DO meter or combination meter equipped with an in-line sample chamber (e.g., YSI 600 series and Horiba U-22).
- Sufficient cable to allow the probe to contact the sample.
- Manufacturer's operation manual.

#### 6.5.4.4 Measurement Techniques for Dissolved Oxygen Determination

DO probes differ as to instructions for use. Follow the manufacturer's instructions to obtain an accurate reading. The following general steps shall be used to measure DO concentrations:

1. Check the DO meter batteries before going to the field.
2. Condition the probe in a water sample for as long a period as practical before use in the field. Long periods of dry storage followed by short periods of use in the field may result in inaccurate readings.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 18 of 33
	Revision 1	Effective Date 03/08

3. Calibrate the instrument in the field according to manufacturer's recommendations or in a freshly air-saturated water sample of known temperature.
4. Record all pertinent information on a water quality meter calibration log sheet or equivalent electronic form.
5. Rinse the probe with deionized water.
6. Immerse the probe in the sample. Be sure to provide for sufficient flow past the membrane by stirring the sample. Probes without stirrers placed in wells may be moved up and down to achieve the required mixing.
7. Record the DO content and temperature of the sample in a field logbook or on a sample log sheet or equivalent electronic form.
8. Rinse the probe with deionized water.
9. Recalibrate the probe when the membrane is replaced, or as needed. Follow the manufacturer's instructions.

Note that in-situ placement of the probe is preferable because sample handling is not involved. This however may not always be practical.

Special care shall be taken during sample collection to avoid turbulence that can lead to increased oxygen solubilization and positive test interferences.

### **6.5.5 Measurement of Oxidation-Reduction Potential**

#### **6.5.5.1 General**

ORP provides a measure of the tendency of organic or inorganic chemicals to exist in an oxidized state. The ORP parameter therefore provides evidence of the likelihood of anaerobic degradation of biodegradable organics or the ratio of activities of reduced to oxidized species in the sample.

#### **6.5.5.2 Principles of Equipment Operation**

When an inert metal electrode, such as platinum, is immersed in a solution, a potential is developed at that electrode depending on the ions present in the solution. If a reference electrode is placed in the same solution, an ORP electrode pair is established. This electrode pair allows the potential difference between the two electrodes to be measured and is dependent on the concentration of the ions in solution. By this measurement, the ability to oxidize or reduce species in solution may be determined. Supplemental measurements, such as DO, may be correlated with ORP to provide knowledge of the quality of the solution, water, or wastewater.

#### **6.5.5.3 Equipment**

The following equipment is needed for measuring the ORP of a solution:

- A combination meter with an in-line sample chamber (e.g., YSI 600 series and Horiba U-22).
- Reference solution as specified by the manufacturer.
- Manufacturer's operation manual.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 19 of 33
	Revision 1	Effective Date 03/08

#### 6.5.5.4 Measurement Techniques for Oxidation-Reduction Potential

The following procedure is used for measuring ORP:

1. Check the equipment using the manufacturer's recommended reference solution and check its batteries before going to the field.
2. Thoroughly rinse the electrode with deionized water.
3. If the probe does not respond properly to the recommended reference solution, verify the sensitivity of the electrodes by noting the change in millivolts when the pH of a test solution is altered. The ORP will increase when the pH of a test solution decreases, and the ORP will decrease when the test solution pH is increased. Place the sample in a clean container and agitate the sample. Insert the electrodes and note that the ORP drops sharply when the caustic is added (i.e., pH increases) thus indicating that the electrodes are sensitive and operating properly. If the ORP increases sharply when the caustic is added, the polarity is reversed and must be corrected in accordance with the manufacturer's instructions or the probe should be replaced.
4. Record all pertinent information on a water quality meter calibration log sheet or equivalent electronic form.

#### ~~6.5.6 Measurement of Salinity~~

##### ~~6.5.6.1 General~~

~~Salinity is a unitless property of industrial and natural waters. It is the measurement of dissolved salts in a given mass of solution. Most field meters determine salinity automatically from conductivity and temperature. The displayed value will be displayed in either parts per thousand (ppt) or percent (e.g., 35 ppt equals 3.5 percent).~~

##### ~~6.5.6.2 Principles of Equipment Operation~~

~~Salinity is determined automatically from the meter's conductivity and temperature readings according to algorithms (such as are found in Standard Methods for the Examination of Water and Wastewater). Depending on the meter, the results are displayed in either ppt or percent. The salinity measurements are carried out in reference to the conductivity of standard seawater (corrected to salinity = 35 ppt).~~

##### ~~6.5.6.3 Equipment~~

~~The following equipment is needed for salinity measurements:~~

- ~~• A multi-parameter water quality meter capable of measuring conductivity and temperature and converting them to salinity (e.g., Horiba U-22 or YSI 600 series).~~
- ~~• Calibration solution as specified by the manufacturer.~~
- ~~• Manufacturer's operation manual.~~

##### ~~6.5.6.4 Measurement Techniques for Salinity~~

~~The steps involved in taking salinity measurements are as follows (standardization shall be conducted according to manufacturer's instructions):~~

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 20 of 33
	Revision 1	Effective Date 03/08

1. Check the expiration date of the solutions used for field calibration and replace them if they are expired.
2. Check batteries and calibrate the meter before going into the field.
3. Calibrate on a daily use basis, according to the manufacturer's instructions and record all pertinent information on a water quality meter calibration log sheet or equivalent electronic form.
4. Rinse the cell with the sample to be tested. This is typically accomplished as the probe is placed in line during the collection of the purge water up to the time of sample acquisition.
5. Immerse the multi-probe in the sample and measure the salinity. Read and record the results in a field logbook or on a sample log sheet or equivalent electronic form.
6. Rinse the probes with deionized water.

### **6.5.7 Measurement of Turbidity**

#### **6.5.7.1 General**

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in a straight line through the sample. Turbidity in water is caused by suspended matter such as clay, silt, or other finely divided organic and inorganic matter and microscopic organisms including plankton.

It is important to obtain a turbidity reading immediately after taking a sample because irreversible changes in turbidity may occur if the sample is stored too long.

#### **6.5.7.2 Principles of Equipment Operation**

Turbidity is measured by the Nephelometric Method, which is based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The higher the scattered light intensity, the higher the turbidity.

Formazin polymer is used as the reference turbidity standard suspension because of its ease of preparation combined with a higher reproducibility of its light-scattering properties than clay or turbid natural water. The turbidity of a specified concentration of formazin suspension is defined as 40 nephelometric units. This same suspension has an approximate turbidity of 40 Jackson units when measured on the candle turbidimeter. Therefore, nephelometric turbidity units (NTUs) based on the formazin preparation will approximate units derived from the candle turbidimeter but will not be identical to them.

#### **6.5.7.3 Equipment**

The following equipment is needed for turbidity measurements:

- A turbidity meter (e.g., LaMotte 2020) that calibrates easily using test cells with standards of 0.0, 1.0, and 10 NTUs, or a combination meter equipped with an in-line sample chamber (e.g., YSI 600 series and Horiba U-22).
- Calibration solution and sample tubes, as specified by the manufacturer.
- Manufacturer's operation manual.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 21 of 33
	Revision 1	Effective Date 03/08

#### 6.5.7.4 Measurement Techniques for Turbidity

The steps involved in taking turbidity measurements utilizing an electrode (e) or light meter (l) are listed below (standardization shall be done according to manufacturer's instructions):

1. Check the expiration date of the solutions used for field calibration and replace them if they are expired.
2. Check batteries and calibrate the instrument before going into the field.
3. Calibrate on a daily basis according to the manufacturer's instructions, and record all pertinent information on a turbidity meter calibration log sheet (Attachment C) or equivalent electronic form.
4. When using the YSI and/or Horiba U-22, rinse the electrode with one or more portions of the sample to be tested or with deionized water.
5. When using the Lamotte 2020, fill the light meter's glass test cell with approximately 5 mL of sample, screw on the cap, wipe off glass to remove all residue that could intercept the instrument's light beam, place the test cell in the light meter, and close the lid.
6. Immerse the electrode in the sample and measure the turbidity.
7. The reading must be taken immediately because suspended solids will settle over time resulting in a lower, inaccurate turbidity reading.
8. Read and record the results in a field logbook or on a sample log sheet or equivalent electronic form. Include a physical description of the sample, including color, qualitative estimate of turbidity, etc.
9. Rinse the electrode or test cell with deionized water.

### 6.6 Sampling

#### 6.6.1 Sampling Plan

The sampling approach consisting of the following shall be developed as part of the project planning documents approved prior to beginning work in the field:

- Background and objectives of sampling.
- Brief description of area and waste characterization.
- Identification of sampling locations, with map or sketch, and applicable well construction data (well size, depth, screened interval, reference elevation).
- Intended number, sequence, volumes, and types of samples. If the relative degree of contamination between wells is insignificant, a sampling sequence that facilitates sampling logistics may be followed. Where some wells are known or strongly suspected of being highly contaminated, these shall be sampled last to reduce the risk of cross-contamination between wells. In situations where the well is not well-characterized and the nature or extent of airborne contamination is unknown, it is recommended that head space analysis using a photoionization detector (PID) or flame ionization detector (FID) is performed to rate the wells, sampling from least contaminated to most contaminated. Refer to the project-specific HASP for appropriate information and direction on air monitoring requirements.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 22 of 33
	Revision 1	Effective Date 03/08

- Sample preservation requirements.
- Work schedule.
- List of team members.
- List of observers and contacts.
- Other information, such as the necessity for a warrant or permission of entry, requirements for split samples, access problems, location of keys, etc.
- The FOL shall ensure that the sampling method(s) to be employed is accurately represented in the HASP, indicating the types of sampling to be employed and the hazards. If the methods are not accurately represented, the FOL should rectify this with the HASP author.
- The FOL shall ensure that sampling teams understand the sampling approach that they are to follow. Where sampling teams are made up of personnel from multiple locations, personal sampling experiences may vary. Therefore the FOL shall review project-specific requirements, SOPs, and protocol to be followed. The FOL will conduct periodic surveys to ensure that these methods are being completed per his/her direction.

#### **6.6.2 Sampling Methods as Related to Low-Flow Sampling**

The collection of a groundwater sample consists of the following steps:

1. Ensure the safety of the sample location. Take a few minutes to evaluate the area for physical hazards (trip hazards, uneven ground, overhanging branches, etc.) and natural hazards (snakes, bees, spiders, etc.) that may exist in the area or that may have constructed nests in the well head. Snakes often like to sun themselves on concrete well pads. Follow provisions in the project-specific HASP and/or HSGM for addressing natural hazards.
2. As indicated earlier, some monitoring wells have the potential to contain pressurized headspace (e.g., through the generation of gases from contaminated groundwater, due to biological processes, degradation of contaminants, or simply based on location such as near a landfill or in areas that intersect lithological abnormalities) or through intentional artificial means such as those associated with air sparging systems. Injection or extraction wells may be artificially pressurized and may remain so for several days after the system has been turned off. This presents a hazard to people opening these wells. The Field Sampling Technician shall employ the following practices to minimize these hazards:
  - Wear safety glasses to protect the eyes. If site-specific observations and conditions indicate that the wells may be pressurized, wear a full-face shield over the safety impact eye protection.
  - DO NOT place your face or any other part of your body over the well when opening because this may place you in a strike zone.
  - Open the well cover at arms length, then step away and allow the well to off gas and stabilize.

Follow directions provided in the project-specific HASP, Work Plan and/or Sampling Plan pertaining to the use of volatile chemical detection equipment (PID or FID) within the breathing zone of the sampler during sampling to determine the need to retreat from the work area and/or for the use of respiratory protection (as specified in the HASP).

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 23 of 33
	Revision 1	Effective Date 03/08

3. When proper respiratory protection has been donned, sound the well for total depth and water level (using clean equipment) and record these data on a groundwater sampling log sheet or equivalent electronic form; then calculate the fluid volume in the well pipe (as previously described in this SOP). It is imperative that downhole equipment be adequately decontaminated between wells to prevent cross-contamination. Just as sampling occurs from the least contaminated to the most contaminated, it is also recommended that groundwater level measurements be taken in this manner.
4. Calculate volume of well water to be removed as described in Section 6.3.
5. Select the appropriate purging equipment (see Attachment A to this SOP) or as designated within your Work Plan/Sampling Plan. If an electric submersible pump with packer is chosen, go to Step 10.
6. Lower the purging equipment or intake into the well to a short distance below the water level or mid-screen as indicated in project-specific documentation and begin water removal. Remember that some contaminants are "bottom dwellers," and in these cases, project-specific direction may specify placing the intake just above (1 to 2 feet) the well bottom. Secure the pump intake at the well and secure the effluent at the collection container and begin pumping. The pumping rate will be determined based on the decrease in the water level (see Section 6.7) or as directed in your project-specific documents or this SOP. Purge water is generally collected in a 5-gallon bucket or similar open- or closed-top container. To minimize the potential for spills and back injuries, do not fill 5-gallon buckets beyond approximately 80 percent of their capacity. Dispose of purge water as indicated in the planning document(s). Where necessary, slow the pumping rate or lower the pump intake as required to maintain submergence.
7. Estimate the approximate rate of discharge frequently and record it on the Low Flow Purge Data Sheet (see Attachment D). Estimate flow rate by noting the amount of discharge in a bucket or graduated cylinder per unit time using a watch with a second hand or a stopwatch.
8. Observe the peristaltic pump tubing intake for degassing "bubbles." If bubbles are abundant and the intake is fully submerged, this pump is not suitable for collecting samples for volatile organics.
9. Purge a minimum of three to five casing volumes before sampling (or as directed by the site-specific SAP). In low-permeability strata (i.e., if the well is pumped to dryness), one volume will suffice. Allow the well to recover to 75 percent of initial water level before sampling. Do not overfill purge containers because this increases the potential for spills and lifting injuries.
10. If sampling using a submersible pump, lower the pump intake to mid-screen (or the middle of the open section in uncased wells) and collect the sample. If sampling with a bailer, lower the bailer to just below the water surface.
11. For pump and packer assemblies only: Lower the assembly into the well so that the packer is positioned just above the screen or open section. Inflate the packer. Purge a volume equal to at least twice the screened interval (or unscreened open section volume below the packer) before sampling. Packers shall always be tested in a casing section above ground to determine proper inflation pressures for good sealing.
12. If the recovery time of the well is very slow (e.g., 24 hours or greater), sample collection can be delayed until the following day. If the well has been purged early in the morning, sufficient water may be standing in the well by the day's end to permit sample collection. If the well is incapable of producing a sufficient volume of sample at any time, take the largest quantity available and record this occurrence in the site logbook or equivalent electronic form. When this occurs, contact the analytical laboratory to alert them that a reduced sample volume(s) will be submitted for analysis.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 24 of 33
	Revision 1	Effective Date 03/08

13. Fill sample containers and preserve and label them as described in SOP SA-6.1. Many sample bottles will contain preservative when they are shipped to the field. In those cases, do not add preservative.
14. Replace the well cap and lock it as appropriate. Make sure the well is readily identifiable as the source of the sample.
15. Process sample containers as described in SOP SA-6.1.
16. Decontaminate equipment as described in SOP SA-7.1.

## **6.7 Low-Flow Purging and Sampling**

### **6.7.1 Scope and Application**

Low-flow purging and sampling techniques may be required for groundwater sampling activities. The purpose of low-flow purging and sampling is to collect groundwater samples that contain "representative" amounts of mobile organic and inorganic constituents in the vicinity of the selected open well interval, at or near natural flow conditions. This minimum-stress procedure emphasizes negligible water level drawdown and low pumping rates to collect samples with minimal alterations in water chemistry. This procedure is designed primarily to be used in wells with a casing diameter of 1 inch or more and a saturated screen length, or open interval, of 10 feet or less. Samples obtained are suitable for analyses of common types of groundwater contaminants (volatile and semivolatile organic compounds, pesticides, polychlorinated biphenyls [PCBs], metals and other inorganic ions [cyanide, chloride, sulfate, etc.]). This low-flow procedure is not designed for collection of non-aqueous phase liquid samples from wells containing light or dense non-aqueous phase liquids (LNAPLs or DNAPLs).

This procedure is flexible for various well construction types and groundwater yields. The goal of the procedure is to obtain a turbidity level of less than 10 NTUs and to achieve a water level drawdown of less than 0.3 foot during purging and sampling. If these goals cannot be achieved, sample collection can take place provided that the remaining criteria in this procedure are met.

### **6.7.2 Equipment**

The following equipment is required (as applicable) for low-flow purging and sampling:

- Adjustable rate submersible pump (e.g., centrifugal or bladder pump constructed of stainless steel or Teflon).
- Disposable clear plastic bottom-filling bailers to be used to check for and obtain samples of LNAPLs or DNAPLs.
- Tubing – Teflon, Teflon-lined polyethylene, polyethylene, polyvinyl chloride (PVC), Tygon, or stainless steel tubing can be used to collect samples for analysis, depending on the analyses to be performed and regulatory requirements.
- Water level measuring device with 0.01-foot accuracy (electronic devices are preferred for tracking water level drawdown during all pumping operations).
- Interface probe.
- Flow measurement supplies.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 25 of 33
	Revision 1	Effective Date 03/08

- Power source (generator, nitrogen tank, etc.). If a gasoline generator is used, it must be located downwind and at a safe distance from the well so that the exhaust fumes do not contaminate the samples.
- Indicator parameter monitoring instruments – pH, turbidity, specific conductance, and temperature. Use of a flow-through cell is recommended. Optional indicators - ORP, salinity, and DO. A flow-through cell (also referred to as an in-line sample chamber) is required.
- Standards to perform field calibration of instruments.
- Decontamination supplies.
- Logbook(s) and other forms (see Attachments B through D) or equivalent electronic form(s).
- Sample bottles.
- Sample preservation supplies (as required by the analytical methods).
- Sample tags and/or labels.
- Well construction data, location map, field data from last sampling event (if available).
- Field Sampling Plan.
- PID or FID instrument for measuring volatile organic compounds (VOCs) per the HASP.

### 6.7.3 Purging and Sampling Procedure

1. Open the monitoring well as stated earlier and step away. Prepare sampling equipment while allowing 3 to 5 minutes to allow the water level to reach equilibrium. In situations where VOCs are the primary contaminants of concern, air monitoring of the samplers' breathing zone areas may be required by the HASP (typically with a PID or FID).
2. Measure the water level immediately prior to placing the pump in the well and record the water level on the Low-Flow Purge Data Form or equivalent electronic form immediately prior to placing the pump or tubing into the well.
3. Lower the measuring device further into the well to collect the total depth measurement. Again wait 3 to 5 minutes to allow the well to equilibrate to the initial water level prior to placing the pump or pump intake in the well.
4. Record the total well depth on the Low-Flow Purge Data Form or equivalent electronic form immediately prior to placing the pump or tubing into the well
5. Lower the pump or tubing slowly into the well so that the pump intake is located at the center of the saturated screen length of the well. If possible, keep the pump intake at least 2 feet above the bottom of the well to minimize mobilization of sediment that may be present in the bottom of the well. Collection of turbidity-free water samples may be difficult if there is 3 feet or less of standing water in the well.
6. Start with the initial pump rate set at approximately 0.1 liter per minute. Use a graduated cylinder and stopwatch to measure the pumping rate. Adjust the pumping rates as necessary to prevent drawdown from exceeding 0.3 foot during purging. If no drawdown is noted, the pump rate may be increased (to

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 26 of 33
	Revision 1	Effective Date 03/08

a maximum of 0.4 liter per minute) to expedite the purging and sampling event. The pump rate will be reduced if turbidity is greater than 10 NTUs after all other field parameters have stabilized. If groundwater is drawn down below the top of the well screen, purging shall cease or the well shall be pumped to dryness and then allowed to recover before purging continues. Well recovery to 75 percent is necessary prior to sampling. Slow-recovering wells should be identified and purged at the beginning of the workday to maximize field work efficiency. If possible, samples should be collected from these wells within the same workday and no later than 24 hours after the end of purging.

7. Measure the water level in the well every 5 to 10 minutes using the water level meter. Record the well water level on the Low Flow Purge Data Form (Attachment D) or equivalent electronic form.
8. Record on the Low Flow Purge Data Form every 5 to 10 minutes the water quality parameters (pH, specific conductance, temperature, turbidity, ORP, DO, and salinity or as specified by the approved site-specific planning document) measured by the water quality meter and turbidity meter. If the cell needs to be cleaned during purging operations, continue pumping (allow the pump to discharge into a container) and disconnect the cell. Rinse the cell with distilled/deionized water. After cleaning is completed, reconnect the flow-through cell and continue purging. Document the cell cleaning on the Low-Flow Purge Data Form or equivalent electronic form.
9. Estimate the flow rate by noting the amount of discharge in a graduated cylinder per unit time using a watch with a second hand. Remeasure the flow rate any time the pump rate is adjusted and periodically during purging. This will determine if a reduction in rate has occurred due to possible battery depletion.
10. During purging, check for the presence of bubbles in the flow-through cell. The presence of bubbles is an indication that connections are not tight. If bubbles are observed, check for loose connections and tighten, repair, or replace them as necessary to achieve a tight connection.
11. Wait until stabilization is achieved, or a minimum of two saturated screen volumes have been removed and three consecutive readings, taken at 5 to 10 minute intervals, are within the following limits, then begin sampling:
  - pH  $\pm 0.2$  standard units
  - Specific conductance  $\pm 10\%$
  - Temperature  $\pm 10\%$
  - Turbidity less than 10 NTUs
  - DO  $\pm 10\%$
12. If the above conditions have not been met after the well has been purged for 4 hours, purging will be considered complete and sampling can begin. Record the final well stabilization parameters from the Low-Flow Purge Data Form onto the Groundwater Sample Log Form or equivalent electronic form.

**NOTE:** VOC samples are preferably collected first, directly into pre-preserved sample containers. Fill all sample containers by allowing the pump discharge to flow gently down the inside of the container with minimal turbulence.

13. If the water column in the pump tubing collapses (water does not completely fill the tubing) before exiting the tubing, use one of the following procedures to collect VOC samples:
  - Collect samples for non-VOC analyses first, then increase the flow rate incrementally until the water column completely fills the tubing, collect the sample for VOCs, and record the new flow rate.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 27 of 33
	Revision 1	Effective Date 03/08

- Reduce the diameter of the existing tubing until the water column fills the tubing either by adding a connector (Teflon or stainless steel) or clamp, which should reduce the flow rate by constricting the end of the tubing. Proceed with sample collection.
- Insert a narrow-diameter Teflon tube into the pump's tubing so that the end of the tubing is in the water column and the other end of the tubing protrudes beyond the pump's tubing, then collect the sample from the narrow diameter tubing.
- Prepare samples for shipping as per SOP SA-6.1.

## 7.0 REFERENCES

American Public Health Association, 1989. Standard Methods for the Examination of Water and Wastewater, 17th Edition, APHA, Washington, D.C.

Barcelona, M. J., J. P. Gibb and R. A. Miller, 1983. A Guide to the Selection of Materials for Monitoring Well Construction and Groundwater Sampling. ISWS Contract Report 327, Illinois State Water Survey, Champaign, Illinois.

Johnson Division, UOP, Inc. 1975. Ground Water and Wells, A Reference Book for the Water Well Industry. Johnson Division, UOP, Inc., Saint Paul, Minnesota.

Nielsen, D. M. and G. L. Yeates, 1985. A Comparison of Sampling Mechanisms Available for Small-Diameter Ground Water Monitoring Wells. Ground Water Monitoring Review 5:83-98.

Scaif, M. R., J. F. McNabb, W. J. Dunlap, R. L. Crosby and J. Fryberger, 1981. Manual of Ground Water Sampling Procedures. R. S. Kerr Environmental Research Laboratory, Office of Research and Development, U.S. EPA, Ada, Oklahoma.

U.S. EPA, 1979. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020.

U.S. EPA, 1980. Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities. Office of Solid Waste, United States Environmental Protection Agency, Washington, D.C.

U.S. EPA, 1994. Groundwater Sampling Procedure - Low Flow Purge and Sampling (Draft Final). U.S. Environmental Protection Agency, Region I.

U.S. Geological Survey, 1984. National Handbook of Recommended Methods for Water Data Acquisition, Chapter 5: Chemical and Physical Quality of Water and Sediment. U.S. Department of the Interior, Reston, Virginia.

Subject GROUNDWATER SAMPLE ACQUISITION AND ONSITE WATER QUALITY TESTING	Number SA-1.1	Page 28 of 33
	Revision 1	Effective Date 03/08

**ATTACHMENT A**  
**PURGING EQUIPMENT SELECTION**

Diameter Casing		Bailer	Peristaltic Pump	Vacuum Pump	Air-lift	Diaphragm "Trash" Pump	Submersible Diaphragm Pump	Submersible Electric Pump	Submersible Electric Pump w/Packer
1.25-Inch	Water level <25 feet	X	X	X	X	X			
	Water Level >25 feet	X			X				
2-Inch	Water level <25 feet	X	X	X	X	X	X		
	Water Level >25 feet	X			X		X		
4-Inch	Water level <25 feet	X	X	X	X	X	X	X	X
	Water Level >25 feet	X			X		X	X	X
6-Inch	Water level <25 feet				X	X		X	X
	Water Level >25 feet				X			X	X
8-Inch	Water level <25 feet				X	X		X	X
	Water Level >25 feet				X			X	X

**ATTACHMENT A**  
**PURGING EQUIPMENT SELECTION**  
**PAGE 2**

Manufacturer	Model Name/Number	Principle of Operation	Maximum Outside Diameter/L ength (Inches)	Construction Materials (w/Lines and Tubing)	Lift Range (ft)	Delivery Rates or Volumes	1982 Price (Dollars)	Comments
BarCad Systems, Inc.	BarCad Sampler	Dedicated; gas drive (positive displacement)	1.5/16	PE, brass, nylon, aluminum oxide	0-150 with std. tubing	1 liter for each 10-15 feet of submergence	\$220-350	Requires compressed gas; custom sizes and materials available; acts as piezometer.
Cole-Parmer Inst. Co.	Master Flex 7570 Portable Sampling Pump	Portable; peristaltic (suction)	<1.0/NA	(not submersible) Tygon®, silicone Viton®	0-30	670 mL/min with 7015-20 pump head	\$500-600	AC/DC; variable speed control available; other models may have different flow rates.
ECO Pump Corp.	SAMPLifier	Portable; venturi	<1.5 or <2.0/NA	PP, PE, PVC, SS, Teflon®, Tefzel®	0-100	0-500 mL/min depending on lift	\$400-700	AC, DC, or gasoline-driven motors available; must be primed.
Geltek Corp.	Bailer 219-4	Portable; grab (positive displacement)	1.66/38	Teflon®	No limit	1,075 mL	\$120-135	Other sizes available.
GeoEngineering, Inc.	GEO-MONITOR	Dedicated; gas drive (positive displacement)	1.5/16	PE, PP, PVC, Viton®	Probably 0-150	Approximately 1 liter for each 10 feet of submergence	\$185	Acts as piezometer; requires compressed gas.
Industrial and Environmental Analysts, Inc. (IEA)	Aquarius	Portable; bladder (positive displacement)	1.75/43	SS, Teflon®, Viton®	0-250	0-2,800 mL/min	\$1,500-3,000	Requires compressed gas; other models available; AC, DC, manual operation possible.
IEA	Syringe Sampler	Portable; grab (positive displacement)	1.75/43	SS, Teflon®	No limit	850 mL sample volume	\$1,100	Requires vacuum and/or pressure from hand pump.
Instrument Specialties Co. (ISCO)	Model 2600 Well Sampler	Portable; bladder (positive displacement)	1.75/50	PC, silicone, Teflon®, PP, PE, Detrin®, acetal	0-150	0-7,500 mL/min	\$990	Requires compressed gas (40 psi minimum).
Keck Geophysical Instruments, Inc.	SP-81 Submersible Sampling Pump	Portable; helical rotor (positive displacement)	1.75/25	SS, Teflon®, PP, EPDM, Viton®	0-160	0-4,500 mL/min	\$3,500	DC operated.
Leonard Mold and Die Works, Inc.	GeoFilter Small Diameter Well Pump (#0500)	Portable; bladder (positive displacement)	1.75/38	SS, Teflon®, PC, Neoprene®	0-400	0-3,500 mL/min	\$1,400-1,500	Requires compressed gas (55 psi minimum); pneumatic or AC/DC control module.
Oil Recovery Systems, Inc.	Surface Sampler	Portable; grab (positive displacement)	1.75/12	acrylic, Detrin®	No limit	Approximately 250 mL	\$125-160	Other materials and models available; for measuring thickness of "floating" contaminants.
Q.E.D. Environmental Systems, Inc.	Well Wizard® Monitoring System (P-100)	Dedicated; bladder (positive displacement)	1.66/36	PVC	0-230	0-2,000 mL/min	\$300-400	Requires compressed gas; piezometric level indicator; other materials available.

Subject  
GROUNDWATER SAMPLE  
ACQUISITION AND ONSITE  
WATER QUALITY TESTING

Number  
SA-1.1  
Revision  
1

Page  
29 of 33  
Effective Date  
03/08

**ATTACHMENT A**  
**PURGING EQUIPMENT SELECTION**  
**PAGE 3**

Manufacturer	Model Name/Number	Principle of Operation	Maximum Outside Diameter/Length (Inches)	Construction Materials (w/Lines and Tubing)	Lift Range (ft)	Delivery Rates or Volumes	1982 Price (Dollars)	Comments
Randolph Austin Co.	Model 500 Vari-Flow Pump	Portable; peristaltic (suction)	<0.5/NA	(Not submersible) Rubber, Tygon®, or Neoprene®	0-30	See comments	\$1,200-1,300	Flow rate dependent on motor and tubing selected; AC operated; other models available.
Robert Bennett Co.	Model 180	Portable; piston (positive displacement)	1.8/22	SS, Teflon®, Delrin® PP, Viton®, acrylic, PE	0-500	0-1,800 mL/min	\$2,600-2,700	Requires compressed gas; water level indicator and flow meter; custom models available.
Slope Indicator Co. (SINCO)	Model 514124 Pneumatic Water Sampler	Portable; gas drive (positive displacement)	1.9/18	PVC, nylon	0-1,100	250 mL/flushing cycle	\$250-350	Requires compressed gas; SS available; piezometer model available; dedicated model available.
Solinst Canada Ltd.	5W Water Sampler	Portable; grab (positive displacement)	1.9/27	PVC, brass, nylon, Neoprene®	0-330	500 mL	\$1,300-1,800	Requires compressed gas; custom models available.
TIMCO Mfg. Co., Inc.	Std. Bailer	Portable; grab (positive displacement)	1.66/Custom	PVC, PP	No limit	250 mL/ft of bailer	\$20-60	Other sizes, materials, models available; optional bottom-emptying device available; no solvents used.
TIMCO	Air or Gas Lift Sampler	Portable; gas drive (positive displacement)	1.66/30	PVC, Tygon®, Teflon®	0-150	350 mL/flushing cycle	\$100-200	Requires compressed gas; other sizes, materials, models available; no solvents used.
Tole Devices Co.	Sampling Pump	Portable; bladder (positive displacement)	1.38/48	SS, silicone, Delrin®, Tygon®	0-125	0-4,000 mL/min	\$800-1,000	Compressed gas required; DC control module; custom built.

## Construction Material Abbreviations:

PE Polyethylene  
 PP Polypropylene  
 PVC Polyvinyl chloride  
 SS Stainless steel  
 PC Polycarbonate  
 EPDM Ethylene-propylene diene (synthetic rubber)

## Other Abbreviations:

NA Not applicable  
 AC Alternating current  
 DC Direct current

NOTE: Other manufacturers market pumping devices which could be used for groundwater sampling, though not expressly designed for this purpose. The list is not meant to be all-inclusive and listing does not constitute endorsement for use. Information in the table is from sales literature and/or personal communication. No skimmer, scavenger-type, or high-capacity pumps are included.

Source: Barcelona et al., 1983.

Subject  
 GROUNDWATER SAMPLE  
 ACQUISITION AND ONSITE  
 WATER QUALITY TESTING

Number  
 SA-1.1  
 Revision  
 1

Page  
 30 of 33  
 Effective Date  
 03/08







<b>STANDARD OPERATING PROCEDURES</b>	Number SA-1.2	Page 1 of 20
	Effective Date 03/08	Revision 1
	Applicability	
	Prepared	
Subject SURFACE WATER AND SEDIMENT SAMPLING	Approved	

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
<b>1.0 PURPOSE .....</b>	<b>2</b>
<b>2.0 SCOPE .....</b>	<b>2</b>
<b>3.0 GLOSSARY .....</b>	<b>2</b>
<b>4.0 RESPONSIBILITIES .....</b>	<b>2</b>
<b>5.0 HEALTH AND SAFETY .....</b>	<b>3</b>
<b>6.0 PROCEDURES .....</b>	<b>5</b>
6.1 INTRODUCTION .....	5
6.1.1 Surface Water Sampling Equipment .....	5
6.1.2 Surface Water Sampling Techniques .....	8
6.2 ONSITE WATER QUALITY TESTING .....	9
6.3 SEDIMENT SAMPLING .....	9
6.3.1 General .....	9
6.3.2 Sampling Equipment and Techniques .....	10
<b>7.0 REFERENCES .....</b>	<b>13</b>
 <b><u>ATTACHMENTS</u></b>	
A SURFACE WATER SAMPLE LOG SHEET .....	15
B SOIL & SEDIMENT SAMPLE LOG SHEET .....	16
C GUIDANCE ON SAMPLE COLLECTION .....	17

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 2 of 20
	Revision 1	Effective Date 03/08

## 1.0 PURPOSE

This Standard Operating Procedure (SOP) describes procedures and equipment commonly used for collecting environmental samples of surface water and aquatic sediment for either onsite examination and chemical testing or for offsite laboratory analysis.

## 2.0 SCOPE

The information presented in this document is applicable to all environmental sampling of surface waters (Section 5.3) and aquatic sediments (Section 5.5), except where the analyte(s) may interact with the sampling equipment. The collection of concentrated sludges or hazardous waste samples from disposal or process lagoons often requires methods, precautions, and equipment different from those described herein.

## 3.0 GLOSSARY

Analyte – Chemical or radiochemical material whose concentration, activity, or mass is measured.

Composite Sample – A sample representing a physical average of grab samples.

Environmental Sample – A quantity of material collected in support of an environmental investigation that does not require special handling or transport considerations as detailed in SOP SA-6.1.

Grab Sample – A portion of material collected to represent material or conditions present at a single unit of space and time.

Hazardous Waste Sample – A sample containing (or suspected to contain) concentrations of contaminants that are high enough to require special handling and/or transport considerations per SOP SA-6.1.

Representativeness – A qualitative description of the degree to which an individual sample accurately reflects population characteristics or parameter variations at a sampling point. It is therefore an important characteristic not only of assessment and quantification of environmental threats posed by the site, but also for providing information for engineering design and construction. Proper sample location selection and proper sample collection methods are important to ensure that a truly representative sample has been collected.

## 4.0 RESPONSIBILITIES AND PERSONNEL QUALIFICATIONS

Project Manager - The Project Manager is responsible for determining the sampling objectives, initial sampling locations, and field procedures used in the collection of soil samples. The Project Manager also has the overall responsibility for seeing that all surface water and sediment sampling activities are properly conducted by appropriately trained personnel in accordance with applicable planning documents.

Field Operations Leader - This individual is primarily responsible for the execution of the planning document containing the Sampling and Analysis Plan (SAP). This is accomplished through management of a field sampling team for the proper acquisition of samples. He or she is responsible for the supervision of onsite analyses; ensuring proper instrument calibration, care, and maintenance; sample collection and handling; the completion and accuracy of all field documentation; and making sure that custody of all samples obtained is maintained according to proper procedures. When appropriate and as directed by the FOL, such responsibilities may be performed by other qualified personnel (e.g., field

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 3 of 20
	Revision 1	Effective Date 03/08

technicians) where credentials and time permit. The FOL is responsible for finalizing the locations for collection of surface water and sediment samples. The FOL is ultimately responsible for adherence to Occupational Safety and Health Administration (OSHA) regulations during these operations through self acquisition or through the management of a field team of samplers.

Site Safety Officer (SSO) - The SSO (or a qualified designee) is responsible for providing the technical support necessary to implement the project Health and Safety Plan (HASP). This includes but is not limited to performing air quality monitoring during sampling and boring and excavation activities, and ensuring that workers and offsite (downwind) individuals are not exposed to hazardous levels of airborne contaminants. The SSO or SSO designee may also be required to advise the FOL on other safety-related matters regarding boring and sampling, such as mitigative measures to address potential hazards from hazardous objects or conditions.

Project Geologist/Sampler - The project geologist/sampler is responsible for the proper acquisition of samples in accordance with this SOP and other project-specific documents. In addition, this individual is responsible for the completion of all required paperwork (e.g., sample log sheets, field notebook, , container labels, custody seals, and chain-of-custody forms) associated with the collection of those samples.

General personnel qualifications for groundwater sample collection and onsite water quality testing include the following:

- Occupational Safety and Health Administration (OSHA) 40-hour and applicable refresher training.
- Capability of performing field work under the expected physical and environmental (i.e., weather) conditions.
- Familiarity with appropriate procedures for sample documentation, handling, packaging, and shipping.

## 5.0 HEALTH AND SAFETY

Precautions to preserve the health and safety of field personnel implementing this SOP are distributed throughout. The following general hazards may also exist during field activities, and the means of avoiding them must be used to preserve the health and safety of field personnel:

**Bridge/Boat Sampling** – Potential hazards associated with this activity include:

- Traffic – one of the primary concerns as samplers move across a bridge because free space of travel is not often provided. Control measures should include:
  - When sampling from a bridge, if the samplers do not have at least 6 feet of free travel space or physical barriers separating them and the traffic patterns, the HASP will include a Traffic Control Plan.
  - The use of warning signs and high-visibility vests are required to warn oncoming traffic and to increase the visibility of sample personnel.
- Slips, trips, and falls from elevated surfaces are a primary concern. Fall protection shall be worn when or if samplers must lean over a rail to obtain sample material. A Fall Protection Competent Person (in accordance with Occupational safety and Health Administration [OSHA] fall protection standards) must be assigned to ensure that fall protection is appropriately and effectively employed
- Water hazards/drowning – if someone enters the water from an elevated surface (such as a bridge or dock) and when sampling from a boat. To minimize this potential, personnel shall wear United States Coast Guard (USCG)-approved floatation devices, and the sampling crew must also have on hand a

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 4 of 20
	Revision 1	Effective Date 03/08

Type IV Throwable Personal Floatation Device with at least 90 feet of 3/8-inch rope. See Section 5.5.2 of this SOP.

- Within the HASP, provisions will also be provided concerning the requirement of a Safe Vessel Certification or the necessity to conduct a boat inspection prior to use. In addition, the HASP shall also specify requirements as to whether the operator must be certified as a commercial boat operator and whether members of the sampling team must have a state-specific safe boating certification.

**Entering Water to Collect Samples** – Several hazards are associated with this activity and can be mitigated as follows:

- Personnel must wear a USCG-approved Floatation Device (selected and identified in the HASP). The SSO shall ensure that the device selected is in acceptable condition and suitable for the individual using it. This includes consideration of the weight of the individual.
- Lifelines shall be employed from a point on the shore. This activity will always be conducted with a Buddy. See Section 6.5.2.
- Personnel shall carry a probe to monitor the bottom ahead of them for drop offs or other associated hazards.
- The person in the water shall exercise caution concerning the path traveled so that the lifeline does not become entangled in underwater obstructions such as logs, branches, stumps, etc., thereby restricting its effectiveness in extracting the person from the water.
- Personnel shall not enter waters on foot in situations where natural hazards including alligators, snakes, as well as sharks, gars, and other predators within inland waterways may exist.
- In all cases, working along and/or entering the water during high currents or flood conditions shall be prohibited.
- Personnel shall not enter bodies of water where known debris exists that could result in injuries from cuts and lacerations.

Sampling in marshes or tidal areas in some instances can be accomplished using an all-terrain vehicle (ATV). This is not the primary recommended approach because the vehicle may become disabled, or weather conditions or tidal changes could result in environmental damage as well as loss of the vehicle. The primary approach is recommended to be on foot where minimal disturbance would occur. The same precautions specified above with regard to sediment disturbance apply as well as the previously described safety concerns associated with natural hazards. The natural hazards include alligators, bees (nests in dead falls and tree trunks), snakes, etc. In addition, moving through and over this terrain is difficult and could result in muscle strain and slips, trips, and falls. Common sense dictates that the sampler selects the most open accessible route over moderate terrain. Move slowly and deliberately through challenging terrain to minimize falls. Mud boots or other supportive PPE should be considered and specified in the HASP to permit samplers to move over soft terrain with the least amount of effort. In these situations, it is also recommended, as the terrain allows, that supplies be loaded and transported in a sled over the soft ground.

Working in these areas, also recognize the following hazards and means of protection against them:

**Insects** are also a primary concern. These include mosquitoes, ticks, spiders, bees, ants, etc. The HASP will identify those particular to your area. Typical preventative measures include:

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 5 of 20
	Revision 1	Effective Date 03/08

- Use insect repellent. Approval of various repellants should be approved by the Project Chemist or Project Manager.
- Wearing light-colored clothing to control heat load due to excessive temperatures. In addition, it makes it easier to detect crawling insects on your clothing.
- Taping pants to boots to deny access. Again, this is recommended to control access to the skin by crawling insects. Consultation with the Project Health and Safety Officer/SSO/Health and Safety Manager is recommended under extreme heat loads because this will create conditions of heat stress.
- Performing a body check to remove insects. The quicker you remove ticks, the less likely they will become attached and transfer bacteria to your bloodstream. Have your Buddy check areas inaccessible to yourself. This includes areas such as the upper back and between shoulder blades where it is difficult for you to examine and even more difficult for you to remove.

**Safety Reminder**

If you are allergic to bee or ant stings, it is especially critical that you carry your doctor-recommended antidote with you in these remote sampling locations due to the extended time required to extract incapacitated individuals as well as the effort required to extract them. In these scenarios, instruct your Buddy in the proper administration of the antidote.

In all cases, if you have received a sting, administer the antidote regardless of the immediate reaction, evacuate, and seek medical attention as necessary. The FOL and/or SSO will determine when and if you may return to the field based on the extent of the immune response and hazards or potential hazards identified in these locations. To the FOL and SSO, this is a serious decision you have to make as to whether to take someone vulnerable to these hazards into a remote location where you may not be able to carry them out. Consider it wisely.

**Poisonous Plants** – To minimize the potential of encountering poisonous plants in the field, at least one member of the field team needs to have basic knowledge of what these plants look like so that they can be recognized, pointed out to other field personnel, and avoided if at all possible. If the field team cannot avoid contact and must move through an area where these plants exist, the level of personal protective equipment (PPE) shall include Tyvek coveralls and enhanced decontamination procedures for the removal of oils from the tooling and/or equipment.

**Temperature-Related Stress** – Excessively cold temperatures may result in cold stress, especially when entering the water either intentionally or by accident. Provisions for combating this hazard should be maintained at the sample location during this activity. Excessively hot temperatures may result in heat stress especially in scenarios where equipment is packed through the marsh.

Because all of these activities are conducted outside, electrical storms are a significant concern. The following measures will be incorporated to minimize this hazard:

- Where possible, utilize commercial warning systems and weather alerts to detect storms moving into the area.
- If on or in the water, get out of the water. Move to vehicles or preferably into enclosed buildings with plumbing and wiring.
- Where warning systems are not available, follow the 30/30 Rule (*if there are less than 30 seconds between thunder and lightning, go inside for at least 30 minutes after the last thunder*).

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 6 of 20
	Revision 1	Effective Date 03/08

See Section 4.0 of the Health and Safety Guidance Manual (HSGM) for additional protective measures.

## 6.0 PROCEDURES

### 6.1 Introduction

Collecting a representative sample of surface water or sediment may be difficult because of water movement, stratification, or heterogeneous distribution of the targeted analytes. To collect representative samples, one must standardize sampling methods related to site selection, sampling frequency, sample collection, sampling devices, and sample handling, preservation, and identification. Regardless of quality control applied during laboratory analyses and subsequent scrutiny of analytical data packages, reported data are no better than the confidence that can be placed in the representativeness of the samples. Consult Appendix C for guidance on sampling that should be considered during project planning and that may be helpful to field personnel.

#### 6.3.4 Surface Water Sampling Equipment

The selection of sampling equipment depends on the site conditions and sample type to be acquired. In general, the most representative samples are obtained from mid-channel at a stream depth of 0.5 foot in a well-mixed stream; however, project-specific planning documents will address site-specific sampling requirements including sample collection points and sampling equipment. The most frequently used samplers include the following:

- Peristaltic pump
- ~~Bailer~~
- Dip sampler
- ~~Weighted bottle~~
- ~~Hand pump~~
- ~~Kemmerer~~
- Depth-integrating sampler

The dip sampler and weighted bottle sampler are used most often, and detailed discussions for these devices and the Kemmerer sampler are addressed subsequently in this section.

The criteria for selecting a sampler include:

1. Disposability and/or easy decontamination.
2. Inexpensive cost (if the item is to be disposed).
3. Ease of operation.
4. Non-reactive/non-contaminating properties - Teflon-coated, glass, stainless-steel or polyvinyl chloride (PVC) sample chambers are preferred (in that order).

Measurements collected for each sample (grab or each aliquot collected for compositing) shall include but not be limited to:

- Specific conductance
- Temperature
- pH
- Dissolved oxygen

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 7 of 20
	Revision 1	Effective Date 03/08

Sample measurements shall be conducted as soon as the sample is acquired. Measurement techniques described in SOP SA-1.1 shall be followed. All pertinent data and results shall be recorded in a field notebook or on sample log sheets (see Attachment A) or an equivalent electronic form(s). These analyses may be selected to provide information on water mixing/stratification and potential contamination. Various types of water bodies have differing potentials for mixing and stratification.

In general, the following equipment if necessary for obtaining surface water samples:

- Required sampling equipment, which may include a remote sampling pole, weighted bottle sampler, Kemmerer sampler, or other device.
- Real-time air monitoring instrument (e.g., PID, FID) as directed in the project-specific planning document.
- Required PPE as directed in the project-specific planning document, which may include:
  - Nitrile surgeon's or latex gloves (layered as necessary).
  - Safety glasses.
  - Other items identified on the Safe Work Permit that may be required based on location-specific requirements (e.g., hearing protection, steel-toed work boots, hard hat). These provisions will be listed in the HASP or addressed by the FOL and/or SSO.

**Safety Reminder**

The use of latex products may elicit an allergic reaction in some people. Should this occur, remove the latex gloves, treat for an allergic reaction, and seek medical attention as necessary.

- Required paperwork (see SOP SA-6.3 and Attachments A and B to this SOP).
- Required decontamination equipment.
- Required sample containers.
- Sealable polyethylene bags (e.g., Ziploc<sup>®</sup> baggies).
- Heavy-duty cooler.
- Ice.
- Paper towels and garbage bags.
- Chain-of-custody records and custody seals.

**Dip Sampling**

Specific procedures for collecting a dip or grab sample of surface water can vary based on site-specific conditions (e.g., conditions near the shore and how closely a sampler can safely get to the shore). The general procedure for collecting a sample using a pole or directly from the water body is as follows:

1. If using a remote sampling pole, securely attach the appropriate sample container to a pole of sufficient length to reach the water to be sampled. Samples for volatile analysis should be collected

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 8 of 20
	Revision 1	Effective Date 03/08

first. Use PPE as described in the HASP. When sample containers are provided pre-preserved or if the pole cannot accommodate a particular sample container, use a dedicated, clean, unpreserved bottle/container for sampling and transfer to an appropriately preserved container.

2. Remove the cap. Do not place the cap on the ground or elsewhere where it might become contaminated.
3. Carefully dip the container into the water just below the surface (or as directed by project-specific planning documents), and allow the bottle to fill. Sample bottles for volatile analysis must be filled with no headspace. Avoid contacting the bottom of the water body because this will disturb sediment that may interfere with the surface water sample.
4. Retrieve the container and carefully replace the cap securely. If using a container other than the sample bottle, pour the water from that container into the sample bottle and replace the cap securely.
5. Use a clean paper towel to clean and dry the outside of the container.
6. Affix a sample label to each container, ensuring that each label is completely carefully, clearly, and completely, addressing all of the categories described in SOP SA-6.3.
7. Proceed with the handling and processing of each sample container as described in SOP SA-6.2.

Constituents measured in grab samples collected near the water surface are only indicative of conditions near the surface of the water and may not be a true representation of the total concentration distributed throughout the water column and in the cross section. Therefore, as possible based on site conditions, the sampler may be required to augment dip samples with samples that represent both dissolved and suspended constituents and both vertical and horizontal distributions.

**CAUTION**

In areas prone to natural hazards such as alligators and snakes, etc., always use a buddy as a watch. Always have and use a lifeline or throwable device to extract persons who could potentially fall into the water. Be attentive to the signs, possible mounds indicating nests, and possible slides into the water. Remember that although snakes are typically encountered on the ground, it is not unheard of to see them on low-hanging branches. Be attentive to your surroundings because these may indicate that hazards are nearby.

Weighted Bottle Sampling

A grab sample can also be collected using a weighted holder that allows a bottle to be lowered to any desired depth, opened for filling, closed, and returned to the surface. This allows discrete sampling with depth. Several of these samples can be combined to provide a vertical composite. Alternatively, an open bottle can be lowered to the bottom and raised to the surface at a uniform rate so that the bottle collects sample throughout the total depth and is just filled on reaching the surface. The resulting sample using either method will roughly approach what is known as a depth-integrated sample.

A closed weighted bottle sampler consists of glass or plastic bottle with a stopper, a weight and/or holding device, and lines to open the stopper and lower or raise the bottle. The general procedure for sampling with this device is as follows:

1. Gently lower the sampler to the desired depth so as not to remove the stopper prematurely (watch for bubbles).

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 9 of 20
	Revision 1	Effective Date 03/08

2. When the desired depth is reached, pull out the stopper with a sharp jerk of the stopper line.
3. Allow the bottle to fill completely, as evidenced by the absence of air bubbles.
4. Raise the sampler and cap the bottle.
5. Use a paper towel to clean and dry the outside of the container. This bottle can be used as the sample container as long as the bottle is an approved container type.
6. Affix a sample label to each container, ensuring that each label is completely carefully, clearly, and completely, addressing all of the categories described in SOP SA-6.3.
7. Proceed with the handling and processing of each sample container as described in SOP SA-6.2.

#### Kemmerer Sampler

If samples are desired at a specific depth, and the parameters to be measured do not require a Teflon-coated sampler, a standard Kemmerer sampler may be used. The Kemmerer sampler is a brass, stainless steel or acrylic cylinder with rubber stoppers that leave the ends open while it is lowered in a vertical position (thus allowing free passage of water through the cylinder). A "messenger" is sent down the line when the sampler is at the designated depth to cause the stoppers to close the cylinder, which is then raised. Water is removed through a valve to fill sample bottles. The general procedure for sampling with this device is as follows:

1. Gently lower the sampler to the desired depth.
2. When the desired depth is reached, send down the messenger to close the cylinder and then raise the sampler.
3. Open the sampler valve to fill each sample bottle (filling bottles for volatile analysis first).
4. Use a paper towel to clean and dry the outside of the container.
5. Affix a sample label to each container, ensuring that each label is completely carefully, clearly, and completely, addressing all of the categories described in SOP SA-6.3.
6. Proceed with the handling and processing of each sample container as described in SOP SA-6.2.

#### **6.3.5 Surface Water Sampling Techniques**

Samples collected during site investigations may be grab samples or composite samples. The following general procedures apply to various types of surface water collection techniques:

- If a clean, pre-preserved sample container is not used, rinse the sample container least once with the water to be sampled before the sample is collected. This is not applicable when sample containers are provided pre-preserved because doing so will wash some or all of the preservative out of the bottle.
- For sampling moving water, collect the farthest downstream sample first, and continue sample collection in an upstream direction. In general, work from zones suspected of low contamination to zones of high contamination.
- Take care to avoid excessive agitation of the water because loss of volatile constituents could result.

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 10 of 20
	Revision 1	Effective Date 03/08

- When obtaining samples in 40 mL vials with septum-lined lids for volatile organics analysis, fill the container completely (with a meniscus) to exclude any air space in the top of the bottle and to be sure that the Teflon liner of the septum faces in after the vial is filled and capped. Turn the vial upside down and tap gently on your wrist to check for air bubbles. If air bubbles rise in the bottle, add additional sample volume to the container.
- Do not sample at the surface, unless sampling specifically for a known constituent that is immiscible and on top of the water. Instead, invert the sample container, lower it to the approximate depth, and hold it at about a 45-degree angle with the mouth of the bottle facing upstream.

#### **6.4      Onsite Water Quality Testing**

Onsite water quality testing shall be conducted as described in SOP SA-1.1.

#### **6.5      Sediment Sampling**

##### **6.5.1      General**

If composite surface water samples are collected, sediment samples are usually collected at the same locations as the associated surface water samples. If only one sediment sample is to be collected, the sampling location shall be approximately at the center of the water body, in a depositional area if possible based on sample location restraints (see below), unless the SAP states otherwise.

Generally, coarser-grained sediments are deposited near the headwaters of reservoirs. Bed sediments near the center of a water body will be composed of fine-grained materials that may, because of their lower porosity and greater surface area available for adsorption, contain greater concentrations of contaminants. The shape, flow pattern, bathymetry (i.e., depth distribution), and water circulation patterns must all be considered when selecting sediment sampling sites. In streams, areas likely to have sediment accumulation (e.g., bends, behind islands or boulders, quiet shallow areas or very deep, low-velocity areas) shall be sampled, in general, and areas likely to show net erosion (i.e., high-velocity, turbulent areas) and suspension of fine solid materials shall be generally avoided. Follow instructions in the SAP, as applicable.

Chemical constituents associated with bottom material may reflect an integration of chemical and biological processes. Bottom samples reflect the historical input to streams, lakes, and estuaries with respect to time, application of chemicals, and land use. Bottom sediments (especially fine-grained material) may act as a sink or reservoir for adsorbed heavy metals and organic contaminants (even if water column concentrations are less than detection limits). Therefore, it is important to minimize the loss of low-density "fines" during any sampling process.

Samples collected for volatile organic compound (VOC) analysis must be collected prior to any sample homogenization. Regardless of the method used for collection, the aliquot for VOC analysis must be collected directly from the sampling device (hand auger bucket, scoop, trowel), to the extent practical. If a device such as a dredge is used, the aliquot should be collected after the sample is placed in the mixing container prior to mixing.

In some cases, the sediment may be soft and not lend itself to collection by plunging Encore™ or syringe samplers into the sample matrix. In these cases, it is appropriate to open the sampling device, (Encore™ barrel or syringe) prior to sample collection, and carefully place the sediment in the device, filling it fully with the required volume of sample.

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 11 of 20
	Revision 1	Effective Date 03/08

On active or former military sites, ordnance items may be encountered in some work areas. Care should be exercised when handling site media (such as if unloading a dredge as these materials may be scooped up). If suspected ordnance items are encountered, stop work immediately, move to shore and notify the Project Manager and Health and Safety Manager.

All relevant information pertaining to sediment sampling shall be documented as applicably described in SOP SA-6.3 and Attachment B or an equivalent electronic form.

### 6.5.2 Sampling Equipment and Techniques for Bottom Materials

A bottom-material sample may consist of a single scoop or core, or may be a composite of several individual samples in the cross section. Sediment samples may be obtained using onshore or offshore techniques.

#### **SAFETY REMINDER**

The following health and safety provisions apply when working on/over/near water:

- At least two people are required to be present at the sampling location in situations where the water depth and/or movement deem it necessary, each wearing a USCG-approved Personal Flotation Devices
- A minimum of three people are required if any of the following conditions are anticipated or observed:
  - Work in a waterway that is turbulent or swift that could sweep a sampler down stream should he or she fall in accidentally.
  - The underwater walking surface (e.g., stream/river bed) is suspected or observed to involve conditions that increase the potential for a worker to fall into the water. Examples include large/uneven rocks or boulders, dense mud or sediment that could entrap worker's feet, etc.
  - Waterway is tidal, and conditions such as those listed above could rapidly change.

The third person in the above condition must be equipped and prepared to render emergency support [e.g., lifeline, tethered Personal Flotation Device (Throwable Type IV, life saver), skiff, means to contact external emergency response support, etc.]

The following samplers may be used to collect sediment samples:

- Scoop sampler
- Dredge samplers
- ~~Coring samplers~~

Each type of sampler is discussed below.

In general, the following equipment if necessary for obtaining sediment samples:

- Required sampling equipment, which may include a scoop sampler, dredge sampler, coring sampler, or stainless steel or pre-cleaned disposable trowel.

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 12 of 20
	Revision 1	Effective Date 03/08

- Stainless bowl or pre-cleaned disposable bowl to homogenize sample.
- Real-time air monitoring instrument (e.g., PID, FID) as directed in the project-specific planning document.
- Required PPE as directed in the project-specific planning document, which may include:
  - Nitrile surgeon's or latex gloves (layered as necessary).
  - Safety glasses.
  - Other items identified on the Safe Work Permit that may be required based on location-specific requirements (e.g., hearing protection, steel-toed work boots, hard hat). These provisions will be listed in the HASP or addressed by the FOL and/or SSO.
  - Required paperwork (see SOP SA-6.3 and Attachments A and B to this SOP).
  - Required decontamination equipment.
  - Required sample containers.
  - Sealable polyethylene bags (e.g., Ziploc® baggies).
  - Heavy-duty cooler.
  - Ice.
  - Paper towels and garbage bags.
  - Chain-of-custody records and custody seals.

#### Scoop Sampler

A scoop sampler consists of a pole to which a jar or scoop is attached. The pole may be made of bamboo, wood, PVC, or aluminum and be either telescoping or of fixed length. The scoop or jar at the end of the pole is usually attached using a clamp.

If the water body can be sampled from the shore or if the sampler can safely wade to the required location, the easiest and best way to collect a sediment sample is to use a scoop sampler. Scoop sampling also reduces the potential for cross-contamination. The general scoop sampling procedure is as follows:

1. Reach over or wade into the water body.
2. While facing upstream (into the current), scoop the sampler along the bottom in an upstream direction. Although it is very difficult not to disturb fine-grained materials at the sediment-water interface when using this method, try to keep disturbances to a minimum.

#### Dredge Samplers

Dredges are generally used to sample sediments that cannot easily be obtained using coring devices (e.g., coarse-grained or partially cemented materials) or when large quantities of sample are required. Dredges generally consist of a clam shell arrangement of two buckets. The buckets may either close upon impact or be activated by use of a "messenger." Some dredges are heavy and may require use of a winch and crane assembly for sample retrieval. The three major types of dredges are Peterson, Eckman and Ponar.

The Peterson dredge is used when the bottom is rocky, in very deep water, or when the flow velocity is high. The Peterson dredge shall be lowered very slowly as it approaches bottom, because it can force out and miss lighter materials if allowed to drop freely.

The Eckman dredge has only limited usefulness. It performs well where bottom material is unusually soft, as when covered with organic sludge or light mud. It is unsuitable, however, for sandy, rocky, and hard bottoms and is too light for use in streams with high flow velocities.

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 13 of 20
	Revision 1	Effective Date 03/08

The Ponar dredge is a Peterson dredge modified by the addition of side plates and a screen on the top of the sample compartment. The screen over the sample compartment permits water to pass through the sampler as it descends, thus reducing the "shock wave." The Ponar dredge is easily operated by one person in the same fashion as the Peterson dredge. The Ponar dredge is one of the most effective samplers for general use on all types of substrates.

The general procedure for using dredge samplers is as follows:

1. Gently lower the dredge to the desired depth.
2. When the desired depth is reached, send the messenger down to cable to close the cylinder and then carefully raise the sampler.
3. Open the sampler to retrieve the sediment.
4. Transfer the sediment to the bowl in which it will be homogenized. Fill the sample bottle(s) for volatile analysis *prior to* homogenization. Homogenize the remainder of the sediment collected.
5. Fill the containers for all analyses other and VOCs.
6. Use a paper towel to clean and dry the outside of each container.
7. Affix a sample label to each container, ensuring that each label is completely carefully, clearly, and completely, addressing all of the categories described in SOP SA-6.3.
8. Proceed with the handling and processing of each sample container as described in SOP SA-6.2.

**SAFETY REMINDER**

Safety concerns using these dredges include lifting hazards, pinches, and compressions (several pinch points exist within the jaws and levers). In all cases, handle the dredge by the rope to avoid capturing fingers/hands.

Coring Samplers

Coring samplers are used to sample vertical columns of sediment. Many types of coring devices have been developed depending on the depth of water from which the sample is to be obtained, the nature of the bottom material, and the length of core to be collected. They vary from hand-push tubes to electronic vibrational core tube drivers.

Coring devices are particularly useful in pollutant monitoring because turbulence created by descent through the water is minimal, thus the fines at the sediment-water interface are only minimally disturbed. The sample is withdrawn intact, permitting the removal of only those layers of interest.

In shallow, wadeable waters, the use of a core liner or tube manufactured of Teflon or plastic is recommended for the collection of sediment samples. Caution should be exercised not to disturb the bottom sediments when the sample is obtained by wading in shallow water. The general procedure to collecting a sediment sample with a core tube is as follows:

1. Push the tube into the substrate until 4 inches or less of the tube is above the sediment-water interface. When sampling hard or coarse substrates, a gentle rotation of the tube while it is being pushed will facilitate greater penetration and decrease core compaction.

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 14 of 20
	Revision 1	Effective Date 03/08

2. Cap the top of the tube to provide suction and reduce the chance of losing the sample.
3. Slowly extract the tube so as not to lose sediment from the bottom of the tube. Cap the bottom of the tube before removing it from the water. This will also help to minimize loss of sample.
4. Transfer the sediment to the bowl in which it will be homogenized. Fill the sample bottle(s) for volatile analysis prior to homogenization. Homogenize the remainder of the sediment collected.
5. Fill the containers for all analyses other and VOCs.
6. Use a paper towel to clean and dry the outside of each container.
7. Affix a sample label to each container, ensuring that each label is completely carefully, clearly, and completely, addressing all of the categories described in SOP SA-6.3.
8. Proceed with the handling and processing of each sample container as described in SOP SA-6.2.

In deeper, non-wadeable water bodies, sediment cores may be collected from a bridge or boat using different coring devices such as Ogeechee Sand Pounders, gravity cores, and vibrating coring devices. All three devices utilize a core barrel with a core liner tube system. The core liners can be removed from the core barrel and replaced with a clean core liner after each sample. Before extracting the sediment from the coring tubes, the clear supernatant above the sediment-water interface in the core should be decanted from the tube. This is accomplished by turning the core tube to its side and gently pouring the liquid out until fine sediment particles appear in the waste liquid. Post-retrieval processing of samples is the same as above.

## 7.0 REFERENCES

American Public Health Association, 19.99 Standard Methods for the Examination of Water and Wastewater, 20th Edition, APHA, Washington, D.C.

Feltz, H. R., 1980. Significance of Bottom Material Data in Evaluating Water Quality in Contaminants and Sediments. Ann Arbor, Michigan, Ann Arbor Science Publishers, Inc., V. 1, p. 271-287.

Kittrell, F. W., 1969. A Practical Guide to Water Quality Studies of Streams. U.S. Federal Water Pollution Control Administration, Washington, D.C., 135 p.

U.S. EPA, 1984. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-84-017.

U.S. EPA, 2001. Environmental Investigations Standard Operating Procedures and Quality Assurance Manual. Water Surveillance Branch, USEPA Surveillance and Analytical Division, Athens, Georgia.

U.S. Geological Survey, 1977. National Handbook of Recommended Methods for Water-Data Acquisition. Office of Water Data Coordination, USGS, Reston, Virginia.



Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 16 of 20
	Revision 1	Effective Date 03/08

**ATTACHMENT B**  
**SOIL & SEDIMENT SAMPLE LOG SHEET**



Tetra Tech NUS, Inc.

**SOIL & SEDIMENT SAMPLE LOG SHEET**

Page \_\_\_ of \_\_\_

Project Site Name: _____	Sample ID No.: _____
Project No.: _____	Sample Location: _____
<input type="checkbox"/> Surface Soil	Sampled By: _____
<input type="checkbox"/> Subsurface Soil	C.O.C. No.: _____
<input type="checkbox"/> Sediment	Type of Sample:
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Low Concentration
<input type="checkbox"/> QA Sample Type: _____	<input type="checkbox"/> High Concentration

GRAB SAMPLE DATA:			
Date:	Depth	Color	Description (Sand, Silt, Clay, Moisture, etc.)
Time: _____			
Method: _____			
Monitor Reading (ppm): _____			

COMPOSITE SAMPLE DATA:				
Date:	Time	Depth	Color	Description (Sand, Silt, Clay, Moisture, etc.)
Method:				
Monitor Readings (Range in ppm):				

SAMPLE COLLECTION INFORMATION:			
Analysis	Container Requirements	Collected	Other

<b>OBSERVATIONS / NOTES:</b>	<b>MAP:</b>

<b>Circle if Applicable:</b>	<b>Signature(s):</b>
MS/MSD      Duplicate ID No.:	

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 17 of 20
	Revision 1	Effective Date 03/08

## APPENDIX C

### GUIDANCE ON SAMPLING DESIGN AND SAMPLE COLLECTION

#### **C.1 Defining the Sampling Program**

Many factors are considered in developing a sampling program for surface water and/or sediment, including study objectives, accessibility, site topography, physical characteristics of the water body (e.g., flow and mixing), point and diffuse sources of contamination, and personnel and equipment available to conduct the study. For waterborne constituents, dispersion depends on vertical and lateral mixing within the body of water. For sediment, dispersion depends on bottom current or flow characteristics, sediment characteristics (e.g., density, size), and geochemical properties (that affect adsorption/desorption). The hydrogeologist developing the sampling plan must therefore know not only the mixing characteristics of streams and lakes but must also understand the role of fluvial-sediment transport, deposition, and chemical sorption.

##### **C.1.1 Sampling Program Objectives**

The scope of the sampling program must consider the sources and potential pathways for transport of contamination to or within a surface water body. Sources may include point sources (leaky tanks, outfalls, etc.) or nonpoint sources (e.g., contaminated runoff). The major pathways for surface water contamination (not including airborne deposition) are overland runoff, leachate influx to the water body, direct waste disposal (solid or liquid) into the water body, and groundwater flow influx from upgradient. The relative importance of these pathways, and therefore the design of the sampling program, is controlled by the physiographic and hydrologic features of the site, the drainage basin(s) that encompasses the site, and the history of site activities.

Physiographic and hydrologic features to be considered include slopes and runoff direction, areas of temporary flooding or pooling, tidal effects, artificial surface runoff controls such as berms or drainage ditches (and when they were constructed relative to site operation), and locations of springs, seeps, marshes, etc. In addition, the obvious considerations such as the locations of man-made discharge points to the nearest stream (intermittent or flowing), pond, lake, estuary, etc. shall be considered.

A more subtle consideration in designing the sampling program is the potential for dispersion of dissolved or sediment-associated contaminants away from the source. The dispersion could lead to a more homogeneous distribution of contamination at low or possibly non-detectable concentrations. Such dispersion does not, however, always readily occur. For example, obtaining a representative sample of contamination from a main stream immediately below an outfall or a tributary is difficult because the inflow frequently follows a stream bank with little lateral mixing for some distance. Sampling alternatives to overcome this situation include: (1) moving the sampling location far enough downstream to allow for adequate mixing, or (2) collecting integrated samples in a cross section. Also, non-homogeneous distribution is a particular problem with regard to sediment-associated contaminants, which may accumulate in low-energy environments (coves, river bends, deep spots, or even behind boulders) near or distant from the source while higher-energy areas (main stream channels) near the source may show no contaminant accumulation.

The distribution of particulates within a sample itself is an important consideration. Many organic compounds are only slightly water soluble and tend to adsorb onto particulate matter. Nitrogen, phosphorus, and heavy metals may also be transported by particulates. Samples must be collected with a representative amount of suspended material; transfer from the sampling device shall include transferring a proportionate amount of the suspended material.

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 18 of 20
	Revision 1	Effective Date 03/08

### C.1.2 Location of Sampling Stations

Accessibility is the primary factor affecting sampling costs. The desirability and utility of a sample for analysis and consideration of site conditions must be balanced against the costs of collection as controlled by accessibility. Bridges or piers are the first choice for locating a sampling station on a stream because bridges provide ready access and also permit the sampling technician to sample any point across the stream. A boat or pontoon (with an associated increase in cost) may be needed to sample locations on lakes, reservoirs, or larger rivers. Frequently, however, a boat will take longer to cross a water body and will hinder manipulation of the sampling equipment. Wading for samples is not recommended unless it is known that contaminant levels are low so that skin contact will not produce adverse health effects. This provides a built in margin of safety in the event that wading boots or other protective equipment should fail to function properly. If it is necessary to wade into the water body to obtain a sample, the sampler shall be careful to minimize disturbance of bottom sediments and must enter the water body downstream of the sampling location. If necessary, the sampling technician shall wait for the sediments to settle before taking a sample.

Under ideal and uniform contaminant dispersion conditions in a flowing stream, the same concentrations of each contaminant would occur at all points along the cross section. This situation is most likely downstream of areas of high turbulence. Careful site selection is needed to ensure, as nearly as possible, that samples are taken where uniform flow or deposition and good mixing conditions exist.

The availability of stream flow and sediment discharge records can be an important consideration in choosing sampling sites in streams. Stream flow data in association with contaminant concentration data are essential for estimating the total contaminant loads carried by the stream. If a gaging station is not conveniently located on a selected stream, the project hydrogeologist shall explore the possibility of obtaining stream flow data by direct or indirect methods. Remember these locations are also where you may encounter natural hazards as these are areas where they hunt. Always exercise extreme caution.

### C.1.3 Frequency of Sampling

The sampling frequency and objectives of the sampling event will be defined by the project planning documents. For single-event site or area characterization sampling, both bottom material and overlying water samples shall be collected at the specified sampling stations. If valid data are available on the distribution of a contaminant between the solid and aqueous phases, it may be appropriate to sample only one phase, although this is not often recommended. If samples are collected primarily for monitoring purposes (i.e., consisting of repetitive, continuing measurements to define variations and trends at a given location), water samples should be collected at a pre-established and constant interval as specified in the project plans (often monthly or quarterly and during droughts and floods). Samples of bottom material should generally be collected from fresh deposits at least yearly, and preferably seasonally, during both spring and fall.

The variability in available water quality data shall be evaluated before determining the number and collection frequency of samples required to maintain an effective monitoring program.

## C.2 Surface Water Sample Collection

### C.2.1 Streams, Rivers, Outfalls and Drainage Features

Methods for sampling streams, rivers, outfalls, and drainage features (ditches, culverts) at a single point vary from the simplest of hand-sampling procedures to the more sophisticated multi-point sampling techniques known as the equal-width-increment (EWI) method or the equal-discharge-increment (EDI) methods (see below).

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 19 of 20
	Revision 1	Effective Date 03/08

Samples from different depths or cross-sectional locations in the watercourse taken during the same sampling episode shall be composited. However, samples collected along the length of the watercourse or at different times may reflect differing inputs or dilutions and therefore shall not be composited. Generally, the number and type of samples to be taken depend on the river's width, depth, and discharge and on the suspended sediment the stream or river transports. The greater the number of individual points that are sampled, the more likely that the composite sample will truly represent the overall characteristics of the water.

In small streams less than about 20 feet wide, a sampling site can generally be found where the water is well mixed. In such cases, a single grab sample taken at mid-depth in the center of the channel is adequate to represent the entire cross section.

For larger streams, at least one vertical composite shall be taken with one sample each from just below the surface, at mid-depth, and just above the bottom. The measurement of dissolved oxygen (DO), pH, temperature, conductivity, etc., shall be made on each aliquot of the vertical composite and on the composite itself. For rivers, several vertical composites shall be collected, as directed in the project planning documents.

### **C.2.2 Lakes, Ponds and Reservoirs**

Lakes, ponds, and reservoirs have a much greater tendency to stratify than rivers and streams. The relative lack of mixing requires that more samples be obtained. The number of water sampling sites on a lake, pond, or impoundment will vary with the size and shape of the basin. In ponds and small lakes, a single vertical composite at the deepest point may be sufficient. Similarly, measurement of DO, pH, temperature, etc. is to be conducted on each aliquot of the vertical composite and on the composite itself. In naturally formed ponds, the deepest point may have to be determined empirically; in impoundments, the deepest point is usually near the dam.

In lakes and larger reservoirs, several vertical composites shall be composited to form a single sample if a sample representative of the water column is required. These vertical composites are often collected along a transect or grid. In some cases, it may be of interest to form separate composites of epilimnetic and hypolimnetic zones. In a stratified lake, the epilimnion is the thermocline that is exposed to the atmosphere. The hypolimnion is the lower, "confined" layer that is only mixed with the epilimnion and vented to the atmosphere during seasonal "overturn" (when density stratification disappears). These two zones may thus have very different concentrations of contaminants if input is only to one zone, if the contaminants are volatile (and therefore vented from the epilimnion but not the hypolimnion), or if the epilimnion only is involved in short-term flushing (i.e., inflow from or outflow to shallow streams). Normally, however, a composite consists of several vertical composites with samples collected at various depths.

In lakes with irregular shape and with bays and coves that are protected from the wind, separate composite samples may be needed to adequately represent water quality because it is likely that only poor mixing will occur. Similarly, additional samples are recommended where discharges, tributaries, land use characteristics, and other such factors are suspected of influencing water quality.

Many lake measurements are now made in situ using sensors and automatic readout or recording devices. Single and multi-parameter instruments are available for measuring temperature, depth, pH, oxidation-reduction potential (ORP), specific conductance, DO, some cations and anions, and light penetration.

Subject SURFACE WATER AND SEDIMENT SAMPLING	Number SA-1.2	Page 20 of 20
	Revision 1	Effective Date 03/08

### ~~C.2.3 Estuaries~~

~~Estuarine areas are, by definition, zones where inland freshwaters (both surface and ground) mix with oceanic saline waters. Knowledge of the estuary type may be necessary to determine sampling locations. Estuaries are generally categorized into one of the following three types dependent on freshwater inflow and mixing properties:~~

- ~~• Mixed Estuary - characterized by the absence of a vertical halocline (gradual or no marked increase in salinity in the water column) and a gradual increase in salinity seaward. Typically, this type of estuary is shallow and is found in major freshwater sheet flow areas. Because this type of estuary is well mixed, sampling locations are not critical.~~
- ~~• Salt Wedge Estuary - characterized by a sharp vertical increase in salinity and stratified freshwater flow along the surface. In these estuaries, the vertical mixing forces cannot override the density differential between fresh and saline waters. In effect, a salt wedge tapering inland moves horizontally back and forth with the tidal phase. If contamination is being introduced into the estuary from upstream, water sampling from the salt wedge may miss it entirely.~~
- ~~• Oceanic Estuary - characterized by salinities approaching full-strength oceanic waters. Seasonally, freshwater inflow is small, with the preponderance of the fresh-saline water mixing occurring near or at the shore line.~~

~~Sampling in estuarine areas is normally based on the tidal phase, with samples collected on successive slack tides (i.e., when the tide turns). Estuarine sampling programs shall include vertical salinity measurements at 1- to 5-foot increments, coupled with vertical DO and temperature profiles.~~

<b>STANDARD OPERATING PROCEDURES</b>	Number SA-1.3	Page 1 of 30
	Effective Date 03/08	Revision 1
	Applicability	
	Prepared	
Subject SOIL SAMPLING	Approved	

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY.....	2
4.0 RESPONSIBILITIES AND PERSONNEL QUALIFICATIONS.....	3
5.0 HEALTH AND SAFETY .....	4
6.0 PROCEDURES .....	5
6.1 Overview .....	5
6.2 Soil Sample Collection .....	6
<del>6.2.1 Procedure for Preserving and Collecting Soil Samples for Volatile Organic Compound Analysis .....</del>	<del>6</del>
6.2.2 Procedure for Collecting Soil Samples for Non-Volatile Analyses.....	9
6.2.3 Procedure for Collecting Undisturbed Soil Samples.....	10
6.3 Surface Soil Sampling .....	12
6.4 Near-Surface Soil Sampling .....	14
6.5 Subsurface Soil Sampling With a Hand Auger .....	15
<del>6.5.1 Sampling Using Stainless Steel Soil Corers .....</del>	<del>16</del>
6.6 Subsurface Soil Sampling with a Split-Barrel Sampler .....	17
6.7 Subsurface Soil Sampling Using Direct-Push Technology.....	18
<del>6.8 Excavation and Sampling of Test Pits and Trenches .....</del>	<del>18</del>
<del>6.8.1 Applicability .....</del>	<del>18</del>
<del>6.8.2 Test Pit and Trench Excavation.....</del>	<del>19</del>
<del>6.8.3 Sampling in Test Pits and Trenches .....</del>	<del>21</del>
<del>6.8.4 Backfilling of Trenches and Test Pits .....</del>	<del>25</del>
6.9 Records .....	25
7.0 REFERENCES .....	26

**ATTACHMENTS**

A	SOIL & SEDIMENT SAMPLE LOG SHEET .....	17
B	SPLIT-SPOON SAMPLER .....	18
<del>C</del>	<del>TEST PIT LOG .....</del>	<del>19</del>
<del>D</del>	<del>REMOTE SAMPLE HOLDER FOR TEST PIT/TRENCH SAMPLING .....</del>	<del>20</del>

Subject  SOIL SAMPLING	Number SA-1.3	Page 2 of 30
	Revision 1	Effective Date 03/08

### 1.0 PURPOSE

This Standard Operating Procedure (SOP) describes the procedures to be used to collect surface, near-surface, and subsurface soil samples. Additionally, it describes the methods for sampling of test pits and trenches to determine subsurface soil and rock conditions and for recovery of small-volume or bulk samples from pits.

### 2.0 SCOPE

This document applies to the collection of surface, near-surface, and subsurface soil samples exposed through hand digging, hand augering, drilling, or machine excavating at hazardous substance sites for laboratory testing, onsite visual examination, and onsite testing.

### 3.0 GLOSSARY

Composite Sample - A composite sample is a combination of more than one grab sample from various locations and/or depths and times that is homogenized and treated as one sample. This type of sample is usually collected when determination of an average waste concentration for a specific area is required. Composite samples shall not be collected for volatile organics analysis.

Confined Space - As stipulated in 29 Code of Federal Regulations (CFR) 1910.146, a confined space means a space that: (1) is large enough and so configured that an employee can bodily enter and perform assigned work; (2) has limited or restricted means for entry or exit (e.g., tanks, vessels, silos, storage bins, hoppers, vaults, pits, and excavations); and (3) is not designed for continuous employee occupancy. TtNUS considers all confined space as permit-required confined spaces.

Grab Sample - One sample collected at one location and at one specific time.

Hand Auger - A sampling device used to extract soil from the ground.

Representativeness - A qualitative description of the degree to which an individual sample accurately reflects population characteristics or parameter variations at a sampling point. It is therefore an important characteristic not only of assessment and quantification of environmental threats posed by the site, but also for providing information for engineering design and construction. Proper sample location selection and proper sample collection methods are important to ensure that a truly representative sample has been collected.

Sample for Non-Volatile Analyses - Includes all chemical parameters other than volatile organics (e.g., semivolatiles, pesticides/PCBs, metals, etc.) and those engineering parameters that do not require undisturbed soil for their analysis.

Split-Barrel Sampler - A steel tube, split in half lengthwise, with the halves held together by threaded collars at either end of the tube. Also called a split-spoon sampler, this device can be driven into resistant materials using a drive weight mounted in the drilling string. A standard split-barrel sampler is typically available in two common lengths, providing either 20-inch or 26-inch longitudinal clearance for obtaining 18-inch or 24-inch-long samples, respectively. These split-barrel samplers commonly range in size from 2 to 3.5 inches OD. The larger sizes are commonly used when a larger volume of sample material is required (see Attachment B).

Test Pit and Trench - Open, shallow excavations, typically rectangular (if a test pit) or longitudinal (if a trench), excavated to determine shallow subsurface conditions for engineering, geological, and soil chemistry exploration and/or sampling purposes. These pits are excavated manually or by machine (e.g., backhoe, clamshell, trencher, excavator, or bulldozer).

Subject  SOIL SAMPLING	Number SA-1.3	Page 3 of 30
	Revision 1	Effective Date 03/08

Thin-Walled Tube Sampler - A thin-walled metal tube (also called a Shelby tube) used to recover relatively undisturbed soil samples. These tubes are available in various sizes, ranging from 2 to 5 inches outside diameter (OD) and from 18 to 54 inches in length.

#### 4.0 RESPONSIBILITIES AND PERSONNEL QUALIFICATIONS

Project Manager - The Project Manager is responsible for determining the sampling objectives, selecting proposed sampling locations, and selecting field procedures used in the collection of soil samples. Additionally, in consultation with other project personnel (geologist, hydrogeologist, etc.), the Project Manager establishes the need for test pits or trenches and determines their approximate locations and dimensions.

Site Safety Officer (SSO) - The SSO (or a qualified designee) is responsible for providing the technical support necessary to implement the project Health and Safety Plan. This will include (but not be limited to) performing air quality monitoring during sampling, boring, and excavation activities and to ensure that workers and offsite (downwind) individuals are not exposed to hazardous levels of airborne contaminants. The SSO/designee may also be required to advise the FOL on other safety-related matters regarding boring, excavation, and sampling, such as mitigative measures to address potential hazards from unstable trench walls, puncturing of drums or other hazardous objects, etc.

Field Operations Leader (FOL) - This individual is primarily responsible for the execution of the planning document containing the Sampling and Analysis Plan (SAP). This is accomplished through management of a field sampling team for the proper acquisition of samples. He or she is responsible for the supervision of onsite analyses; ensuring proper instrument calibration, care, and maintenance; sample collection and handling; the completion and accuracy of all field documentation; and making sure that custody of all samples obtained is maintained according to proper procedures. When appropriate and as directed by the FOL, such responsibilities may be performed by other qualified personnel (e.g., field technicians) where credentials and time permit. The FOL is responsible for finalizing the locations for collection of surface, near-surface, and subsurface (hand and machine borings, test pits/trenches) soil samples. He/she is ultimately responsible for the sampling and backfilling of boreholes, test pits, and trenches and for adherence to Occupational Safety and Health Administration (OSHA) regulations during these operations through self acquisition or through the management of a field team of samplers.

Project Geologist/Sampler - The project geologist/sampler is responsible for the proper acquisition of samples in accordance with this SOP and/or other project-specific documents. In addition, this individual is responsible for the completion of all required paperwork (e.g., sample log sheets, field notebook, boring logs, test pit logs, container labels, custody seals, and chain-of-custody forms) associated with the collection of those samples.

Competent Person - A Competent Person, as defined in 29 CFR 1929.650 of Subpart P - Excavations, means one who is capable of identifying existing and predictable hazards in the surroundings, or working conditions that are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them.

General personnel qualifications for groundwater sample collection and onsite water quality testing include the following:

- Occupational Safety and Health Administration (OSHA) 40-hour and applicable refresher training.
- Capability of performing field work under the expected physical and environmental (i.e., weather) conditions.
- Familiarity with appropriate procedures for sample documentation, handling, packaging, and shipping.

Subject  SOIL SAMPLING	Number SA-1.3	Page 4 of 30
	Revision 1	Effective Date 03/08

## 5.0 HEALTH AND SAFETY

Health and safety precautions are identified for individual sample collection procedures throughout this SOP. In addition to those precautions, the following general hazards may be incurred during sampling activities:

- Knee injuries from kneeling on hard or uneven surfaces
- Slips, trips, and falls
- Cuts and lacerations
- Traffic hazards associated with sampling in parking areas, along roadways and highways.

Methods of avoiding these hazards are provided below.

**Knee injuries** – If kneeling is required during soil sampling, this could result in knee injuries from stones/foreign objects and general damage due to stress on the joints. To minimize this hazard:

- Clear any foreign objects from the work area.
- Wear hard-sided knee pads.
- Stretch ligaments, tendons and muscles before, during and after. Take breaks as frequently as necessary.
- Report pre-existing conditions to the SSO if you feel this activity will aggravate an existing condition.

**Slips, Trips, and Falls** – These hazards exist while traversing varying terrains carrying equipment to sample locations. To minimize these hazards:

- Pre-survey sampling locations. Eliminate, barricade, or otherwise mark physical hazards leading to the locations.
- Carry small loads that do not restrict the field of vision.
- Travel the safest and clearest route (not necessarily the shortest).

**Cuts and Lacerations** - To prevent cuts and lacerations associated with soil sampling, the following provisions are required:

- Always cut away from yourself and others when cutting tubing or rope. This will prevent injury to yourself and others if the knife slips.
- Do not place items to be cut in your hand or on your knee.
- Change blades as necessary to maintain a sharp cutting edge. Many accidents result from struggling with dull cutting attachments.
- Whenever practical, wear cut-resistant gloves (e.g., leather or heavy cotton work gloves) at least on the hand not using the knife.
- Keep cutting surfaces clean and smooth.
- Secure items to be cut – do not hold them against the opposing hand, a leg, or other body part.
- When transporting glassware, keep it in a hard-sided container such as a cooler so that if there is a fall, you will be less likely to get cut by broken glass.

Subject  SOIL SAMPLING	Number SA-1.3	Page 5 of 30
	Revision 1	Effective Date 03/08

- DO NOT throw broken sample jars or glass ampoules into garbage bags. Place broken glass and glass ampoules in hard-sided containers such as a cardboard box or directly into a dumpster. DO NOT reach into garbage bags to retrieve any item accidentally thrown away. Empty the contents onto a flat surface to avoid punctures and lacerations from reaching where you cannot see.

**Vehicular and Foot Traffic Hazards** – When sampling along the roadway or near traffic patterns, follow the following precautions:

- Motorists may be distracted by onsite activities – ASSUME THEY DO NOT SEE YOU OR MEMBERS OF YOUR FIELD CREW.
- DO NOT place obstructions (such as vehicles) along the sides of the road that may cause site personnel to move into the flow of traffic to avoid your activities or equipment or that will create a blind spot.
- **Provide a required free space of travel.** Maintain at least 6 feet of space between you and moving traffic. Where this is not possible, use flaggers and/or signs to warn oncoming traffic of activities near or within the travel lanes.
- Face Traffic. Whenever feasible, if you must move within the 6 feet of the required free space or into traffic, attempt to face moving traffic at all times. Always leave yourself an escape route.
- Wear high-visibility vests to increase visual recognition by motorists.
- Do not rely on the vehicle operator's visibility, judgment, or ability. Make eye contact with the driver. Carefully and deliberately use hand signals so they will not startle or confuse motorists or be mistaken for a flagger's direction before moving into traffic.
- Your movements may startle a motorist and cause an accident, so move deliberately. Do not make sudden movements that might confuse a motorist.

## 6.0 PROCEDURES

The following procedures address surface and subsurface sampling.

### **CAUTION**

Each situation must be evaluated individually to determine the applicability and necessity for obtaining a utility clearance ticket/dig permit. Common sense dictates, prior to digging or boring with power equipment, no matter what the depth, or digging by hand in a manner that could damage unprotected underground utilities, that a dig permit is required. See SOP HS-1.0, Utility Locating and Excavation Clearance, for additional clarification. If you do not know or are unsure as to whether a ticket is necessary – **Get the Ticket.**

### 6.1 Overview

Soil sampling is an important adjunct to groundwater monitoring. Sampling of the soil horizons above the groundwater table can detect contaminants before they migrate to the water table, and can establish the amount of contamination absorbed or adsorbed on aquifer solids that have the potential of contributing to groundwater contamination.

Soil types can vary considerably on a hazardous waste site. These variations, along with vegetation, can affect the rate of contaminant migration through the soil. It is important, therefore, that a detailed record

Subject  SOIL SAMPLING	Number SA-1.3	Page 6 of 30
	Revision 1	Effective Date 03/08

be maintained during sampling operations, particularly noting sampling locations, depths, and such characteristics as grain size, color, and odor. Subsurface conditions are often stable on a daily basis and may demonstrate only slight seasonal variation especially with respect to temperature, available oxygen and light penetration. Changes in any of these conditions can radically alter the rate of chemical reactions or the associated microbiological community, thus further altering specific site conditions. Certain vegetation species can create degradation products that can alter contaminant concentrations in soil. This is why vegetation types and extent of degradation of this foliage must be recorded. To prevent degradation, samples must be kept at their at-depth temperature or lower, protected from direct light, sealed tightly in approved glass containers, and be analyzed as soon as possible after collection. In addition, to the extent possible, vegetation should be removed from the sample.

The physical properties of the soil, its grain size, cohesiveness, associated moisture, and such factors as depth to bedrock and water table, will limit the depth from which samples can be collected and the method required to collect them. It is the intent of this document to present the most commonly employed soil sampling methods used at hazardous waste sites.

## **6.2 Soil Sample Collection**

### **6.2.1 Procedure for Preserving and Collecting Soil Samples for Volatile Organic Compound Analysis**

Samples collected using traditional methods such as collection in a jar with no preservation have been known to yield non-representative samples due to loss of volatile organic compounds (VOCs). To prevent such losses, preservation of samples with methanol or sodium bisulfate may be used to minimize volatilization and biodegradation. This preservation may be performed either in the field or laboratory, depending on the sampling methodology employed. Because of the large number of sampling methods and associated equipment required, careful coordination between field and laboratory personnel is needed.

Soil samples to be preserved by the laboratory are currently being collected using Method SW-846, 5035. For samples preserved in the field, laboratories are currently performing low-level analyses (sodium bisulfate preservation) and high- to medium-level analyses (methanol preservation) depending on the needs of the end user.

The following procedures outline the necessary steps for collecting soil samples to be preserved at the laboratory, and for collecting soil samples to be preserved in the field with methanol or sodium bisulfate.

#### **6.2.1.1 Soil Samples to be Preserved at the Laboratory**

Soil samples collected for volatile organic analysis that are to be preserved at the laboratory shall be obtained using a hermetically sealed sample vial such as an EnCore™ sampler. Each sample shall be obtained using a reusable sampling handle (T-handle) that can be provided with the EnCore™ sampler when requested and purchased. Collect the sample in the following manner for each EnCore™ sampler:

1. Scene Safety - Evaluate the area where sampling will occur. Ensure that the area is safe from physical, chemical, and natural hazards. Clear or barricade those hazards that have been identified.
2. Wear the appropriate personal protective equipment (PPE). This will include, at a minimum, safety glasses and nitrile surgeon's gloves. If you must kneel on the ground or place equipment on the surface being sampled, cover the ground surface with plastic to minimize surface contamination of your equipment and clothing. Wear knee pads to protect your knees from kneeling on hard or uneven surfaces.

Subject  SOIL SAMPLING	Number SA-1.3	Page 7 of 30
	Revision 1	Effective Date 03/08

3. Load the Encore™ sampler into the T-handle with the plunger fully depressed.
4. Expose the area to be sampled using a hand trowel or similar device to remove surface debris.
5. Press the T-handle against the freshly exposed soil surface, forcing soil into the sampler. The plunger will be forced upward as the cavity fills with soil.
6. When the sampler is full, rotate the plunger and lock it into place. If the plunger does not lock, the sampler is not full. This method ensures there is no headspace. Soft soil may require several plunges or forcing soil against a hard surface such as a sample trowel to ensure that headspace is eliminated.
7. Use a paper towel to remove soil from the side of the sampler so a tight seal can be made between the sample cap and the rubber O-ring.
8. With soil slightly piled above the rim of the sampler, force the cap on until the catches hook the side of the sampler.
9. Remove any surface soil from the outside of the sampler and place in the foil bag provided with the sampler. Good work hygiene practices and diligent decontamination procedures prevents the spread of contamination even on the outside of the containers.
10. Label the bag with appropriate information in accordance with SOP SA-6.3.
11. Place the full sampler inside a lined cooler with ice and cool to 4°C ± 2 °C. Make sure any required trip blanks and temperature blanks are also in the cooler. Secure custody of the cooler in accordance with SOP SA-6.3.
12. Typically, collect three Encore™ samplers at each location. Consult the SAP or laboratory to determine the required number of Encore™ samplers to be collected.
13. The T-handle shall be decontaminated before moving to the next interval or location using a soap and water wash and rinse, and where applicable, the selected solvent as defined in the project planning documents.

Using this type of sampling device eliminates the need for field preservation and the shipping restrictions associated with preservatives. A complete set of instructions is included with each Encore™ sampler.

After the Encore™ samples are collected, they should be placed on ice immediately and delivered to the laboratory within 48 hours (following the chain-of-custody and documentation procedures outlined in SOP SA-6.1). Samples must be preserved by the laboratory within 48 hours of sample collection.

#### 6.2.1.2 Soil Samples to be Preserved in the Field

Soil samples preserved in the field may be prepared for analyses using both the low-level (sodium bisulfate preservation) and high- to medium-level (methanol preservation) methods.

Subject  SOIL SAMPLING	Number SA-1.3	Page 8 of 30
	Revision 1	Effective Date 03/08

**Safety Reminder**

When using chemicals in the field to preserve samples, the FOL and/or SSO must ensure that Materials Safety Data Sheets (MSDSs) have been provided with the chemicals to be used. They also must ensure that these chemicals have been added to the Chemical Inventory List contained within Section 5.0, Hazard Communication, of your Health and Safety Guidance Manual (HSGM). Lastly, but most importantly, the FOL and/or SSO must review the hazards with personnel using these chemicals and ensure that provisions are available for recommended PPE and emergency measures (e.g., eyewash, etc.).

**Methanol Preservation (High to Medium Level):**

Bottles may be pre-spiked with methanol in the laboratory or prepared in the field. Soil samples to be preserved in the field with methanol shall utilize 40 to 60 mL glass vials with septum-lined lids. Each sample bottle shall be filled with 25 mL of demonstrated analyte-free purge-and-trap grade methanol. The preferred method for adding methanol to the sample bottle is by removing the lid and using a pipette or scaled syringe to add the methanol directly to the bottle.

**CAUTION**

NEVER attempt to pipette by mouth

In situations where personnel are required to spike the septum using a hypodermic needle, the following provisions for handling sharps must be in place:

- Training of personnel regarding methods for handling of sharps
- Hard-sided containers for the disposal of sharps
- Provisions for treatment in cases where persons have received a puncture wound

Soil shall be collected with the use of a decontaminated (or disposable), small-diameter coring device such as a disposable tube/plunger-type syringe with the tip cut off. The outside diameter of the coring device must be smaller than the inside diameter of the sample bottle neck.

A small electronic balance or manual scale will be necessary for measuring the volume of soil to be added to the methanol-preserved sample bottle. Calibration of the scale shall be performed prior to use and intermittently throughout the day according to the manufacturer's requirements.

The sample should be collected as follows:

1. Weigh the unused syringe and plunger to the nearest 0.01 gram.
2. Pull the plunger back and insert the syringe into the soil to be sampled.
3. Collect 8 to 12 grams of soil by pushing the syringe barrel into the soil.
4. Weigh the sample and adjust until obtaining the required amount of sample.
5. Record the sample weight to the nearest 0.01 gram in the field logbook and/or on the sample log sheet.
6. Extrude the weighed soil sample into the methanol-preserved sample bottle taking care not to contact the sample container with the syringe.

Subject  SOIL SAMPLING	Number SA-1.3	Page 9 of 30
	Revision 1	Effective Date 03/08

7. If dirty, wipe soil particles from the threads of the bottle and cap. Cap the bottle tightly.
8. After capping the bottle, swirl the sample (do not shake) in the methanol and break up the soil such that all of the soil is covered with methanol.
9. Place the sample on ice immediately and prepare for shipment to the laboratory as described in SOP SA-6.1.

**Sodium Bisulfate Preservation (Low Level):**

**CAUTION**

Care should be taken when adding the soil to the sodium bisulfate solution. A chemical reaction of soil containing carbonates (limestone) may cause the sample to effervesce or the vial to possibly explode. To avoid this hazard or hazards of this type, a small sample aliquot should be subjected to the sample preservative. If it effervesces in an open air environment, utilize an alternative method such as Encore™ or 2-ounce jar.

Bottles may be prepared in the laboratory or in the field with sodium bisulfate solution. Samples to be preserved in the field using the sodium bisulfate method are to be prepared and collected as follows:

1. Add 1 gram of sodium bisulfate to 5 mL of laboratory-grade deionized water in a 40 to 60 mL glass vial with septum-lined lid.
2. Collect the soil sample and record the sample weight to the nearest 0.01 gram in the field logbook or on the sample log sheet as described for methanol preservation
3. Add the weighed sample to the sample vial.
4. Collect duplicate samples using the methanol preservation method on a one-for-one sample basis because it is necessary for the laboratory to perform both low-level and medium-level analyses.
5. Place the samples on ice immediately and prepare for shipment to the laboratory as described in SOP SA-6.1.

**NOTE**

If lower detection limits are necessary, an option to field preserving with sodium bisulfate may be to collect EnCore™ samplers at a given sample location. Consult the planning documents to determine whether this is required. If it is, collect samples in accordance with the Encore™ sampling procedure above and then send all samplers to the laboratory to perform the required preservation and analyses.

**6.2.2 Procedure for Collecting Soil Samples for Non-Volatile Analyses**

Samples collected for non-volatile analyses may be collected as either grab or composite samples as follows:

1. With a stainless steel trowel or other approved tool, transfer a portion of soil to be sampled to a stainless steel bowl or disposable inert plastic tray.
2. Remove roots, vegetation, sticks, and stones larger than the size of a green pea.

Subject  SOIL SAMPLING	Number SA-1.3	Page 10 of 30
	Revision 1	Effective Date 03/08

3. Thoroughly mix the soil in the bowl or tray to obtain as uniform a texture and color as practicable. The soil type, moisture content, amount of vegetation, and other factors may affect the amount of time required to obtain a properly mixed sample. In some cases, it may be impossible to obtain a uniform sample appearance. Use the field logbook to describe any significant difficulties encountered in obtaining a uniform mixture.
4. Transfer the mixed soil to the appropriate sample containers and close the containers.
5. Label the sample containers in accordance with SOP SA-6.3.
6. Place the containers in a cooler of ice as soon after collection as possible.
7. Prepare the sample shipment and ship the samples in accordance with SOP SA-6.1.

**NOTE**  
Cooling may not be required for some samples depending on the scheduled analyses. Consult the planning documents if in doubt regarding correct sample preservation conditions. When in doubt – Cool to 4°C.

**NOTE**  
Head space is permitted in soil sample containers for non-volatile analyses to allow for sample expansion.

**6.2.3 Procedure for Collecting Undisturbed Soil Samples**

**NOTE**  
Use of thin-walled undisturbed tube samplers is restricted by the consistency of the soil to be sampled. Often, very loose and/or wet samples cannot be retrieved by the samplers, and soil with a consistency in excess of very stiff cannot be penetrated by the sampler. Devices such as Dennison or Pitcher core samplers can be used to obtain undisturbed samples of stiff soil. Using these devices normally increases sampling costs, and therefore their use should be weighed against the need for acquiring an undisturbed sample. These devices are not discussed in this SOP because they are not commonly used.

When it is necessary to acquire undisturbed samples of soil for purposes of engineering parameter analysis (e.g., permeability), a thin-walled, seamless tube sampler (Shelby tube) shall be employed using the following collection procedure:

1. In preparation for sampling utilizing a drill rig, field personnel must complete the following activities:
  - Ensure that all subsurface drilling activities are preceded by a utility clearance for the area to be investigated. This includes activities described in SOP HS-1.0, Utility Location and Excavation Clearance, as well as any location-specific procedures that may apply.

**REMEMBER**  
If you are digging near a marked utility (within the diameter of an underground utility that has been marked plus 18 inches), you must first locate the utility through vacuum extraction or hand digging to ensure that your activities will not damage the utility.

Subject  SOIL SAMPLING	Number SA-1.3	Page 11 of 30
	Revision 1	Effective Date 03/08

- Complete an Equipment Inspection Checklist for the drill rig or direct-push technology (DPT) rig. This checklist will be provided in the HASP.
  - Review the Safe Work Permit prior to conducting the activity.
  - Review the activity to be conducted.
2. Remove all surface debris (e.g., vegetation, roots, twigs, etc.) from the specific sampling location and drill and/or clean out the borehole to the desired sampling depth. Be careful to minimize potential disturbance of the material to be sampled. In saturated material, withdraw the drill bit slowly to prevent loosening of the soil around the borehole and to maintain the water level in the hole at or above groundwater level.

**CAUTION**

The use of bottom-discharge bits or jetting through an open-tube sampler to clean out the borehole shall not be allowed. Only the use of side-discharge bits is permitted.

4. Determine whether a stationary piston-type sampler is required to limit sample disturbance and aid in retaining the sample. Either the hydraulically operated or control rod activated-type of stationary piston sampler may be used.
5. Prior to inserting the tube sampler into the borehole, check to ensure that the sampler head contains a check valve. The check valve is necessary to keep water in the rods from pushing the sample out the tube sampler during sample withdrawal. In addition, the check valve maintains a positive suction within the tube to help retain the sample.
6. A stainless steel tube sampler is typically used to minimize chemical reaction between the sample and the sampling tube.
7. With the sampling tube resting on the bottom of the hole and the water level in the boring at groundwater level or above, push the tube into the soil with a continuous and rapid motion, without impacting or twisting. If the soil is too hard to penetrate by pushing alone, careful hammering may be used by minimizing drop distance (tapping) of the hammer. Before pulling the tube, turn it at least one revolution to shear the sample off at the bottom. In no case shall the tube be pushed farther than the length provided for the soil sample. Allow about 3 inches in the tube for cuttings and sludge.
8. Upon removal of the sampling tube from the hole, measure the length of sample in the tube and also the length penetrated.
9. Remove disturbed material in the upper end of the tube and measure the length of sample again.
10. After removing at least 1 inch of soil from the lower end, place enough packing material (clean inert material such as paper or cloth) tightly in each end of the Shelby tube and then pour melted wax into each end to make at least a ½-inch wax plug and then add more packing material to fill the voids at both ends.
11. Place plastic caps on the ends, tape the caps in place, and dip the ends in wax to prevent loss of soil.
12. Affix label(s) to the tube as required and record sample number, depth, penetration, and recovery length on the label.
13. Mark the "up" direction on the side and upper end of the tube with indelible ink.

Subject  SOIL SAMPLING	Number SA-1.3	Page 12 of 30
	Revision 1	Effective Date 03/08

14. Complete a chain-of-custody form (see SOP SA-6.3) and other required forms (including Attachment A of this SOP).
15. Ship samples protected with suitable resilient packing material to reduce shock, vibration, and disturbance.

**CAUTION**

To preserve sample integrity do not allow tubes to freeze, and store the samples vertically with the same orientation they had in the ground, (i.e., top of sample is up) in a cool place out of the sun at all times.

**CAUTION**

A primary concern in the preparation of the wax plugs is the potential for the heat source and melted wax to cause a fire and/or burns. Follow the directions below to prevent injury or fire.

**Electrical Heating**

Using hot plates to melt the wax is acceptable. In an outdoor setting, make sure a Ground Fault Circuit Interrupter (GFCI) is employed within the electrical circuit. If a portable generator is used, ensure that the generator is an adequate distance from the sampling operation (at least 50 feet). Ensure that the extension cord is rated for the intended load and for outdoor use and is free from recognizable damage. Ensure flammable preservatives are not employed or stored near the hot plate. Although a Hot Work Permit is not required, scene safety evaluation by site personnel of the above elements is. As always, if a fire potential exists, the provisions for extinguishing must be immediately accessible as well as any provisions for first aid measures.

**Open Flame**

If an open flame is used, the following provisions are necessary:

- Complete a Hot Work Permit and any local permit required for elevated temperature applications. The Hot Work Permit, provided in your HASP, will aid the FOL and/or the SSO in ensuring that fire protection provisions (extinguishers, fire watches, etc.) are in place as well as ensuring that local requirements have been addressed.
- Ensure that water is available to address any wax splashes or contact. If possible, immerse the contacted area. Where this is not possible, run water over the area and apply cold compresses. The need for medical attention or first aid shall be determined on site under the direction of the SSO.

**6.3 Surface Soil Sampling**

The simplest, most direct method of collecting surface soil samples for subsequent analysis is by use of a stainless steel shovel, hand auger, soil corer, or stainless steel or disposable plastic trowel.

Subject  SOIL SAMPLING	Number SA-1.3	Page 13 of 30
	Revision 1	Effective Date 03/08

**NOTE**

Multiple depth intervals are used to describe surface soil. Sometimes surface soil is defined as soil from 0 to 2 inches below ground surface (bgs), and sometimes it is defined as soil from other depths such as 0 to 2 feet bgs. Ensure that the definition of surface soil depth is clear before collecting surface soil samples.

For the purposes of instruction, the terms "surface soil" and "near-surface soil" are used in this SOP as follows:

- Surface soil - 0 to 6 inches bgs
- Near-surface soil - 6 to 18 inches bgs

If these intervals are defined differently in the planning documents, substitute the appropriate depth ranges.

In general, the following equipment is necessary for obtaining surface soil samples:

- Stainless steel or pre-cleaned disposable trowel.
- Stainless steel hand auger, soil corer, or shovel.
- Real-time air monitoring instrument (e.g., PID, FID) as directed in project planning document.
- Required PPE.
  - Nitrile surgeon's or latex gloves may be used, layered as necessary.
  - Safety glasses
  - Other – Items identified on the Safe Work Permit may be required based on location-specific requirements such as hearing protection, steel-toed work boots, and a hard hat when working near a drill rig. These provisions will be listed in the HASP or directed by the FOL and/or SSO.

**Safety Reminder**

The use of latex products may elicit an allergic reaction in some people. Should this occur, remove the latex gloves, treat for an allergic reaction, and seek medical attention as necessary.

- Required paperwork (see SOP SA-6.3 and Attachment A of this SOP)
- Required decontamination equipment
- Required sample container(s)
- Wooden stakes or pin flags
- Sealable polyethylene bags (e.g., Ziploc® baggies)
- Heavy duty cooler

Subject  SOIL SAMPLING	Number SA-1.3	Page 14 of 30
	Revision 1	Effective Date 03/08

- Ice
- Chain-of-custody records and custody seals

When acquiring surface soil samples, use the following procedure:

1. Place padding or use knee pads when kneeling near the sample location. If necessary, place plastic sheeting to provide a clean surface for sample equipment to avoid possible cross-contamination.
2. Carefully remove vegetation, roots, twigs, litter, etc. to expose an adequate soil surface area to accommodate sample volume requirements.
3. Using a precleaned syringe or EnCore™ samplers, follow the procedure in Section 6.2.1 for collecting surface soil samples for volatile analysis. Surface soil samples for volatile organic analysis should be collected deeper than 6 inches bgs because shallower material has usually lost most of the volatiles through evaporation. Ensure that the appropriate surface soil depth is being analyzed in accordance with the planning document.
4. Using decontaminated sampling tools, thoroughly mix in place a sufficient amount of soil to fill the remaining sample containers. See Section 6.5 of this procedure for hand auger instruction, as needed.
5. Transfer the sample into those containers utilizing a stainless steel trowel.
6. Cap and securely tighten all sample containers.
7. Affix a sample label to each container. Be sure to fill out each label carefully and clearly, addressing all the categories described in SOP SA-6.3.
8. Proceed with the handling and processing of each sample container as described in SOP SA-6.2.
9. Site restoration – Whenever removing sample materials, always restore the surface. It is our intent to leave the area better than we found it. Do NOT create trip hazards in areas when pedestrian traffic may exist.

#### **6.4 Near-Surface Soil Sampling**

Collection of samples from near the surface (depth of 6 to 18 inches) can be accomplished with tools such as shovels, hand auger, soil corers, and stainless steel or pre-cleaned disposable trowels and the equipment listed under Section 6.5 of this procedure.

To obtain near-surface soil samples, the following protocol shall be used:

1. With a clean shovel, make a series of vertical cuts in the soil to the depth required to form a square approximately 1 foot by 1 foot.
2. Lever out the formed plug and scrape the bottom of the freshly dug hole with a decontaminated stainless steel or pre-cleaned disposable trowel to remove any loose soil.
3. Follow steps 1 through 9 of Section 6.3.

Subject  SOIL SAMPLING	Number SA-1.3	Page 15 of 30
	Revision 1	Effective Date 03/08

## 6.5 Subsurface Soil Sampling With a Hand Auger

A hand augering system generally consists of a variety of stainless steel bucket bits (approximately 6.5 inches long and 2, 2.75, 3.25, and 4 inches in diameter), series of extension rods (available in 2-, 3-, 4- and 5-inch lengths), and a T-handle connected to extension rods and to the auger bucket. A larger-diameter bucket bit is commonly used to bore a hole to the desired sampling depth and then it is withdrawn. The larger-diameter bit is then replaced with a smaller-diameter bit, lowered down the hole, and slowly turned into the soil to the completion depth (approximately 6 inches). The apparatus is then withdrawn and the soil sample collected.

The hand auger can be used in a wide variety of soil conditions. It can be used to sample soil either from the surface, or to depths in excess of 12 feet. However, the presence of subsurface rocks and landfill material and collapse of the borehole normally limit sampling depth.

To accomplish soil sampling using a hand augering system, the following equipment is required:

- Complete hand auger assembly (variety of bucket bit sizes)
- Stainless steel mixing bowls
- The equipment listed in Section 6.3
- Miscellaneous hand tools as required to assemble and disassemble the hand auger units

### **CAUTION**

Potential hazards associated with hand augering include:

- Muscle strain and sprain due to over twisting and/or over compromising yourself.
- Equipment failure due to excessive stress on the T-handle or rods through twisting. Failure of any of these components will result in a sudden release and potential injury due to that failure.

As in all situations, any intrusive activities that could damage underground utilities shall be preceded by a Dig/Excavation permit/ticket. Call the Utility Locating service in the area or your Project Health and Safety Officer for more information. When in doubt – **Get the Ticket!**

To obtain soil samples using a hand auger, use the following procedure:

1. Wearing designated PPE, attach a properly decontaminated bucket bit to a clean extension rod and attach the T-handle to the extension rod.
2. Clear the area to be sampled of any surface debris (vegetation, twigs, rocks, litter, etc.).
3. Twist the bucket into the ground while pushing vertically downward on the auger. The cutting shoes fill the bucket as it is advanced into the ground.
4. As the auger bucket fills with soil, periodically remove any unneeded soil.
5. Add rod extensions as necessary to extend the reach of the auger. Also, note (in a field notebook, boring log, and/or on a standardized data sheet) any changes in the color, texture or odor of the soil as a function of depth. The project-specific planning document (SAP, HASP, etc.) describe

Subject  SOIL SAMPLING	Number SA-1.3	Page 16 of 30
	Revision 1	Effective Date 03/08

requirements for scanning the soil with a real-time air monitoring instrument (e.g., PID, FID, etc.) and recording the measurements.

6. After reaching the desired depth (e.g., the top of the interval to be sampled), slowly and carefully withdraw the apparatus from the borehole to prevent or minimize movement of soil from shallower intervals to the bottom of the hole.
7. Remove the soiled bucket bit from the rod extension and replace it with another properly decontaminated bucket bit. The bucket bit used for sampling is to be smaller in diameter than the bucket bit employed to initiate the borehole.
8. Carefully lower the apparatus down the borehole. Care must be taken to avoid scraping the borehole sides.
9. Slowly turn the apparatus until the bucket bit is advanced approximately 6 inches.
10. Discard the top of the core (approximately 1 inch), which represents any loose material collected by the bucket bit before penetrating the sample material.
11. Using a precleaned syringe or EnCore™ samplers, follow the procedure in Section 6.2.1 for collecting a soil sample for volatile compound analysis directly from the bucket bit.
12. Utilizing a properly decontaminated stainless steel trowel or dedicated disposable trowel, remove the remaining sample material from the bucket bit and place into a properly decontaminated stainless steel mixing bowl.
13. Homogenize the sample material as thoroughly as practicable then fill the remaining sample containers. Refer to Section 6.2.2.
14. Follow steps 4 through 7 listed in Section 6.3.

#### **6.5.1 Sampling Using Stainless Steel Soil Corers**

A soil corer is a stainless steel tube equipped with a cutting shoe and sample window in the side. The soil corer is advanced into the soil by applying downward pressure (body weight). The soil is unloaded by then forcing a ram towards the cutting shoe, which results in the discharge of the soil core through a window in the sleeve.

Use, application, and sample protocol is the same as for hand augering provided above, but without necessarily rotating the corer while advancing it.

#### **SAFETY REMINDER**

Hand augering and soil corer sampling can be physically demanding based on the type of geology and subsurface encumbrances encountered. Soil coring has some added hazards such the corer collapsing under your weight. To reduce the potential for muscle strain and damage, the following measures will be incorporated:

- Stretch and limber your muscles before heavy exertion. This hazard becomes more predominant in the early morning hours (prior to muscles becoming limber) and later in the day (as a result of fatigue).
- Job rotation – Share the duties so that repetitive actions do not result in fatigue and injury.

Subject  SOIL SAMPLING	Number SA-1.3	Page 17 of 30
	Revision 1	Effective Date 03/08

- Increase break frequencies as needed, especially as ambient conditions of heat and/or cold stress may dictate.
- Do not force the hand tools or use cheater pipes or similar devices to bypass an obstruction. Move to another location near the sampling point. Exerting additional forces on the sampling devices can result in damage and/or failure that could potentially injure someone in the immediate vicinity.
- Do not over compromise yourself when applying force to the soil corer or hand auger. If there is a sudden release, it could result in a fall or muscle injury due to strain.

### 6.6 Subsurface Soil Sampling with a Split-Barrel Sampler

A split-barrel (split-spoon) sampler consists of a heavy carbon steel or stainless steel sampling tube that can be split into two equal halves to reveal the soil sample (see Attachment B). A drive head is attached to the upper end of the tube and serves as a point of attachment for the drill rod. A removable tapered nosepiece/drive shoe attaches to the lower end of the tube and facilitates cutting. A basket-like sample retainer can be fitted to the lower end of the split tube to hold loose, dry soil samples in the tube when the sampler is removed from the drill hole. This split-barrel sampler is made to be attached to a drill rod and forced into the ground by means of a 140-pound or larger casing driver.

#### Safety Reminder

It is intended through the Equipment Inspection for Drill Rigs form provided in the HASP that the hammer and hemp rope, where applicable, associated with this activity will be inspected (no physical damage is obvious), properly attached to the hammer (suitable knots or sufficient mechanical devices), and is in overall good condition.

Split-barrel samplers are used to collect soil samples from a wide variety of soil types and from depths greater than those attainable with other soil sampling equipment.

The following equipment is used for obtaining split-barrel samples:

- Drilling equipment (provided by subcontractor).
- Split-barrel samplers (2-inch OD, 1-3/8-inch ID, either 20 inches or 26 inches long); Larger OD samplers are available if a larger volume of sample is needed.
- Drive weight assembly, 140-pound weight, driving head, and guide permitting free fall of 30 inches.
- Stainless steel mixing bowls.
- Equipment listed in Section 6.3.

The following steps shall be followed to obtain split-barrel samples (Steps 1 through 4 are typically performed by the drilling subcontractor):

1. Attach the split-barrel sampler to the sampling rods.
2. Lower the sampler into the borehole inside the hollow stem auger bits.
3. Advance the split-barrel sampler by hammering the length (typically 18 or 24 inches) of the split-barrel sampler into the soil using 140-pound or larger hammer.
4. When the desired depth is achieved, extract the drill rods and sampler from the augers and/or borehole.

Subject  SOIL SAMPLING	Number SA-1.3	Page 18 of 30
	Revision 1	Effective Date 03/08

5. Detach the sampler from the drill rods.
6. Place the sampler securely in a vise so it can be opened using pipe wrenches.

**CAUTION**

Pipe wrenches are used to separate the split spoon into several components. The driller's helper should not apply excessive force through the use of cheater pipes or push or pull in the direction where, if the wrench slips, hands or fingers will be trapped against an immovable object.

7. Remove the drive head and nosepiece with the wrenches, and open the sampler to reveal the soil sample.
8. Immediately scan the sample core with a real-time air monitoring instrument (e.g., FID, PID, etc.) (as project-specific planning documents dictate). Carefully separate (or cut) the soil core, with a decontaminated stainless steel knife or trowel, at about 6-inch intervals while scanning the center of the core for elevated readings. Also scan stained soil, soil lenses, and anomalies (if present), and record readings.
9. If elevated vapor readings were observed, collect the sample scheduled for volatile analysis from the center of the core where elevated readings occurred. If no elevated readings were encountered, the sample material should be collected from the core's center (this area represents the least disturbed area with minimal atmospheric contact) (refer to Section 6.2.1).
10. Using the same trowel, remove remaining sample material from the split-barrel sampler (except for the small portion of disturbed soil usually found at the top of the core sample) and place the soil into a decontaminated stainless steel mixing bowl.
11. Homogenize the sample material as thoroughly as practicable then fill the remaining sample containers (refer to Section 6.2.2).
12. Follow steps 4 through 7 in Section 6.3.

**6.7 Subsurface Soil Sampling Using Direct-Push Technology**

Subsurface soil samples can be collected to depths of 40+ feet using DPT. DPT equipment, responsibilities, and procedures are described in SOP SA-2.5.

~~**6.8 Excavation and Sampling of Test Pits and Trenches**~~

~~**6.8.1 Applicability**~~

~~This subsection presents routine test pit or trench excavation techniques and specialized techniques that are applicable under certain conditions.~~

Subject  SOIL SAMPLING	Number SA-1.3	Page 19 of 30
	Revision 1	Effective Date 03/08

**CAUTION**

During the excavation of trenches or pits at hazardous waste sites, several health and safety concerns arise from the method of excavation. No personnel shall enter any test pit or excavation over 4 feet deep except as a last resort, and then only under direct supervision of a Competent Person (as defined in 29 CFR 1929.650 of Subpart P - Excavations). Whenever possible, all required chemical and lithological samples should be collected using the excavator bucket or other remote sampling apparatus. If entrance is required, all test pits or excavations must be stabilized by bracing the pit sides using specifically designed wooden, steel, or aluminum support structures or through sloping and benching. Personnel entering the excavation may be exposed to toxic or explosive gases and oxygen-deficient environments; therefore, monitoring will be conducted by the Competent Person to determine if it is safe to enter. Any entry into a trench greater than 4 feet deep will constitute a Confined Space Entry and must be conducted in conformance with OSHA standard 29 CFR 1910.146. In all cases involving entry, substantial air monitoring, before entry, appropriate respiratory gear and protective clothing determination, and rescue provisions are mandatory. There must be at least three people present at the immediate site before entry by one of the field team members. This minimum number of people will increase based on the potential hazards or complexity of the work to be performed. The reader shall refer to OSHA regulations 29 CFR 1926.650, 29 CFR 1910.120, 29 CFR 1910.134, and 29 CFR 1910.146. High-hazard entries such as this will be supported by members of the Health Sciences Group professionally trained in these activities.

Excavations are generally not practical where a depth of more than about 15 to 20-feet is desired, and they are usually limited to a few feet below the water table. In some cases, a pumping system may be required to control water levels within the pit, providing that pumped water can be adequately stored or disposed. If soil data at depths greater than 15-feet are required, the data are usually obtained through test borings instead of test pits.

In addition, hazardous wastes may be brought to the surface by excavation equipment. This material, whether removed from the site or returned to the subsurface, must be properly handled according to any and all applicable federal, state, and local regulations.

### **6.8.2 Test Pit and Trench Excavation**

Test pits or trench excavations are constructed with the intent that they will provide an open view of subsurface lithology and/or disposal conditions that a boring will not provide. These procedures describe the methods for excavating and logging test pits and trenches installed to determine subsurface soil and rock conditions. Test pit operations shall be logged and documented (see Attachment C).

Test pits and trenches may be excavated by hand or power equipment to permit detailed descriptions of the nature and contamination of the in-situ materials. The size of the excavation will depend primarily on the following:

- The purpose and extent of the exploration
- The space required for efficient excavation
- The chemicals of concern
- The economics and efficiency of available equipment

Subject  SOIL SAMPLING	Number SA-1.3	Page 20 of 30
	Revision 1	Effective Date 03/08

Test pits normally have a cross section that is 4 to 10 feet square; test trenches are usually 3 to 6 feet wide and may be extended for any length required to reveal conditions along a specific line. The following table provides guidelines for design consideration based on equipment efficiencies.

Equipment	Typical Widths, in Feet
Trenching machine	0.25 to 1.0
Backhoe/Track Hoe	2 to 6

The lateral limits of excavation of trenches and the position of test pits shall be carefully marked on area base maps. If precise positioning is required to indicate the location of highly hazardous materials, nearby utilities, or dangerous conditions, the limits of the excavation shall be surveyed. Also, if precise determination of the depth of buried materials is needed for design or environmental assessment purposes, the elevation of the ground surface at the test pit or trench location shall also be determined by survey. If the test pit/trench will not be surveyed immediately, it shall be backfilled and its position identified with stakes placed in the ground at the margin of the excavation for later surveying.

The construction of test pits and trenches shall be planned and designed in advance as much as possible. However, the following field conditions may necessitate revisions to the initial plans:

- Subsurface utilities
- Surface and subsurface encumbrances
- Vehicle and pedestrian traffic patterns
- Purpose for excavation (e.g., the excavation of potential ordnance items)

The final depth and construction method shall be collectively determined by the FOL and designated Competent Person. The actual layout of each test pit, temporary staging area, and spoils pile may further be predicated based on site conditions and wind direction at the time the test pit is excavated. Prior to excavation, the area may be surveyed by magnetometer or metal detector or other passive methods specified in SOP HS1.0, Utility Location and Excavation Clearance, to identify the presence of underground utilities or drums. Where possible, the excavator should be positioned upwind and preferably within an enclosed cab.

No personnel shall enter any test pit or excavation except as a last resort, and then only under direct supervision of a Competent Person. If entrance is required, OSHA requirements must be met (e.g., walls must be braced with wooden or steel braces, ladders must be placed for every 25 feet of lateral travel and extended 3 feet above ground surface). A temporary guard rail or vehicle stop must be placed along the surface of the hole before entry in situations where the excavation may be approached by traffic. Spoils will be stockpiled no closer than 2 feet from the sidewall of the excavation. The excavation equipment operator shall be careful not to undercut sidewalls and will, where necessary, bench back to increase stability. The top cover, when considered clean, will be placed separately from the subsurface materials to permit clean cover. It is emphasized that the project data needs should be structured such that required samples can be collected without requiring entrance into the excavation. For example, samples of leachate, groundwater, or sidewall soil can be collected with telescoping poles or similar equipment.

Dewatering and watering may be required to ensure the stability of the side walls, to prevent the bottom of the pit from heaving, and to keep the excavation stable. This is an important consideration for excavations in cohesionless material below the groundwater table and for excavations left open greater than a day. Liquids removed as a result of dewatering operations must be handled as potentially contaminated materials. Procedures for the collection and disposal of such materials should be discussed in the site-specific project plans.

Subject  SOIL SAMPLING	Number SA-1.3	Page 21 of 30
	Revision 1	Effective Date 03/08

Where possible excavations and test pits shall be opened and closed within the same working day. Where this is not possible, the following engineering controls shall be put in place to control access:

- Trench covers/street plates
- Fences encompassing the entire excavation intended to control access
- Warning signs warning personnel of the hazards
- Amber flashing lights to demarcate boundaries of the excavation at night

Excavations left open will have emergency means to exit should someone accidentally enter.

### **6.8.3 Sampling in Test Pits and Trenches**

#### **6.8.3.1 General**

Log test pits and trenches as they are excavated in accordance with the Test Pit Log presented in Attachment C. These records include plan and profile sketches of the test pit/trench showing materials encountered, their depth and distribution in the pit/trench, and sample locations. These records also include safety and sample screening information.

Entry of test pits by personnel is extremely dangerous, shall be avoided unless absolutely necessary, and can occur only after all applicable health and safety and OSHA requirements have been met as stated above. These provisions will be reiterated as appropriate in the project-specific HASP.

The final depth and type of samples obtained from each test pit will be determined at the time the test pit is excavated. Sufficient samples are usually obtained and analyzed to quantify contaminant distribution as a function of depth for each test pit. Additional samples of each waste phase and any fluids encountered in each test pit may also be collected.

In some cases, samples of soil may be extracted from the test pit for reasons other than waste sampling and chemical analysis, for instance, to obtain geotechnical information. Such information includes soil types, stratigraphy, strength, etc., and could therefore entail the collection of disturbed (grab or bulk) or relatively undisturbed (hand-carved or pushed/driven) samples that can be tested for geotechnical properties. The purposes of such explorations are very similar to those of shallow exploratory or test borings, but often test pits offer a faster, more cost-effective method of sampling than installing borings.

#### **6.8.3.2 Sampling Equipment**

The following equipment is needed for obtaining samples for chemical or geotechnical analysis from test pits and trenches:

- Backhoe or other excavating machinery.
- Shovels, picks, hand augers, and stainless steel trowels/disposable trowels.
- Sample container - bucket with locking lid for large samples; appropriate bottle ware for chemical or geotechnical analysis samples.
- Polyethylene bags for enclosing sample containers; buckets.
- Remote sampler consisting of 10-foot sections of steel conduit (1-inch-diameter), hose clamps, and right angle adapter for conduit (see Attachment D).

Subject  SOIL SAMPLING	Number SA-1.3	Page 22 of 30
	Revision 1	Effective Date 03/08

### 6.8.3.3 Sampling Methods

The methods discussed in this section refer to test pit sampling from grade level. If test pit entry is required, see Section 6.8.3.4.

- Excavate the trench or pit in several 0.5- to 1.0-foot depth increments. Where soil types support the use of a sand bar cutting plate, use of this device is recommended to avoid potentially snagging utilities with the excavator teeth. It is recommended that soil probes or similar devices be employed where buried items or utilities may be encountered. This permits the trench floor to be probed prior to the next cut.
- After each increment:
  - the operator shall wait while the sampler inspects the test pit from grade level
  - the sampler shall probe the next interval where this is considered necessary. Practical depth increments for lithological evaluations may range from 2 to 4 feet or where lithological changes are noted.
- The backhoe operator, who will have the best view of the test pit, shall immediately cease digging if:
  - Any fluid phase, including groundwater seepage, is encountered in the test pit
  - Any drums, other potential waste containers, obstructions, or utility lines are encountered
  - Distinct changes of material being excavated are encountered

This action is necessary to permit proper sampling of the test pit and to prevent a breach of safety protocol. Depending on the conditions encountered, it may be required to excavate more slowly and carefully with the backhoe.

For obtaining test pit samples from grade level, the following procedure shall be followed:

- Use the backhoe to remove loose material from the excavation walls and floor to the greatest extent possible.
- Secure the walls of the pit, if necessary. (There is seldom any need to enter a pit or trench that would justify the expense of shoring the walls. All observations and samples should be taken from the ground surface.)
- Samples of the test pit material are to be obtained either directly from the backhoe bucket or from the material after it has been deposited on the ground, as follows:
  - a. The sampler or FOL shall direct the backhoe operator to remove material from the selected depth or location within the test pit/trench.
  - b. The backhoe operator shall bring the bucket over to a designated location on the sidewall a sufficient distance from the pit (at least 5 feet) to allow the sampler to work around the bucket.
  - c. After the bucket has been set on the ground, the backhoe operator shall either disengage the controls or shut the machine down.
  - d. When signaled by the operator that it is safe to do, the sampler will approach the bucket.

Subject  SOIL SAMPLING	Number SA-1.3	Page 23 of 30
	Revision 1	Effective Date 03/08

- e. The soil shall be monitored with a photoionization or flame ionization detector (PID or FID) as directed in the project -specific planning documents.
- f. The sampler shall collect the sample from the center of the bucket or pile in accordance with surface soil sampling procedures of Section 6.3 or 6.4, as applicable. Collecting samples from the center of a pile or bucket eliminates cross-contamination from the bucket or other depth intervals.
- If a composite sample is desired, several depths or locations within the pit/trench will be selected, and the bucket will be filled from each area. It is preferable to send individual sample bottles filled from each bucket to the laboratory for compositing under the more controlled laboratory conditions. However, if compositing in the field is required, each sample container shall be filled from materials that have been transferred into a mixing bucket and homogenized. Note that homogenization/compositing is not applicable for samples to be subjected to volatile organic analysis.

**CAUTION**

Care must be exercised when using the remote sampler described in the next step because of potential instability of trench walls. In situations where someone must move closer than 2 feet to the excavation edge, a board or platform should be used to displace the sampler's weight to minimize the chance of collapse of the excavation edge. Fall protection should also be employed when working near the edges or trenches greater than 6 feet deep. An immediate means to extract people who have fallen into the trench will be immediately available. These means may include ladders or rope anchor points.

- Using the remote sampler shown in Attachment D, samples can be taken at the desired depth from the sidewall or bottom of the pit as follows:
  - a. Scrape the face of the pit/trench using a long-handled shovel or hoe to remove the smeared zone that has contacted the backhoe bucket.
  - b. Collect the sample directly into the sample jar, by scraping with the jar edge, eliminating the need for sample handling equipment and minimizing the likelihood of cross-contamination.
  - c. Cap the sample jar, remove it from the remote sampler assembly, and package the sample for shipment in accordance with SOP SA-6.3.
- Complete documentation as described in SOP SA-6.3 and Attachment C of this SOP.

**6.8.3.4 In-Pit Sampling**

Under rare conditions, personnel may be required to enter the test pit/trench. This is necessary only when soil conditions preclude obtaining suitable samples from the backhoe bucket (e.g., excessive mixing of soil or wastes within the test pit/trench) or when samples from relatively small discrete zones within the test pit are required. This approach may also be necessary to sample any seepage occurring at discrete levels or zones in the test pit that are not accessible with remote samplers.

In general, personnel shall sample and log pits and trenches from the ground surface, except as provided for by the following criteria:

Subject  SOIL SAMPLING	Number SA-1.3	Page 24 of 30
	Revision 1	Effective Date 03/08

- There are no practical alternative means of obtaining such data.
- The SSO and Competent Person determine that such action can be accomplished without breaching site safety protocol. This determination will be based on actual monitoring of the pit/trench after it is dug (including, at a minimum, measurements of oxygen concentration, flammable gases, and toxic compounds, in that order). Action levels will be provided in project-specific planning documents.
- A company-designated Competent Person determines that the pit/trench is stable through soil classification evaluation/inspections or is made stable (by cutting/grading the sidewalls or using shoring) prior to entrance of any personnel. OSHA requirements shall be strictly observed.

If these conditions are satisfied, only one person may enter the pit/trench. On potentially hazardous waste sites, this individual shall be dressed in selected PPE as required by the conditions in the pit. He/she shall be affixed to a harness and lifeline and continuously monitored while in the pit.

A second and possible third individual shall be fully dressed in protective clothing including a self-contained breathing device and on standby during all pit entry operations to support self rescue or assisted self rescue. The individual entering the pit shall remain therein for as brief a period as practical, commensurate with performance of his/her work. After removing the smeared zone, samples shall be obtained with a decontaminated trowel or spoon. [TMD1]

#### 6.8.3.5 Geotechnical Sampling

In addition to the equipment described in Section 6.8.3.2, the following equipment is needed for geotechnical sampling:

- Soil sampling equipment, similar to that used in shallow drilled boring (i.e., thin-walled tube samplers), that can be pushed or driven into the floor of the test pit.
- Suitable driving (e.g., sledge hammer) or pushing (e.g., backhoe bucket) equipment used to advance the sampler into the soil.
- Knives, spatulas, and other suitable devices for trimming hand-carved samples.
- Suitable containers (bags, jars, tubes, boxes, etc.), labels, wax, etc. for holding and safely transporting collected soil samples.
- Geotechnical equipment (pocket penetrometer, torvane, etc.) for field testing collected soil samples for classification and strength properties.

Disturbed grab or bulk geotechnical soil samples may be collected for most soil in the same manner as comparable soil samples for chemical analysis. These collected samples may be stored in jars or plastic-lined sacks (larger samples), which will preserve their moisture content. Smaller samples of this type are usually tested for their index properties to aid in soil identification and classification; larger bulk samples are usually required to perform compaction tests.

Relatively undisturbed samples are usually extracted in cohesive soil using thin-walled tube samplers, and such samples are then tested in a geotechnical laboratory for their strength, permeability, and/or compressibility. The techniques for extracting and preserving such samples are similar to those used in performing Shelby tube sampling in borings, except that the sampler is advanced by hand or backhoe, rather than by a drill rig. Also, the sampler may be extracted from the test pit by excavation around the tube when it is difficult to pull it out of the ground. If this excavation requires entry of the test pit, the requirements described in Section 6.8.3.4 shall be followed. The thin-walled tube sampler shall be

Subject  SOIL SAMPLING	Number SA-1.3	Page 25 of 30
	Revision 1	Effective Date 03/08

pushed or driven vertically into the floor or steps excavated in the test pit at the desired sampling elevations. Extracting tube samples horizontally from the walls of the test pit is not appropriate because the sample will not have the correct orientation.

A sledge hammer or backhoe may be used to drive or push the tube into the ground. Place a piece of wood over the top of the sampler or sampling tube to prevent damage during driving/pushing of the sample. Pushing the sampler with a constant thrust is always preferable to driving it with repeated blows, thus minimizing disturbance to the sample. When using a sledge hammer, it is recommended that the sampler be stabilized using a rope/strap wrench or pipe wrench to remove the person's hands holding the sampler from the strike zone. If the sample cannot be extracted by rotating it at least two revolutions (to shear off the sample at the bottom), hook the sampler to the excavator or backhoe and extract. This means an alternative head will be used as a connection point or that multiple choke hitches will be applied to extract the sampler. If this fails and the excavator can dig deeper without potentially impacting subsurface utilities, excavate the sampler. If this fails or if the excavator cannot be used due to subsurface utilities, hand-excavate to remove the soil from around the sides of the sampler. If hand-excavation requires entry into the test pit, the requirements in Section 6.8.3.4 must be followed. Prepare the sample as described in Steps 9 through 13 in Section 6.2.3, and label, pack and transport the sample in the required manner, as described in SOPs SA-6.3 and SA-6.1.

#### **6.8.4 Backfilling of Trenches and Test Pits**

All test pits and excavations must be either backfilled, covered, or otherwise protected at the end of each day. No excavations shall remain open during non-working hours unless adequately covered or otherwise protected.

Before backfilling, the onsite crew may photograph, if required by the project-specific work plan, all significant features exposed by the test pit and trench and shall include in the photograph a scale to show dimensions. Photographs of test pits shall be marked to include site number, test pit number, depth, description of feature, and date of photograph. In addition, a geologic description of each photograph shall be entered in the site logbook. All photographs shall be indexed and maintained as part of the project file for future reference.

After inspection, backfill material shall be returned to the pit under the direction of the FOL. Backfill should be returned to the trench or test pit in 6-inch to 1-foot lifts and compacted with the bucket. Remote controlled tampers or rollers may be lowered into the trench and operated from top side. This procedure will continue to the grade surface. It is recommended that the trench be tracked or rolled in. During excavation, clean soil from the top 2 feet may have been separated to be used to cover the last segments. Where these materials are not clean, it is recommended that clean fill be used for the top cover.

If a low-permeability layer is penetrated (resulting in groundwater flow from an upper contaminated flow zone into a lower uncontaminated flow zone), backfill material must represent original conditions or be impermeable. Backfill could consist of a soil-bentonite mix prepared in a proportion specified by the FOL (representing a permeability equal to or less than original conditions). Backfill can be covered by "clean" soil and graded to the original land contour. Revegetation of the disturbed area may also be required.

#### **6.9 Records**

The appropriate sample log sheet (see Attachment A of this SOP) must be completed by the site geologist/sampler for all samples collected. All soil sampling locations should be documented by tying in the location of two or more nearby permanent landmarks (building, telephone pole, fence, etc.) or obtaining GPS coordinates; and shall be noted on the appropriate sample log sheet, site map, or field notebook. Surveying may also be necessary, depending on the project requirements.

Subject  SOIL SAMPLING	Number SA-1.3	Page 26 of 30
	Revision 1	Effective Date 03/08

Test pit logs (see Attachment C of this SOP) shall contain a sketch of pit conditions. If the project-specific work plan requires photographs, at least one photograph with a scale for comparison shall be taken of each pit. Included in the photograph shall be a card showing the test pit number. Boreholes, test pits, and trenches shall be logged by the field geologist in accordance with SOP GH-1.5.

Other data to be recorded in the field logbook include the following:

- Name and location of job
- Date of boring and excavation
- Approximate surface elevation
- Total depth of boring and excavation
- Dimensions of pit
- Method of sample acquisition
- Type and size of samples
- Soil and rock descriptions
- Photographs if required
- Groundwater levels
- PID/FID/LEL/O<sub>2</sub> meter readings
- Other pertinent information, such as waste material encountered

In addition, site-specific documentation to be maintained by the SSO and/or Competent Person will be required including:

- Calibration logs
- Excavation inspection checklists
- Soil type classification

## 7.0 REFERENCES

American Society for Testing and Materials, 1987. ASTM Standards D1587-83 and D1586-84. ASTM Annual Book of Standards. ASTM. Philadelphia, Pennsylvania. Volume 4.08.

NUS Corporation, 1986. Hazardous Material Handling Training Manual.

NUS Corporation and CH2M Hill, August, 1987. Compendium of Field Operation Methods. Prepared for the U.S. EPA.

OSHA, Excavation, Trenching and Shoring 29 CFR 1926.650-653.

OSHA, Confined Space Entry 29 CFR 1910.146.

USEPA, November 2001. Environmental Investigations Standard Operating Procedures and Quality Assurance Manual.

Subject  SOIL SAMPLING	Number SA-1.3	Page 27 of 30
	Revision 1	Effective Date 03/08

**ATTACHMENT A**  
**SOIL & SEDIMENT SAMPLE LOG SHEET**



Tetra Tech NUS, Inc.

**SOIL & SEDIMENT SAMPLE LOG SHEET**

Page \_\_\_ of \_\_\_

Project Site Name: _____	Sample ID No.: _____
Project No.: _____	Sample Location: _____
<input type="checkbox"/> Surface Soil	Sampled By: _____
<input type="checkbox"/> Subsurface Soil	C.O.C. No.: _____
<input type="checkbox"/> Sediment	Type of Sample:
<input type="checkbox"/> Other: _____	<input type="checkbox"/> Low Concentration
<input type="checkbox"/> QA Sample Type: _____	<input type="checkbox"/> High Concentration

GHAB SAMPLE DATA:			
Date:	Depth	Color	Description (Sand, Silt, Clay, Moisture, etc.)
Time: _____			
Method: _____			
Monitor Reading (ppm): _____			

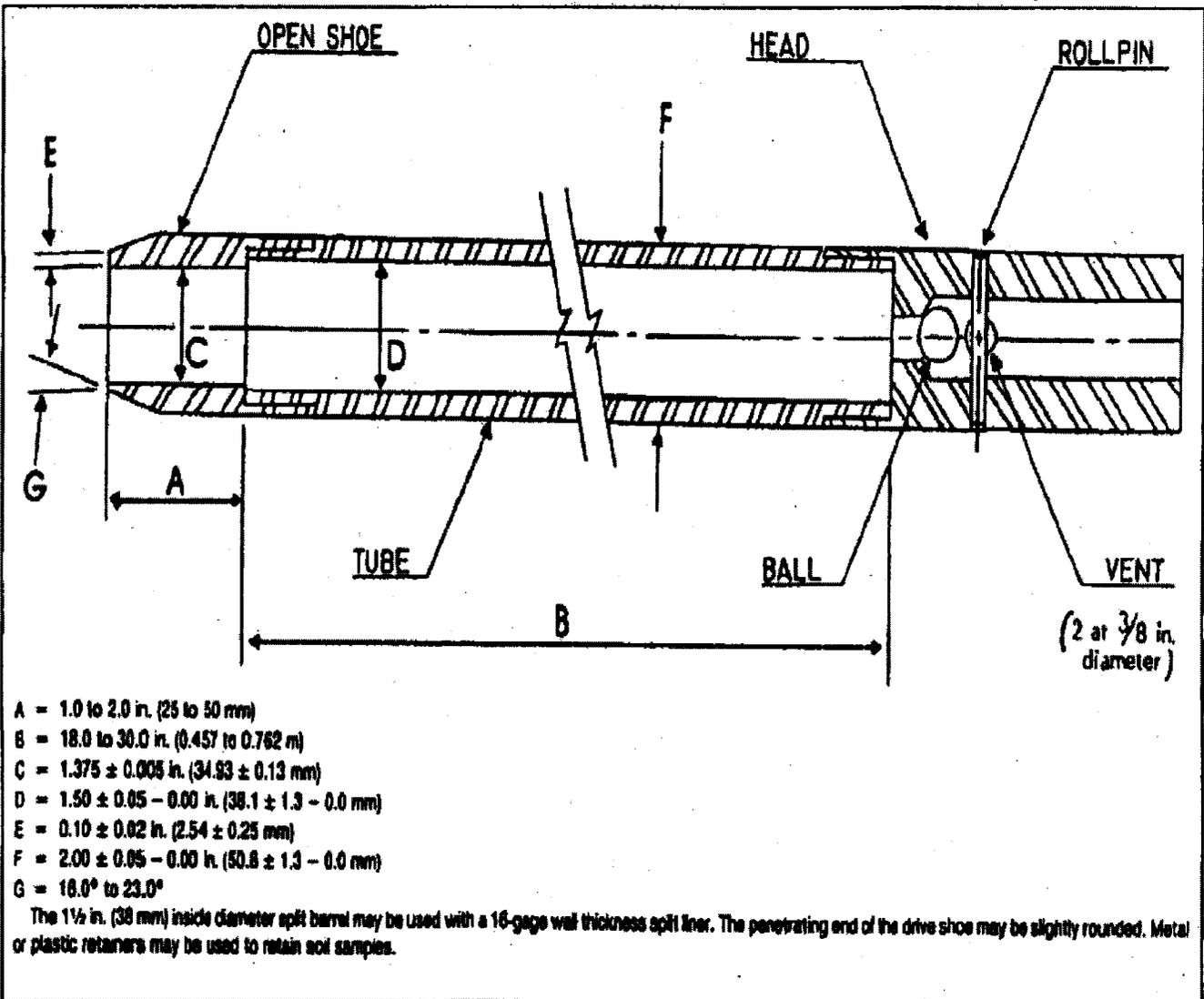
COMPOSITE SAMPLE DATA:				
Date:	Time	Depth	Color	Description (Sand, Silt, Clay, Moisture, etc.)
Method:				
Monitor Readings (Range in ppm):				

SAMPLE COLLECTION INFORMATION:			
Analysis	Container Requirements	Collected	Other

<b>OBSERVATIONS / NOTES:</b>	<b>MAP:</b>

<b>Circle if Applicable:</b>		<b>Signature(s):</b>
MS/MSD	Duplicate ID No.:	

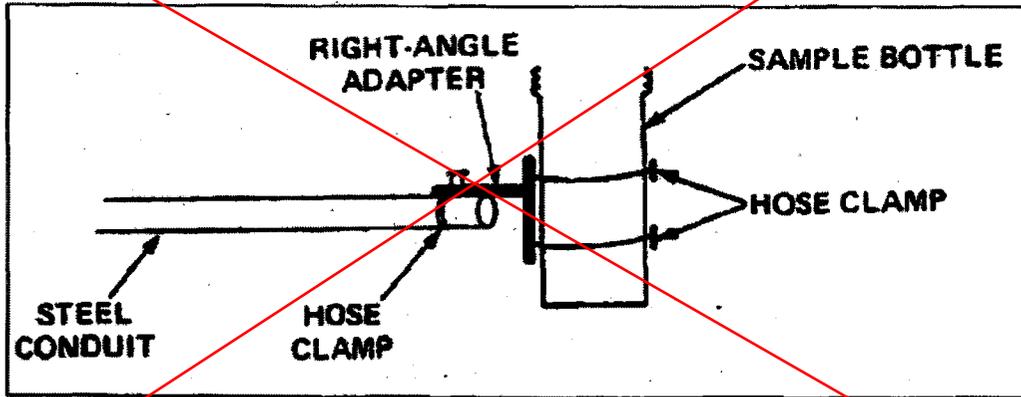
ATTACHMENT B  
SPLIT-SPOON SAMPLER





**ATTACHMENT D**

**REMOTE SAMPLE HOLDER FOR TEST PIT/TRENCH SAMPLING**



## TECHNICAL GUIDE

### COLLECTING GROUNDWATER SAMPLES FOR PERCHLORATE

**Prepared by:** DoD Environmental Data Quality Workgroup      **Date:** \_\_\_\_\_

**Reviewed by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

**Approved by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

## 1.0 Scope & Application

- 1.1 This Technical Guide (TG) has been developed to generate consistency across DoD for the collection and analysis of groundwater samples for perchlorate.
- 1.2 The use of this TG is restricted to individuals familiar with groundwater sampling methods.

## 2.0 Summary of Method

- 2.1 Low-Flow Purging and Sampling (LFPS) procedures are the preferred method for sampling groundwater wells for perchlorate. However, because of the solubility and stability of perchlorate, samples may be collected using any standard groundwater sampling method that meets the project-specific data quality objectives (DQOs) for sample representativeness.
- 2.2 Materials typically used in the construction of wells or the manufacture of sampling equipment do not affect perchlorate.
- 2.3 Analyses of perchlorate samples must be performed by laboratories that meet the requirements of the *DoD Perchlorate Handbook* and the *DoD Quality Systems Manual for Environmental Laboratories* (DoD-QSM) (<http://www.navylabs.navy.mil/ManualsDocs.htm>).

## 3.0 Health and Safety Warnings

- 3.1 This guide does not attempt to address all health and safety issues. The user must determine applicable requirements and establish appropriate health and safety protective measures.
- 3.2 Users of this guide should review the site health and safety plan with specific emphasis placed on hazards related to well sampling tasks. Follow standard safe operating practices.
- 3.3 When working with potentially hazardous materials, follow U.S. EPA, OSHA and Service-specific health and safety regulations, policies and procedures.

## 4.0 Interferences

- 4.1 The use of disposable/dedicated sampling equipment is recommended to eliminate the potential for sample contamination from documented sources of interferences such as detergents.
- 4.2 If non-disposable/dedicated sampling equipment is used, proper field decontamination techniques must be followed.
- 4.3 If perchlorate is the only target analyte, an acceptable decontamination procedure is to use a non-phosphate soap wash, followed by a deionized water rinse and air drying.
- 4.4 If the investigation includes additional target analytes, then samplers should follow standard decontamination practices for those analytes, except that non-phosphate detergent must be used.
- 4.5 Field samplers must use a rinsate blank to determine that the decontamination has been effective.
- 4.6 Filtration is used to remove microorganisms and suspended solids.

## 5.0 Equipment and Supplies

- 5.1 Sampling equipment is typically constructed from Teflon®, stainless steel, PVC, polyethylene, or polypropylene. These materials are all suitable for perchlorate sampling.

## 6.0 Sample Collection

- 6.1 Standard groundwater sampling equipment and procedures may be used to collect groundwater samples for perchlorate analysis. Dissolved perchlorate will not volatilize, so agitation of the sample or entrained air bubbles from the sampling equipment does not interfere with the analytical results. Standard Low-Flow Purging and Sampling (LFPS) procedures are the preferred method to be used to collect representative groundwater samples. Examples of low-flow purging and sampling procedures are:
- EPA Region I Low Stress (low flow) Purging and Sampling Procedure for the Collection of Ground Water Samples from Monitoring Wells, July 30, 1996, Revision 2.
  - Puls, R.W. and Barcelona, M.J., "Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedure", U.S. Environmental Protection Agency, Office of Research and Development, Publication # EPA/540/5-95/, pp. 12.
  - ASTM D6771-2, "Standard Practice For Low Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations"
- 6.1.1 Wells that are continuously pumped or under regular use, so that water in the wells does not have an opportunity to become stagnant (e.g., operating recovery wells, municipal supply wells, and domestic supply wells), can be sampled without additional purging. In such cases the well can be sampled using any appropriate technique. Approval by the regulatory agency may be required.
- 6.1.2 In those situations where the groundwater conditions and well construction make it appropriate, no-purge sampling methods with devices (e.g. Hydrasleeve and Snap sampler) that are demonstrated to collect representative samples for perchlorate may be used. Approval by the regulatory agency may be required.
- 6.2 If sample collection is required for other analytes, sampling methods and procedures will be dictated by the sampling requirements for the most sensitive parameters.
- 6.2.1 Samples must be collected in order of decreasing volatility of target analytes. Samples for volatile organic compounds are normally collected first, followed by semivolatile organic compounds and finally inorganic compounds. The sampling order will be specified by the sampling and analysis plan or permit.
- 6.3 Once sampling is complete, all field documentation records and chain-of-custody forms must be completed.
- 6.4 Some sites may be contaminated with light non-aqueous-phase liquids (LNAPLs) or dense non-aqueous-phase liquids (DNAPL), or both, in addition to perchlorate. The presence of DNAPLs and LNAPLs should not affect the sampling procedures for perchlorate. When possible, collect the sample above the DNAPLs or below the LNAPLs.
- 6.5 If there is potential for high-density perchlorate solutions to occur at a site (Perchlorate concentrations > 10,000 ppm) the solution will likely behave like a DNAPL. If monitoring for perchlorate is required in the presence of a high-density perchlorate brine solution, consult the DoD Perchlorate Handbook for additional guidance.

## 7.0 Sample Handling and Preservation

- 7.1 Filter the sample through a sterile 0.2µm filter, to remove microorganisms and eliminate

suspended solids. In cases where it is difficult to filter the sample through the 0.2 $\mu$ m filter, pre-filtering through a 0.45 $\mu$ M may be necessary. Collect 80 mL filtered sample in the sterile sample container. After filtering, store the samples with headspace in order to minimize the possibility of anaerobic conditions developing during sample storage.

7.2 Samples should be cooled as specified by the applicable method. If no guidance is provided, store the samples at  $4 \pm 2$  °C.

7.3 Samples that are stored and collected in the manner described in this TG may be held for a maximum of 28 days before analysis.

7.4 Contact your laboratory to clarify all preservation requirements.

## **8.0 Data and Records Management**

8.1 Once sampling is complete, all field documentation records and chain-of-custody forms must be completed.

8.2 Logbooks should be used and, as with any groundwater sampling event, the logbook should contain such things as: maps showing sample locations, a narrative of the sampling event, a list of all personnel involved with sample collection, water depth, volume purged, and sampling method.

## **9.0 Field Sample Quality Control and Quality Assurance**

9.1 The following field quality control samples/checks shall be performed:

9.1.1 Field Duplicate – One field duplicate sample must be taken per sampling event, or one per 10 samples, whichever is more frequent.

9.1.2 Field Equipment or Rinse Blank – One rinsate blank must be taken per sampling event. (Only required when decontamination of sampling equipment is performed in the field.)

9.1.3 Matrix Spike/Matrix Spike Duplicate – One sample per sampling event, or one per 20 samples, whichever is more frequent, must be designated for use as a Matrix Spike/Matrix Spike Duplicate.

## **10.0 Laboratory Selection, Quality Control, and Quality Assurance**

10.1 The laboratory selected to perform the analysis must be approved by a DoD Component and meet the requirements of the National Environmental Laboratory Accreditation Program (NELAP) and the latest version of the DoD QSM. More information about laboratory and method selection is contained in Appendix G of the *DoD Perchlorate Handbook*.

## TECHNICAL GUIDE

### COLLECTING SURFACE WATER AND WASTEWATER SAMPLES FOR PERCHLORATE

**Prepared by:** DoD Environmental Data Quality Workgroup      **Date:** \_\_\_\_\_

**Reviewed by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

**Approved by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

## 1.0 Scope & Application

- 1.1 This Technical Guide (TG) has been developed to generate consistency across DoD for the collection and analysis of surface water and wastewater samples for perchlorate.
- 1.2 The use of this TG is restricted to individuals trained and experienced in surface water or wastewater sampling methods. It should be used in conjunction with professional judgment, taking site-specific requirements into consideration.
- 1.3 If sampling and testing activities have been requested by a regulatory agency, or are subject to regulatory oversight, then installations should obtain regulatory authority review and comment on the QAPP or SAP.

## 2.0 Summary of Method

- 2.1 Samples may be collected using the same process specified in the current permit or standard wastewater sampling procedures, as detailed in *Standard Methods for the Examination of Water and Wastewater*, 20th Edition, Section, "1060 - Collection and Preservation of Samples".
- 2.2 Materials typically used in the sampling of surface water and wastewater do not affect sampling for perchlorate.
- 2.3 Analyses of perchlorate samples must be performed by laboratories that meet the requirements of the *DoD Perchlorate Handbook* and the *DoD Quality Systems Manual for Environmental Laboratories* (DoD-QSM) (<http://www.navylabs.navy.mil/ManualsDocs.htm>).

## 3.0 Health and Safety Warnings

- 3.1 This guide does not attempt to address all health and safety issues. The user must determine applicable requirements and establish appropriate health and safety protective measures.
- 3.2 Users of this guide should review the site health and safety plan with specific emphasis placed on hazards related to surface water and wastewater sampling tasks. Follow standard safe operating practices.
- 3.3 When working with potentially hazardous materials, follow U.S. EPA, OSHA and Service-specific health and safety regulations, policies and procedures.

## 4.0 Interferences

- 4.1 The use of disposable or dedicated sampling equipment is recommended to eliminate the potential for sample cross-contamination.
- 4.2 If non-disposable/dedicated sampling equipment is used, proper field decontamination techniques must be followed.
- 4.3 If perchlorate is the only target analyte, an acceptable decontamination procedure is to use a non-phosphate soap/detergent wash, followed by a deionized water rinse and air drying.
- 4.4 If the investigation includes additional target analytes, then samplers should follow standard decontamination practices for those analytes, except that non-phosphate detergent must be used.
- 4.5 A rinsate blank should be collected to demonstrate that the decontamination has been effective.

## 5.0 Equipment and Supplies

- 5.1 Sampling equipment is typically constructed from stainless steel, PVC, polyethylene, or polypropylene. These materials are all suitable for perchlorate sampling.

## 6.0 Sample Collection

- 6.1 Standard surface water or wastewater sampling procedures may be used to collect samples for perchlorate analysis (*Standard Methods for the Examination of Water and Wastewater*, 20th Edition, Section, "1060 - Collection and Preservation of Samples"). Dissolved perchlorate will not volatilize so agitation of the sample or entrained air bubbles will not interfere with the analytical results.
- 6.2 If sample collection is required for other analytes, sampling methods and procedures will be dictated by the sampling requirements for the most sensitive parameters.
  - 6.2.1 Samples must be collected in order of decreasing volatility of target analytes. Samples for volatile organic compounds are normally collected first, followed by semivolatile organic compounds and finally inorganic compounds. The sampling order will be specified by the sampling and analysis plan or permit.
- 6.3 If waste stream has multiple phases, each phase needs to be collected and analyzed separately.

## 7.0 Sample Handling and Preservation

- 7.1 Collect 80 mL of sample and store with headspace in order to minimize the possibility of anaerobic conditions developing during sample storage.
- 7.2 Samples should be cooled as specified by the applicable method. If no guidance is provided, store the samples at  $4 \pm 2$  °C.
- 7.3 Samples that are stored and collected in the manner described in this TG may be held for a maximum of 28 days before analysis.
- 7.4 Contact your laboratory to clarify all preservation requirements.

## 8.0 Data and Records Management

- 8.1 Once sampling is complete, all field documentation records and chain-of-custody forms must be completed.
- 8.2 Logbooks should be used and contain such things as: sample locations, time and date of collection, list of all personnel involved with sample collection and any field measurements take (e.g. pH).

## 9.0 Field Sample Quality Control and Quality Assurance

- 9.1 Matrix Spike/Matrix Spike Duplicate – One sample per sampling event, or one per 20 samples per matrix, whichever is more frequent, must be designated for use as a Matrix Spike/Matrix Spike Duplicate.

## 10.0 Laboratory Selection, Quality Control, and Quality Assurance

- 10.1 The laboratory selected to perform the analysis must be approved by a DoD Component and meet the requirements of the National Environmental Laboratory Accreditation Program (NELAP) and the latest version of the DoD QSM. More information about laboratory and method selection is contained in Appendix G of the *DoD Perchlorate Handbook*.

## TECHNICAL GUIDE

### COLLECTING SOLID SAMPLES FOR PERCHLORATE

**Prepared by:** DoD Environmental Data Quality Workgroup      **Date:** \_\_\_\_\_

**Reviewed by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

**Approved by:** \_\_\_\_\_ **Date:** \_\_\_\_\_

## 1.0 Scope & Application

- 1.1 This Technical Guide (TG) has been developed to generate consistency across DoD for the collection and analysis of solid for perchlorate.
- 1.2 The use of this TG is restricted to individuals trained and experienced in soil and sediment sampling methods. It should be used in conjunction with professional judgment, taking site-specific requirements into consideration.
- 1.3 If sampling and testing activities have been requested by a regulatory agency, or are subject to regulatory oversight, then installations should obtain regulatory authority review and comment on the QAPP or SAP. In this case, the collection of split samples is strongly recommended (i.e. where a portion of each sample is sent to a second laboratory).

## 2.0 Summary of Method

- 2.1 Solid samples for perchlorate can be collected with many types of sampling equipment (e.g. trowels, hand augers, split spoons, direct-push samplers, Ekman dredges, Ponar dredges, Gravity corers).
- 2.2 Care must be taken to ensure that each sample represents the location, sample medium, and depth being evaluated. Poor sampling techniques will produce misleading results and lead to incorrect decisions.
- 2.3 Analysis of perchlorate samples must be performed by laboratories that meet the requirements of the *DoD Perchlorate Handbook* and the *DoD Quality Systems Manual for Environmental Laboratories* (DoD QSM) (<http://www.navylabs.navy.mil/ManualsDocs.htm>).
- 2.4 Definitive methods (e.g., those employing mass spectrometry (MS)) must be used for the analysis of soil and sediment samples for perchlorate. The use of EPA Method 314.0 or one of its modifications is not appropriate.

## 3.0 Health and Safety Warnings

- 3.1 This guide does not attempt to address all health and safety issues. The user must determine applicable requirements and establish appropriate health and safety protective measures.
- 3.2 Users of this guide should review the site health and safety plan with specific emphasis placed on hazards related to soil and sediment sampling tasks. Follow standard safe operating practices.
- 3.3 When working in the presence of potentially hazardous materials, energetics or ordnance, follow U.S. EPA, OSHA and Service-specific health and safety regulations, policies and procedures.

## 4.0 Interferences

- 4.1 The use of disposable or dedicated sampling equipment is recommended to eliminate the potential for sample cross-contamination.
- 4.2 If non-disposable/dedicated sampling equipment is used, proper field decontamination techniques must be followed.
- 4.3 If perchlorate is the only target analyte, an acceptable decontamination procedure is to use a non-phosphate soap/detergent wash, followed by a deionized water rinse and air drying.
- 4.4 If the investigation includes additional target analytes, then samplers should follow standard

decontamination practices for those analytes, except that non-phosphate detergent must be used.

- 4.5 A rinsate blank should be collected to demonstrate that the decontamination has been effective.

## 5.0 Equipment and Supplies

- 5.1 Sampling equipment is typically constructed from Teflon®, stainless steel, PVC, polyethylene, or polypropylene. These materials are all suitable for perchlorate sampling.

## 6.0 Sample Collection

- 6.1 Because of its high solubility, it is unlikely that perchlorate will reside in sediments. For this reason, in most situations it will be unnecessary to sample sediments for perchlorate. Sediment sampling may be required in rare situations where large quantities of perchlorate have been released and an evaporative environment exists (waste impoundment associated with munitions demilitarization activities). When this situation exists, standard procedures for sampling sediment should be employed.
- 6.2 Standard soil sampling equipment and procedures may be used to collect samples for perchlorate analysis. Examples include those described in ASTM publication ENV SITE 02, *ASTM Standards Related to Environmental Site Characterization*, 2<sup>nd</sup> edition and ASTM D4700-91(1998) *Standard Guide for Soil Sampling from the Vadose Zone*.
- 6.3 Avoid unusual areas, such as eroded areas, rock outcroppings, and fence lines, unless these features have been specifically designated as sample points in the SAP.
- 6.4 If no contradictory guidance is provided in the QAPP or SAP, remove debris such as sticks, rocks, and vegetation from the soil surface before collecting the samples.
- 6.5 If perchlorate is expected to be distributed homogeneously (e.g. a former wastewater impoundment area at a manufacturing plant) then discrete samples can be taken. If the distribution is expected to be heterogeneous (e.g. retained in propellant matrices, distributed in soil, and not immediately dissolved) or is unknown, then composite (or incremental) soil sampling techniques are recommended. In this case, a sample representing a particular sampling unit (area or volume of soil) should consist of at least five subsamples collected within the sampling unit. Subsamples should be as close to the same size (in terms of mass) as possible.
- 6.6 Following the collection of all subsamples representing a particular sample unit, the sample should be mixed until it achieves a consistent physical appearance.
- 6.7 Well-mixed samples should be placed in clean 4-oz amber glass bottles.

## 7.0 Sample Handling and Preservation

- 7.1 Samples should be cooled as specified by the applicable method. If no guidance is provided, the samples should be stored at  $4 \pm 2$  °C.
- 7.2 Samples that are stored and collected in the manner described in this TG may be held for a maximum of 28 days before analysis.
- 7.3 Contact your laboratory to clarify all preservation requirements.

## 8.0 Data and Records Management

- 8.1 Once sampling is complete, all field documentation records and chain-of-custody forms

must be completed.

- 8.2 Logbooks should be used and, as with any sampling event, they include: maps showing sample locations, a narrative description of the sampling event, a list of all personnel involved with sample collection, and sampling method.

## **9.0 Field Sample Quality Control and Quality Assurance**

- 9.1 Field Duplicate (Field Split) – One field duplicate sample must be taken per sampling event, or one per 10 samples, whichever is more frequent.
- 9.2 Field Equipment or Rinsate Blank – One rinsate blank must be taken per sampling event. (Only required when decontamination of sampling equipment is performed in the field.)
- 9.3 Matrix Spike/Matrix Spike Duplicate – One sample per matrix per sampling event, or one per 20 samples of the same matrix, whichever is more frequent, must be designated for use as a Matrix Spike/Matrix Spike Duplicate.

## **10.0 Laboratory Selection, Quality Control, and Quality Assurance**

- 10.1 The laboratory selected to perform the analysis must be approved by a DoD Component and meet the requirements of the National Environmental Laboratory Accreditation Program (NELAP) or the American Association for Laboratory Accreditation (A2LA) and the latest version of the DoD QSM. More information about laboratory and method selection is contained in Appendix G of the *DoD Perchlorate Handbook*.

<b>STANDARD OPERATING PROCEDURES</b>	Number SA-2.5	Page 1 of 6
	Effective Date 02/04	Revision 0
	Applicability	
	Prepared	
Subject DIRECT PUSH TECHNOLOGY (GEOPROBE®/HYDROPUNCH™)	Approved	

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY .....	2
4.0 RESPONSIBILITIES .....	2
5.0 SOIL SAMPLING PROCEDURES .....	3
5.1 GENERAL .....	3
5.2 SAMPLING EQUIPMENT .....	3
5.3 DPT SAMPLING METHODOLOGY .....	3
<del>6.0 GROUNDWATER SAMPLING PROCEDURES .....</del>	<del>4</del>
<del>    6.1 GENERAL .....</del>	<del>4</del>
<del>    6.2 SAMPLING EQUIPMENT .....</del>	<del>4</del>
<del>    6.3 DPT TEMPORARY WELL POINT INSTALLATION AND SAMPLING         METHODOLOGY .....</del>	<del>5</del>
7.0 RECORDS .....	5
 <b><u>ATTACHMENTS</u></b>	
1 SAFE WORK PERMIT .....	6

Subject DIRECT PUSH TECHNOLOGY (GEOPROBE®/HYDROPUNCH™)	Number SA-2.5	Page 2 of 6
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

The purpose of this procedure is to provide general reference information on Direct Push Technology (DPT). DPT is designed to collect soil, groundwater, and soil gas samples without using conventional drilling techniques. The advantage of using DPT over conventional drilling includes the generation of little or no drill cuttings, sampling in locations with difficult accessibility, reduced overhead clearance requirements, no fluid introduction during probing, and typical lower costs per sample than with conventional techniques. Disadvantages include a maximum penetration depth of approximately 15 to 40 feet in dense soils (although it may be as much as 60 to 80 feet in certain types of geological environments), reduced capability of obtaining accurate water-level measurements, and the inability to install permanent groundwater monitoring wells. The methods and equipment described herein are for collection of surface and subsurface soil samples and groundwater samples. Soil gas sampling is discussed in SOP SA-2.4.

## 2.0 SCOPE

This procedure provides information on proper sampling equipment and techniques for DPT. Review of the information contained herein will facilitate planning of the field sampling effort by describing standard sampling techniques. The techniques described shall be followed whenever applicable, noting that site-specific conditions or project-specific plans may require adjustments in methodology.

## 3.0 GLOSSARY

Direct Push Technology (DPT) - DPT refers to sampling tools and sensors that are driven directly into the ground without the use of conventional drilling equipment. DPT typically utilizes hydraulic pressure and/or percussion hammers to advance the sampling tools. A primary advantage of DPT over conventional drilling techniques is that DPT results in the generation of little or no investigation derived waste.

Geoprobe® - Geoprobe® is a manufacturer of a hydraulically-powered, percussion/probing machines utilizing DPT to collect subsurface environmental samples. Geoprobe® relies on a relatively small amount of static weight (vehicle) combined with percussion as the energy for advancement of a tool string. The Geoprobe® equipment can be mounted in a multitude of vehicles for access to all types of environmental sites.

HydroPunch™ - HydroPunch™ is a manufacturer of stainless steel and Teflon® sampling tools that are capable of collecting representative groundwater and/or soil samples without requiring the installation of a groundwater monitoring well or conventional soil boring. HydroPunch™ is an example of DPT sampling equipment.

Flame Ionization Detector (FID) - A portable instrument for the measurement of many combustible organic compounds and a few inorganic compounds in air at parts-per million levels. The basis for the detection is the ionization of gaseous species utilizing a flame as the energizing source.

Photo Ionization Detector (PID) - A portable instrument for the measurement of many combustible organic compounds and a few inorganic compounds in air at parts-per million levels. The basis for the detection is the ionization of gaseous species utilizing ultraviolet radiation as the energizing source.

## 4.0 RESPONSIBILITIES

Project Manager - The Project Manager is responsible for selecting and/or reviewing the appropriate DPT drilling procedure required to support the project objectives.

Subject DIRECT PUSH TECHNOLOGY (GEOPROBE®/HYDROPUNCH™)	Number SA-2.5	Page 3 of 6
	Revision 0	Effective Date 02/04

Field Operations Leader (FOL)- The FOL is primarily responsible for performing the DPT in accordance with the project-specific plan.

## 5.0 SOIL SAMPLING PROCEDURES

### 5.1 General

The common methodology for the investigation of the vadose zone is soil boring drilling and soil sampling. However, drilling soil borings can be very expensive. Generally the advantage of DPT for subsurface soil sampling is the reduced cost of disposal of drilling cuttings and shorter sampling times.

### 5.2 Sampling Equipment

Equipment needed for conducting DPT drilling for subsurface soil sampling includes, but is not limited to, the following:

- Geoprobe® Sampling Kit
- Cut-resistant gloves
- 4-foot x 1.5-inch diameter macrocore sampler
- Probe sampling adapters
- Roto-hammer with 1.5-inch bit
- Disposable acetate liners for soil macrocore sampler
- Cast aluminum or steel drive points
- Geoprobe® AT-660 Series Large Bore Soil Sampler, or equivalent
- Standard decontamination equipment and solutions

For health and safety equipment and procedures, follow the direction provided in the Safe Work Permit in Attachment 1, or the more detailed directions provided in the project's Health and Safety Plan.

### 5.3 DPT Sampling Methodology

There are several methods for the collection of soil samples using DPT drilling. The most common method is discussed in the following section. Variations of the following method may be conducted upon approval of the Project Manager in accordance with the project-specific plan.

- Macrocore samplers fitted with detachable aluminum or steel drive points are driven into the ground using hydraulic pressure. If there is concrete or pavement over a sampling location, a Roto-hammer is used to drill a minimum 1.5-inch diameter hole through the surface material. A Roto-hammer may also be used if very dense soils are encountered.
- The sampler is advanced continuously in 4-foot intervals or less if desired. No soil cuttings are generated because the soil which is not collected in the sampler is displaced within the formation.
- The sampler is retracted from the hole, and the 4-foot continuous sample is removed from the outer coring tube. The sample is contained within an inner acetate liner.
- Attach the metal trough from the Geoprobe® Sampling Kit firmly to the tail gate of a vehicle. If a vehicle with a tail gate is not available, secure the trough on another suitable surface.
- Place the acetate liner containing the soils in the trough.

Subject DIRECT PUSH TECHNOLOGY (GEOPROBE®/HYDROPUNCH™)	Number SA-2.5	Page 4 of 6
	Revision 0	Effective Date 02/04

- While wearing cut-resistant gloves (constructed of leather or other suitable material), cut the acetate liner through its entire length using the double-bladed knife that accompanies the Geoprobe® Sampling Kit. Then remove the strip of acetate from the trough to gain access to the collected soils. Do not attempt to cut the acetate liner while holding it in your hand.
- Field screen the sample with an FID or PID, and observe/examine the sample (according to SOP GH-1.3). If appropriate, transfer the sample to sample bottles for laboratory analysis. If additional volume is required, push an additional boring adjacent to the first and composite/mix the same interval. Field compositing is usually not acceptable for sample requiring volatile organics analysis.
- Once sampling has been completed, the hole is backfilled with bentonite chips or bentonite cement grout, depending upon project requirements. Asphalt or concrete patch is used to cap holes through paved or concrete areas. All holes should be finished smooth to existing grade.
- In the event the direct push van/truck cannot be driven to a remote location or a sampling location with difficult accessibility, sampling probes may be advanced and sampled manually or with air/electric operated equipment (e.g., jack hammer).
- Sampling equipment is decontaminated prior to collecting the next sample.

## **6.0 GROUNDWATER SAMPLING PROCEDURES**

### **6.1 General**

The most common methodology for the investigation of groundwater is the installation and sampling of permanent monitoring wells. If only groundwater screening is required, the installation and sampling of temporary well points may be performed. The advantage of temporary well point installation using DPT is reduced cost due to no or minimal disposal of drilling cuttings and well construction materials, and shorter installation/times sampling.

Two disadvantages of DPT drilling for well point installation are:

- In aquifers with low yields, well points may have to be sampled without purging or development.
- If volume requirements are high, this method can be time consuming for low yield aquifers.

### **6.2 Sampling Equipment**

Equipment needed for temporary well installation and sampling using DPT includes, but is not limited, to the following:

- 2-foot x 1-inch diameter mill-slotted (0.005 to 0.02-inch) well point
- Connecting rods
- Roto-hammer with 1.5-inch bit
- Mechanical jack
- 1/4-inch OD polyethylene tubing
- 3/8-inch OD polyethylene tubing
- Peristaltic pump
- Standard decontamination equipment and solutions

Subject DIRECT PUSH TECHNOLOGY (GEOPROBE®/HYDROPUNCH™)	Number SA-2.5	Page 5 of 6
	Revision 0	Effective Date 02/04

### **6.3 DPT Temporary Well Point Installation and Sampling Methodology**

There are several methods for the installation and sampling of temporary well points using DPT. The most common methodology is discussed below. Variations of the following method may be conducted upon approval of the Project Manager in accordance with the project specific plan.

- A 2-foot x 1-inch diameter mill-slotted (0.005 to 0.02-inch) well point attached to connecting rods is driven into the ground to the desired depth using a rotary electric hammer or other direct push drill rig. If there is concrete or pavement over a sampling location, a Roto-hammer or electric coring machine is used to drill a hole through the surface material.
- The well point will be allowed to equilibrate for at least 15 minutes, after which a measurement of the static water level will be taken. The initial measurement of the water level will be used to assess the amount of water which is present in the well point and to determine the amount of silt and sand infiltration that may have occurred.
- The well point will be developed using a peristaltic pump and polyethylene tubing to remove silt and sand which may have entered the well point. The well point is developed by inserting polyethylene tubing to the bottom of the well point and lifting and lowering the tubing slightly while the pump is operating. The pump will be operated at a maximum rate of approximately 2 liters per minute. After removal of sediment from the bottom of the well point, the well point will be vigorously pumped at maximum capacity until discharge water is visibly clear and no further sediments are being generated. Measurements of pH, specific conductance, temperature, and turbidity shall be recorded every 5 to 10 minutes during the purging process. After two consistent readings of pH, specific conductance, temperature and turbidity ( $\pm 10$  percent), the well may be sampled.
- A sample will be collected using the peristaltic pump set at the same or reduced speed as during well development. Samples (with the exception of the samples to be analyzed for volatile organic compounds, VOCs) will be collected directly from the pump discharge. Sample containers for VOCs will be filled by (first shutting off the pump) crimping the discharge end of the sample tubing when filled, removing the inlet end of the sample tubing from the well, suspending the inlet tubing above the vial, and allowing water to fill each vial by gravity flow.
- Once the groundwater sample has been collected, the connecting rods and well point will be removed from the hole with the direct push rig hydraulics. The hole will be backfilled with bentonite chips or bentonite cement grout, depending upon project requirements. Asphalt or concrete patch will be used to cap holes through paved or concrete areas. All holes will be finished smooth to existing grade.
- In the event the direct push van/truck cannot be driven to a remote location or sampling location with difficult accessibility, sampling probes may be advanced and sampled manually or with air/electric-operated equipment (e.g., jack hammer).
- Decontaminate the equipment before moving to the next location.

### **7.0 RECORDS**

A record of all field procedures, tests, and observations must be recorded in the field logbook, boring logs, and sample log sheets, as needed. Entries should include all pertinent data regarding the investigation. The use of sketches and field landmarks will help to supplement the investigation and evaluation.

Subject DIRECT PUSH TECHNOLOGY (GEOPROBE®/HYDROPUNCH™)	Number SA-2.5	Page 6 of 6
	Revision 0	Effective Date 02/04

**ATTACHMENT 1  
SAFE WORK PERMIT FOR DPT OPERATIONS**

Permit No. \_\_\_\_\_ Date: \_\_\_\_\_ Time: From \_\_\_\_\_ to \_\_\_\_\_

**SECTION I: General Job Scope**

- I. Work limited to the following (description, area, equipment used): Monitoring well drilling and installation through direct push technology
- II. Required Monitoring Instruments: \_\_\_\_\_
- III. Field Crew: \_\_\_\_\_
- IV. On-site inspection conducted  Yes  No Initials of Inspector TtNUS

**SECTION II: General Safety Requirements (To be filled in by permit issuer)**

- |  |  |  |
|--|--|--|
| V. Protective equipment required   | Respiratory equipment required         |  |
| Level D <input checked="" type="checkbox"/> Level B <input type="checkbox"/> | Full face APR <input type="checkbox"/> | Escape Pack <input type="checkbox"/>     |
| Level C <input type="checkbox"/> Level A <input type="checkbox"/>            | Half face APR <input type="checkbox"/> | SCBA <input type="checkbox"/>            |
| Detailed on Reverse  | SKA-PAC SAR <input type="checkbox"/>   | Bottle Trailer <input type="checkbox"/>  |
|  | Skid Rig <input type="checkbox"/>      | None <input checked="" type="checkbox"/> |

Level D Minimum Requirements: Sleeved shirt and long pants, safety footwear, and work gloves. Safety glasses, hard hats, and hearing protection will be worn when working near or sampling in the vicinity of the DPT rig.

**Modifications/Exceptions.**

VI. Chemicals of Concern	Action Level(s)	Response Measures
_____	_____	_____

VII. Additional Safety Equipment/Procedures

- |                               |   |                                  |   |
|-------------------------------|---|----------------------------------|---|
| Hard-hat                      | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No | Hearing Protection (Plugs/Muffs) | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No |
| Safety Glasses                | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No | Safety belt/harness              | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No |
| Chemical/splash goggles       | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No | Radio                            | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No |
| Splash Shield                 | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No | Barricades                       | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No |
| Splash suits/coveralls        | <input type="checkbox"/> Yes <input type="checkbox"/> No            | Gloves (Type - _____)            | <input type="checkbox"/> Yes <input type="checkbox"/> No            |
| Steel toe Work shoes or boots | <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No | Work/warming regimen             | <input type="checkbox"/> Yes <input type="checkbox"/> No            |

Modifications/Exceptions: Reflective vests for high traffic areas.

- |  |                                     |                                     |                   |                          |
|--|-------------------------------------|-------------------------------------|-------------------|--------------------------|
| VIII. Procedure review with permit acceptors | Yes                                 | NA                                  | Yes               | NA                       |
| Safety shower/eyewash (Location & Use)       | <input type="checkbox"/>            | <input checked="" type="checkbox"/> | Emergency alarms  | <input type="checkbox"/> |
| Daily tail gate meetings                     | <input checked="" type="checkbox"/> | <input type="checkbox"/>            | Evacuation routes | <input type="checkbox"/> |
| Contractor tools/equipment/PPE inspected     | <input type="checkbox"/>            | <input type="checkbox"/>            | Assembly points   | <input type="checkbox"/> |

IX. Site Preparation

- |   |  |
|---|--|
| Utility Clearances obtained for areas of subsurface investigation | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Physical hazards removed or blockaded                             | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Site control boundaries demarcated/signage                        | <input type="checkbox"/> Yes <input type="checkbox"/> No |

X. Equipment Preparation

- |   |   |
|---|---|
| Equipment drained/depressurized                       | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> NA |
| Equipment purged/cleaned                              | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> NA |
| Isolation checklist completed                         | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> NA |
| Electrical lockout required/field switch tested       | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> NA |
| Blinds/misalignments/blocks & bleeds in place         | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> NA |
| Hazardous materials on walls/behind liners considered | <input type="checkbox"/> Yes <input checked="" type="checkbox"/> NA |

XI. Additional Permits required (Hot work, confined space entry)  Yes  No

*If yes, complete permit required or contact Health Sciences, Pittsburgh Office*

XII. Special instructions, precautions:

\_\_\_\_\_

\_\_\_\_\_

Permit Issued by: \_\_\_\_\_ Permit Accepted by: \_\_\_\_\_

# STANDARD OPERATING PROCEDURES

Number SA-2.2	Page 1 of 8
Effective Date 02/04	Revision 0
Applicability	
Prepared	
Approved	

Subject  
AIR MONITORING AND SAMPLING

## TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY .....	2
4.0 RESPONSIBILITIES .....	2
5.0 PROCEDURES .....	2
5.1 INTRODUCTION .....	2
<del>5.2 AIR SAMPLING .....</del>	<del>3</del>
<del>5.3 MEDIA FOR COLLECTING AIR SAMPLES .....</del>	<del>4</del>
5.3.1 Other Methods .....	5
5.3.2 NIOSH Methods .....	5
5.4 COLLECTION AND ANALYSIS .....	5
5.4.1 Selecting Monitoring Constituents .....	5
5.4.2 Specifying Meteorological Considerations .....	5
5.4.3 Design of Monitoring Network .....	6
5.4.4 Air Monitoring Documentation/Data Reduction .....	6
5.5 PERSONNEL MONITORING .....	6
5.6 CALIBRATION .....	7
5.7 METEOROLOGICAL CONSIDERATIONS .....	7
6.0 REFERENCES .....	8
7.0 ATTACHMENTS .....	8

Subject  AIR MONITORING AND SAMPLING	Number SA-2.2	Page 2 of 8
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

The objective of this Standard Operating Procedure is to specify the proper approach and methodologies to identify and quantify airborne chemical contamination levels through the use of direct reading instrumentation and air sample collection. The results of these activities provide vital information for site characterization and risk assessment considerations.

## 2.0 SCOPE

Applies to all Tetra Tech NUS site activities where the potential for personnel exposures to respiratory health hazards exists.

## 3.0 GLOSSARY

Direct Reading Instruments (DRIs) - Instrumentation operating on various detection principles such as flame ionization or photoionization providing real time readings of ambient contaminants in air.

Personal/Area Air Sampling - Personal/area air sampling is conducted utilizing an air sampling pump and a specific collection media to quantify airborne contaminants.

Meteorological Considerations - Meteorological information must be collected on site to properly determine air sampling results, as well as aid in the characterization of contaminant potential plume migration and intensity. This information will also be used to support the selection of sampling locations and determine which samples should be analyzed. The meteorological information will be used to estimate downwind concentration levels based on short-term field levels encountered at the source.

## 4.0 RESPONSIBILITIES

Project Manager (PM) - Responsible for all aspects of project implementation and direction. The project manager is responsible for providing the necessary resources in support of all air monitoring and sampling applications.

Field Operations Leader (FOL) - Responsible for implementing the air monitoring program as detailed in approved project plans for the specific site. Air monitoring requirements will be included in both the Field Sampling and Analysis Plan (FSAP) and the site-specific Health and Safety Plan (HASP).

Health and Safety Officer (HSO) - The health and safety officer provides technical assistance to the FOL concerning air monitoring and sampling applications, collection methodologies, data interpretations, and establishes action items based on results. This information is further used to assess atmospheric migration of airborne chemical contaminants.

## 5.0 PROCEDURES

### 5.1 Introduction

Air monitoring is used to help establish criteria for worker safety, document potential exposures, and determine protective measures for the site personnel and the surrounding public. To accomplish this, it is necessary for an effective air surveillance program to be tailored to meet the conditions found at each work site.

During site operations, data are collected concerning air contaminants representative for site operations. Monitoring for vapors, gases, and particulates is performed using DRIs, air sampling systems, and

Subject  AIR MONITORING AND SAMPLING	Number SA-2.2	Page 3 of 8
	Revision 0	Effective Date 02/04

meteorological considerations. DRIs can be used to detect many organics as well as a few inorganics and can provide approximate total concentrations through applications of relative response ratios of contaminants to reference standards. If specific chemicals (organics and inorganics) have been identified, then properly calibrated DRIs can be used for more accurate onsite assessments.

The most accurate method for evaluating any air contaminant is to collect samples and analyze them at a qualified laboratory. Although accurate, this method presents two disadvantages: (1) cost and (2) the time required to obtain results. Analyzing large numbers of laboratory samples can be expensive, especially if results are needed quickly. Onsite laboratories tend to reduce the turnaround time, but unless they can analyze other types of samples, they may also be costly. In emergencies, time is often not available for laboratory analysis of samples either on site or off site.

To obtain air monitoring data rapidly at the site, DRI utilizing flame ionization detectors (FIDs), photoionization detectors (PIDs), and other detection methodology can be used. Some of these may be used as survey instruments or operated as gas chromatographs. As gas chromatographs, these instruments can provide real-time, qualitative/quantitative data when calibrated with standards of known air contaminants. Combined with selective laboratory analysis of samples, they provide a tool for evaluating airborne organic hazards on a real-time basis and at a lower cost than analyzing samples in a laboratory.

## ~~5.2 Air Sampling~~

~~For more complete information about air contaminants, measurements obtained with DRIs can be supplemented by collecting and analyzing air samples. To assess air contaminants more thoroughly, air sampling devices equipped with appropriate collection media may be placed at various locations throughout the area and on persons with at-risk occupations. These samples provide air quality information for the period of time they are taken, and can indicate contaminant types and concentrations over the sampling period. As a result, careful selection of sampling types, numbers, and locations, by a qualified health and safety professional is essential to obtain representative information. As data is obtained (from the analysis of samples, DRIs, knowledge about materials involved, site operations, and the potential for airborne toxic hazards), adjustments can be in the types of samples, number of samples collected, frequency of sampling, and analysis required. In addition to air samplers, area monitoring stations may also include DRIs equipped with data logging capabilities and operated as continuous air monitors.~~

~~Area air sampling locations may be located in various places as required by project and site needs. Area air sampling stations may include, but are not limited to:~~

- ~~• Upwind - Industrial operations, vehicle traffic, spills and other contributing sources may cause or otherwise result in the generation of air pollutants. Upwind samples establish background levels~~
- ~~• Support Zone (SZ) - Samples may be taken near the command post or other support facilities to ensure that they are, in fact, located in an unaffected area, and that the area remains clean throughout operations at the site.~~
- ~~• Contamination Reduction Zone (CRZ) - Air samples may be collected along the decontamination line to ensure that decontamination workers are properly protected and that onsite workers are not removing their respiratory protective gear in a contaminated area.~~
- ~~• Exclusion Zone (EZ) - The Exclusion Zone presents the greatest risk of release/generation of contaminants and requires the highest concern for air sampling. The location of sampling stations shall be based upon factors such as hot-spots detected by DRIs, types of substances present, and potential for airborne contaminants. The data from these stations, in conjunction with intermittent~~

Subject  AIR MONITORING AND SAMPLING	Number SA-2.2	Page 4 of 8
	Revision 0	Effective Date 02/04

walk-around surveys with DRIs, are used to verify the selection of proper levels of worker protection and EZ boundaries as well as to provide a continual record of air contaminants.

- Downwind - One or more sampling stations may be located downwind from the site to indicate if any air contaminants are leaving the site. If there are indications of airborne hazards in populated areas, appropriate response action must be taken and additional samplers should be placed downwind. Downwind locations are further determined based on meteorological considerations concerning generation, air plume migration, and intensity.

### 5.3 Media for Collecting Air Samples

Hazardous material incidents and abandoned waste sites can involve thousands of potentially dangerous substances, such as gases, vapors, and particulates that could become airborne. A variety of media are used to collect these substances. Sampling systems typically include a calibrated air sampling pump, which draws air into selected collection media. It is essential that appropriate, approved air sampling methodologies (such as those published by NIOSH, OSHA, and EPA) be followed for the collection of each specific analyte. Some of the most common types of samples and the collection media used for them are described in the following information:

One of the most common types of collection media is activated carbon which is an excellent adsorbent for most organic vapors. However, other solid adsorbents (such as Tenax, silica gel, and Florisil) are routinely used to sample specific organic compounds or classes of compounds that do not adsorb or desorb well onto activated carbon. To avoid stocking a large number of sorbents for collecting samples for various chemicals, a smaller number is generally chosen for collecting the widest range of materials or for chemicals known to be present. The vapors are collected using an industrial hygiene personal sampling pump with either one sampling port or a manifold capable of simultaneously collecting samples on several sorbent tubes (provided that sampling parameters such as flow rates and sample volumes are satisfied). For example, in a manifold with four sorbent tubes (or on individual pumps with varying flow rates), the tubes might contain:

- Activated carbon to collect vapors of materials with a boiling point above zero degrees Centigrade. Common materials collected on activated carbon include organic vapors such as solvents, BTEX, and ketones.
- A porous polymer, such as Tenax or Chromosorb, to collect substances (such as high-molecular-weight hydrocarbons, organophosphorus compounds, and the vapors of certain pesticides) that adsorb poorly onto activated carbon. Some of these porous polymers also absorb organic materials at low ambient temperatures more efficiently than carbon.
- A polar sorbent, such as silica gel, to collect organic vapors (aromatic amines, for example) that exhibit a relatively high dipole moment.
- Another specialty absorbent selected for the specific site. For example, a Florisil tube could be used if polychlorinated biphenyls are expected.
- Liquid impingers - aldehydes, ketones, phosgene, phenols.
- Glass fiber filters, membrane filters, Teflon filters - Inorganics and other semivolatile compounds.
- Airborne particulates can be either solid or liquid. Examples of common particulate analytes include some metals, fibers such as asbestos, and condensed particulates such as welding fumes. Dusts, fumes, smoke, and fibers are dispersed solids; mists and fogs are dispersed liquids. For air sampling, most particulates are collected using glass fiber, mixed cellulose ester, or polyvinyl chloride filters.

Subject  AIR MONITORING AND SAMPLING	Number SA-2.2	Page 5 of 8
	Revision 0	Effective Date 02/04

~~depending on the filter's ability to collect the subject material and its suitability for laboratory analysis. A cyclone is used to collect particles of respirable size. Atomic Absorption Spectrophotometry, Emission Spectroscopy, Phase Contrast Microscopy, and other techniques are used to analyze various types of particulates. Direct-reading monitors are also used to quantify particulate concentrations, and are usually based on the light-scattering properties of the particulate matter.~~

### 5.3.1 Other Methods

Colorimetric detector tubes can also be used with a sampling pump when monitoring for some specific compounds. A detector tube is a vial that contains a chemical preparation that reacts with the measured substance by changing color. Most detector tubes are scale tubes that permit a comparison of the length of the stain to an indicated concentration. Passive organic vapor monitors can be substituted for the active monitoring if they are available for the types of materials suspected to be present at a given site.

### 5.3.2 NIOSH Methods

The National Institute for Occupational Safety and Health's (NIOSH) Manual of Analytical Methods, 4th ed., contains acceptable methods for collecting and analyzing air samples for a variety of chemical substances. Consult these volumes for specific procedures.

## 5.4 Collection and Analysis

Collection and analysis of air samples is a multi-faceted task, and is part of the overall air surveillance program. The program is structured to cover the following air pathway analyses:

### 5.4.1 Selecting Monitoring Constituents

Applications within this program are accomplished using two considerations:

- Air surveillance for specific constituents is based on quantity of the pollutant and the likelihood for vapor release or generation.
- Controlling toxicity - These substances, even when represented in limited quantities, present the greatest threat to the public or worker safety, and influence environmental impact.

### 5.4.2 Specifying Meteorological Considerations

The following factors will influence sample collection:

- Wind direction and speed
- Sigma theta (atmospheric stability)
- Temperature
- Barometric pressure
- Humidity

These factors will provide information essential to properly arrive at accurate air sampling concentration results. This information is also used to identify how airborne chemical contaminants will react for modeling and for monitoring purposes. The results will provide indicators of plume movement, intensity, and dilution.

Subject  AIR MONITORING AND SAMPLING	Number SA-2.2	Page 6 of 8
	Revision 0	Effective Date 02/04

### 5.4.3 Design of Monitoring Network

The air surveillance network is structured to consider:

- Source characteristics (physical state; vapor release and/or generation; emission rates; and disturbance of the source impacting these aspects)
- Receptor sites (receptor sites are monitored and tracked based on priority)
- Meteorological consideration
- Air modeling input
- Data quality objectives

### 5.4.4 Air Monitoring Documentation/Data Reduction

#### 5.4.4.1 Air Monitoring Documentation

Elements of the air surveillance program are used to provide documentation valuable to safely performing/containing site activities.

Air monitoring results from DRIs must be recorded, such as on instrument results reporting forms, or in the field logbook. This information, where applicable, will be correlated to air sampling information if/when collected.

Air sampling results for personnel and area measurement efforts must be validated, prior to notifying affected individuals. Personal air sampling results notification is accomplished through verbal or written communications.

Results of air monitoring/sampling activities can be identified on site maps. This information is used to structure operational zones and identify levels of protection.

#### 5.4.4.2 Data Reduction

Data reduction combines and correlates the DRI results, air sampling results, and meteorological information to determine area and source airborne contaminant levels and movement.

All air sampling surveillance efforts must incorporate appropriate and approved NIOSH, OSHA, or EPA analytical methods. These procedures identify specific sample collection media, sampling methodologies, and analytical procedures. Sample analysis for health and safety considerations must be further supported by using American Industrial Hygiene Association accredited laboratories.

### 5.5 Personnel Monitoring

In addition to area atmospheric sampling, personnel monitoring -- both active and passive -- can be used to sample for air contaminants. Representative workers must be identified, and equipped with appropriate personal sampling systems to determine contaminants at specific locations or for specific work being performed. When sampling devices are placed on workers (generally within 1 foot of the mouth and nose) the results are used to indicate worker exposures.

Subject  AIR MONITORING AND SAMPLING	Number SA-2.2	Page 7 of 8
	Revision 0	Effective Date 02/04

## 5.6 Calibration

As a rule, the entire air sampling system shall be calibrated. Proper pre-and post-calibration activities are essential for correct operation and for accurate data. In some instances, additional calibration during the sampling period may be required. The overall frequency of calibration will depend upon the particular sampling event, including the general handling and use of a given sampling system. Pump mechanisms shall be calibrated after repair, when newly purchased, and following suspected abuse. All DRIs will be calibrated according to manufacturers instructions. All calibration activities for both air monitoring and sampling equipment must be properly documented, such as through the use of a calibration form. This form will be kept on site throughout the life of the project. The calibration log will be submitted as documentation that instrument calibration was performed on a regular basis.

## 5.7 Meteorological Considerations

Meteorological information is an integral part of an air surveillance program. Data concerning wind speed and direction, temperature, barometric pressure, and humidity (singularly or in combination) are needed for:

- Selecting air sampling locations
- Calculating accurate air sampling results
- Calculating air dispersion
- Calibrating instruments
- Determining population at risk or environmental exposure from airborne contaminants

Knowledge of wind speed and direction is necessary to effectively place air samplers. In source-oriented ambient air sampling, samplers need to be located downwind (at different distances) of the source and others need to be placed to collect background samples. Shifts in wind direction must be known. Consequently, the samplers must be relocated or corrections made for these shifts. In addition, atmospheric simulation models for predicting contaminant dispersion and concentration need windspeed and direction as inputs for predictive calculations. Information may be needed concerning the frequency and intensity that winds blow from certain directions (windrose data). Consequently, the wind direction must be continually monitored when use of this type of data is contemplated.

Air sampling systems need to be calibrated before use. This must include corrections in the calibration curves for actual temperatures and pressures during the sampling event. After sampling, collected air volumes are also mathematically corrected for temperature and pressure conditions.

Air sampling is sometimes designed to assess population exposure (and frequently potential worker exposure). Air samplers are generally located in population centers, irrespective of wind direction. Even in these instances, however, meteorological data is needed for air dispersion modeling. Models are then used to predict or verify population-oriented sampling results.

Proper data is collected by having meteorological stations on site or by obtaining the information from one or more of several government or private organizations, which routinely collect this data. The choice of how information is obtained depends on the availability of reliable data at the location desired, resources needed to obtain meteorological equipment, accuracy of information needed, and use of information.

The collection, handling, and analysis of air samples is an intricate, involved process. Appropriate methodologies, media, and equipment must be used to collect accurate data. Furthermore, selection of appropriate numbers, types, and locations of samples is essential if the data collected are to be used for personnel exposure criteria. For these reasons, air sampling activities must be coordinated and conducted by properly qualified and experienced industrial hygiene professionals. Air monitoring activities also need to be established and monitored carefully. However, as the proper use of these instruments is

Subject  AIR MONITORING AND SAMPLING	Number SA-2.2	Page 8 of 8
	Revision 0	Effective Date 02/04

not as complicated as air sampling, it is commonly acceptable to cross-train capable environmental professionals to use DRIs, with adequate technical support provided by health and safety professionals.

**6.0 REFERENCES**

Standard Operating Safety Guides, EPA, November 1984.  
NIOSH Manual of Analytical Methods, 4th Edition.

**7.0 ATTACHMENTS**

None.

# STANDARD OPERATING PROCEDURES

Number SA-6.1	Page 1 of 11
Effective Date 02/04	Revision 0
Applicability	
Prepared	
Approved	

Subject  
NON-RADIOLOGICAL SAMPLE HANDLING

## TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY .....	2
4.0 RESPONSIBILITIES .....	3
5.0 PROCEDURES .....	3
5.1 SAMPLE CONTAINERS .....	3
5.2 SAMPLE PRESERVATION .....	3
5.2.1 Overview .....	4
5.2.2 Preparation and Addition of Reagents .....	4
5.3 FIELD FILTRATION .....	5
5.4 SAMPLE PACKAGING AND SHIPPING .....	6
5.4.1 Environmental Samples .....	6
6.0 REFERENCES .....	7
 <u>ATTACHMENTS</u>	
A GENERAL SAMPLE CONTAINER AND PRESERVATION REQUIREMENTS .....	8
B ADDITIONAL REQUIRED CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES .....	9

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 2 of 11
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

The purpose of this Standard Operating Procedure (SOP) is to provide information on sample preservation, packaging, and shipping procedures to be used in handling environmental samples submitted for chemical constituent, biological, or geotechnical analysis. Sample chain-of-custody procedures and other aspects of field documentation are addressed in SOP SA-6.3. Sample identification is addressed in SOP CT-04.

## 2.0 SCOPE

This procedure describes the appropriate containers to be used for samples depending on the analyses to be performed, and the steps necessary to preserve the samples when shipped off site for chemical analysis.

## 3.0 GLOSSARY

Hazardous Material - A substance or material which has been determined by the Secretary of Transportation to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce, and which has been so designated. Under 49 CFR, the term includes hazardous substances, hazardous wastes, marine pollutants, and elevated temperature materials, as well as materials designated as hazardous under the provisions of §172.101 and §172.102 and materials that meet the defining criteria for hazard classes and divisions in Part 173. With slight modifications, IATA has adopted DOT "hazardous materials" as IATA "Dangerous Goods."

Hazardous Waste - Any substance listed in 40 CFR, Subpart D (y261.30 et seq.), or otherwise characterized as ignitable, corrosive, reactive, or toxic (as defined by Toxicity Characteristic Leaching Procedure, TCLP, analysis) as specified under 40 CFR, Subpart C (y261.20 et seq.), that would be subject to manifest requirements specified in 40 CFR 262. Such substances are defined and regulated by EPA.

Marking - A descriptive name, identification number, instructions, cautions, weight, specification or UN marks, or combination thereof required on outer packaging of hazardous materials.

n.o.i. - Not otherwise indicated (may be used interchangeably with n.o.s.).

n.o.s. - Not otherwise specified.

Packaging - A receptacle and any other components or materials necessary for compliance with the minimum packaging requirements of 49 CFR 174, including containers (other than freight containers or overpacks), portable tanks, cargo tanks, tank cars, and multi-unit tank-car tanks to perform a containment function in conformance with the minimum packaging requirements of 49 CFR 173.24(a) & (b).

Placard - Color-coded, pictorial sign which depicts the hazard class symbol and name and which is placed on the side of a vehicle transporting certain hazardous materials.

### Common Preservatives:

- Hydrochloric Acid - HCl
- Sulfuric Acid - H<sub>2</sub>SO<sub>4</sub>
- Nitric Acid - HNO<sub>3</sub>
- Sodium Hydroxide - NaOH

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 3 of 11
	Revision 0	Effective Date 02/04

#### Other Preservatives

- Zinc Acetate
- Sodium Thiosulfate - Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>

Normality (N) - Concentration of a solution expressed as equivalent per liter, an equivalent being the amount of a substance containing 1 gram-atom of replaceable hydrogen or its equivalent.

Reportable Quantity (RQ) - For the purposes of this SOP, means the quantity specified in column 3 of the Appendix to DOT 49 CFR §172.101 for any material identified in column 1 of the appendix. A spill greater than the amount specified must be reported to the National Response Center.

Sample - A sample is physical evidence collected from a facility or the environment, which is representative of conditions at the location and time of collection.

#### **4.0 RESPONSIBILITIES**

Field Operations Leader - Directly responsible for the bottling, preservation, labeling, packaging, shipping, and custody of samples up to and including release to the shipper.

Field Samplers - Responsible for initiating the Chain-of-Custody Record (per SOP SA-6.3), implementing the packaging and shipping requirements, and maintaining custody of samples until they are relinquished to another custodian or to the shipper.

#### **5.0 PROCEDURES**

Sample identification, labeling, documentation, and chain-of-custody are addressed by SOP SA-6.3.

##### **5.1 Sample Containers**

Different types of chemicals react differently with sample containers made of various materials. For example, trace metals adsorb more strongly to glass than to plastic, whereas many organic chemicals may dissolve various types of plastic containers. Attachments A and B show proper containers (as well as other information) per 40 CFR 136. In general, the sample container shall allow approximately 5-10 percent air space ("ullage") to allow for expansion/vaporization if the sample warms during transport. However, for collection of volatile organic compounds, head space shall be omitted. The analytical laboratory will generally provide certified-clean containers for samples to be analyzed for chemical constituents. Shelby tubes or other sample containers are generally provided by the driller for samples requiring geotechnical analysis. Sufficient lead time shall be allowed for a delivery of sample container orders. Therefore, it is critical to use the correct container to maintain the integrity of the sample prior to analysis.

Once opened, the container must be used at once for storage of a particular sample. Unused but opened containers are to be considered contaminated and must be discarded. Because of the potential for introduction of contamination, they cannot be reclosed and saved for later use. Likewise, any unused containers which appear contaminated upon receipt, or which are found to have loose caps or a missing Teflon liner (if required for the container), shall be discarded.

##### **5.2 Sample Preservation**

Many water and soil samples are unstable and therefore require preservation to prevent changes in either the concentration or the physical condition of the constituent(s) requiring analysis. Although complete and irreversible preservation of samples is not possible, preservation does retard the chemical and biological

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 4 of 11
	Revision 0	Effective Date 02/04

changes that inevitably take place after the sample is collected. Preservation techniques are usually limited to pH control, chemical addition(s), and refrigeration/ freezing (certain biological samples only).

### 5.2.1 Overview

The preservation techniques to be used for various analytes are listed in Attachments A and B. Reagents required for sample preservation will either be added to the sample containers by the laboratory prior to their shipment to the field or be added in the field (in a clean environment). Only high purity reagents shall be used for preservation. In general, aqueous samples of low-concentration organics (or soil samples of low- or medium-concentration organics) are cooled to 4°C. Medium-concentration aqueous samples, high-hazard organic samples, and some gas samples are typically not preserved. Low-concentration aqueous samples for metals are acidified with HNO<sub>3</sub>, whereas medium-concentration and high-hazard aqueous metal samples are not preserved. Low- or medium-concentration soil samples for metals are cooled to 4°C, whereas high-hazard samples are not cooled.

The following subsections describe the procedures for preparing and adding chemical preservatives. Attachments A and B indicate the specific analytes which require these preservatives.

The FOL is responsible for ensuring that an accurate Chemical Inventory is created and maintained for all hazardous chemicals brought to the work site (see Section 5 of the TtNUS Health and Safety Guidance Manual). Furthermore, the FOL must ensure that a corresponding Material Safety Data Sheet (MSDS) is collected for every substance entered on the site Chemical Inventory, and that all persons using/handling/ disposing of these substances review the appropriate MSDS for substances they will work with. The Chemical Inventory and the MSDSs must be maintained at each work site in a location and manner where they are readily-accessible to all personnel.

### 5.2.2 Preparation and Addition of Reagents

Addition of the following acids or bases may be specified for sample preservation; these reagents shall be analytical reagent (AR) grade or purer and shall be diluted to the required concentration with deionized water before field sampling commences. To avoid uncontrolled reactions, be sure to Add Acid to water (not vice versa). A dilutions guide is provided below.

Acid/Base	Dilution	Concentration	Estimated Amount Required for Preservation
Hydrochloric Acid (HCl)	1 part concentrated HCl: 1 part double-distilled, deionized water	6N	5-10 mL
Sulfuric Acid (H <sub>2</sub> SO <sub>4</sub> )	1 part concentrated H <sub>2</sub> SO <sub>4</sub> : 1 part double-distilled, deionized water	18N	2 - 5 mL
Nitric Acid (HNO <sub>3</sub> )	Undiluted concentrated HNO <sub>3</sub>	16N	2 - 5 mL
Sodium Hydroxide (NaOH)	400 grams solid NaOH dissolved in 870 mL double-distilled, deionized water; yields 1 liter of solution	10N	2 mL

The amounts required for preservation shown in the above table assumes proper preparation of the preservative and addition of the preservative to one liter of aqueous sample. This assumes that the sample is initially at pH 7, is poorly buffered, and does not contain particulate matter; as these conditions vary, more preservative may be required. Consequently, the final sample pH must be checked using narrow-range pH paper, as described in the generalized procedure detailed below:

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 5 of 11
	Revision 0	Effective Date 02/04

- Pour off 5-10 mL of sample into a dedicated, clean container. Use some of this sample to check the initial sample pH using wide range (0-14) pH paper. Never dip the pH paper into the sample; always apply a drop of sample to the pH paper using a clean stirring rod or pipette.
- Add about one-half of the estimated preservative required to the original sample bottle. Cap and invert gently several times to mix. Check pH (as described above) using medium range pH paper (pH 0-6 or pH 7.5-14, as applicable).
- Cap sample bottle and seal securely.

Additional considerations are discussed below:

- To test if ascorbic acid must be used to remove oxidizing agents present in the sample before it can be properly preserved, place a drop of sample on KI-starch paper. A blue color indicates the need for ascorbic acid addition.

If required, add a few crystals of ascorbic acid to the sample and retest with the KI-starch paper. Repeat until a drop of sample produces no color on the KI-starch paper. Then add an additional 0.6 grams of ascorbic acid per each liter of sample volume.

Continue with proper base preservation of the sample as described above.

- Samples for sulfide analysis must be treated by the addition of 4 drops (0.2 mL) of 2N zinc acetate solution per 100 ml of sample.

The 2N zinc acetate solution is made by dissolving 220 grams of zinc acetate in 870 mL of double-distilled, deionized water to make 1 liter of solution.

The sample pH is then raised to 9 using the NaOH preservative.

- Sodium thiosulfate must be added to remove residual chlorine from a sample. To test the sample for residual chlorine use a field test kit specially made for this purpose.

If residual chlorine is present, add 0.08 grams of sodium thiosulfate per liter of sample to remove the residual chlorine.

Continue with proper acidification of the sample as described above.

For biological samples, 10% buffered formalin or isopropanol may also be required for preservation. Questions regarding preservation requirements should be resolved through communication with the laboratory before sampling begins.

### 5.3 Field Filtration

At times, field-filtration may be required to provide for the analysis of dissolved chemical constituents. Field-filtration must be performed prior to the preservation of samples as described above. General procedures for field filtration are described below:

- The sample shall be filtered through a non-metallic, 0.45-micron membrane filter, immediately after collection. The filtration system shall consist of dedicated filter canister, dedicated tubing, and a peristaltic pump with pressure or vacuum pumping squeeze action (since the sample is filtered by mechanical peristalsis, the sample travels only through the tubing).

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 6 of 11
	Revision 0	Effective Date 02/04

- To perform filtration, thread the tubing through the peristaltic pump head. Attach the filter canister to the discharge end of the silicon tubing (note flow direction arrow); attach the aqueous sample container to the intake end of the silicon tubing. Turn the peristaltic pump on and perform filtration. Run approximately 100 ml of sample through the filter and discard prior to sample collection.
- Continue by preserving the filtrate (contained in the filter canister), as applicable and generally described above.

#### 5.4 Sample Packaging and Shipping

Only employees who have successfully completed the TtNUS "Shipping Hazardous Materials" training course are authorized to package and ship hazardous substances. These trained individuals are responsible for performing shipping duties in accordance with this training.

Samples collected for shipment from a site shall be classified as either environmental or hazardous material samples. Samples from drums containing materials other than Investigative Derived Waste (IDW) and samples obtained from waste piles or bulk storage tanks are generally shipped as hazardous materials. A distinction must be made between the two types of samples in order to:

- Determine appropriate procedures for transportation of samples (if there is any doubt, a sample shall be considered hazardous and shipped accordingly.)
- Protect the health and safety of transport and laboratory personnel receiving the samples (special precautions are used by the shipper and at laboratories when hazardous materials are received.)

Detailed procedures for packaging environmental samples are outlined in the remainder of this section.

##### 5.4.1 Environmental Samples

Environmental samples are packaged as follows:

- Place properly identified sample container, with lid securely fastened, in a plastic bag (e.g. Ziploc baggie), and seal the bag.
- Place sample in a cooler constructed of sturdy material which has been lined with a large, plastic bag (e.g. "garbage" bag). Drain plugs on coolers must be taped shut.
- Pack with enough cushioning materials such as bubble wrap (shoulders of bottles must be iced if required) to minimize the possibility of the container breaking.
- If cooling is required (see Attachments A and B), place ice around sample container shoulders, and on top of packing material (minimum of 8 pounds of ice for a medium-size cooler).
- Seal (i.e., tape or tie top in knot) large liner bag.
- The original (top, signed copy) of the COC form shall be placed inside a large Ziploc-type bag and taped inside the lid of the shipping cooler. If multiple coolers are sent but are included on one COC form, the COC form should be sent with the cooler containing the vials for VOC analysis. The COC form should then state how many coolers are included with that shipment.
- Close and seal outside of cooler as described in SOP SA-6.3. Signed custody seals must be used.

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 7 of 11
	Revision 0	Effective Date 02/04

Coolers must be marked as containing "Environmental Samples." The appropriate side of the container must be marked "This End Up" and arrows placed appropriately. No DOT marking or labeling is required; there are no DOT restrictions on mode of transportation.

## 6.0 REFERENCES

American Public Health Association, 1981. Standard Methods for the Examination of Water and Wastewater, 15th Edition. APHA, Washington, D.C.

International Air Transport Association (latest issue). Dangerous Goods Regulations, Montreal, Quebec, Canada.

U.S. Department of Transportation (latest issue). Hazardous Materials Regulations, 49 CFR 171-177.

U.S. EPA, 1984. "Guidelines Establishing Test Procedures for the Analysis of Pollutants under Clean Water Act." Federal Register, Volume 49 (209), October 26, 1984, p. 43234.

U.S. EPA, 1979. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020, U.S. EPA-EMSL, Cincinnati, Ohio.

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 8 of 11
	Revision 0	Effective Date 02/04

**ATTACHMENT A**

**GENERAL SAMPLE CONTAINER AND PRESERVATION REQUIREMENTS**

Sample Type and Concentration	Container <sup>(1)</sup>	Sample Size	Preservation <sup>(2)</sup>	Holding Time <sup>(2)</sup>
-------------------------------	--------------------------	-------------	-----------------------------	-----------------------------

**WATER**

Organics (GC&GC/MS)	VOC	Low	Borosilicate glass	2 x 40 mL	Cool to 4°C HCl to ≤ 2	14 days <sup>(9)</sup>
	Extractables SVOCs and pesticide/PCBs)	(Low	Amber glass	2x2 L or 4x1 L	Cool to 4°C	7 days to extraction; 40 days after extraction
	Extractables SVOCs and pesticide/PCBs)	(Medium	Amber glass	2x2 L or 4x1 L	None	7 days to extraction; 40 days after extraction
Inorganics	Metals	Low	High-density polyethylene	1 L	HNO <sub>3</sub> to pH ≤ 2	6 months (Hg-28 days)
		Medium	Wide-mouth glass	16 oz.	None	6 months
	Cyanide	Low	High-density polyethylene	1 L	NaOH to pH>12	14 days
	Cyanide	Medium	Wide-mouth glass	16 oz.	None	14 days
Organic/ Inorganic	High Hazard		Wide-mouth glass	8 oz.	None	14 days

**SOIL**

Organics (GC&GC/MS)	VOC		EnCore Sampler	(3) 5 g Samplers	Cool to 4°C	48 hours to lab preservation
	Extractables SVOCs and pesticides/PCBs)	(Low	Wide-mouth glass	8 oz.	Cool to 4°C	14 days to extraction; 40 days after extraction
	Extractables SVOCs and pesticides/PCBs)	(Medium	Wide-mouth glass	8 oz.	Cool to 4°C	14 days to extraction; 40 days after extraction
Inorganics	Low/Medium		Wide-mouth glass	8 oz.	Cool to 4°C	6 months (Hg - 28 days) Cyanide (14 days)
Organic/Inorga nic	High Hazard		Wide-mouth glass	8 oz.	None	NA
Dioxin/Furan	All		Wide-mouth glass	4 oz.	None	35 days until extraction; 40 days after extraction
TCLP	All		Wide-mouth glass	8 oz.	None	7 days until preparation; analysis as per fraction

**AIR**

Volatile Organics	Low/Medium		Charcoal tube -- 7 cm long, 6 mm OD, 4 mm ID	100 L air	Cool to 4°C	5 days recommended
----------------------	------------	--	---	-----------	-------------	--------------------

- 1 All glass containers should have Teflon cap liners or septa.
- 2 See Attachment E. Preservation and maximum holding time allowances per 40 CFR 136.

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 9 of 11
	Revision 0	Effective Date 02/04

**ATTACHMENT B**

**ADDITIONAL REQUIRED CONTAINERS, PRESERVATION TECHNIQUES,  
AND HOLDING TIMES**

Parameter Number/Name	Container <sup>(1)</sup>	Preservation <sup>(2)(3)</sup>	Maximum Holding Time <sup>(4)</sup>
-----------------------	--------------------------	--------------------------------	-------------------------------------

**INORGANIC TESTS:**

Acidity	P, G	Cool, 4°C	14 days
Alkalinity	P, G	Cool, 4°C	14 days
Ammonia - Nitrogen	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Biochemical Oxygen Demand (BOD)	P, G	Cool, 4°C	48 hours
Bromide	P, G	None required	28 days
Chemical Oxygen Demand (COD)	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Chloride	P, G	None required	28 days
Chlorine, Total Residual	P, G	None required	Analyze immediately
Color	P, G	Cool, 4°C	48 hours
Cyanide, Total and Amenable to Chlorination	P, G	Cool, 4°C; NaOH to pH 12; 0.6 g ascorbic acid <sup>(5)</sup>	14 days <sup>(6)</sup>
Fluoride	P	None required	28 days
Hardness	P, G	HNO <sub>3</sub> to pH 2; H <sub>2</sub> SO <sub>4</sub> to pH 2	6 months
Total Kjeldahl and Organic Nitrogen	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Nitrate - Nitrogen	P, G	None required	48 hours
Nitrate-Nitrite - Nitrogen	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Nitrite - Nitrogen	P, G	Cool, 4°C	48 hours
Oil & Grease	G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Total Organic Carbon (TOC)	P, G	Cool, 4°C; HCl or H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Orthophosphate	P, G	Filter immediately; Cool, 4°C	48 hours
Oxygen, Dissolved-Probe	G Bottle & top	None required	Analyze immediately
Oxygen, Dissolved-Winkler	G Bottle & top	Fix on site and store in dark	8 hours
Phenols	G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Phosphorus, Total	P, G	Cool, 4°C; H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days
Residue, Total	P, G	Cool, 4°C	7 days
Residue, Filterable (TDS)	P, G	Cool, 4°C	7 days
Residue, Nonfilterable (TSS)	P, G	Cool, 4°C	7 days
Residue, Settleable	P, G	Cool, 4°C	48 hours
Residue, Volatile (Ash Content)	P, G	Cool, 4°C	7 days
Silica	P	Cool, 4°C	28 days
Specific Conductance	P, G	Cool, 4°C	28 days
Sulfate	P, G	Cool, 4°C	28 days

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 10 of 11
	Revision 0	Effective Date 02/04

**ATTACHMENT B  
ADDITIONAL REQUIRED CONTAINERS, PRESERVATION TECHNIQUES,  
AND HOLDING TIMES  
PAGE TWO**

Parameter Number/Name	Container <sup>(1)</sup>	Preservation <sup>(2)(3)</sup>	Maximum Holding Time <sup>(4)</sup>
-----------------------	--------------------------	--------------------------------	-------------------------------------

**INORGANIC TESTS (Cont'd):**

Sulfide	P, G	Cool, 4°C; add zinc acetate plus sodium hydroxide to pH 9	7 days
Sulfite	P, G	None required	Analyze immediately
Turbidity	P, G	Cool, 4°C	48 hours

**METALS:<sup>(7)</sup>**

Chromium VI (Hexachrome)	P, G	Cool, 4°C	24 hours
Mercury (Hg)	P, G	HNO <sub>3</sub> to pH 2	28 days
Metals, except Chromium VI and Mercury	P, G	HNO <sub>3</sub> to pH 2	6 months

**ORGANIC TESTS:<sup>(8)</sup>**

Purgeable Halocarbons	G, Teflon-lined septum	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	14 days
Purgeable Aromatic Hydrocarbons	G, Teflon-lined septum	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup> HCl to pH 2 <sup>(9)</sup>	14 days
Acrolein and Acrylonitrile	G, Teflon-lined septum	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup> adjust pH to 4-5 <sup>(10)</sup>	14 days
Phenols <sup>(11)</sup>	G, Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction; 40 days after extraction
Benzidines <sup>(11), (12)</sup>	G, Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction <sup>(13)</sup>
Phthalate esters <sup>(17)</sup>	G, Teflon-lined cap	Cool, 4°C	7 days until extraction; 40 days after extraction
Nitrosamines <sup>(11), (14)</sup>	G, Teflon-lined cap	Cool, 4°C; store in dark; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction; 40 days after extraction
PCBs <sup>(11)</sup>	G, Teflon-lined cap	Cool, 4°C	7 days until extraction; 40 days after extraction
Nitroaromatics & Isophorone <sup>(11)</sup>	G, Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup> ; store in dark	7 days until extraction; 40 days after extraction
Polynuclear Aromatic Hydrocarbons (PAHs) <sup>(11), (14)</sup>	G, Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup> ; store in dark	7 days until extraction; 40 days after extraction
Haloethers <sup>(11)</sup>	G, Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction; 40 days after extraction
Dioxin/Furan (TCDD/TCDF) <sup>(11)</sup>	G, Teflon-lined cap	Cool, 4°C; 0.008% Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> <sup>(5)</sup>	7 days until extraction; 40 days after extraction

Subject NON-RADIOLOGICAL SAMPLE HANDLING	Number SA-6.1	Page 11 of 11
	Revision 0	Effective Date 02/04

**ATTACHMENT B  
ADDITIONAL REQUIRED CONTAINERS, PRESERVATION TECHNIQUES,  
AND HOLDING TIMES  
PAGE THREE**

- (1) Polyethylene (P): generally 500 ml or Glass (G): generally 1L.
- (2) Sample preservation should be performed immediately upon sample collection. For composite chemical samples each aliquot should be preserved at the time of collection. When use of an automated sampler makes it impossible to preserve each aliquot, then chemical samples may be preserved by maintaining at 4°C until compositing and sample splitting is completed.
- (3) When any sample is to be shipped by common carrier or sent through the United States Mail, it must comply with the Department of Transportation Hazardous Materials Regulations (49 CFR Part 172).
- (4) Samples should be analyzed as soon as possible after collection. The times listed are the maximum times that samples may be held before analysis and still be considered valid. Samples may be held for longer periods only if the permittee, or monitoring laboratory, has data on file to show that the specific types of samples under study are stable for the longer periods, and has received a variance from the Regional Administrator.
- (5) Should only be used in the presence of residual chlorine.
- (6) Maximum holding time is 24 hours when sulfide is present. Optionally, all samples may be tested with lead acetate paper before pH adjustments are made to determine if sulfide is present. If sulfide is present, it can be removed by the addition of cadmium nitrate powder until a negative spot test is obtained. The sample is filtered and then NaOH is added to pH 12.
- (7) Samples should be filtered immediately on site before adding preservative for dissolved metals.
- (8) Guidance applies to samples to be analyzed by GC, LC, or GC/MS for specific compounds.
- (9) Sample receiving no pH adjustment must be analyzed within 7 days of sampling.
- (10) The pH adjustment is not required if acrolein will not be measured. Samples for acrolein receiving no pH adjustment must be analyzed within 3 days of sampling.
- (11) When the extractable analytes of concern fall within a single chemical category, the specified preservative and maximum holding times should be observed for optimum safeguard of sample integrity. When the analytes of concern fall within two or more chemical categories, the sample may be preserved by cooling to 4°C, reducing residual chlorine with 0.008% sodium thiosulfate, storing in the dark, and adjusting the pH to 6-9; samples preserved in this manner may be held for 7 days before extraction and for 40 days after extraction. Exceptions to this optional preservation and holding time procedure are noted in footnote 5 (re: the requirement for thiosulfate reduction of residual chlorine) and footnotes 12, 13 (re: the analysis of benzidine).
- (12) If 1,2-diphenylhydrazine is likely to be present, adjust the pH of the sample to 4.0±0.2 to prevent rearrangement to benzidine.
- (13) Extracts may be stored up to 7 days before analysis if storage is conducted under an inert (oxidant-free) atmosphere.
- (14) For the analysis of diphenylnitrosamine, add 0.008% Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> and adjust pH to 7-10 with NaOH within 24 hours of sampling.
- (15) The pH adjustment may be performed upon receipt at the laboratory and may be omitted if the samples are extracted within 72 hours of collection. For the analysis of aldrin, add 0.008% Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>.

<b>STANDARD OPERATING PROCEDURES</b>	Number SA-6.3	Page 1 of 11
	Effective Date 02/04	Revision 0
	Applicability	
	Prepared	
Subject FIELD DOCUMENTATION	Approved	

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
<b>1.0 PURPOSE .....</b>	<b>2</b>
<b>2.0 SCOPE .....</b>	<b>2</b>
<b>3.0 GLOSSARY.....</b>	<b>2</b>
<b>4.0 RESPONSIBILITIES .....</b>	<b>2</b>
<b>5.0 PROCEDURES .....</b>	<b>2</b>
5.1 SITE LOGBOOK.....	2
5.1.1 General.....	2
5.1.2 Photographs .....	3
5.2 FIELD NOTEBOOKS.....	3
5.3 FIELD FORMS.....	4
5.3.1 Sample Collection, Labeling, Shipment, Request for Analysis, and Field Test Results ..	4
5.3.2 Hydrogeological and Geotechnical Forms.....	5
5.3.3 Equipment Calibration and Maintenance Form .....	6
5.4 FIELD REPORTS .....	6
5.4.1 Daily Activities Report.....	6
5.4.2 Weekly Status Reports .....	7
<b>6.0 SAMPLE FIELD FORMS .....</b>	<b>7</b>

**ATTACHMENTS**

<b>A</b>	<b>TYPICAL SITE LOGBOOK ENTRY.....</b>	<b>8</b>
<b>B</b>	<b>SAMPLE LABEL.....</b>	<b>9</b>
<b>C</b>	<b>CHAIN-OF-CUSTODY RECORD FORM .....</b>	<b>10</b>
<b>D</b>	<b>CHAIN-OF-CUSTODY SEAL .....</b>	<b>11</b>

Subject  FIELD DOCUMENTATION	Number SA-6.3	Page 2 of 11
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

The purpose of this Standard Operating Procedure (SOP) is to identify and designate the field data record forms, logs and reports generally initiated and maintained for documenting field activities.

## 2.0 SCOPE

Documents presented within this procedure (or equivalents) shall be used for all contractor field activities, as applicable. Other or additional documents may be required by specific client contracts or project planning documents.

## 3.0 GLOSSARY

None

## 4.0 RESPONSIBILITIES

Project Manager (PM) - The Project Manager is responsible for obtaining hardbound, controlled-distribution logbooks (from the appropriate source), as needed. In addition, the Project Manager is responsible for placing all field documentation used in site activities (i.e., records, field reports, sample data sheets, field notebooks, and the site logbook) in the project's central file upon the completion of field work.

Field Operations Leader (FOL) - The Field Operations Leader is responsible for ensuring that the site logbook, notebooks, and all appropriate and current forms and field reports illustrated in this guideline (and any additional forms required by the contract) are correctly used, accurately filled out, and completed in the required time-frame.

## 5.0 PROCEDURES

### 5.1 Site Logbook

#### 5.1.1 General

The site logbook is a hard-bound, paginated, controlled-distribution record book in which all major onsite activities are documented. At a minimum, the following activities/events shall be recorded or referenced (daily) in the site logbook:

- All field personnel present
- Arrival/departure of site visitors
- Time and date of H&S training
- Arrival/departure of equipment
- Time and date of equipment calibration
- Start and/or completion of borehole, trench, monitoring well installation, etc.
- Daily onsite activities performed each day
- Sample pickup information
- Health and Safety issues (level of protection observed, etc.)
- Weather conditions

A site logbook shall be maintained for each project. The site logbook shall be initiated at the start of the first onsite activity (e.g., site visit or initial reconnaissance survey). Entries are to be made for every day

Subject  FIELD DOCUMENTATION	Number SA-6.3	Page 3 of 11
	Revision 0	Effective Date 02/04

that onsite activities take place which involve contractor or subcontractor personnel. Upon completion of the fieldwork, the site logbook must become part of the project's central file.

The following information must be recorded on the cover of each site logbook:

- Project name
- Contractor project number
- Sequential book number
- Start date
- End date

Information recorded daily in the site logbook need not be duplicated in other field notebooks (see Section 5.2), but must summarize the contents of these other notebooks and refer to specific page locations in these notebooks for detailed information (where applicable). An example of a typical site logbook entry is shown in Attachment A.

If measurements are made at any location, the measurements and equipment used must either be recorded in the site logbook or reference must be made to the field notebook in which the measurements are recorded (see Attachment A).

All logbook, notebook, and log sheet entries shall be made in indelible ink (black pen is preferred). No erasures are permitted. If an incorrect entry is made, the entry shall be crossed out with a single strike mark, and initialed and dated. At the completion of entries by any individual, the logbook pages used must be signed and dated. The site logbook must also be signed by the Field Operations Leader at the end of each day.

### **5.1.2 Photographs**

When movies, slides, or photographs are taken of a site or any monitoring location, they must be numbered sequentially to correspond to logbook/notebook entries. The name of the photographer, date, time, site location, site description, and weather conditions must be entered in the logbook/notebook as the photographs are taken. A series entry may be used for rapid-sequence photographs. The photographer is not required to record the aperture settings and shutter speeds for photographs taken within the normal automatic exposure range. However, special lenses, films, filters, and other image-enhancement techniques must be noted in the logbook/notebook. If possible, such techniques shall be avoided, since they can adversely affect the accuracy of photographs. Chain-of-custody procedures depend upon the subject matter, type of camera (digital or film), and the processing it requires. Film used for aerial photography, confidential information, or criminal investigation require chain-of-custody procedures. Once processed, the slides of photographic prints shall be consecutively numbered and labeled according to the logbook/notebook descriptions. The site photographs and associated negatives and/or digitally saved images to compact disks must be docketed into the project's central file.

### **5.2 Field Notebooks**

Key field team personnel may maintain a separate dedicated field notebook to document the pertinent field activities conducted directly under their supervision. For example, on large projects with multiple investigative sites and varying operating conditions, the Health and Safety Officer may elect to maintain a separate field notebook. Where several drill rigs are in operation simultaneously, each site geologist assigned to oversee a rig must maintain a field notebook.

Subject  FIELD DOCUMENTATION	Number SA-6.3	Page 4 of 11
	Revision 0	Effective Date 02/04

### 5.3 Field Forms

Example field forms are listed in Section 6.0 of this SOP. Forms may be altered or revised for project-specific needs contingent upon client approval. Care must be taken to ensure that all essential information can be documented. Guidelines for completing these forms can be found in the related sampling SOP.

#### 5.3.1 **Sample Collection, Labeling, Shipment, Request for Analysis, and Field Test Results**

##### 5.3.1.1 Sample Log Sheet

Sample Log Sheets are used to record specified types of data while sampling. The data recorded on these sheets are useful in describing the sample as well as pointing out any problems, difficulties, or irregularities encountered during sampling. A log sheet must be completed for each sample obtained, including field quality control (QC) samples.

##### 5.3.1.2 Sample Label

A typical sample label is illustrated in Attachment B. Adhesive labels must be completed and applied to every sample container. Sample labels can usually be obtained from the appropriate Program source electronically generated in-house, or are supplied from the laboratory subcontractor.

##### 5.3.1.3 Chain-of-Custody Record Form

The Chain-of-Custody (COC) Record is a multi-part form that is initiated as samples are acquired and accompanies a sample (or group of samples) as they are transferred from person to person. This form must be used for any samples collected for chemical or geotechnical analysis whether the analyses are performed on site or off site. One carbonless copy of the completed COC form is retained by the field crew, one copy is sent to the Project Manager (or designee), while the original is sent to the laboratory. The original (top, signed copy) of the COC form shall be placed inside a large Ziploc-type bag and taped inside the lid of the shipping cooler. If multiple coolers are sent but are included on one COC form, the COC form should be sent with the cooler containing vials for VOC analysis or the cooler with the air bill attached. The air bill should then state how many coolers are included with that shipment. An example of a Chain-of-Custody Record form is provided as Attachment C. Once the samples are received at the laboratory, the sample cooler and contents are checked and any problems are noted on the enclosed COC form (any discrepancies between the sample labels and COC form and any other problems that are noted are resolved through communication between the laboratory point-of-contact and the contractor Project Manager). The COC form is signed and copied. The laboratory will retain the copy while the original becomes part of the samples' corresponding analytical data package.

##### 5.3.1.4 Chain-of-Custody Seal

Attachment D is an example of a custody seal. The Custody seal is an adhesive-backed label. It is part of a chain-of-custody process and is used to prevent tampering with samples after they have been collected in the field and sealed in coolers for transport to the laboratory. The COC seals are signed and dated by the sampler(s) and affixed across the lid and body of each cooler (front and back) containing environmental samples (see SOP SA-6.1). COC seals may be available from the laboratory; these seals may also be purchased from a supplier.

##### 5.3.1.5 Geochemical Parameters Log Sheets

Field Analytical Log Sheets are used to record geochemical and/or natural attenuation field test results.

Subject  FIELD DOCUMENTATION	Number SA-6.3	Page 5 of 11
	Revision 0	Effective Date 02/04

### 5.3.2 Hydrogeological and Geotechnical Forms

#### 5.3.2.1 Groundwater Level Measurement Sheet

A Groundwater Level Measurement Sheet must be filled out for each round of water level measurements made at a site.

#### 5.3.2.2 Data Sheet for Pumping Test

During the performance of a pumping test (or an in-situ hydraulic conductivity test), a large amount of data must be recorded, often within a short time period. The Pumping Test Data Sheet facilitates this task by standardizing the data collection format for the pumping well and observation wells, and allowing the time interval for collection to be laid out in advance.

#### 5.3.2.3 Packer Test Report Form

A Packer Test Report Form must be completed for each well upon which a packer test is conducted.

#### 5.3.2.4 Boring Log

During the progress of each boring, a log of the materials encountered, operation and driving of casing, and location of samples must be kept. The Summary Log of Boring, or Boring Log is used for this purpose and must be completed for each soil boring performed. In addition, if volatile organics are monitored on cores, samples, cuttings from the borehole, or breathing zone, (using a PID or FID), these readings must be entered on the boring log at the appropriate depth. The "Remarks" column can be used to subsequently enter the laboratory sample number, the concentration of key analytical results, or other pertinent information. This feature allows direct comparison of contaminant concentrations with soil characteristics.

#### 5.3.2.5 Monitoring Well Construction Details Form

A Monitoring Well Construction Details Form must be completed for every monitoring well, piezometer, or temporary well point installed. This form contains specific information on length and type of well riser pipe and screen, backfill, filter pack, annular seal and grout characteristics, and surface seal characteristics. This information is important in evaluating the performance of the monitoring well, particularly in areas where water levels show temporal variation, or where there are multiple (immiscible) phases of contaminants. Depending on the type of monitoring well (in overburden or bedrock, stick-up or flush mount), different forms are used.

#### 5.3.2.6 Test Pit Log

When a test pit or trench is constructed for investigative or sampling purposes, a Test Pit Log must be filled out by the responsible field geologist or sampling technician.

#### 5.3.2.7 Miscellaneous Monitoring Well Forms

Monitoring Well Materials Certificate of Conformance should be used as the project directs to document all materials utilized during each monitoring well installation.

The Monitoring Well Development Record should be used as the project directs to document all well development activities.

Subject  FIELD DOCUMENTATION	Number SA-6.3	Page 6 of 11
	Revision 0	Effective Date 02/04

### 5.3.2.8 Miscellaneous Field Forms - QA and Checklists

Container Sample and Inspection Sheet may be used as the project directs each time a container (drum, tank, etc.) is sampled and/or inspected.

QA Sample Log Sheet may be used at the project directs each time a QA sample is collected, such as Rinsate Blank, Source Blank, etc.

Field Task Modification Request (FTMR) will be prepared for all deviations from the project planning documents. The FOL is responsible for initiating the FTMRs. Copies of all FTMRs will be maintained with the onsite planning documents and originals will be placed in the final evidence file.

The Field Project Daily Activities Check List and Field Project Pre-Mobilization Checklist may be used during both the planning and field effort to assure that all necessary tasks are planned for and completed. These two forms are not a requirement but a useful tool for most field work.

### 5.3.3 **Equipment Calibration and Maintenance Form**

The calibration or standardization of monitoring, measuring or test equipment is necessary to assure the proper operation and response of the equipment, to document the accuracy, precision or sensitivity of the measurement, and determine if correction should be applied to the readings. Some items of equipment require frequent calibration, others infrequent. Some are calibrated by the manufacturer, others by the user.

Each instrument requiring calibration has its own Equipment Calibration Log which documents that the manufacturer's instructions were followed for calibration of the equipment, including frequency and type of standard or calibration device. An Equipment Calibration Log must be maintained for each electronic measuring device used in the field; entries must be made for each day the equipment is used or in accordance with the manufacturer's recommendations.

### 5.4 **Field Reports**

The primary means of recording onsite activities is the site logbook. Other field notebooks may also be maintained. These logbooks and notebooks (and supporting forms) contain detailed information required for data interpretation or documentation, but are not easily useful for tracking and reporting of progress. Furthermore, the field logbook/notebooks remain onsite for extended periods of time and are thus not accessible for timely review by project management.

#### 5.4.1 **Daily Activities Report**

To provide timely oversight of onsite contractors, Daily Activities Reports are completed and submitted as described below.

##### 5.4.1.1 Description

The Daily Activities Report (DAR) documents the activities and progress for each day's field work. This report must be filled out on a daily basis whenever there are drilling, test pitting, well construction, or other related activities occurring which involve subcontractor personnel. These sheets summarize the work performed and form the basis of payment to subcontractors. An example DAR form can be found in Appendix E.

Subject  FIELD DOCUMENTATION	Number SA-6.3	Page 7 of 11
	Revision 0	Effective Date 02/04

#### 5.4.1.2 Responsibilities

It is the responsibility of the rig geologist to complete the DAR and obtain the driller's signature acknowledging that the times and quantities of material entered are correct.

#### 5.4.1.3 Submittal and Approval

At the end of the shift, the rig geologist must submit the Daily Activities Report to the Field Operations Leader (FOL) for review and filing. The Daily Activities Report is not a formal report and thus requires no further approval. The DAR reports are retained by the FOL for use in preparing the site logbook and in preparing weekly status reports for submission to the Project Manager.

#### 5.4.2 **Weekly Status Reports**

To facilitate timely review by project management, photocopies of logbook/notebook entries may be made for internal use.

It should be noted that in addition to summaries described herein, other summary reports may also be contractually required.

### 6.0 **SAMPLE FIELD FORMS**

Example field forms can be found in Attachment C of the Master SAP.

- Groundwater Sample Log Sheet
- Surface Water Sample Log Sheet
- Soil/Sediment Sample Log Sheet
- Groundwater Level Measurement Sheet
- Pumping Test Data Sheet
- Packer Test Report Form
- Boring Log
- Monitoring Well Construction Bedrock Flush Mount
- Monitoring Well Construction Bedrock Open Hole
- Monitoring Well Construction Bedrock Stick Up
- Monitoring Well Construction Confining Layer
- Monitoring Well Construction Overburden Flush Mount
- Monitoring Well Construction Overburden Stick Up
- Test Pit Log
- Monitoring Well Development Record
- Daily Activities Record
- Field Task Modification Request
- Hydraulic Conductivity Test Data Sheet
- Low Flow Purge Data Sheet
- Equipment Calibration Log

Subject  FIELD DOCUMENTATION	Number SA-6.3	Page 8 of 11
	Revision 0	Effective Date 02/04

**ATTACHMENT A  
TYPICAL SITE LOGBOOK ENTRY**

START TIME: \_\_\_\_\_ DATE: \_\_\_\_\_

SITE LEADER: \_\_\_\_\_

PERSONNEL: \_\_\_\_\_

CONTRACTOR	DRILLER	SITE VISITORS
_____	_____	_____
_____	_____	_____
_____	_____	_____

WEATHER: Clear, 68°F, 2-5 mph wind from SE

ACTIVITIES:

1. Steam jenny and fire hoses were set up.
2. Drilling activities at well \_\_\_\_\_ resumes. Rig geologist was \_\_\_\_\_. See Geologist's Notebook, No. 1, page 29-30, for details of drilling activity. Sample No. 123-21-S4 collected; see sample logbook, page 42. Drilling activities completed at 11:50 and a 4-inch stainless steel well installed. See Geologist's Notebook, No. 1, page 31, and well construction details for well \_\_\_\_\_.
3. Drilling rig No. 2 steam-cleaned at decontamination pit. Then set up at location of well \_\_\_\_\_.
4. Well \_\_\_\_\_ drilled. Rig geologist was \_\_\_\_\_. See Geologist's Notebook, No. 2, page \_\_\_\_\_ for details of drilling activities. Sample numbers 123-22-S1, 123-22-S2, and 123-22-S3 collected; see sample logbook, pages 43, 44, and 45.
5. Well \_\_\_\_\_ was developed. Seven 55-gallon drums were filled in the flushing stage. The well was then pumped using the pitcher pump for 1 hour. At the end of the hour, water pumped from well was "sand free."
6. EPA remedial project manger arrives on site at 14:25 hours.
7. Large dump truck arrives at 14:45 and is steam-cleaned. Backhoe and dump truck set up over test pit \_\_\_\_\_.
8. Test pit \_\_\_\_\_ dug with cuttings placed in dump truck. Rig geologist was \_\_\_\_\_. See Geologist's Notebook, No. 1, page 32, for details of test pit activities. Test pit subsequently filled. No samples taken for chemical analysis. Due to shallow groundwater table, filling in of test pit \_\_\_\_\_ resulted in a very soft and wet area. A mound was developed and the area roped off.
9. Express carrier picked up samples (see Sample Logbook, pages 42 through 45) at 17:50 hours. Site activities terminated at 18:22 hours. All personnel off site, gate locked.

\_\_\_\_\_  
Field Operations Leader

Subject  FIELD DOCUMENTATION	Number SA-6.3	Page 9 of 11
	Revision 0	Effective Date 02/04

**ATTACHMENT B**

	Tetra Tech NUS, Inc. 661 Andersen Drive Pittsburgh, 15220 (412)921-7090		<b>Project:</b>
			<b>Site:</b>
		<b>Location:</b>	
<b>Sample No:</b>		<b>Matrix:</b>	
<b>Date:</b>	<b>Time:</b>	<b>Preserve:</b>	
<b>Analysis:</b>			
<b>Sampled by:</b>		<b>Laboratory:</b>	



Subject  FIELD DOCUMENTATION	Number SA-6.3	Page 11 of 11
	Revision 0	Effective Date 02/04

**ATTACHMENT D**

**CHAIN-OF-CUSTODY SEAL**

<b>Signature</b> <hr/> <b>Date</b> <hr/> <b>CUSTODY SEAL</b>		<b>CUSTODY SEAL</b> <hr/> <b>Date</b> <hr/> <b>Signature</b>
--	--	--

<b>STANDARD OPERATING PROCEDURES</b>	Number SA-7.1	Page 1 of 15
	Effective Date 03/08	Revision 1
	Applicability	
	Prepared	
Subject DECONTAMINATION OF FIELD EQUIPMENT		Approved

**TABLE OF CONTENTS**

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE AND APPLICABILITY .....	2
3.0 GLOSSARY.....	2
4.0 RESPONSIBILITIES AND PERSONNEL QUALIFICATIONS.....	3
5.0 HEALTH AND SAFETY .....	3
6.0 EQUIPMENT LIST .....	3
7.0 PROCEDURES .....	4
7.1 Decontamination Pad Design/Construction Considerations.....	5
7.1.1 Temporary Decontamination Pads .....	5
7.1.2 Decontamination Activities at Drill Rigs/DPT Units.....	7
7.1.3 Decontamination Activities at Remote Sample Locations .....	7
7.2 Equipment Decontamination Procedures .....	7
7.2.1 Monitoring Well Sampling Equipment.....	7
7.2.2 Downhole Drilling Equipment.....	9
7.2.3 Soil/Sediment Sampling Equipment .....	11
7.3 Contact Waste/Materials .....	11
7.3.1 Investigation-Derived Wastes - Decontamination Wash Waters and Sediments .....	12
7.4 Decontamination Evaluation .....	13
 <b><u>ATTACHMENTS</u></b>	
A INVESTIGATION-DERIVED WASTE LABEL .....	8

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 2 of 15
	Revision 1	Effective Date 03/08

## 1.0 PURPOSE

Decontamination is the process of removing and/or neutralizing site contaminants that have contacted and/or accumulated on equipment. The purpose of this Standard Operating Procedure (SOP) is to protect site personnel, the general public, and the environment while preserving or maintaining sample integrity. It is further intended through this procedure to describe the steps necessary for proper decontamination of drilling equipment, earth-moving equipment, chemical sampling equipment and field operation and analytical equipment.

## 2.0 SCOPE AND APPLICABILITY

This procedure applies to all equipment used to provide access to/acquire environmental samples that may have become contaminated through direct contact with contaminated media including air, water, and soil. This equipment includes drilling and heavy equipment and chemical sampling and field analytical equipment. Where technologically and economically feasible, single-use sealed disposable equipment will be employed to minimize the potential for cross-contamination. This SOP also provides general reference information on the control of contaminated materials.

Decontamination methods and equipment requirements may differ from one project to another. General equipment items are specified in Section 6.0, but project-specific equipment must be obtained to address the project-specific decontamination procedures presented in Section 7.0 and applicable subsections.

## 3.0 GLOSSARY

Alconox/Liquinox - A brand of phosphate-free laboratory-grade detergent.

Decontamination Solution - A solution selected/identified in the Health and Safety Plan or Project-Specific Quality Assurance Plan. The solution is selected and employed as directed by the project chemist/health and safety professional.

Deionized Water (DI) - Tap water that has been treated by passing through a standard deionizing resin column. This water may also pass through additional filtering media to attain various levels of analyte-free status. The DI water should meet College of American Pathologists (CAP) and National Committee for Clinical Laboratory Standards (NCCLS) specifications for reagent-grade Type I water.

Potable Water - Tap water from any municipal water treatment system. Use of an untreated potable water supply is not an acceptable substitute for tap water.

Pressure Washing - Process employing a high-pressure pump and nozzle configuration to create a high-pressure spray of potable water. High-pressure spray is employed to remove solids from equipment.

Solvent - A liquid in which solid chemicals or other liquids are dissolved. The solvent of choice is pesticide-grade isopropanol. Use of other solvents (methanol, acetone, or hexane) may be required for particular projects or for a particular purpose (e.g., removal of concentrated waste) and must be justified in the project planning documents. For example, it may be necessary to use hexane when analyzing for trace levels of pesticides, PCBs, or fuels. In addition, because many of these solvents are not miscible in water, the equipment should be air dried prior to use. Solvents should not be used on PVC equipment or well construction materials.

Steam Pressure Washing - A cleaning method employing a high-pressure spray of heated potable water to remove various organic/inorganic chemicals from equipment.

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 3 of 15
	Revision 1	Effective Date 03/08

#### 4.0 RESPONSIBILITIES AND PERSONNEL QUALIFICATIONS

Project Manager - Responsible for ensuring that all field activities are conducted in accordance with approved project plan(s) requirements.

Decontamination Personnel - Individuals assigned the task of decontamination. It is the responsibility of these individuals to understand the use and application of the decontamination process and solutions as well as the monitoring of that process to ensure that it is working properly. This is accomplished through visual evaluation, monitoring instrument scanning of decontaminated items, and/or through the collection of rinsate blanks to verify contaminant removal.

Field Operations Leader (FOL) - Responsible for the implementation of project-specific planning documents. This includes on-site verification that all field activities are performed in compliance with approved SOPs or as otherwise dictated by the approved project plan(s). The FOL is also responsible for the completion and accuracy of all field documentation.

Site Safety Officer (SSO) - Exercises shared responsibility with the FOL concerning decontamination effectiveness. All equipment arriving on site (as part of the equipment inspection), leaving the site, and moving between locations is required to go through a decontamination evaluation. This is accomplished through visual examination and/or instrument screening to determine the effectiveness of the decontamination process. Improper or incomplete decontamination is sufficient to restrict equipment from entering the site, exiting the site, or moving to a new location on the site until the objectives are successfully completed.

General personnel qualifications for decontamination activities include the following:

- Occupational Safety and Health Administration (OSHA) 40-hour and applicable refresher training.
- Capability of performing field work under the expected physical and environmental (i.e., weather) conditions.
- Familiarity with appropriate decontamination procedures.

#### 5.0 HEALTH AND SAFETY

In addition to the health and safety issues and reminders specified in subsections of this SOP, the following considerations and requirements must be observed as SOPs for field equipment decontamination activities:

- If any solvents or hazardous chemicals (e.g., isopropyl alcohol) are to be used in equipment decontamination activities, the FOL must first obtain the manufacturer's/supplier's Material Safety Data Sheet (MSDS) and assure that it is reviewed by all users (prior to its use), added to the site Hazardous Chemical Inventory, and maintained on site as part of the project Hazard Communication Program.
- Review and observe specific health and safety requirements (e.g., personal protective equipment [PPE]) specified in the project-specific health and safety plan for this activity.

#### 6.0 EQUIPMENT LIST

- Wood for decontamination pad construction, when applicable (see Section 7.1).
- Tools for constructing decontamination pad frame, when applicable (see Section 7.1).

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 4 of 15
	Revision 1	Effective Date 03/08

- Visqueen sheeting or comparable material to cover decontamination pad frame, when applicable (see Section 7.1).
- Wash/drying racks for auger flights and drill/drive rods, when applicable (see Section 7.2).
- PPE as specified in the project health and safety plan.
- Soap and water for washing and rinsing.
- Deionized water for final rinsing.
- Solvents (e.g., pesticide-grade isopropanol) for rinsing (see applicable portions of Section 7.2).
- Tubs, buckets, etc. for containerizing rinse water (see applicable portions of Section 7.2).
- Sample bottles for collecting rinsate blanks (see Section 7.2).
- Calibrated photoionization detector (PID) or flame ionization detector (FID) to monitor decontaminated equipment for organic vapors generated through the existence of residual contamination or the presence of decontamination solvent remaining after the piece was rinsed.
- Aluminum foil or clear clean plastic bag for covering cleaned equipment (see applicable portions of Section 7.2).
- Paper towels or cloths for wiping.
- Brushes, scrapers, or other hand tools useful for removing solid materials from equipment.
- Clear plastic wrap for covering or wrapping large decontaminated equipment items (see Section 7.2.2).
- Drum-moving equipment for moving filled waste drums (optional) (see Section 7.3).
- Drum labels for waste drums (see Attachment A).

## 7.0 PROCEDURES

The process of decontamination is accomplished through the removal of contaminants, neutralization of contaminants, or isolation of contaminants. To accomplish this activity, preparation is required including site preparation, equipment selection, and evaluation of the decontamination requirements and processes. Site contaminant types, concentrations, and media types are primary drivers in the selection of the types of decontamination and where it will be conducted. For purposes of this SOP, discussion is limited to decontamination procedures for general environmental investigations.

Decontamination processes will be performed at the location(s) specified in project-specific planning documents. Typical decontamination locations include the following:

- Temporary decontamination pads/facilities
- Sample locations
- Centralized decontamination pad/facilities
- Combination of some or all of the above

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 5 of 15
	Revision 1	Effective Date 03/08

The following discussion includes general considerations for the decontamination process. Specific construction and implementation procedures will be as specified in the project-specific planning documents and/or may be as dictated by site-specific conditions as long as the intent of the requirements in the planning documents is met. This intent is to contain any residual fluids and solids generated through the decontamination process.

## 7.1 Decontamination Pad Design/Construction Considerations

### 7.1.1 Temporary Decontamination Pads

Temporary decontamination pads may be constructed at satellite locations within the site area in support of temporary work areas. These structures are generally constructed to support the decontamination of heavy equipment such as drill rigs and earth-moving equipment but can be employed for smaller articles.

The purpose of the decontamination pad is to contain wash waters and potentially contaminated soil generated during decontamination procedures. Therefore, construction of these pads should take into account the following considerations:

- Site location – The decontamination site selected should be far enough from the work site to maximize decontamination effectiveness while minimizing travel distance. The location of the decontamination site shall be selected to provide, in the judgment of the FOL or FOL designee, compliance with as many of the following characteristics as practicable:
  - Well removed from pedestrian/vehicle thoroughfares.
  - Avoidance of areas where control/custody cannot be maintained.
  - Avoidance of areas where potential releases of contaminated media or decontamination fluids may be compounded through access to storm water transport systems, streams, or other potentially sensitive areas.
  - Avoidance of potentially contaminated areas.
  - Avoidance of areas too close to the ongoing operation, where cross-contamination may occur.

The selected decontamination site should include the following, where possible:

- Areas where potable water and electricity are provided.

#### **Safety Reminder**

When utilizing electrical power sources, either hard-wired or portable-generated sources, ensure that:

- All power is routed through a Ground Fault Circuit Interrupter (GFCI).
- All power cords are in good condition (no physical damage), rated for the intended energy load, and designated for outdoor use.

In situations where accomplishing these elements is not possible, it will be necessary to implement a site electrical grounding program.

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 6 of 15
	Revision 1	Effective Date 03/08

- Areas where support activities such as removing decontamination waters soil and sediment are possible without entering an active exclusion zone.
- Areas that offer sufficient size to carry out the specific decontamination sequence.
- Decontamination pad (decon pad) – The decon pad shall be constructed to meet the following characteristics:
  - Size – The size of the pad should be sufficient to accept the equipment to be decontaminated as well as permitting free movement around the equipment by the personnel conducting the decontamination. The size should permit these movements utilizing pressure/steam washer wands and hoses and minimizing splash due to work in close quarters.
  - Slope – An adequate slope will be constructed to permit the collection of water and potentially contaminated soil within a trough or sump constructed at one end. The collection point for wash waters should be of adequate distance that the decontamination workers do not have to walk through the wash waters while completing their tasks. Because the pad will be sloped, place a light coating of sand over the plastic to minimize potential slips and falls. See the text about liners below.
  - Sidewalls – The sidewalls shall be at least 6 inches in height (or as high as possible if 6 inches is not achievable) to provide adequate containment for wash waters and soil. If splash represents a potential problem, splash guards should be constructed to control overspray. Sidewalls may be constructed of wood, inflatables, sand bags, etc. to permit containment. Splash guards are typically wood frames with Visqueen coverings to control overspray.
  - Liner – Depending on the types of equipment and decontamination method to be used, the liner should be of sufficient thickness to provide a puncture-resistant barrier between the decontamination operation and the unprotected environment. Care should be taken to examine the surface area prior to placing the liner to remove sharp articles (sticks, stones, debris) that could puncture the liner. Liners are intended to form an impermeable barrier. The thickness may vary from a minimum recommended thickness of 10 mil to 30 mil. The desired thickness may be achieved through layering materials of lighter construction. It should be noted that various materials (rubber, polyethylene sheeting) become slippery when wet. To minimize this potential hazard associated with a sloped liner, a light coating of sand shall be applied to provide traction as necessary.
  - Wash/drying racks – Auger flights, drill/drive rods, and similar equipment require racks positioned off of the ground to permit these articles to be washed, drained, and dried while secured from falling during this process.

For decontamination of direct-push technology (DPT) equipment, the pad may be as simple as a mortar tub containing buckets of soapy water for washing and an empty bucket to capture rinse waters. Decontamination may be conducted at the rear of the rig to permit rapid tool exchange.

- Maintenance – Maintain the decontamination area by:
  - Periodically clearing the work area of standing water, soil, and debris, and coiling hoses to aid in eliminating slip, trip, and fall hazards. In addition, these articles will reduce potential backsplash and cross-contamination.
  - Regularly changing the decontamination fluids to ensure proper cleaning and prevent cross-contamination.

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 7 of 15
	Revision 1	Effective Date 03/08

- PPE – Periodically evaluate the condition of, and maintain the decontamination equipment, including regular cleaning of face shields and safety glasses. This is critical to ensuring the safety of decontamination personnel and the integrity of the decontamination process, and it will ensure that equipment is functioning properly.

### 7.1.2 Decontamination Activities at Drill Rigs/DPT Units

During subsurface sampling activities including drilling and DPT activities, decontamination of drive rods, Macro Core Samplers, split spoons, etc. is typically conducted at an area adjacent to the operation. Decontamination is generally accomplished using a soap/water wash and rinse utilizing buckets and brushes. This area requires sufficient preparation to accomplish the decontamination objectives.

Buckets shall be placed within mortar tubs or similar secondary containment tubs to prevent splash and spills from reaching unprotected environmental media. Drying racks shall be employed as directed for temporary pads to permit parts to dry and be evaluated prior to use/reuse. Methodology regarding this activity is provided in Section 7.2.

### 7.1.3 Decontamination Activities at Remote Sample Locations

When sampling at remote locations, sampling equipment such as trowels and pumps/tubing should be evacuated of potentially contaminated media to the extent possible. This equipment should be wrapped in plastic for transport to the temporary/centralized decontamination location for final cleaning and disposition. Flushing and cleaning of single-use equipment such as disposable trowels, tubing, and surgeon's gloves may allow disposal of this equipment after visible soil and water remnants have been removed.

## 7.2 Equipment Decontamination Procedures

The following represents procedures to be employed for the decontamination of equipment that may have contacted and/or accumulated contamination through site investigation activities.

### 7.2.1 Monitoring Well Sampling Equipment

#### 7.2.1.1 Groundwater sampling equipment – This includes pumps inserted into monitoring wells such as bladder pumps, Whale pumps, and Redi-Flo pumps and reusable bailers, etc.

1. Evacuate to the extent possible, any purge water within the pump/bailer.
2. Scrub using soap and water and/or steam clean the outside of the pump/bailer and, if applicable, the pump tubing.
3. Insert the pump and tubing/bailer into a clean container of soapy water. Pump/run a sufficient amount of soapy water through the pump/bailer to flush out any residual well water. After the pump is flushed, circulate soapy water through the pump to ensure that the internal components are thoroughly flushed.
4. Remove the pump and tubing/bailer from the container
5. Rinse external pump components using tap water.
6. Insert the pump and tubing/bailer into a clean container of tap water. Pump/run a sufficient amount of tap water through the pump/bailer to evacuate all of the soapy water (until clear).

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 8 of 15
	Revision 1	Effective Date 03/08

**CAUTION**

Do not rinse PE, PVC, and associated tubing with solvents –  
Use the procedures defined in the project-specific planning documents. If they are not defined, contact the FOL for guidance. The solvent rinse described in Step 7 may be omitted if groundwater does not contain oil, grease, PAHs, PCBs, or other hard to remove organic materials.

7. If groundwater contains or is suspected to contain oil, grease, PAHs, PCBs, or other hard to remove organic materials, rinse the equipment to be cleaned with pesticide-grade isopropanol.
8. Pass deionized water through the hose to flush out the tap water and solvent residue as applicable.
9. Drain residual deionized water to the extent possible.
10. Allow components of the equipment to air dry.
11. For bladder pumps, disassemble the pump and wash the internal components with soap and water, then rinse with tap water, isopropanol, and deionized water and allow to dry. After the parts are dry, conduct a visual inspection and a monitoring instrument scan to ensure that potential contaminants and all decontamination solvent have been removed. Collect a rinsate blank in accordance with the project-specific planning documents to ensure that the decontamination process is functioning as intended. The typical frequency of collection for rinsate blanks is 1 per 20 field samples. In addition, wipe samples or field tests such as UV light may be used.
12. Wrap pump/bailer in aluminum foil or a clear clean plastic bag for storage.

**SAFETY REMINDER**

Remember when handling powered equipment to disconnect the power source and render the equipment to a zero energy state (both potential and kinetic) before opening valves, disconnecting lines, etc.

7.2.1.2 Electronic Water Level Indicators/Sounders/Tapes

During water level measurements, rinsing the extracted tape and probe with deionized water and wiping the surface of the extracted tape between locations is acceptable. However, periodic full decontamination should be conducted as follows:

1. Wash with soap and water
2. Rinse with tap water
3. Rinse with deionized water

**NOTE**

In situations where oil, grease, free product, other hard to remove materials are encountered, probes and exposed tapes should be washed in hot soapy water. If probes or tapes cannot be satisfactorily decontaminated (they are still stained, discolored, etc.), they should be removed from service.

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 9 of 15
	Revision 1	Effective Date 03/08

### 7.2.1.3 Miscellaneous Equipment

Miscellaneous equipment including analytical equipment (water quality testing equipment) shall be cleaned per manufacturers' instructions. This generally includes wiping the sensor housing and rinsing with tap and deionized water.

Coolers/shipping containers employed to ship samples are received from the laboratory in a variety of conditions including marginal to extremely poor. Coolers shall be evaluated prior to use for the following:

- Structural integrity – Coolers missing handles or having breaks in the outer housing should be removed and not used. Notify the laboratory that the risk of shipping samples in the cooler(s) provided is too great and request a replacement unit.
- Cleanliness – As per protocol, only volatile organic samples are accompanied by a trip blank. If a cooler's cleanliness is in question (visibly dirty/stained) or if there are noticeable odors, the cooler should be decontaminated prior to use as follows:
  1. Wash with soap and water
  2. Rinse with tap water
  3. Dry

If these measures fail to clean the cooler to an acceptable level, remove the unit from use as a shipping container and ask the cooler provider (e.g., the analytical laboratory) to provide a replacement unit.

### 7.2.2 Downhole Drilling Equipment

This includes any portion of the drill rig that is over the borehole, including auger flights, drill stems, rods, and associated tooling that would extend over the borehole. The following procedure is to be employed prior to initiating the drilling/sampling activity, then between locations:

**CAUTION**

Exercise care when using scrapers to remove soil and debris from downhole drilling equipment. Inadvertent slips of scrapers have resulted in cuts, scrapes, and injured knuckles, so use scrapers carefully when removing soil from these items.

1. Remove loose soil using shovels, scrapers, etc.
2. Through a combination of scrubbing using soap and water and/or steam cleaning or pressure washing, remove visible dirt/soil from the equipment being decontaminated.

**CAUTION**

In Step 3, do not rinse PE, PVC, and associated tubing with solvents. The appropriate procedures should be defined within the project-specific planning documents. If they are not defined, contact the FOL for guidance. The solvent rinse described in Step 4 may be omitted if groundwater does not contain oil, grease, PAHs, PCBs, or other hard to remove organic materials.

3. Rinse the equipment with tap water, where applicable (steam cleaning and pressure washing incorporate rinsing as part of the process).

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 10 of 15
	Revision 1	Effective Date 03/08

4. If the equipment has directly or indirectly contacted contaminated sample media and is known or suspected of being contaminated with oil, grease, PAHs, PCBs, or other hard to remove organic materials, rinse equipment with pesticide-grade isopropanol
5. To the extent possible, allow components to air dry.
6. If the decontaminated equipment is to be used immediately after decontamination, screen it with a calibrated photoionization detector (PID)/flame ionization detector (FID) to ensure that all contaminants and possible decontamination solvents (if they were used) have been adequately removed.
7. Wrap or cover equipment in clear plastic until it is time to be used.

**SAFETY REMINDER**

Even when equipment is disconnected from power sources, dangers such as the following may persist:

Falls - An auger flight standing on its end may fall and injure someone. Secure all loose articles to prevent heavy articles from falling onto people or equipment.

Burns - Steam cleaner water is heated to more than 212 °F and exhibits thermal energy that can cause burns. Prevent contact of skin with hot water or surfaces.

High water pressure - Pressure washer discharge can have 2,000 to 4,000 psi of water pressure. Water under this amount of pressure can rupture skin and other human tissues. Water at 4,000 psi exiting a 0° tip can be dangerous because of its relatively high cutting power. The exit velocity and cutting power of the water are reduced when exiting a 40° fan tip, but damage to soft tissues is still possible.

In general, follow the rules below to avoid injury, equipment damage, or incomplete decontamination:

1. Read the operating manual and follow the manufacturers' recommended safety practices before operating pressure washers and steam cleaners.
2. Never point the pressure washer or steam cleaner at another person or use to clean your boots or other parts of your body. Water lacerations and burns may appear to be minor at first but can be life threatening. Do not attempt to hold small parts in your hand while washing them with high-temperature or high-pressure water.
3. Always wear PPE as specified in the HASP such as:
  - Hard hat, safety glasses, splash shield, impermeable apron or splash suit, and hearing protection. Remember that excessive noise is a hazard when operating gas-powered engines and electrically driven pressure washers. PPE will be identified in your project specific planning documents.
4. Inspect each device before use. An inspection checklist will be provided in the project-specific planning documents. If it is a rented device, safety measures are typically provided by the vendor. In all cases, if you are not familiar with the operation of a pressure washer/steam cleaner, do not operate it until you obtain and thoroughly review operating instructions and recommended safety practices.
5. Do not modify equipment unless the manufacturer has approved the modifications.

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 11 of 15
	Revision 1	Effective Date 03/08

### 7.2.3 Soil/Sediment Sampling Equipment

This section applies to soil sampling equipment including but not limited to hand augers, stainless steel trowels/spoons, bowls, dredges, scoops, split spoons, Macro Core samplers, etc.

1. Remove all loose soil from the equipment through manual means.
2. Through a combination of scrubbing using soap and water and/or steam cleaning or pressure washing, remove visible dirt/soil from the equipment.
3. Rinse the equipment with tap water.

**CAUTION**

Do not rinse PE, PVC, and associated tubing with solvents. The appropriate procedures should be defined within the project-specific planning documents. If they are not defined, contact the FOL for guidance. The solvent rinse described in Step 4 may be omitted if groundwater does not contain oil, grease, PAHs, PCBs, or other hard to remove organic materials.

4. If the equipment is contaminated or suspected to be contaminated with oil, grease, PAHs, PCBs, or other hard to remove organic materials, rinse the equipment with pesticide-grade isopropanol.
5. Rinse the equipment with deionized water.
6. To the extent possible, allow components to air dry.
7. If the equipment is to be used immediately after decontamination, screen it with a calibrated PID/FID to ensure that all solvents (if they were used) and trace contaminants have been adequately removed.
8. After the equipment has dried, wrap it in aluminum foil for storage until use.

Dredges employed in sediment sampling are typically decontaminated as follows:

- Remove the sediment sample from the sampling device
- If sufficient associated surface water is available at the sampling site, place the dredge in the water and flush to remove visible sediment.
- Extract the dredge and wash it in soap and water per the project-specific planning documents.

**CAUTION**

When handling dredges, the primary safety concern is trapping fingers or extremities in the larger dredge samplers within the jaws or pinch points of the mechanical jaws. Keep hands, fingers, and extremities away from these pinch and compression points. Either handle the device by the rope or preferably lock the jaws in place to control the potential for closing during maintenance and/or cleaning.

### 7.3 Contact Waste/Materials

During the course of field investigations, disposable/single-use equipment becomes contaminated. These items include tubing, trowels, PPE (gloves, overboots, splash suits, etc.), and broken sample containers.

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 12 of 15
	Revision 1	Effective Date 03/08

With the exception of the broken glass, single-use articles should be cleaned (washed and rinsed) of visible materials and disposed as normal refuse. The exception to this rule is that extremely soiled materials that cannot be cleaned shall be containerized for disposal in accordance with applicable federal, state, and local regulations.

### 7.3.1 Investigation-Derived Wastes - Decontamination Wash Waters and Sediments

**NOTE**  
Requirements for waste storage may differ from one facility to the next. Facility-specific directions for waste storage areas will be provided in project-specific documents, or separate direction will be provided by the Project Manager.

1. Assume that all investigation-derived waste (IDW) generated from decontamination activities contains the hazardous chemicals associated with the site unless there are analytical or other data to the contrary. Waste solution volumes could vary from a few gallons to several hundred gallons in cases where large equipment required cleaning.
2. Where possible, use filtering systems to extend the use of water within a closed system wash unit to recycle water and to reduce possible waste amounts.

**NOTE**  
Containerized waste rinse solutions are best stored in 55-gallon drums (or equivalent containers) that can be sealed until ultimate disposal at an approved facility.

3. Label waste storage containers appropriately labeled (see Attachment A).
4. Ensure that the IDW storage area is configured to meet the following specifications to permit access to the containers and to conduct spill/leak monitoring, sampling, and extraction when the disposal route is determined:
  - Enclose areas accessible by the general public using construction fencing and signs.
  - Stored materials in 55-gallon drums on pallets with four (or fewer) drums per pallet.
  - Maintain the retaining bolt and label on the outside of storage containers where readily visible.
  - Provide at least 4 feet of room between each row of pallets to allow access to containers for sampling, drum removal, and spill response.
  - As directed in project-specific planning documents, maintain an IDW Inventory List and provide the list to the site Point of Contact at the termination of each shift.
  - Maintain spill response equipment at the IDW storage area in case it is required for immediate access.
  - Where possible, use equipment for moving containers. Where not possible, obtain help to manipulate containers.

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 13 of 15
	Revision 1	Effective Date 03/08

**CAUTION**

Each container of water can weigh up to 490 pounds. Each 55-gallon drum of wet soil can weigh more than 750 pounds. Fill drums and temporary containers to 80 percent capacity to minimize spill and handling difficulties. Use drum carts to move filled drums.

See safe lifting techniques provided in Section 4.4 of the Tetra Tech NUS, Inc. Health and Safety Guidance Manual.

When placing drums, keep your fingers out of pinch and smash points such as between the drums. In some cases such as well development and/or purge water, you can place the drums to be filled on the pallet and transport materials in smaller easier to handle containers.

**7.4 Decontamination Evaluation**

Upon decontamination of equipment, determine the effectiveness of the decontamination process in the following manner:

- Visual evaluation – A visual evaluation will be conducted to ensure the removal of particulate matter. This shall be done to ensure that the washing/rinsing process is working as intended.
- Instrument Screening – A properly calibrated PID/FID should be used to evaluate the presence of site contaminants and solvents used in the cleaning process. The air intake of the instrument shall be passed over the article to be evaluated. Avoid placing the instrument probe into residual waters. A PID/FID reading greater than the daily established background level requires a repeat of the decontamination process, followed by rescreening with the PID/FID. This sequence must be repeated until no instrument readings greater than the daily established background level are observed. It should be noted that the instrument scan is only viable if the contaminants are detectable within the instrument's capabilities.

**NOTE**

When required by project-specific planning documents, collection of rinsate blanks (see next step) shall be completed without exception unless approval to not collect these samples is obtained from the Project Manager.

- Collection of Rinsate Blanks – It is recommended that rinsate samples be collected to:
  - Evaluate the decontamination procedure representing different equipment applications (pumps versus drilling equipment) and different decontamination applications.
  - Single-use disposable equipment – The number of samples should represent different types of equipment as well as different lot numbers of single-use articles.
  - The collection and the frequency of collection of rinsate samples are as follows unless specified differently in the project-specific planning documents:
    - Per decontamination method
    - Per disposable article/batch number of disposable articles

Subject DECONTAMINATION OF FIELD EQUIPMENT	Number SA-7.1	Page 14 of 15
	Revision 1	Effective Date 03/08

**NOTE**

It is recommended that an initial rinsate sample be collected early in the project to ensure that the decontamination process is functioning properly and to avoid using a contaminated batch of single-use articles. It is recommended that a follow-up sample be collected later during the execution of the project to ensure that those conditions do not change.

Rinsate samples collection may be driven by types of and/or levels of contaminant. Difficult to remove contaminants, oils/greases, some PAHs/PCBs, etc. may also support the collection of additional rinsates due to the obvious challenges to the decontamination process. This is a field consideration to be determined by the FOL.

# STANDARD OPERATING PROCEDURES

Subject DECONTAMINATION OF FIELD EQUIPMENT

Number	SA-7.1	Page	15 of 15
--------	--------	------	----------

Effective Date	03/08	Revision	1
----------------	-------	----------	---

Applicability

Prepared

Approved

Attachment A IDW Label

## INVESTIGATION DERIVED WASTE

GENERATOR INFORMATION:

SITE \_\_\_\_\_ JOB NO. \_\_\_\_\_

LOCATION \_\_\_\_\_

DATE \_\_\_\_\_

DRUM# \_\_\_\_\_

CONTENTS \_\_\_\_\_

VOLUME \_\_\_\_\_

CONTACT \_\_\_\_\_

EMERGENCY PHONE NUMBER \_\_\_\_\_

# STANDARD OPERATING PROCEDURES

Number HS-1.0	Page 1 of 15
Effective Date 02/04	Revision 0
Applicability	
Prepared	
Approved	

Subject  
UTILITY LOCATING AND EXCAVATION CLEARANCE

## TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1.0 PURPOSE .....	2
2.0 SCOPE .....	2
3.0 GLOSSARY .....	2
4.0 RESPONSIBILITIES .....	3
5.0 PROCEDURES .....	3
5.1 BURIED UTILITIES .....	3
5.2 OVERHEAD POWER LINES .....	5
6.0 UNDERGROUND LOCATING TECHNIQUES .....	5
6.1 GEOPHYSICAL METHODS .....	5
6.2 PASSIVE DETECTION SURVEYS .....	6
6.3 INTRUSIVE DETECTION SURVEYS .....	6
7.0 INTRUSIVE ACTIVITIES SUMMARY .....	7
8.0 REFERENCES .....	8

### ATTACHMENTS

1 Listing of Underground Utility Clearance Resources .....	9
2 Frost Line Penetration Depths by Geographic Location .....	11
3 Utility Clearance Form .....	12
4 OSHA Letter of Interpretation .....	13

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 2 of 15
	Revision 0	Effective Date 02/04

## 1.0 PURPOSE

Utilities such as electric service lines, natural or propane gas lines, water and sewage lines, telecommunications, and steam lines are very often in the immediate vicinity of work locations. Contact with underground or overhead utilities can have serious consequences including employee injury/fatality, property and equipment damage, substantial financial impacts, and loss of utility service to users.

The purpose of this procedure is to provide minimum requirements and technical guidelines regarding the appropriate procedures to be followed when performing subsurface and overhead utility locating services. It is the policy of Tetra Tech NUS, Inc. (TtNUS) to provide a safe and healthful work environment for the protection of our employees. The purpose of this Standard Operating Procedure (SOP) is to aid in achieving the objectives of this policy, to present the acceptable procedures pertaining to utility locating and excavation clearance activities, and to present requirements and restrictions relevant to these types of activities. This SOP must be reviewed by any employee potentially involved with underground or overhead utility locating and avoidance activities.

## 2.0 SCOPE

This procedure applies to all TtNUS field activities where there may be potential contact with underground or overhead utilities. This procedure provides a description of the principles of operation, instrumentation, applicability, and implementability of typical methods used to determine the presence and avoidance of contact with utility services. This procedure is intended to assist with work planning and scheduling, resource planning, field implementation, and subcontractor procurement. Utility locating and excavation clearance requires site-specific information prior to the initiation of any such activities on a specific project. This SOP is not intended to provide a detailed description of methodology and instrument operation. Specialized expertise during both planning and execution of several of the methods presented may also be required.

## 3.0 GLOSSARY

Electromagnetic Induction (EMI) Survey - A geophysical exploration method whereby electromagnetic fields are induced in the ground and the resultant secondary electromagnetic fields are detected as a measure of ground conductivity.

Magnetometer - A device used for precise and sensitive measurements of magnetic fields.

Magnetic Survey - A geophysical survey method that depends on detection of magnetic anomalies caused by the presence of buried ferromagnetic objects.

Metal Detection - A geophysical survey method that is based on electromagnetic coupling caused by underground conductive objects.

Vertical Gradiometer - A magnetometer equipped with two sensors that are vertically separated by a fixed distance. It is best suited to map near surface features and is less susceptible to deep geologic features.

Ground Penetrating Radar - Ground Penetrating Radar (GPR) involves specialized radar equipment whereby a signal is sent into the ground via a transmitter. Some portion of the signal will be reflected from the subsurface material, which is then recorded with a receiver and electronically converted into a graphic picture.

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 3 of 15
	Revision 0	Effective Date 02/04

#### 4.0 RESPONSIBILITIES

Project Manager (PM)/Task Order Manager (TOM) - Responsible for ensuring that all field activities are conducted in accordance with this procedure.

Site Manager (SM)/Field Operations Leader (FOL) - Responsible for the onsite verification that all field activities are performed in compliance with approved SOPs or as otherwise directed by the approved project plan(s).

Site Health & Safety Officer (SHSO) – Responsible to provide technical assistance and verify full compliance with this SOP. The SHSO is also responsible for reporting any deficiencies to the Corporate Health and Safety Manager (HSM) and to the PM/TOM.

Health & Safety Manager (HSM) – Responsible for preparing, implementing, and modifying corporate health and safety policy and this SOP.

Site Personnel – Responsible for performing their work activities in accordance with this SOP and the TtNUS Health and Safety Policy.

#### 5.0 PROCEDURES

This procedure addresses the requirements and technical procedures that must be performed to minimize the potential for contact with underground and overhead utility services. These procedures are addressed individually from a buried and overhead standpoint.

##### 5.1 Buried Utilities

Buried utilities present a heightened concern because their location is not typically obvious by visual observation, and it is common that their presence and/or location is unknown or incorrectly known on client properties. This procedure must be followed prior to beginning any subsurface probing or excavation that might potentially be in the vicinity of underground utility services. In addition, the Utility Clearance Form (Attachment 3) must be completed for every location or cluster of locations where intrusive activities will occur.

Where the positive identification and de-energizing of underground utilities cannot be obtained and confirmed using the following steps, the PM/TOM is responsible for arranging for the procurement of a qualified, experienced, utility locating subcontractor who will accomplish the utility location and demarcation duties specified herein.

1. A comprehensive review must be made of any available property maps, blue lines, or as-builts prior to site activities. Interviews with local personnel familiar with the area should be performed to provide additional information concerning the location of potential underground utilities. Information regarding utility locations shall be added to project maps upon completion of this exercise.
- 2., A visual site inspection must be performed to compare the site plan information to actual field conditions. Any findings must be documented and the site plan/maps revised. The area(s) of proposed excavation or other subsurface activities must be marked at the site in white paint or pin flags to identify those locations of the proposed intrusive activities. The site inspection should focus on locating surface indications of potential underground utilities. Items of interest include the presence of nearby area lights, telephone service, drainage grates, fire hydrants, electrical service vaults/panels, asphalt/concrete scars and patches, and topographical depressions. Note the location of any emergency shut off switches. Any additional information regarding utility

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 4 of 15
	Revision 0	Effective Date 02/04

locations shall be added to project maps upon completion of this exercise and returned to the PM/TOM.

3. If the planned work is to be conducted on private property (e.g., military installations, manufacturing facilities, etc.) the FOL must identify and contact appropriate facility personnel (e.g., public works or facility engineering) before any intrusive work begins to inquire about (and comply with) property owner requirements. It is important to note that private property owners may require several days to several weeks advance notice prior to locating utilities.
4. If the work location is on public property, the state agency that performs utility clearances must be notified (see Attachment 1). State "one-call" services must be notified prior to commencing fieldwork per their requirements. Most one-call services require, by law, 48- to 72-hour advance notice prior to beginning any excavation. Such services typically assign a "ticket" number to the particular site. This ticket number must be recorded for future reference and is valid for a specific period of time, but may be extended by contacting the service again. The utility service will notify utility representatives who then mark their respective lines within the specified time frame. It should be noted that most military installations own their own utilities but may lease service and maintenance from area providers. Given this situation, "one call" systems may still be required to provide location services on military installations.
5. Utilities must be identified and their locations plainly marked using pin flags, spray paint, or other accepted means. The location of all utilities must be noted on a field sketch for future inclusion on project maps. Utility locations are to be identified using the following industry-standard color code scheme, unless the property owner or utility locator service uses a different color code:

white	excavation/subsurface investigation location
red	electrical
yellow	gas, oil, steam
orange	telephone, communications
blue	water, irrigation, slurry
green	sewer, drain

6. Where utility locations are not confirmed with a high degree of confidence through drawings, schematics, location services, etc., the work area must be thoroughly investigated prior to beginning the excavation. In these situations, utilities must be identified using safe and effective methods such as passive and intrusive surveys, or the use of non-conductive hand tools. Also, in situations where such hand tools are used, they should always be used in conjunction with suitable detection equipment, such as the items described in Section 6.0 of this SOP. Each method has advantages and disadvantages including complexity, applicability, and price. It also should be noted that in some states, initial excavation is required by hand to a specified depth.
7. At each location where trenching or excavating will occur using a backhoe or other heavy equipment, and where utility identifications and locations cannot be confirmed prior to groundbreaking, the soil must be probed using a device such as a tile probe which is made of non-conductive material such as fiberglass. If these efforts are not successful in clearing the excavation area of suspect utilities, hand shoveling must be performed for the perimeter of the intended excavation.
8. All utilities uncovered or undermined during excavation must be structurally supported to prevent potential damage. Unless necessary as an emergency corrective measure, TtNUS shall not make any repairs or modifications to existing utility lines without prior permission of the utility owner, property owner, and Corporate HSM. All repairs require that the line be locked-out/tagged-out prior to work.

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 5 of 15
	Revision 0	Effective Date 02/04

## 5.2 Overhead Power Lines

If it is necessary to work within the minimum clearance distance of an overhead power line, the overhead line must be de-energized and grounded, or re-routed by the utility company or a registered electrician. If protective measures such as guarding, isolating, or insulating are provided, these precautions must be adequate to prevent employees from contacting such lines directly with any part of their body or indirectly through conductive materials, tools, or equipment.

The following table provides the required minimum clearances for working in proximity to overhead power lines.

<u>Nominal Voltage</u>	<u>Minimum Clearance</u>
0 -50 kV	10 feet, or one mast length; whichever is greater
50+ kV	10 feet plus 4 inches for every 10 kV over 50 kV or 1.5 mast lengths; whichever is greater

## 6.0 UNDERGROUND LOCATING TECHNIQUES

A variety of supplemental utility locating approaches are available and can be applied when additional assurance is needed. The selection of the appropriate method(s) to employ is site-specific and should be tailored to the anticipated conditions, site and project constraints, and personnel capabilities.

### 6.1 Geophysical Methods

Geophysical methods include electromagnetic induction, magnetics, and ground penetrating radar. Additional details concerning the design and implementation of electromagnetic induction, magnetics, and ground penetrating radar surveys can be found in one or more of the TtNUS SOPs included in the References (Section 8.0).

#### **Electromagnetic Induction**

Electromagnetic Induction (EMI) line locators operate either by locating a background signal or by locating a signal introduced into the utility line using a transmitter. A utility line acts like a radio antenna, producing electrons, which can be picked up with a radiofrequency receiver. Electrical current carrying conductors have a 60HZ signal associated with them. This signal occurs in all power lines regardless of voltage. Utilities in close proximity to power lines or used as grounds may also have a 60HZ signal, which can be picked up with an EM receiver. A typical example of this type of geophysical equipment is an EM-61.

EMI locators specifically designed for utility locating use a special signal that is either indirectly induced onto a utility line by placing the transmitter above the line or directly induced using an induction clamp. The clamp induces a signal on the specific utility and is the preferred method of tracing since there is little chance of the resulting signals being interfered with. A good example of this type of equipment is the Schonstedt® MAC-51B locator. The MAC-51B performs inductively traced surveys, simple magnetic locating, and traced nonmetallic surveys.

When access can be gained inside a conduit to be traced, a flexible insulated trace wire can be used. This is very useful for non-metallic conduits but is limited by the availability of gaining access inside the pipe.

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 6 of 15
	Revision 0	Effective Date 02/04

## Magnetics

Magnetic locators operate by detecting the relative amounts of buried ferrous metal. They are incapable of locating or identifying nonferrous utility lines but can be very useful for locating underground storage tanks (UST's), steel utility lines, and buried electrical lines. A typical example of this type of equipment is the Schonstedt® GA-52Cx locator. The GA-52Cx is capable of locating 4-inch steel pipe up to 8 feet deep.

Non-ferrous lines are often located by using a typical plumbing tool (snake) fed through the line. A signal is then introduced to the snake that is then traced.

## Ground Penetrating Radar

Ground Penetrating Radar (GPR) involves specialized radar equipment whereby a signal is sent into the ground via a transmitter. Some portion of the signal will be reflected from the subsurface material, which is then recorded with a receiver and electronically converted into a graphic picture. In general, an object which is harder than the surrounding soil will reflect a stronger signal. Utilities, tunnels, UST's, and footings will reflect a stronger signal than the surrounding soil. Although this surface detection method may determine the location of a utility, this method does not specifically identify utilities (i.e., water vs. gas, electrical vs. telephone); hence, verification may be necessary using other methods. This method is somewhat limited when used in areas with clay soil types or with a high water table.

### 6.2 Passive Detection Surveys

#### Acoustic Surveys

Acoustic location methods are generally most applicable to waterlines or gas lines. A highly sensitive Acoustic Receiver listens for background sounds of water flowing (at joints, leaks, etc.) or to sounds introduced into the water main using a transducer. Acoustics may also be applicable to determine the location of plastic gas lines.

#### Thermal Imaging

Thermal (i.e., infrared) imaging is a passive method for detecting the heat emitted by an object. Electronics in the infrared camera convert subtle heat differentials into a visual image on the viewfinder or a monitor. The operator does not look for an exact temperature; rather they look for heat anomalies (either elevated or suppressed temperatures) characteristic of a potential utility line.

The thermal fingerprint of underground utilities results from differences in temperature between the atmosphere and the fluid present in a pipe or the heat generated by electrical resistance. In addition, infrared scanners may be capable of detecting differences in the compaction, temperature and moisture content of underground utility trenches. High-performance thermal imagery can detect temperature differences to hundredths of a degree.

### 6.3 Intrusive Detection Surveys

#### Vacuum Excavation

Vacuum excavation is used to physically expose utility services. The process involves removing the surface material over approximately a 1' x 1' area at the site location. The air-vacuum process proceeds with the simultaneous action of compressed air-jets to loosen soil and vacuum extraction of the resulting

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 7 of 15
	Revision 0	Effective Date 02/04

debris. This process ensures the integrity of the utility line during the excavation process, as no hammers, blades, or heavy mechanical equipment comes into contact with the utility line, eliminating the risk of damage to utilities. The process continues until the utility is uncovered. Vacuum excavation can be used at the proposed site location to excavate below the "utility window" which is usually 8 feet.

### Hand Excavation

When the identification and location of underground utilities cannot be positively confirmed through document reviews and/or other methods, borings and excavations may be cleared via the use of non-conductive hand tools. This should always be done in conjunction with the use of detection equipment. This would be required for all locations where there is a potential to impact buried utilities. The minimum hand-excavation depth that must be reached is to be determined considering the geographical location of the work site. This approach recognizes that the placement of buried utilities is influenced by frost line depths that vary by geographical region. Attachment 2 presents frost line depths for the regions of the contiguous United States. At a minimum, hand excavation depths must be at least to the frost line depth (see Attachment 2) plus two (2) feet, but never less than 4 feet below ground surface (bgs). For hand excavation, the hole created must be reamed large enough to be at least the diameter of the drill rig auger or bit prior to drilling. For soil gas surveys, the survey probe shall be placed as close as possible to the cleared hand excavation. It is important to note that a post-hole digger must not be used in this type of hand excavation activity.

### Tile Probe Surveys

For some soil types, site conditions, and excavation requirements, non-conductive tile probes may be used. A tile probe is a "T"-handled rod of varying lengths that can be pushed into the soil to determine if any obstructions exist at that location. Tile probes constructed of fiberglass or other nonconductive material are readily-available from numerous vendors. Tile probes must be performed to the same depth requirements as previously specified. As with other types of hand excavating activities, the use of a non-conductive tile probe, should always be in conjunction with suitable utility locating detection equipment.

## 7.0 INTRUSIVE ACTIVITIES SUMMARY

The following list summarizes the activities that must be performed prior to beginning subsurface activities:

1. Map and mark all subsurface locations and excavation boundaries using white paint or markers specified by the client or property owner.
2. Notify the property owner and/or client that the locations are marked. At this point, drawings of locations or excavation boundaries shall be provided to the property owner and/or client so they may initiate (if applicable) utility clearance.

Note: Drawings with confirmed locations should be provided to the property owner and/or client as soon as possible to reduce potential time delays.

3. Notify "One Call" service. If possible, arrange for an appointment to show the One Call representative the surface locations or excavation boundaries in person. This will provide a better location designation to the utilities they represent. You should have additional drawings should you need to provide plot plans to the One Call service.
4. Implement supplemental utility detection techniques as necessary and appropriate to conform utility locations or the absence thereof.

Subject	Number HS-1.0	Page 8 of 15
UTILITY LOCATING AND EXCAVATION CLEARANCE	Revision 0	Effective Date 02/04

5. Complete Attachment 3, Utility Clearance Form. This form should be completed for each excavation location. In situations where multiple subsurface locations exist within the close proximity of one another, one form may be used for multiple locations provided those locations are noted on the Utility Clearance Form. Upon completion, the Utility Clearance Form and revised/annotated utility location map becomes part of the project file.

## 8.0 REFERENCES

OSHA Letter of Interpretation, Mr. Joseph Caldwell, Attachment 4  
 OSHA 29 CFR 1926(b)(2)  
 OSHA 29 CFR 1926(b)(3)  
 TtNUS Utility Locating and Clearance Policy  
 TtNUS SOP GH-3.1; Resistivity and Electromagnetic Induction  
 TtNUS SOP GH-3.2; Magnetic and Metal Detection Surveys  
 TtNUS SOP GH-3.4; Ground-penetrating Radar Surveys

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 9 of 15
	Revision 0	Effective Date 02/04

**ATTACHMENT 1  
LISTING OF UNDERGROUND UTILITY CLEARANCE RESOURCES**



**American Public Works Association**  
2345 Grand Boulevard, Suite 500, Kansas City, MO 64108-2625  
Phone (816) 472-6100 • Fax (816) 472-1610  
Web [www.apwa.net](http://www.apwa.net) • E-mail [apwa@apwa.net](mailto:apwa@apwa.net)

**ONE-CALL SYSTEMS INTERNATIONAL  
CONDENSED DIRECTORY**

**Alabama**  
Alabama One-Call  
1-800-292-8525

**Alaska**  
Locate Call Center of Alaska, Inc.  
1-800-478-3121

**Arizona**  
Arizona Blue Stake  
1-800-782-5348

**Arkansas**  
Arkansas One Call System, Inc.  
1-800-482-8998

**California**  
Underground Service Alert North  
1-800-227-2600  
Underground Service Alert of Southern  
California  
1-800-227-2600

**Colorado**  
Utility Notification Center of Colorado  
1-800-922-1987

**Connecticut**  
Call Before You Dig  
1-800-922-4455

**Delaware**  
Miss Utility of Delmarva  
1-800-282-8555

**Florida**  
Sunshine State One-Call of Florida, Inc.  
1-800-432-4770

**Georgia**  
Underground Protection Center, Inc.  
1-800-282-7411

**Hawaii**  
Underground Service Alert North  
1-800-227-2600

**Idaho**  
Dig Line Inc.  
1-800-342-1585  
Kootenai County One-Call  
1-800-428-4950  
Shoshone - Benewah One-Call  
1-800-398-3285

**Illinois**  
JULIE, Inc.  
1-800-892-0123  
Digger (Chicago Utility Alert Network)  
312-744-7000

**Indiana**  
Indiana Underground Plant Protection  
Service  
1-800-382-5544

**Iowa**  
Iowa One-Call  
1-800-292-8989

**Kansas**  
Kansas One-Call System, Inc.  
1-800-344-7233

**Kentucky**  
Kentucky Underground Protection Inc.  
1-800-752-6007

**Louisiana**  
Louisiana One Call System, Inc.  
1-800-272-3020

**Maine**  
Dig Safe System, Inc.  
1-888-344-7233

**Maryland**  
Miss Utility  
1-800-257-7777  
Miss Utility of Delmarva  
1-800-282-8555

**Massachusetts**  
Dig Safe System, Inc.  
1-888-344-7233

**Michigan**  
Miss Dig System, Inc.  
1-800-482-7171

**Minnesota**  
Gopher State One Call  
1-800-252-1166

**Mississippi**  
Mississippi One-Call System, Inc.  
1-800-227-6477

**Missouri**  
Missouri One-Call System, Inc.  
1-800-344-7483

**Montana**  
Utilities Underground Protection Center  
1-800-424-5555  
Montana One Call Center  
1-800-551-8344

**Nebraska**  
Diggers Hotline of Nebraska  
1-800-331-5666

**Nevada**  
Underground Service Alert North  
1-800-227-2600

**New Hampshire**  
Dig Safe System, Inc.  
1-888-344-7233

**New Jersey**  
New Jersey One Call  
1-800-272-1000

**New Mexico**  
New Mexico One Call System, Inc.  
1-800-321-2537  
Las Cruces- Dona Ana Blue Stakes  
1-888-526-0400

**New York**  
Dig Safely New York  
1-800-962-7962  
New York City- Long Island One Call  
Center  
1-800-272-4480

**North Carolina**  
The North Carolina One-Call Center,  
Inc.  
1-800-632-4949

**North Dakota**  
North Dakota One-Call  
1-800-795-0555

**Ohio**  
Ohio Utilities Protection Service  
1-800-362-2764  
Oil & Gas Producers Underground  
Protect'n Svc  
1-800-925-0988

**Oklahoma**  
Call Okie  
1-800-522-6543

**Oregon**  
Oregon Utility Notification Center/One  
Call Concepts  
1-800-332-2344

**Pennsylvania**  
Pennsylvania One Call System, Inc.  
1-800-242-1776

**Rhode Island**  
Dig Safe System, Inc.  
1-888-344-7233

**South Carolina**  
Palmetto Utility Protection Service Inc.  
1-888-721-7877

**South Dakota**  
South Dakota One Call  
1-800-781-7474

**Tennessee**  
Tennessee One-Call System, Inc.  
1-800-351-1111

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 10 of 15
	Revision 0	Effective Date 02/04

**ATTACHMENT 1 (Continued)**

**Texas**

Texas One Call System  
1-800-245-4545  
Texas Excavation Safety System, Inc.  
1-800-344-8377  
Lone Star Notification Center  
1-800-669-8344

**Utah**

Blue Stakes of Utah  
1-800-662-4111

**Vermont**

Dig Safe System, Inc.  
1-888-344-7233

**Virginia**

Miss Utility of Virginia  
1-800-552-7001  
Miss Utility (Northern Virginia)  
1-800-257-7777

**Washington**

Utilities Underground Location Center  
1-800-424-5555  
Northwest Utility Notification Center  
1-800-553-4344  
Inland Empire Utility Coordinating  
Council  
509-456-8000

**West Virginia**

Miss Utility of West Virginia, Inc.  
1-800-245-4848

**Wisconsin**

Diggers Hotline, Inc.  
1-800-242-8511

**Wyoming**

Wyoming One-Call System, Inc.  
1-800-348-1030  
Call Before You Dig of Wyoming  
1-800-849-2476

**District of Columbia**

Miss Utility  
1-800-257-7777

**Alberta**

Alberta One-Call Corporation  
1-800-242-3447

**British Columbia**

BC One Call  
1-800-474-6886

**Ontario**

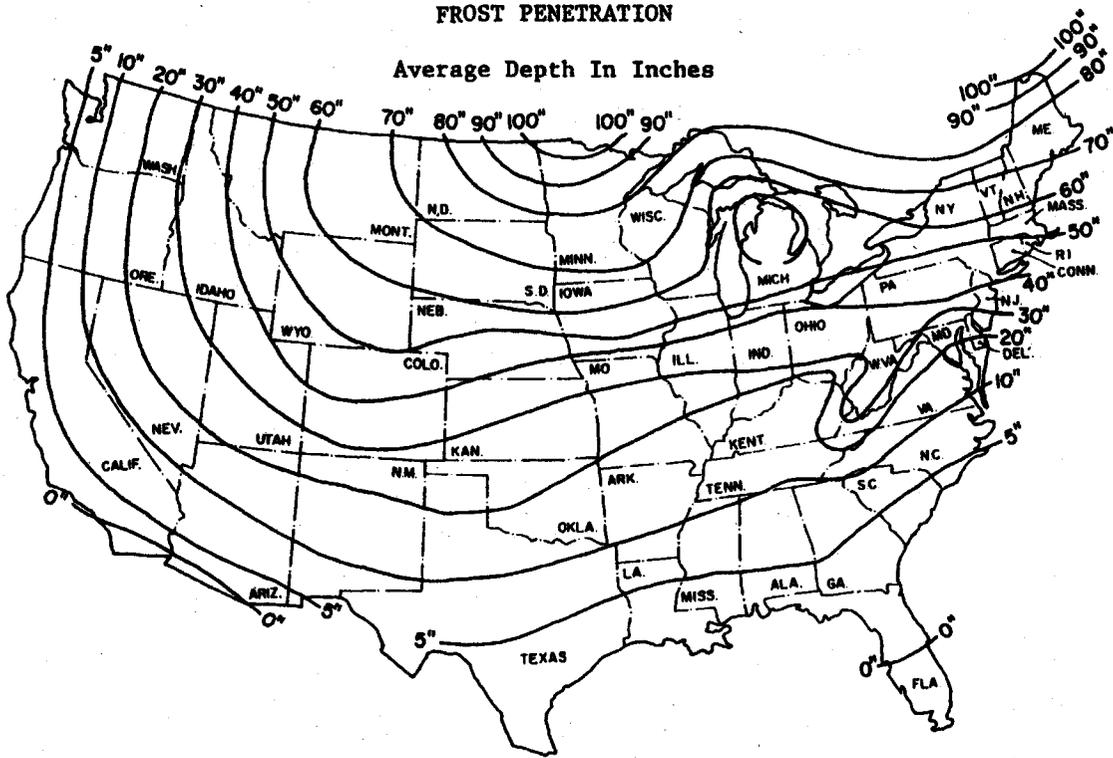
Ontario One-Call System  
1-800-400-2255

**Quebec**

Info-Excavation  
1-800-663-9228

ATTACHMENT 2

FROST LINE PENETRATION DEPTHS BY GEOGRAPHIC LOCATION



Courtesy U.S. Department Of Commerce

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 12 of 15
	Revision 0	Effective Date 02/04

**ATTACHMENT 3  
UTILITY CLEARANCE FORM**

Client: \_\_\_\_\_ Project Name: \_\_\_\_\_  
 Project No.: \_\_\_\_\_ Completed By: \_\_\_\_\_  
 Location Name: \_\_\_\_\_ Work Date: \_\_\_\_\_  
 Excavation Method/Overhead Equipment: \_\_\_\_\_

1. **Underground Utilities** Circle One
- a) Review of existing maps? yes no N/A
  - b) Interview local personnel? yes no N/A
  - c) Site visit and inspection? yes no N/A
  - d) Excavation areas marked in the field? yes no N/A
  - e) Utilities located in the field? yes no N/A
  - f) Located utilities marked/added to site maps? yes no N/A
  - g) Client contact notified yes no N/A  
 Name \_\_\_\_\_ Telephone: \_\_\_\_\_ Date: \_\_\_\_\_
  - g) State One-Call agency called? yes no N/A  
 Caller: \_\_\_\_\_  
 Ticket Number: \_\_\_\_\_ Date: \_\_\_\_\_
  - h) Geophysical survey performed? yes no N/A  
 Survey performed by: \_\_\_\_\_  
 Method: \_\_\_\_\_ Date: \_\_\_\_\_
  - i) Hand excavation performed (with concurrent use of utility yes no N/A  
 detection device)?  
 Completed by: \_\_\_\_\_  
 Total depth: \_\_\_\_\_ feet Date: \_\_\_\_\_
  - j) Trench/excavation probed? yes no N/A  
 Probing completed by: \_\_\_\_\_  
 Depth/frequency: \_\_\_\_\_ Date: \_\_\_\_\_

2. **Overhead Utilities** **Present Absent**
- a) Determination of nominal voltage yes no N/A
  - b) Marked on site maps yes no N/A
  - c) Necessary to lockout/insulate/re-route yes no N/A
  - d) Document procedures used to lockout/insulate/re-route yes no N/A
  - e) Minimum acceptable clearance (SOP Section 5.2): \_\_\_\_\_

3. **Notes:**  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Approval:**  
 \_\_\_\_\_  
 Site Manager/Field Operations Leader Date

c: PM/Project File  
 Program File

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 13 of 15
	Revision 0	Effective Date 02/04

**ATTACHMENT 4  
OSHA LETTER OF INTERPRETATION**

Mr. Joseph Caldwell  
Consultant  
Governmental Liaison  
Pipeline Safety Regulations  
211 Wilson Boulevard  
Suite 700  
Arlington, Virginia 22201

Re: Use of hydro-vacuum or non-conductive hand tools to locate underground utilities.

Dear Mr. Caldwell:

In a letter dated July 7, 2003, we responded to your inquiry of September 18, 2002, regarding the use of hydro-vacuum equipment to locate underground utilities by excavation. After our letter to you was posted on the OSHA website, we received numerous inquiries that make it apparent that aspects of our July 7 letter are being misunderstood. In addition, a number of industry stakeholders, including the National Utility Contractors Association (NUCA), have provided new information regarding equipment that is available for this work.

To clarify these issues, we are withdrawing our July 7 letter and issuing this replacement response to your inquiry.

***Question:** Section 1926.651 contains several requirements that relate to the safety of employees engaged in excavation work. Specifically, paragraphs (b)(2) and (b)(3) relate in part to the safety of the means used to locate underground utility installations that, if damaged during an uncovering operation, could pose serious hazards to employees.*

*Under these provisions, what constitutes an acceptable method of uncovering underground utility lines, and further, would the use of hydro-vacuum excavation be acceptable under the standard?*

**Answer**

**Background**

Two sections of 29 CFR 1926 Subpart P (Excavations), 1926.651 (Specific excavation requirements), govern methods for uncovering underground utility installations. Specifically, paragraph (b)(2) states:

When utility companies or owners cannot respond to a request to locate underground utility installations within 24 hours \* \* \* or cannot establish the exact location of these installations, the employer may proceed, provided the employer does so with caution, and provided detection equipment or other acceptable means to locate utility installations are used. (emphasis added).

Paragraph (b)(3) provides:

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 14 of 15
	Revision 0	Effective Date 02/04

#### ATTACHMENT 4 (Continued)

When excavation operations approach the estimated location of underground installations, the exact location of the installations shall be determined by safe and acceptable means. (emphasis added).

Therefore, "acceptable means" must be used where the location of the underground utilities have not been identified by the utility companies and detection equipment is not used.

Subpart P does not contain a definition of either "other acceptable means" or "safe and acceptable means." The preambles to both the proposed rule and the final rule discussed the rationale behind the wording at issue. For example, the preamble to the proposed rule, 52 Fed. Reg. 12301 (April 15, 1987), noted that a 1972 version of this standard contained language that specified "careful probing or hand digging" as the means to uncover utilities. The preamble then noted that an amendment to the 1972 standard later deleted that language "to allow other, *equally effective means* of locating such installations." The preamble continued that in the 1987 proposed rule, OSHA again proposed using language in section (b)(3) that would provide another example of an acceptable method of uncovering utilities that could be used where the utilities have not been marked and detection equipment is not being used – "probing with hand-held tools." This method was rejected in the final version of 29 CFR 1926. As OSHA explained in the preamble to the final rule, 54 Fed. Reg. 45916 (October 31, 1989):

OSHA received two comments \*\*\* and input from ACCSH [OSHA's Advisory Committee on Construction Safety and Health] \*\*\* on this provision. All commenters recommended dropping 'such as probing with hand-held tools' from the proposed provision, because this could create a hazard to employees by damaging the installation or its insulation.

In other words, the commenters objected to the use of hand tools being used unless detection equipment was used in conjunction with them. OSHA then concluded its discussion relative to this provision by agreeing with the commentators and ultimately not including any examples of "acceptable means" in the final provision.

#### Non-conductive hand tools are permitted

This raises the question of whether the standard permits the use of hand tools alone -- without also using detection equipment. NUCA and other industry stakeholders have recently informed us that non-conductive hand tools that are appropriate to be used to locate underground utilities are now commonly available.

Such tools, such as a "shooter" (which has a non-conductive handle and a snub nose) and non-conductive or insulated probes were not discussed in the rulemaking. Since they were not considered at that time, they were not part of the class of equipment that was thought to be unsafe for this purpose. Therefore, we conclude that the use of these types of hand tools, when used with appropriate caution, is an "acceptable means" for locating underground utilities.

Subject  UTILITY LOCATING AND EXCAVATION CLEARANCE	Number HS-1.0	Page 15 of 15
	Revision 0	Effective Date 02/04

**ATTACHMENT 4 (Continued)**

Hydro-vacuum excavation

It is our understanding that some hydro-vacuum excavation equipment can be adjusted to use a minimum amount of water and suction pressure. When appropriately adjusted so that the equipment will not damage underground utilities (especially utilities that are particularly vulnerable to damage, such as electrical lines), use of such equipment would be considered a "acceptable means" of locating underground utilities. However, if the equipment cannot be sufficiently adjusted, then this method would not be acceptable under the standard.

Other technologies

We are not suggesting that these are the only devices that would be "acceptable means" under the standard. Industry stakeholders have informed us that there are other types of special excavation equipment designed for safely locating utilities as well.

We apologize for any confusion our July 7 letter may have caused. If you have further concerns or questions, please feel free to contact us again by fax at: U.S. Department of Labor, OSHA, Directorate of Construction, Office of Construction Standards and Compliance Assistance, fax # 202-693-1689. You can also contact us by mail at the above office, Room N3468, 200 Constitution Avenue, N.W., Washington, D.C. 20210, although there will be a delay in our receiving correspondence by mail.

Sincerely,

Russell B. Swanson, Director  
Directorate of Construction

**NOTE:** OSHA requirements are set by statute, standards and regulations. Our interpretation letters explain these requirements and how they apply to particular circumstances, but they cannot create additional employer obligations. This letter constitutes OSHA's interpretation of the requirements discussed. Note that our enforcement guidance may be affected by changes to OSHA rules. Also, from time to time we update our guidance in response to new information. To keep apprised of such developments, you can consult OSHA's website at <http://www.osha.gov>.

## FIELD TASK MODIFICATION REQUEST FORM

<hr/> <b>Project/Installation Name</b>	<hr/> <b>CTO &amp; Project Number</b>	<hr/> <b>Task Mod. Number</b>
<hr/> <b>Modification To (e.g. Work Plan)</b>	<hr/> <b>Site/Sample Location</b>	<hr/> <b>Date</b>
<b>Activity Description:</b> _____ _____ _____		
<b>Reason for Change:</b> _____ _____ _____		
<b>Recommended Disposition:</b> _____ _____ _____		
<hr/> <b>Field Operations Leader (Signature)</b>		<hr/> <b>Date</b>
<b>Approved Disposition:</b> _____ _____ _____		
<hr/> <b>Project/Task Order Manager (Signature)</b>		<hr/> <b>Date</b>
<b>Distribution:</b>		
Program/Project File –		Other: _____
Project/Task Order Manager –		_____
Field Operations Leader –		_____

**Appendix C**  
**ELAP Certifications**





# CERTIFICATE OF ACCREDITATION

**ANSI-ASQ National Accreditation Board/AClass**  
500 Montgomery Street, Suite 625, Alexandria, VA 22314, 877-344-3044

This is to certify that

**APPL, Inc.**  
**908 N. Temperance Avenue**  
**Clovis, CA 93611**

has been assessed by AClass  
and meets the requirements of

**ISO/IEC 17025:2005 and DoD-ELAP**

while demonstrating technical competence in the field(s) of

**TESTING**

Refer to the accompanying Scope(s) of Accreditation for information regarding the types of tests to which this accreditation applies.

ADE-1410

Certificate Number

AClass Approval



Certificate Valid: 10/23/2011-10/23/2013  
Version No. 003 Issued: 12/08/2011



This laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025:2005. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (refer to joint ISO-ILAC-IAF Communiqué dated January 2009).



# ANSI-ASQ National Accreditation Board

## SCOPE OF ACCREDITATION TO ISO/IEC 17025:2005 & DoD-ELAP

### APPL, Inc.

908 N. Temperance Avenue, Clovis, CA 93611  
Diane Anderson Phone: 559-275-2175

### TESTING

Valid to: October 23, 2013

Certificate Number: ADE- 1410

#### I. Environmental

MATRIX	SPECIFIC TEST or GROUP OF ANALYTES**	SPECIFICATION OR STANDARD METHOD (all EPA unless specified)	* KEY EQUIPMENT OR TECHNOLOGY USED
Water / Wastewater	Acid Digestion for Metals Analysis	3010A	
Solid / Solid Waste	Acid digestion for Metals Analysis	3050B	
Water / Wastewater	Mercury Digestion and Analysis	245.1 / 7470A	AAS
Solid / Solid Waste	Mercury Digestion and Analysis	7471B	AAS
Water / Wastewater	Microwave assisted Acid Digestion for Metals Analysis	3015A	Microwave
Solid / Solid Waste	Microwave assisted Acid Digestion for Metals Analysis	3051A	Microwave
Water / Wastewater	Purge and Trap for Aqueous Samples	5030B / 5030C	
Solid / Solid Waste	Closed-system purge and trap extraction for VOA analysis	5035 / 5035A	
Water / Wastewater	Separatory Funnel Extraction	3510C	
Solid / Solid Waste	Ultrasonic Extraction	3550B	Ultrasonic waterbath



<b>MATRIX</b>	<b>SPECIFIC TEST or GROUP OF ANALYTES**</b>	<b>SPECIFICATION OR STANDARD METHOD (all EPA unless specified)</b>	<b>* KEY EQUIPMENT OR TECHNOLOGY USED</b>
Solid / Solid Waste	Soxhlet Extraction	3540C	Soxhlet Extractors
Water / Wastewater	Liquid-Liquid Extraction	3520C	Liquid-Liquid Extractor
Water / Wastewater / Solid / Solid Waste	Silica gel cleanup	3630C	
Solid / Solid Waste	Incremental sampling	8330B, Appendix A	Puck mill grinder
Water / Wastewater / Solid / Solid Waste	Sulfur cleanup	3660B	
Water / Wastewater / Solid / Solid Waste	Sulfuric acid – permanganate cleanup	3665A	
Water / Wastewater / Solid / Solid Waste	Gel permeation cleanup	3640A	
Solid / Solid Waste	TCLP extraction	1311	Rotary Tumbler
Solid / Solid Waste	SPLP extraction	1312	Rotary Tumbler
Solid / Solid Waste	Waste Extraction Test (WET)	CCR Chapter 11, Article 5, Appendix II	Rotary Tumbler
Water / Wastewater	Total Dissolved Solids	160.1 / 2540C	Gravimetric
Water / Wastewater	Total Suspended Solids	2540D	Gravimetric
Water / Wastewater	Anion analysis	300.0 / 9056 / 9056A	Dionex Ion Chromatography
Solid / Solid Waste	Anion analysis	9056 / 9056A	Dionex Ion Chromatography



<b>MATRIX</b>	<b>SPECIFIC TEST or GROUP OF ANALYTES**</b>	<b>SPECIFICATION OR STANDARD METHOD (all EPA unless specified)</b>	<b>* KEY EQUIPMENT OR TECHNOLOGY USED</b>
Water / Wastewater / Solid / Solid Waste	Perchlorate analysis	314.0	Dionex Ion Chromatography
Water / Wastewater / Solid / Solid Waste	Ammonia	350.1	Lachat Flow Injection Analysis
Water / Wastewater / Solid / Solid Waste	TKN	351.2	Lachat Flow Injection Analysis
Water / Wastewater / Solid / Solid Waste	Nitrate / Nitrite	353.2	Lachat Flow Injection Analysis
Water / Wastewater / Solid / Solid Waste	Sulfide	4200S2F	Titrimetric
Drinking Water / Water / Wastewater / Solid / Solid Waste	PCB Congeners	1668A	High Resolution GC/MS
Water / Wastewater / Solid / Solid Waste	Perchlorate	6850	HPLC/Electrospray Ionization/MS
Water / Wastewater	Oil & Grease	1664A	Gravimetric
Water / Wastewater	Oil & Grease	SM 5520B	Gravimetric
Water / Wastewater	TRPH	SM 5520BF	Gravimetric
Water / Wastewater / Solid / Solid Waste	Total Metals	6010B / 6010C	ICP
Water / Wastewater / Solid / Solid Waste	Total Metals	6020 / 6020A	ICP/MS
Water / Wastewater / Solid / Solid Waste	Hexavalent Chromium	7196A	UV/Vis
Solid / Solid Waste	Alkaline digestion of Hexavalent Chromium	3060A	



<b>MATRIX</b>	<b>SPECIFIC TEST or GROUP OF ANALYTES**</b>	<b>SPECIFICATION OR STANDARD METHOD (all EPA unless specified)</b>	<b>* KEY EQUIPMENT OR TECHNOLOGY USED</b>
Water / Wastewater / Solid / Solid Waste	Hexavalent Chromium	218.6 / 7199	Dionex Ion Chromatography
Water / Wastewater / Solid / Solid Waste	Total Cyanide Distillation	9010C	Midi-Distillation unit
Water / Wastewater / Solid / Solid Waste	Total Cyanide Analysis	9014	UV/Vis
Water / Wastewater	Corrosivity - pH	9040C	Ion Selective Electrode
Solid / Solid Waste	Corrosivity - pH	9045D	Ion Selective Electrode
Water / Wastewater / Solid / Solid Waste	Chlorinated & Brominated Hydrocarbons	8011	GC/ECD
Water / Wastewater / Solid / Solid Waste	DRO/GRO	8015B/C/D	GC/FID
Water / Solid	OP Pesticides	8141A / 8141B	GC/ECD
Water / Wastewater / Solid / Solid Waste	OCL Pesticides	8081A / 8081B	GC/ECD
Water / Waste Water	PCB	608	GC/ECD
Water / Wastewater / Solid / Solid Waste	PCB	8082 / 8082A	GC/ECD
Water / Wastewater / Solid / Solid Waste	Herbicides	8151A	GC/ECD
Water / Wastewater / Solid / Solid Waste	VOA	8260B / 8260C	GC/MS
Water / Wastewater / Solid / Solid Waste	PAH	8270C SIM / 8270D SIM	GC/MS
Water / Wastewater / Solid / Solid Waste	Semi-VOA	8270C / 8270D	GC/MS



MATRIX	SPECIFIC TEST or GROUP OF ANALYTES**	SPECIFICATION OR STANDARD METHOD (all EPA unless specified)	* KEY EQUIPMENT OR TECHNOLOGY USED
Water / Wastewater / Solid / Solid Waste	Dioxins	8290	HRGC/HRMS
Water / Wastewater / Solid / Solid Waste	Nitroaromatics & Nitramines & Nitroguanidine PGDN Picric Acid	8330A / 8330B / 8321A	HPLC
Water / Wastewater / Solid / Solid Waste	Carbamates	8321A	HPLC
Solid / Solid Waste	Ignitability	1030	
Solid / Solid Waste	TOC	Walkley-Black	Titration
Water	DOC / TOC	SM 5310B / 9060A	TOC Analyzer
Water	Ethane / Ethene / Methane	RSK175	GC / FID
Water	Alkalinity	SM 2320B	Titrimetric
Water	MBAS	SM 5540C	UV/Vis
Water	Electrical Conductance	SM 2510B	EC meter

**Notes:**

1. \* = As Applicable
2. \*\* = Refer to Accredited Analytes Listing for specific analytes in which the laboratory is accredited
3. This scope is part of and must be included with the Certificate of Accreditation No. ADE- 1410



\_\_\_\_\_  
Vice President



**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :	APPL, Inc.				
City/State :	Clovis, CA				
PartName	PartNumber	NELACCCode	AnalyteName	EPA Method	PT results
WP Minerals #1	55144	1955	Total Dissolved Solids (TDS)	160.1	Approved
Oil & Grease	4120	1860	Oil & Grease	1664A	Approved
Oil & Grease - n-Hexadecane & Stearic	55084	1860	Oil & Grease	1664A	Approved
PCB Congeners in Water	PEO-403	9070	2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180)	1668A	Approved
PCB Congeners in Water	PEO-403	9025	2,2',3,4,4',5'-Hexachlorobiphenyl (PCB 138)	1668A	Approved
PCB Congeners in Water	PEO-403	9040	2,2',4,4',5,5'-Hexachlorobiphenyl (PCB 153)	1668A	Approved
PCB Congeners in Water	PEO-403	8980	2,2',4,5,5'-Pentachlorobiphenyl (PCB 101)	1668A	Approved
PCB Congeners in Water	PEO-403	8955	2,2',5,5'-Tetrachlorobiphenyl (PCB 52)	1668A	Approved
PCB Congeners in Water	PEO-403	9085	2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189)	1668A	Approved
PCB Congeners in Water	PEO-403	9050	2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 156)	1668A	Approved
PCB Congeners in Water	PEO-403	9045	2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157)	1668A	Approved
PCB Congeners in Water	PEO-403	8985	2,3,3',4,4'-Pentachlorobiphenyl (PCB 105)	1668A	Approved
PCB Congeners in Water	PEO-403	9055	2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167)	1668A	Approved
PCB Congeners in Water	PEO-403	9005	2,3,4,4',5-Pentachlorobiphenyl (PCB 114)	1668A	Approved
PCB Congeners in Water	PEO-403	8995	2,3,4,4',5-Pentachlorobiphenyl (PCB 118)	1668A	Approved
PCB Congeners in Water	PEO-403	9000	2,3',4,4',5'-Pentachlorobiphenyl (PCB 123)	1668A	Approved
PCB Congeners in Water	PEO-403	8936	2,4,4'-Trichlorobiphenyl (PCB 28)	1668A	Approved
PCB Congeners in Water	PEO-403	9060	3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169)	1668A	Approved
PCB Congeners in Water	PEO-403	9015	3,3',4,4',5-Pentachlorobiphenyl (PCB 126)	1668A	Approved
PCB Congeners in Water	PEO-403	8965	3,3',4,4'-Tetrachlorobiphenyl (PCB 77)	1668A	Approved
PCB Congeners in Water	PEO-403	8970	3,4,4',5-Tetrachlorobiphenyl (PCB 81)	1668A	Approved
PCB Congeners in Water	PEO-403	9025	PCB (129)+(138)+(163)	1668A	Approved
PCB Congeners in Water	PEO-403	9040	PCB (153)+(168)	1668A	Approved
PCB Congeners in Water	PEO-403	9046	PCB (156)+(157)	1668A	Approved
PCB Congeners in Water	PEO-403	9070	PCB (180)+(193)	1668A	Approved
PCB Congeners in Water	PEO-403	8936	PCB (20)+(28)	1668A	Approved
PCB Congeners in Water	PEO-403	8980	PCB (90)+(101)+(113)	1668A	Approved
PCB Congeners in Water	PEO-403	8870	PCBs, total	1668A	Approved
WP Hexavalent Chromium	55096	1045	Chromium VI	218.6	Approved
SWA Anions	55131	1540	Bromide	300.0	Approved
WP Minerals #1	55144	1575	Chloride	300.0	Approved
WP & DMRQA Nutrients	55035	1810	Nitrate as N	300.0	Approved
WP & DMRQA Nutrients	55035	1870	Orthophosphate as P	300.0	Approved
WP Nitrate & Nitrite	55130	1810	Nitrate as N	300.0	Approved
WP Nitrate & Nitrite	55130	1820	Nitrite + Nitrate as N	300.0	Approved
WP Nitrate & Nitrite	55130	1840	Nitrite as N	300.0	Approved
WP Minerals #2	55145	1730	Fluoride	300.0	Approved
WP Minerals #2	55145	2000	Sulfate	300.0	Approved
WP Perchlorate	55116	1895	Perchlorate	314.0	Approved
WP & DMRQA Nutrients	55035	1515	Ammonia as N	350.1	Approved
WP & DMRQA Nutrients #2	55064	1795	Total Kjeldahl Nitrogen	351.2	Approved
WP & DMRQA Nutrients	55035	1810	Nitrate as N	353.2	Approved
WP Nitrate & Nitrite	55130	1810	Nitrate as N	353.2	Approved
WP Nitrate & Nitrite	55130	1820	Nitrite + Nitrate as N	353.2	Approved
WP Nitrate & Nitrite	55130	1840	Nitrite as N	353.2	Approved
WP & DMRQA Trace Elements	55024	1000	Aluminum	6010B	Approved
WP Trace Elements	55025	1005	Antimony	6010B	Approved
WP & DMRQA Trace Elements	55024	1010	Arsenic	6010B	Approved
WP Trace Elements	55025	1015	Barium	6010B	Approved
WP Trace Elements	55025	1015	Barium	6010B	Approved
WP Trace Elements	55025	1020	Beryllium	6010B	Approved
WP Trace Elements	55025	1020	Beryllium	6010B	Approved
WP Trace Elements	55025	1025	Boron	6010B	Approved
WP & DMRQA Trace Elements	55024	1030	Cadmium	6010B	Approved
WP Minerals #1	55144	1035	Calcium	6010B	Approved
WP & DMRQA Trace Elements	55024	1040	Chromium	6010B	Approved
WP & DMRQA Trace Elements	55024	1050	Cobalt	6010B	Approved
WP & DMRQA Trace Elements	55024	1055	Copper	6010B	Approved
WP & DMRQA Trace Elements	55024	1070	Iron	6010B	Approved
WP & DMRQA Trace Elements	55024	1075	Lead	6010B	Approved
WP Minerals #1	55144	1085	Magnesium	6010B	Approved
WP & DMRQA Trace Elements	55024	1090	Manganese	6010B	Approved
WP Trace Elements	55025	1100	Molybdenum	6010B	Approved
WP & DMRQA Trace Elements	55024	1105	Nickel	6010B	Approved
WP Minerals #2	55145	1125	Potassium	6010B	Approved
WP & DMRQA Trace Elements	55024	1140	Selenium	6010B	Approved
WP Trace Elements	55025	1150	Silver	6010B	Approved
WP Minerals #2	55145	1155	Sodium	6010B	Approved
WP Trace Elements	55025	1160	Strontium	6010B	Approved
WP Trace Elements	55025	1165	Thallium	6010B	Approved
WP Tin	55095	1175	Tin	6010B	Approved
WP Tin	55095	1175	Tin	6010B	Approved
WP Trace Elements	55025	1180	Titanium	6010B	Approved
WP & DMRQA Trace Elements	55024	1185	Vanadium	6010B	Approved

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :		APPL, Inc.			
City/State :		Clovis, CA			
PartName	PartNumber	NELACCCode	AnalyteName	EPA Method	PT results
WP & DMRQA Trace Elements	55024	1190	Zinc	6010B	Approved
NPTA			Zirconium	6010B	Approved
WP & DMRQA Trace Elements	55024	1000	Aluminum	6010C	Approved
WP Trace Elements	55025	1005	Antimony	6010C	Approved
WP & DMRQA Trace Elements	55024	1010	Arsenic	6010C	Approved
WP Trace Elements	55025	1015	Barium	6010C	Approved
WP Trace Elements	55025	1015	Barium	6010C	Approved
WP Trace Elements	55025	1020	Beryllium	6010C	Approved
WP Trace Elements	55025	1020	Beryllium	6010C	Approved
WP Trace Elements	55025	1025	Boron	6010C	Approved
WP & DMRQA Trace Elements	55024	1030	Cadmium	6010C	Approved
	55144	1035	Calcium	6010C	Approved
WP & DMRQA Trace Elements	55024	1040	Chromium	6010C	Approved
WP & DMRQA Trace Elements	55024	1050	Cobalt	6010C	Approved
WP & DMRQA Trace Elements	55024	1055	Copper	6010C	Approved
WP & DMRQA Trace Elements	55024	1070	Iron	6010C	Approved
WP & DMRQA Trace Elements	55024	1075	Lead	6010C	Approved
WP & DMRQA Trace Elements	55024	1090	Manganese	6010C	Approved
WP Trace Elements	55025	1100	Molybdenum	6010C	Approved
WP & DMRQA Trace Elements	55024	1105	Nickel	6010C	Approved
	55145	1125	Potassium	6010C	Approved
WP & DMRQA Trace Elements	55024	1140	Selenium	6010C	Approved
WP Trace Elements	55025	1150	Silver	6010C	Approved
WP Trace Elements	55025	1160	Strontium	6010C	Approved
WP Trace Elements	55025	1165	Thallium	6010C	Approved
WP Trace Elements	55095	1175	Tin	6010C	Approved
WP Trace Elements	55025	1180	Titanium	6010C	Approved
WP & DMRQA Trace Elements	55024	1185	Vanadium	6010C	Approved
WP & DMRQA Trace Elements	55024	1190	Zinc	6010C	Approved
NPTA			Zirconium	6010C	Approved
WP & DMRQA Trace Elements	55024	1000	Aluminum	6020	Approved
WP Trace Elements	55025	1005	Antimony	6020	Approved
WP & DMRQA Trace Elements	55024	1010	Arsenic	6020	Approved
WP Trace Elements	55025	1015	Barium	6020	Approved
WP Trace Elements	55025	1020	Beryllium	6020	Approved
WP Trace Elements	55025	1025	Boron	6020	Approved
WP & DMRQA Trace Elements	55024	1030	Cadmium	6020	Approved
	55144	1035	Calcium	6020	Approved
WP & DMRQA Trace Elements	55024	1040	Chromium	6020	Approved
WP & DMRQA Trace Elements	55024	1050	Cobalt	6020	Approved
WP & DMRQA Trace Elements	55024	1055	Copper	6020	Approved
WP & DMRQA Trace Elements	55024	1070	Iron	6020	Approved
WP & DMRQA Trace Elements	55024	1075	Lead	6020	Approved
WP & DMRQA Trace Elements	55024	1090	Manganese	6020	Approved
WP Trace Elements	55025	1100	Molybdenum	6020	Approved
WP & DMRQA Trace Elements	55024	1105	Nickel	6020	Approved
NPTA			Total Phosphorous	6020	Approved
	55145	1125	Potassium	6020	Approved
WP & DMRQA Trace Elements	55024	1140	Selenium	6020	Approved
WP Trace Elements	55025	1150	Silver	6020	Approved
WP Trace Elements	55025	1160	Strontium	6020	Approved
WP Trace Elements	55025	1165	Thallium	6020	Approved
WP Tin	55095	1175	Tin	6020	Approved
WP Trace Elements	55025	1180	Titanium	6020	Approved
WP & DMRQA Trace Elements	55024	1185	Vanadium	6020	Approved
WP & DMRQA Trace Elements	55024	1190	Zinc	6020	Approved
NPTA			Zirconium	6020	Approved
WP & DMRQA Trace Elements	55024	1000	Aluminum	6020A	Approved
WP Trace Elements	55025	1005	Antimony	6020A	Approved
WP & DMRQA Trace Elements	55024	1010	Arsenic	6020A	Approved
WP Trace Elements	55025	1015	Barium	6020A	Approved
WP Trace Elements	55025	1020	Beryllium	6020A	Approved
WP Trace Elements	55025	1025	Boron	6020A	Approved
WP & DMRQA Trace Elements	55024	1030	Cadmium	6020A	Approved
	55144	1035	Calcium	6020A	Approved
WP & DMRQA Trace Elements	55024	1040	Chromium	6020A	Approved
WP & DMRQA Trace Elements	55024	1050	Cobalt	6020A	Approved
WP & DMRQA Trace Elements	55024	1055	Copper	6020A	Approved
WP & DMRQA Trace Elements	55024	1070	Iron	6020A	Approved
WP & DMRQA Trace Elements	55024	1075	Lead	6020A	Approved
WP & DMRQA Trace Elements	55024	1090	Manganese	6020A	Approved
WP Trace Elements	55025	1100	Molybdenum	6020A	Approved
WP & DMRQA Trace Elements	55024	1105	Nickel	6020A	Approved
NPTA			Total Phosphorous	6020A	Approved

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :	APPL, Inc.				
City/State :	Clovis, CA				
PartName	PartNumber	NELACCCode	AnalyteName	EPA Method	PT results
	55145	1125	Potassium	6020A	Approved
WP & DMRQA Trace Elements	55024	1140	Selenium	6020A	Approved
WP Trace Elements	55025	1150	Silver	6020A	Approved
WP Trace Elements	55025	1160	Strontium	6020A	Approved
WP Trace Elements	55025	1165	Thallium	6020A	Approved
	55095	1175	Tin	6020A	Approved
WP Trace Elements	55025	1180	Titanium	6020A	Approved
WP & DMRQA Trace Elements	55024	1185	Vanadium	6020A	Approved
WP & DMRQA Trace Elements	55024	1190	Zinc	6020A	Approved
NPTA			Zirconium	6020A	Approved
WP Perchlorate	55116	1895	Perchlorate	6850	Approved
WP Hexavalent Chromium	55096	1045	Chromium VI	7196A	Approved
WP Hexavalent Chromium	55096	1045	Chromium VI	7199	Approved
WP & DMRQA Trace Elements	55024	1095	Mercury	7470A	Approved
Volatiles	PEO-120-3B	5180	1,2,3-Trichloropropane	8011	Approved
Volatiles	PEO-120-3B	4570	1,2-Dibromo-3-chloropropane (DBCP)	8011	Approved
Volatiles	PEO-120-3B	4585	1,2-Dibromomethane (EDB, Ethylene dibromide)	8011	Approved
Volatiles	PEO-010	9408	Gasoline Range Organics, C6-C10	8015B	Approved
			Motor Oil	8015B	Approved
Petroleum Hydrocarbons in Water	PEO-010	99990	Total Purgeable Hydrocarbons	8015B	Approved
Petroleum Hydrocarbons in Water	PEO-011	9369	Diesel Range Organics (C10-C28)	8015B	Approved
Volatiles	PEO-010	9408	Gasoline Range Organics, C6-C10	8015C	Approved
			Motor Oil	8015C	Approved
Petroleum Hydrocarbons in Water	PEO-010	99990	Total Purgeable Hydrocarbons	8015C	Approved
Petroleum Hydrocarbons in Water	PEO-011	9369	Diesel Range Organics (C10-C28)	8015C	Approved
Volatiles	PEO-010	9408	Gasoline Range Organics, C6-C10	8015D	Approved
			Motor Oil	8015D	Approved
Petroleum Hydrocarbons in Water	PEO-010	99990	Total Purgeable Hydrocarbons	8015D	Approved
Petroleum Hydrocarbons in Water	PEO-011	9369	Diesel Range Organics (C10-C28)	8015D	Approved
WP Pesticide Amp 2	38046	7250	Chlordane	8081A	Approved
WP Organochlorine Pesticides	38122	7810	4,4'-Methoxychlor	8081A	Approved
WP Organochlorine Pesticides	38122	7355	4,4'-DDD	8081A	Approved
WP Organochlorine Pesticides	38122	7360	4,4'-DDE	8081A	Approved
WP Organochlorine Pesticides	38122	7365	4,4'-DDT	8081A	Approved
WP Organochlorine Pesticides	38122	7110	a-BHC	8081A	Approved
WP Organochlorine Pesticides	38122	7240	a-Chlordane	8081A	Approved
WP Organochlorine Pesticides	38122	7025	Aldrin	8081A	Approved
WP Organochlorine Pesticides	38122	7115	b-BHC	8081A	Approved
WP Organochlorine Pesticides	38122	7105	d-BHC	8081A	Approved
WP Organochlorine Pesticides	38122	7470	Dieldrin	8081A	Approved
WP Organochlorine Pesticides	38122	7510	Endosulfan I	8081A	Approved
WP Organochlorine Pesticides	38122	7515	Endosulfan II	8081A	Approved
WP Organochlorine Pesticides	38122	7520	Endosulfan sulfate	8081A	Approved
WP Organochlorine Pesticides	38122	7540	Endrin	8081A	Approved
WP Organochlorine Pesticides	38122	7530	Endrin aldehyde	8081A	Approved
WP Organochlorine Pesticides	38122	7535	Endrin ketone	8081A	Approved
WP Organochlorine Pesticides	38122	7120	g-BHC (Lindane)	8081A	Approved
WP Organochlorine Pesticides	38122	7245	g-Chlordane	8081A	Approved
WP Organochlorine Pesticides	38122	7685	Heptachlor	8081A	Approved
WP Organochlorine Pesticides	38122	7690	Heptachlor epoxide	8081A	Approved
			Hexachlorobenzene	8081A	Approved
WP Toxaphene	38125	8250	Toxaphene	8081A	Approved
WP Pesticide Amp 2	38046	7250	Chlordane	8081B	Approved
WP Organochlorine Pesticides	38122	7810	4,4'-Methoxychlor	8081B	Approved
WP Organochlorine Pesticides	38122	7355	4,4'-DDD	8081B	Approved
WP Organochlorine Pesticides	38122	7360	4,4'-DDE	8081B	Approved
WP Organochlorine Pesticides	38122	7365	4,4'-DDT	8081B	Approved
WP Organochlorine Pesticides	38122	7110	a-BHC	8081B	Approved
WP Organochlorine Pesticides	38122	7240	a-Chlordane	8081B	Approved
WP Organochlorine Pesticides	38122	7025	Aldrin	8081B	Approved
WP Organochlorine Pesticides	38122	7115	b-BHC	8081B	Approved
WP Organochlorine Pesticides	38122	7105	d-BHC	8081B	Approved
WP Organochlorine Pesticides	38122	7470	Dieldrin	8081B	Approved
WP Organochlorine Pesticides	38122	7510	Endosulfan I	8081B	Approved
WP Organochlorine Pesticides	38122	7515	Endosulfan II	8081B	Approved
WP Organochlorine Pesticides	38122	7520	Endosulfan sulfate	8081B	Approved
WP Organochlorine Pesticides	38122	7540	Endrin	8081B	Approved
WP Organochlorine Pesticides	38122	7530	Endrin aldehyde	8081B	Approved
WP Organochlorine Pesticides	38122	7535	Endrin ketone	8081B	Approved
WP Organochlorine Pesticides	38122	7120	g-BHC (Lindane)	8081B	Approved
WP Organochlorine Pesticides	38122	7245	g-Chlordane	8081B	Approved
WP Organochlorine Pesticides	38122	7685	Heptachlor	8081B	Approved
WP Organochlorine Pesticides	38122	7690	Heptachlor epoxide	8081B	Approved
			Hexachlorobenzene	8081B	Approved

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :	APPL, Inc.					
City/State :	Clovis, CA					
PartName	PartNumber	NELACCCode	AnalyteName	EPA Method	PT results	
WP Toxaphene	38125	8250	Toxaphene	8081B	Approved	
WP PCBs in Water #2	38091	8880	Aroclor 1016	8082	Approved	
WP PCBs in Water #2	38091	8885	Aroclor 1221	8082	Approved	
WP PCBs in Water #2	38091	8890	Aroclor 1232	8082	Approved	
WP PCBs in Water #2	38091	8895	Aroclor 1242	8082	Approved	
WP PCBs in Water #2	38091	8900	Aroclor 1248	8082	Approved	
WP PCBs in Water #2	38091	8905	Aroclor 1254	8082	Approved	
WP PCBs in Water #2	38091	8910	Aroclor 1260	8082	Approved	
WP PCBs in Transformer Oil #2	38092	8880	PCB in Oil 1016 or 1242	8082	Approved	
WP PCBs in Transformer Oil #2	38092	100	PCB in Oil 1254	8082	Approved	
WP PCBs in Transformer Oil #2	38092	8910	PCB in Oil 1260	8082	Approved	
WP PCBs in Water #1	38094	8880	Aroclor 1016	8082	Approved	
WP PCBs in Water #1	38094	8885	Aroclor 1221	8082	Approved	
WP PCBs in Water #1	38094	8890	Aroclor 1232	8082	Approved	
WP PCBs in Water #1	38094	8895	Aroclor 1242	8082	Approved	
WP PCBs in Water #1	38094	8900	Aroclor 1248	8082	Approved	
WP PCBs in Water #1	38094	8905	Aroclor 1254	8082	Approved	
WP PCBs in Water #1	38094	8910	Aroclor 1260	8082	Approved	
WP PCBs in Water	38095	8880	PCB in Oil 1016 or 1242	8082	Approved	
WP PCBs in Water	38095	100	PCB in Oil 1254	8082	Approved	
WP PCBs in Water	38095	101	PCB in Oil 1260	8082	Approved	
WS PCBs in Water	38133	8880	Aroclor 1016	8082	Approved	
WS PCBs in Water	38133	8885	Aroclor 1221	8082	Approved	
WS PCBs in Water	38133	8890	Aroclor 1232	8082	Approved	
WS PCBs in Water	38133	8895	Aroclor 1242	8082	Approved	
WS PCBs in Water	38133	8900	Aroclor 1248	8082	Approved	
WS PCBs in Water	38133	8905	Aroclor 1254	8082	Approved	
WS PCBs in Water	38133	8910	Aroclor 1260	8082	Approved	
PCBs in Water	PEO-020	8912	Aroclor 1016/1242	8082	Approved	
PCBs in Water	PEO-020	8912	Aroclor 1016/1242	8082	Approved	
PCBs in Water	PEO-020	8880	Aroclor-1016 (PCB-1016)	8082	Approved	
PCBs in Water	PEO-020	8880	Aroclor-1016 (PCB-1016)	8082	Approved	
PCBs in Water	PEO-020	8885	Aroclor-1221 (PCB-1221)	8082	Approved	
PCBs in Water	PEO-020	8885	Aroclor-1221 (PCB-1221)	8082	Approved	
PCBs in Water	PEO-020	8890	Aroclor-1232 (PCB-1232)	8082	Approved	
PCBs in Water	PEO-020	8890	Aroclor-1232 (PCB-1232)	8082	Approved	
PCBs in Water	PEO-020	8895	Aroclor-1242 (PCB-1242)	8082	Approved	
PCBs in Water	PEO-020	8895	Aroclor-1242 (PCB-1242)	8082	Approved	
PCBs in Water	PEO-020	8900	Aroclor-1248 (PCB-1248)	8082	Approved	
PCBs in Water	PEO-020	8900	Aroclor-1248 (PCB-1248)	8082	Approved	
PCBs in Water	PEO-020	8905	Aroclor-1254 (PCB-1254)	8082	Approved	
PCBs in Water	PEO-020	8905	Aroclor-1254 (PCB-1254)	8082	Approved	
PCBs in Water	PEO-020	8910	Aroclor-1260 (PCB-1260)	8082	Approved	
PCBs in Water	PEO-020	8910	Aroclor-1260 (PCB-1260)	8082	Approved	
WP PCBs in Water #2	38091	8880	Aroclor 1016	8082A	Approved	
WP PCBs in Water #2	38091	8885	Aroclor 1221	8082A	Approved	
WP PCBs in Water #2	38091	8890	Aroclor 1232	8082A	Approved	
WP PCBs in Water #2	38091	8895	Aroclor 1242	8082A	Approved	
WP PCBs in Water #2	38091	8900	Aroclor 1248	8082A	Approved	
WP PCBs in Water #2	38091	8905	Aroclor 1254	8082A	Approved	
WP PCBs in Water #2	38091	8910	Aroclor 1260	8082A	Approved	
WP PCBs in Transformer Oil #2	38092	8880	PCB in Oil 1016 or 1242	8082A	Approved	
WP PCBs in Transformer Oil #2	38092	100	PCB in Oil 1254	8082A	Approved	
WP PCBs in Transformer Oil #2	38092	8910	PCB in Oil 1260	8082A	Approved	
WP PCBs in Water #1	38094	8880	Aroclor 1016	8082A	Approved	
WP PCBs in Water #1	38094	8885	Aroclor 1221	8082A	Approved	
WP PCBs in Water #1	38094	8890	Aroclor 1232	8082A	Approved	
WP PCBs in Water #1	38094	8895	Aroclor 1242	8082A	Approved	
WP PCBs in Water #1	38094	8900	Aroclor 1248	8082A	Approved	
WP PCBs in Water #1	38094	8905	Aroclor 1254	8082A	Approved	
WP PCBs in Water #1	38094	8910	Aroclor 1260	8082A	Approved	
WP PCBs in Water	38095	8880	PCB in Oil 1016 or 1242	8082A	Approved	
WP PCBs in Water	38095	100	PCB in Oil 1254	8082A	Approved	
WP PCBs in Water	38095	101	PCB in Oil 1260	8082A	Approved	
WS PCBs in Water	38133	8880	Aroclor 1016	8082A	Approved	
WS PCBs in Water	38133	8885	Aroclor 1221	8082A	Approved	
WS PCBs in Water	38133	8890	Aroclor 1232	8082A	Approved	
WS PCBs in Water	38133	8895	Aroclor 1242	8082A	Approved	
WS PCBs in Water	38133	8900	Aroclor 1248	8082A	Approved	
WS PCBs in Water	38133	8905	Aroclor 1254	8082A	Approved	
WS PCBs in Water	38133	8910	Aroclor 1260	8082A	Approved	
PCBs in Water	PEO-020	8912	Aroclor 1016/1242	8082A	Approved	
PCBs in Water	PEO-020	8912	Aroclor 1016/1242	8082A	Approved	
PCBs in Water	PEO-020	8880	Aroclor-1016 (PCB-1016)	8082A	Approved	

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :	APPL, Inc.					
City/State :	Clovis, CA					
PartName	PartNumber	NELACCCode	AnalyteName	EPA Method	PT results	
PCBs in Water	PEO-020	8880	Aroclor-1016 (PCB-1016)	8082A	Approved	
PCBs in Water	PEO-020	8885	Aroclor-1221 (PCB-1221)	8082A	Approved	
PCBs in Water	PEO-020	8885	Aroclor-1221 (PCB-1221)	8082A	Approved	
PCBs in Water	PEO-020	8890	Aroclor-1232 (PCB-1232)	8082A	Approved	
PCBs in Water	PEO-020	8890	Aroclor-1232 (PCB-1232)	8082A	Approved	
PCBs in Water	PEO-020	8895	Aroclor-1242 (PCB-1242)	8082A	Approved	
PCBs in Water	PEO-020	8895	Aroclor-1242 (PCB-1242)	8082A	Approved	
PCBs in Water	PEO-020	8900	Aroclor-1248 (PCB-1248)	8082A	Approved	
PCBs in Water	PEO-020	8900	Aroclor-1248 (PCB-1248)	8082A	Approved	
PCBs in Water	PEO-020	8905	Aroclor-1254 (PCB-1254)	8082A	Approved	
PCBs in Water	PEO-020	8905	Aroclor-1254 (PCB-1254)	8082A	Approved	
PCBs in Water	PEO-020	8910	Aroclor-1260 (PCB-1260)	8082A	Approved	
PCBs in Water	PEO-020	8910	Aroclor-1260 (PCB-1260)	8082A	Approved	
CWA Organophosphorous Pesticides	38135	7075	Azinphosmethyl	8141A	Approved	
WP Organophosphorous Pesticides	38135	7075	Azinphosmethyl (Guthion)	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7300	Chlorpyrifos	8141A	Approved	
WP Organophosphorous Pesticides	38135	7390	Demeton, (Mix of Isomers O:S [35%:56%])	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7390	Demeton, (Mix of Isomers O:S)	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7410	Diazinon	8141A	Approved	
WP Organophosphorous Pesticides	38135	7410	Diazinon	8141A	Approved	
CWA Organophosphorous Pesticides	38135	8610	Dichlorvos	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7475	Dimethoate	8141A	Approved	
CWA Organophosphorous Pesticides	38135	8625	Disulfoton	8141A	Approved	
WP Organophosphorous Pesticides	38135	8625	Disulfoton	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7565	Ethion	8141A	Approved	
WP Organophosphorous Pesticides	38135	7565	Ethion	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7570	Ethoprop	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7770	Malathion	8141A	Approved	
WP Organophosphorous Pesticides	38135	7770	Malathion	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7955	Parathion ethyl	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7825	Parathion methyl	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7985	Phorate	8141A	Approved	
CWA Organophosphorous Pesticides	38135	8110	Ronnel	8141A	Approved	
CWA Organophosphorous Pesticides	38135	8200	Stirophos	8141A	Approved	
CWA Organophosphorous Pesticides	38135	7075	Azinphosmethyl	8141B	Approved	
WP Organophosphorous Pesticides	38135	7075	Azinphosmethyl (Guthion)	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7300	Chlorpyrifos	8141B	Approved	
WP Organophosphorous Pesticides	38135	7390	Demeton, (Mix of Isomers O:S [35%:56%])	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7390	Demeton, (Mix of Isomers O:S)	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7410	Diazinon	8141B	Approved	
WP Organophosphorous Pesticides	38135	7410	Diazinon	8141B	Approved	
CWA Organophosphorous Pesticides	38135	8610	Dichlorvos	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7475	Dimethoate	8141B	Approved	
CWA Organophosphorous Pesticides	38135	8625	Disulfoton	8141B	Approved	
WP Organophosphorous Pesticides	38135	8625	Disulfoton	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7565	Ethion	8141B	Approved	
WP Organophosphorous Pesticides	38135	7565	Ethion	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7570	Ethoprop	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7770	Malathion	8141B	Approved	
WP Organophosphorous Pesticides	38135	7770	Malathion	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7955	Parathion ethyl	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7825	Parathion methyl	8141B	Approved	
CWA Organophosphorous Pesticides	38135	7985	Phorate	8141B	Approved	
CWA Organophosphorous Pesticides	38135	8110	Ronnel	8141B	Approved	
CWA Organophosphorous Pesticides	38135	8200	Stirophos	8141B	Approved	
WP Herbicide Acid Mix #2	38136	8655	2,4,5-T	8151A	Approved	
WP Acrolein & Acrylonitrile	38126	8545	2,4-D (2,4-Dichlorophenoxyacetic acid)	8151A	Approved	
WP Herbicide Acid Mix #2	38136	8560	2,4-DB	8151A	Approved	
WP Herbicide Acid Mix #2	38136	8600	3,5-Dichlorobenzoic acid	8151A	Approved	
WP Herbicide Acid Mix #2	38136	6500	4-Nitrophenol	8151A	Approved	
WP Acrolein & Acrylonitrile	38126	8505	Acifluorfen	8151A	Approved	
WP Herbicide Acid Mix #2	38136	8530	Bentazon	8151A	Approved	
WP Herbicide Acid Mix #2	38136	8540	Chloramben	8151A	Approved	
WP Herbicide Acid Mix #2	38136	8550	Dacthal	8151A	Approved	
WP Acrolein & Acrylonitrile	38126	8555	Dalapon	8151A	Approved	
WP Acrolein & Acrylonitrile	38126	8595	Dicamba	8151A	Approved	
WP Herbicide Acid Mix #2	38136	8605	Dichlorprop	8151A	Approved	
WP Acrolein & Acrylonitrile	38126	8620	Dinoseb (2-sec-Butyl-4,6-dinitrophenol)	8151A	Approved	
NPTA			MCPA	8151A	Approved	
NPTA			MCPP	8151A	Approved	
WP Acrolein & Acrylonitrile	38126	6605	Pentachlorophenol	8151A	Approved	
WP Acrolein & Acrylonitrile	38126	8645	Picloram	8151A	Approved	
WP Acrolein & Acrylonitrile	38126	8650	Silvex (2,4,5-TP)	8151A	Approved	
Volatiles in Non-Portable Water	38083	5105	1,1,1,2-Tetrachloroethane	8260B	Approved	

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :	APPL, Inc.				
City/State :	Clovis, CA				
PartName	PartNumber	NELACCode	AnalyteName	EPA Method	PT results
Volatiles in Non-Portable Water	38083	5160	1,1,1-Trichloroethane	8260B	Approved
Volatiles in Non-Portable Water	38083	5110	1,1,2,2-Tetrachloroethane	8260B	Approved
Volatiles in Non-Portable Water	38083	5165	1,1,2-Trichloroethane	8260B	Approved
WP Oxygenates	38157	5185	1,1,2-Trichlorotrifluoroethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4630	1,1-Dichloroethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4640	1,1-Dichloroethene	8260B	Approved
Volatiles in Non-Portable Water	38083	4670	1,1-Dichloropropene	8260B	Approved
Volatiles in Non-Portable Water	38083	5150	1,2,3-Trichlorobenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	5180	1,2,3-Trichloropropane	8260B	Approved
Volatiles in Non-Portable Water	38083	5155	1,2,4-Trichlorobenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	5210	1,2,4-Trimethylbenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4570	1,2-Dibromo-3-chloropropane	8260B	Approved
Volatiles in Non-Portable Water	38083	4585	1,2-Dibromoethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4610	1,2-Dichlorobenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4635	1,2-Dichloroethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4655	1,2-Dichloropropane	8260B	Approved
Volatiles in Non-Portable Water	38083	5215	1,3,5-Trimethylbenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4615	1,3-Dichlorobenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4660	1,3-Dichloropropane	8260B	Approved
Volatiles in Non-Portable Water	38083	4620	1,4-Dichlorobenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4665	2,2-Dichloropropane	8260B	Approved
WP Ketones	38134	4410	2-Butanone	8260B	Approved
WP Ketones	38134	4410	2-Butanone	8260B	Approved
WP 2-Chloroethyl vinyl ether	38128	4500	2-Chloroethyl vinyl ether	8260B	Approved
Volatiles in Non-Portable Water	38083	4535	2-Chlorotoluene	8260B	Approved
WP Ketones	38134	4860	2-Hexanone	8260B	Approved
WP Ketones	38134	4860	2-Hexanone	8260B	Approved
Volatiles in Non-Portable Water	38083	4540	4-Chlorotoluene	8260B	Approved
Volatiles in Non-Portable Water	38083	4995	4-methyl-2-pentanone	8260B	Approved
WP Ketones	38134	4995	4-Methyl-2-pentanone	8260B	Approved
WP Ketones	38134	4995	4-Methyl-2-pentanone	8260B	Approved
WP Ketones	38134	4315	Acetone	8260B	Approved
WP Ketones	38134	4315	Acetone	8260B	Approved
WP Acrolein & Acrylonitrile	38123	0150	Acrolein	8260B	Approved
WP Acrolein & Acrylonitrile	38123	4325	Acrolein	8260B	Approved
WP Acrolein & Acrylonitrile	38123	1051	Acrolein	8260B	Approved
WP Acrolein & Acrylonitrile	38123	1051	Acrylonitrile	8260B	Approved
Volatiles in Non-Portable Water	38083	4375	Benzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4385	Bromobenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4390	Bromochloromethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4395	Bromodichloromethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4400	Bromoform	8260B	Approved
Volatiles in Non-Portable Water	38083	4950	Bromomethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4450	Carbon disulphide	8260B	Approved
Volatiles in Non-Portable Water	38083	4455	Carbon tetrachloride	8260B	Approved
Volatiles in Non-Portable Water	38083	4475	Chlorobenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4485	Chloroethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4505	Chloroform	8260B	Approved
Volatiles in Non-Portable Water	38083	4960	Chloromethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4645	cis-1,2-Dichloroethene	8260B	Approved
Volatiles in Non-Portable Water	38083	4680	cis-1,3-Dichloropropene	8260B	Approved
Volatiles in Non-Portable Water	38083	4575	Dibromochloromethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4595	Dibromomethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4625	Dichlorodifluoromethane	8260B	Approved
Volatiles in Non-Portable Water	38083	4765	Ethyl benzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4835	Hexachlorobutadiene	8260B	Approved
Volatiles in Non-Portable Water	38083	4840	Hexachloroethane	8260B	Approved
WP Oxygenates	38157	9375	Isopropyl ether (DIPE)	8260B	Approved
Volatiles in Non-Portable Water	38083	4900	Isopropylbenzene	8260B	Approved
NPTA			Methyl Ethyl Ketone	8260B	Approved
Volatiles in Non-Portable Water	38083	5000	Methyl tert-butyl ether (MTBE)	8260B	Approved
WP Oxygenates	38157	5000	Methyl tert-butyl ether (MTBE)	8260B	Approved
Volatiles in Non-Portable Water	38083	4975	Methylene chloride (Dichloromethane)	8260B	Approved
Volatiles in Non-Portable Water	38083	5005	Naphthalene	8260B	Approved
Volatiles in Non-Portable Water	38083	4435	n-Butyl benzene	8260B	Approved
Volatiles in Non-Portable Water	38083	5015	Nitrobenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	5090	n-Propylbenzene	8260B	Approved
WP Oxygenates	38157	5090	n-Propylbenzene	8260B	Approved
Volatiles in Non-Portable Water	38083	4440	sec-Butyl benzene	8260B	Approved
Volatiles in Non-Portable Water	38083	5100	Styrene	8260B	Approved
WP Oxygenates	38157	4370	tert-Amyl methyl ether (TAME)	8260B	Approved
WP Oxygenates	38157	4420	tert-Butyl alcohol (t-Butanol)	8260B	Approved
Volatiles in Non-Portable Water	38083	4445	tert-Butyl benzene	8260B	Approved
WP Oxygenates	38157	4770	tert-Butyl ethyl ether (ETBE)	8260B	Approved

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :	APPL, Inc.					
City/State :	Clovis, CA					
PartName	PartNumber	NELACCode	AnalyteName	EPA Method	PT results	
Volatiles in Non-Portable Water	38083	5115	Tetrachloroethene	8260B	Approved	
Volatiles in Non-Portable Water	38083	5140	Toluene	8260B	Approved	
Volatiles in Non-Portable Water	38083	5260	Total Xylenes	8260B	Approved	
Volatiles in Non-Portable Water	38083	4700	trans-1,2-Dichloroethene	8260B	Approved	
Volatiles in Non-Portable Water	38083	4685	trans-1,3-Dichloropropene	8260B	Approved	
Volatiles in Non-Portable Water	38083	5170	Trichloroethene	8260B	Approved	
Volatiles in Non-Portable Water	38083	5175	Trichlorofluoromethane	8260B	Approved	
Volatiles in Non-Portable Water	38083	5235	Vinyl chloride	8260B	Approved	
NPTA			Cyclohexane	8260B	Approved	
NPTA			Methyl Acetate	8260B	Approved	
NPTA			Methylcyclohexane	8260B	Approved	
NPTA			m&p Xylenes	8260B	Approved	
NPTA			o-Xylene	8260B	Approved	
NPTA			p-isopropyltoluene	8260B	Approved	
NPTA			Vinyl Acetate	8260B	Approved	
Volatiles in Non-Portable Water	38083	5105	1,1,1,2-Tetrachloroethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	5160	1,1,1-Trichloroethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	5110	1,1,2,2-Tetrachloroethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	5165	1,1,2-Trichloroethane	8260C	Approved	
WP Oxygenates	38157	5185	1,1,2-Trichlorotrifluoroethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4630	1,1-Dichloroethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4640	1,1-Dichloroethene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4670	1,1-Dichloropropene	8260C	Approved	
Volatiles in Non-Portable Water	38083	5150	1,2,3-Trichlorobenzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	5180	1,2,3-Trichloropropane	8260C	Approved	
Volatiles in Non-Portable Water	38083	5155	1,2,4-Trichlorobenzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	5210	1,2,4-Trimethylbenzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4570	1,2-Dibromo-3-chloropropane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4585	1,2-Dibromoethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4610	1,2-Dichlorobenzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4635	1,2-Dichloroethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4655	1,2-Dichloropropane	8260C	Approved	
Volatiles in Non-Portable Water	38083	5215	1,3,5-Trimethylbenzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4615	1,3-Dichlorobenzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4660	1,3-Dichloropropane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4620	1,4-Dichlorobenzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4665	2,2-Dichloropropane	8260C	Approved	
WP Ketones	38134	4410	2-Butanone	8260C	Approved	
WP 2-Chloroethyl vinyl ether	38128	4500	2-Chloroethyl vinyl ether	8260C	Approved	
Volatiles in Non-Portable Water	38083	4535	2-Chlorotoluene	8260C	Approved	
WP Ketones	38134	4860	2-Hexanone	8260C	Approved	
Volatiles in Non-Portable Water	38083	4540	4-Chlorotoluene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4995	4-methyl-2-pentanone	8260C	Approved	
WP Ketones	38134	4995	4-Methyl-2-pentanone	8260C	Approved	
WP Ketones	38134	4315	Acetone	8260C	Approved	
WP Acrolein & Acrylonitrile	38123	4325	Acrolein (Propenal)	8260C	Approved	
WP Acrolein & Acrylonitrile	38123	1051	Acrylonitrile	8260C	Approved	
Volatiles in Non-Portable Water	38083	4375	Benzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4385	Bromobenzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4390	Bromochloromethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4395	Bromodichloromethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4400	Bromoform	8260C	Approved	
Volatiles in Non-Portable Water	38083	4950	Bromomethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4450	Carbon disulphide	8260C	Approved	
Volatiles in Non-Portable Water	38083	4455	Carbon tetrachloride	8260C	Approved	
Volatiles in Non-Portable Water	38083	4475	Chlorobenzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4485	Chloroethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4505	Chloroform	8260C	Approved	
Volatiles in Non-Portable Water	38083	4960	Chloromethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4645	cis-1,2-Dichloroethene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4680	cis-1,3-Dichloropropene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4575	Dibromochloromethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4595	Dibromomethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4625	Dichlorodifluoromethane	8260C	Approved	
Volatiles in Non-Portable Water	38083	4765	Ethyl benzene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4835	Hexachlorobutadiene	8260C	Approved	
Volatiles in Non-Portable Water	38083	4840	Hexachloroethane	8260C	Approved	
WP Oxygenates	38157	9375	Isopropyl ether (DIPE)	8260C	Approved	
Volatiles in Non-Portable Water	38083	4900	Isopropylbenzene	8260C	Approved	
NPTA			Methyl Ethyl Ketone	8260C	Approved	
Volatiles in Non-Portable Water	38083	5000	Methyl tert-butyl ether (MTBE)	8260C	Approved	
WP Oxygenates	38157	5000	Methyl tert-butyl ether (MTBE)	8260C	Approved	
Volatiles in Non-Portable Water	38083	4975	Methylene chloride (Dichloromethane)	8260C	Approved	
Volatiles in Non-Portable Water	38083	5005	Naphthalene	8260C	Approved	

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :	APPL, Inc.				
City/State :	Clovis, CA				
PartName	PartNumber	NELACCCode	AnalyteName	EPA Method	PT results
Volatiles in Non-Portable Water	38083	4435	n-Butyl benzene	8260C	Approved
Volatiles in Non-Portable Water	38083	5015	Nitrobenzene	8260C	Approved
Volatiles in Non-Portable Water	38083	5090	n-Propylbenzene	8260C	Approved
WP Oxygenates	38157	5090	n-Propylbenzene	8260C	Approved
Volatiles in Non-Portable Water	38083	4910	p-isopropyl toluene	8260C	Approved
Volatiles in Non-Portable Water	38083	4440	sec-Butyl benzene	8260C	Approved
Volatiles in Non-Portable Water	38083	5100	Styrene	8260C	Approved
WP Oxygenates	38157	4370	tert-Amyl methyl ether (TAME)	8260C	Approved
WP Oxygenates	38157	4420	tert-Butyl alcohol (t-Butanol)	8260C	Approved
Volatiles in Non-Portable Water	38083	4445	tert-Butyl benzene	8260C	Approved
WP Oxygenates	38157	4770	tert-Butyl ethyl ether (ETBE)	8260C	Approved
Volatiles in Non-Portable Water	38083	5115	Tetrachloroethene	8260C	Approved
Volatiles in Non-Portable Water	38083	5140	Toluene	8260C	Approved
Volatiles in Non-Portable Water	38083	5260	Total Xylenes	8260C	Approved
Volatiles in Non-Portable Water	38083	4700	trans-1,2-Dichloroethene	8260C	Approved
Volatiles in Non-Portable Water	38083	4685	trans-1,3-Dichloropropene	8260C	Approved
Volatiles in Non-Portable Water	38083	5170	Trichloroethene	8260C	Approved
Volatiles in Non-Portable Water	38083	5175	Trichlorofluoromethane	8260C	Approved
Volatiles in Non-Portable Water	38083	5235	Vinyl chloride	8260C	Approved
NPTA			Cyclohexane	8260C	Approved
NPTA			Methyl Acetate	8260C	Approved
NPTA			Methylcyclohexane	8260C	Approved
NPTA			m&p Xylenes	8260C	Approved
NPTA			o-Xylene	8260C	Approved
NPTA			p-isopropyltoluene	8260C	Approved
NPTA			Vinyl Acetate	8260C	Approved
Base/Neutrals	PEO-121-2A	5155	1,2,4-Trichlorobenzene	8270C	Approved
Base/Neutrals	PEO-121-2A	5155	1,2,4-Trichlorobenzene	8270C	Approved
Base/Neutrals	PEO-121-2A	4610	1,2-Dichlorobenzene	8270C	Approved
Base/Neutrals	PEO-121-2A	4615	1,3-Dichlorobenzene	8270C	Approved
Base/Neutrals	PEO-121-2A	4620	1,4-Dichlorobenzene	8270C	Approved
Acid Compounds	PEO-022	6735	2,3,4,6-Tetrachlorophenol	8270C	Approved
Acid Compounds	PEO-022	6835	2,4,5-Trichlorophenol	8270C	Approved
Acid Compounds	PEO-022	6840	2,4,6-Trichlorophenol	8270C	Approved
Acid Compounds	PEO-022	6000	2,4-Dichlorophenol	8270C	Approved
Acid Compounds	PEO-022	6130	2,4-Dimethylphenol	8270C	Approved
Acid Compounds	PEO-022	6175	2,4-Dinitrophenol	8270C	Approved
Base/Neutrals	PEO-121-2A	6185	2,4-Dinitrotoluene (2,4-DNT)	8270C	Approved
Acid Compounds	PEO-022	6005	2,6-Dichlorophenol	8270C	Approved
Base/Neutrals	PEO-121-2A	6190	2,6-Dinitrotoluene (2,6-DNT)	8270C	Approved
Base/Neutrals	PEO-121-2A	5795	2-Chloronaphthalene	8270C	Approved
Acid Compounds	PEO-022	5800	2-Chlorophenol	8270C	Approved
Acid Compounds	PEO-022	6360	2-Methyl-4,6-Dinitrophenol	8270C	Approved
Base/Neutrals	PEO-121-2A	6385	2-Methylnaphthalene	8270C	Approved
Acid Compounds	PEO-022	6400	2-Methylphenol	8270C	Approved
Base/Neutrals	PEO-121-2B	6460	2-Nitroaniline	8270C	Approved
Acid Compounds	PEO-022	6490	2-Nitrophenol	8270C	Approved
Base/Neutrals	PEO-121-2A	5945	3,3'-Dichlorobenzidine	8270C	Approved
Base/Neutrals	PEO-121-2B	6465	3-Nitroaniline	8270C	Approved
Acid Compounds	PEO-022	6410	3 & 4-Methylphenol	8270C	Approved
Base/Neutrals	PEO-121-2A	5660	4-Bromophenyl phenyl ether	8270C	Approved
Acid Compounds	PEO-022	5700	4-Chloro-3-methylphenol	8270C	Approved
Base/Neutrals	PEO-121-2B	5745	4-Chloroaniline	8270C	Approved
Base/Neutrals	PEO-121-2A	5825	4-Chlorophenyl-phenylether	8270C	Approved
Base/Neutrals	PEO-121-2B	6470	4-Nitroaniline	8270C	Approved
Acid Compounds	PEO-022	6500	4-Nitrophenol	8270C	Approved
Base/Neutrals	PEO-121-1	5500	Acenaphthene	8270C	Approved
Base/Neutrals	PEO-121-1	5505	Acenaphthylene	8270C	Approved
Base/Neutrals	PEO-121-2B	5545	Aniline	8270C	Approved
Base/Neutrals	PEO-121-1	5555	Anthracene	8270C	Approved
Base/Neutrals	PEO-121-2A	5595	Benzidine	8270C	Approved
Base/Neutrals	PEO-121-1	5575	Benzo(a)anthracene	8270C	Approved
Base/Neutrals	PEO-121-1	5580	Benzo(a)pyrene	8270C	Approved
Base/Neutrals	PEO-121-1	5585	Benzo(b)fluoranthene	8270C	Approved
Base/Neutrals	PEO-121-1	5601	Benzo(b+k)fluoranthene	8270C	Approved
Base/Neutrals	PEO-121-1	5590	Benzo(g,h,i)perylene	8270C	Approved
Base/Neutrals	PEO-121-1	5600	Benzo(k)fluoranthene	8270C	Approved
Acid Compounds	PEO-022	5610	Benzoic acid	8270C	Approved
Base/Neutrals	PEO-121-2B	5630	Benzyl alcohol	8270C	Approved
Base/Neutrals	PEO-121-2A	5670	Benzyl butyl phthalate	8270C	Approved
Base/Neutrals	PEO-121-2A	5760	bis(2-Chloroethoxy) methane	8270C	Approved
Base/Neutrals	PEO-121-2A	5765	bis(2-Chloroethyl) ether	8270C	Approved
Base/Neutrals	PEO-121-2A	5780	bis(2-Chloroisopropyl) ether	8270C	Approved
Base/Neutrals	PEO-121-2A	6255	bis(2-Ethylhexyl) phthalate	8270C	Approved

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :	APPL, Inc.				
City/State :	Clovis, CA				
PartName	PartNumber	NELACCCode	AnalyteName	EPA Method	PT results
Base/Neutrals	PEO-121-2B	7180	Caprolactam	8270C	Approved
Base/Neutrals	PEO-121-2B	5680	Carbazole	8270C	Approved
Base/Neutrals	PEO-121-1	5855	Chrysene	8270C	Approved
Base/Neutrals	PEO-121-1	5895	Dibenz(a,h) anthracene	8270C	Approved
Base/Neutrals	PEO-121-2A	5905	Dibenzofuran	8270C	Approved
Base/Neutrals	PEO-121-2A	6070	Diethyl phthalate	8270C	Approved
Base/Neutrals	PEO-121-2A	6135	Dimethyl phthalate	8270C	Approved
Base/Neutrals	PEO-121-2A	5925	Di-n-butylphthalate	8270C	Approved
Base/Neutrals	PEO-121-2A	6200	Di-n-octylphthalate	8270C	Approved
Base/Neutrals	PEO-121-1	6265	Fluoranthene	8270C	Approved
Base/Neutrals	PEO-121-1	6270	Fluorene	8270C	Approved
Base/Neutrals	PEO-121-2A	6275	Hexachlorobenzene	8270C	Approved
Base/Neutrals	PEO-121-2A	4835	Hexachlorobutadiene	8270C	Approved
Base/Neutrals	PEO-121-2A	6285	Hexachlorocyclopentadiene	8270C	Approved
Base/Neutrals	PEO-121-2A	4840	Hexachloroethane	8270C	Approved
Base/Neutrals	PEO-121-1	6315	Indeno(1,2,3-cd) pyrene	8270C	Approved
Base/Neutrals	PEO-121-2A	6320	Isophorone	8270C	Approved
Base/Neutrals	PEO-121-1	5005	Naphthalene	8270C	Approved
Base/Neutrals	PEO-121-2A	5015	Nitrobenzene	8270C	Approved
Base/Neutrals	PEO-121-2A	6530	N-nitrosodimethylamine	8270C	Approved
Base/Neutrals	PEO-121-2A	6545	N-nitrosodi-n-propylamine	8270C	Approved
Base/Neutrals	PEO-121-2A	6535	N-nitrosodiphenylamine	8270C	Approved
Acid Compounds	PEO-022	6605	Pentachlorophenol	8270C	Approved
Base/Neutrals	PEO-121-1	6615	Phenanthrene	8270C	Approved
Acid Compounds	PEO-022	6625	Phenol	8270C	Approved
Base/Neutrals	PEO-121-1	6665	Pyrene	8270C	Approved
Base/Neutrals	PEO-121-2B	5095	Pyridine	8270C	Approved
Low Level PAHs	PEO-259	5500	Acenaphthene	8270C SIM	Approved
Low Level PAHs	PEO-259	5505	Acenaphthylene	8270C SIM	Approved
Low Level PAHs	PEO-259	5555	Anthracene	8270C SIM	Approved
Low Level PAHs	PEO-259	5575	Benzo(a)anthracene	8270C SIM	Approved
Low Level PAHs	PEO-259	5580	Benzo(a)pyrene	8270C SIM	Approved
Low Level PAHs	PEO-259	5585	Benzo(b)fluoranthene	8270C SIM	Approved
Low Level PAHs	PEO-259	5590	Benzo(g,h,i)perylene	8270C SIM	Approved
Low Level PAHs	PEO-259	5600	Benzo(k)fluoranthene	8270C SIM	Approved
Low Level PAHs	PEO-259	5855	Chrysene	8270C SIM	Approved
Low Level PAHs	PEO-259	5895	Dibenzo(a,h)anthracene	8270C SIM	Approved
Low Level PAHs	PEO-259	6265	Fluoranthene	8270C SIM	Approved
Low Level PAHs	PEO-259	6270	Fluorene	8270C SIM	Approved
Low Level PAHs	PEO-259	6315	Indeno(1,2,3-cd) pyrene	8270C SIM	Approved
Low Level PAHs	PEO-259	5005	Naphthalene	8270C SIM	Approved
Low Level PAHs	PEO-259	6615	Phenanthrene	8270C SIM	Approved
Low Level PAHs	PEO-259	6665	Pyrene	8270C SIM	Approved
Low Level PAHs			2-Methylnaphthalene	8270C SIM	Approved
Base/Neutrals	PEO-121-2A	5155	1,2,4-Trichlorobenzene	8270D	Approved
Base/Neutrals	PEO-121-2A	4610	1,2-Dichlorobenzene	8270D	Approved
Base/Neutrals	PEO-121-2A	4615	1,3-Dichlorobenzene	8270D	Approved
Base/Neutrals	PEO-121-2A	4620	1,4-Dichlorobenzene	8270D	Approved
Acid Compounds	PEO-022	6735	2,3,4,6-Tetrachlorophenol	8270D	Approved
Acid Compounds	PEO-022	6835	2,4,5-Trichlorophenol	8270D	Approved
Acid Compounds	PEO-022	6840	2,4,6-Trichlorophenol	8270D	Approved
Acid Compounds	PEO-022	6000	2,4-Dichlorophenol	8270D	Approved
Acid Compounds	PEO-022	6130	2,4-Dimethylphenol	8270D	Approved
Acid Compounds	PEO-022	6175	2,4-Dinitrophenol	8270D	Approved
Base/Neutrals	PEO-121-2A	6185	2,4-Dinitrotoluene (2,4-DNT)	8270D	Approved
Acid Compounds	PEO-022	6005	2,6-Dichlorophenol	8270D	Approved
Base/Neutrals	PEO-121-2A	6190	2,6-Dinitrotoluene (2,6-DNT)	8270D	Approved
Base/Neutrals	PEO-121-2A	5795	2-Chloronaphthalene	8270D	Approved
Acid Compounds	PEO-022	5800	2-Chlorophenol	8270D	Approved
Acid Compounds	PEO-022	6360	2-Methyl-4,6-Dinitrophenol	8270D	Approved
Base/Neutrals	PEO-121-2A	6385	2-Methylnaphthalene	8270D	Approved
Acid Compounds	PEO-022	6400	2-Methylphenol	8270D	Approved
Base/Neutrals	PEO-121-2B	6460	2-Nitroaniline	8270D	Approved
Acid Compounds	PEO-022	6490	2-Nitrophenol	8270D	Approved
Base/Neutrals	PEO-121-2A	5945	3,3'-Dichlorobenzidine	8270D	Approved
Base/Neutrals	PEO-121-2B	6465	3-Nitroaniline	8270D	Approved
Acid Compounds	PEO-022	6410	4 & 4-Methylphenol	8270D	Approved
Base/Neutrals	PEO-121-2A	5660	4-Bromophenyl phenyl ether	8270D	Approved
Acid Compounds	PEO-022	5700	4-Chloro-3-methylphenol	8270D	Approved
Base/Neutrals	PEO-121-2B	5745	4-Chloroaniline	8270D	Approved
Base/Neutrals	PEO-121-2A	5825	4-Chlorophenyl-phenylether	8270D	Approved
Base/Neutrals	PEO-121-2B	6470	4-Nitroaniline	8270D	Approved
Acid Compounds	PEO-022	6500	4-Nitrophenol	8270D	Approved
Base/Neutrals	PEO-121-2B	5545	Aniline	8270D	Approved

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :	APPL, Inc.					
City/State :	Clovis, CA					
PartName	PartNumber	NELACCCode	AnalyteName	EPA Method	PT results	
Base/Neutrals	PEO-121-2A	5595	Benzidine	8270D	Approved	
Acid Compounds	PEO-022	5610	Benzoic acid	8270D	Approved	
Base/Neutrals	PEO-121-2B	5630	Benzyl alcohol	8270D	Approved	
Base/Neutrals	PEO-121-2A	5670	Benzyl butyl phthalate	8270D	Approved	
Base/Neutrals	PEO-121-2A	5760	bis(2-Chloroethoxy) methane	8270D	Approved	
Base/Neutrals	PEO-121-2A	5765	bis(2-Chloroethyl) ether	8270D	Approved	
Base/Neutrals	PEO-121-2A	5780	bis(2-Chloroisopropyl) ether	8270D	Approved	
Base/Neutrals	PEO-121-2A	6255	bis(2-Ethylhexyl) phthalate	8270D	Approved	
Base/Neutrals	PEO-121-2B	7180	Caprolactam	8270D	Approved	
Base/Neutrals	PEO-121-2B	5680	Carbazole	8270D	Approved	
Base/Neutrals	PEO-121-2A	5905	Dibenzofuran	8270D	Approved	
Base/Neutrals	PEO-121-2A	6070	Diethyl phthalate	8270D	Approved	
Base/Neutrals	PEO-121-2A	6135	Dimethyl phthalate	8270D	Approved	
Base/Neutrals	PEO-121-2A	5925	Di-n-butylphthalate	8270D	Approved	
Base/Neutrals	PEO-121-2A	6200	Di-n-octylphthalate	8270D	Approved	
Base/Neutrals	PEO-121-2A	6275	Hexachlorobenzene	8270D	Approved	
Base/Neutrals	PEO-121-2A	4835	Hexachlorobutadiene	8270D	Approved	
Base/Neutrals	PEO-121-2A	6285	Hexachlorocyclopentadiene	8270D	Approved	
Base/Neutrals	PEO-121-2A	4840	Hexachloroethane	8270D	Approved	
Base/Neutrals	PEO-121-2A	6320	Isophorone	8270D	Approved	
Base/Neutrals	PEO-121-2A	5015	Nitrobenzene	8270D	Approved	
Base/Neutrals	PEO-121-2A	6530	N-nitrosodimethylamine	8270D	Approved	
Base/Neutrals	PEO-121-2A	6545	N-nitrosodi-n-propylamine	8270D	Approved	
Base/Neutrals	PEO-121-2A	6535	N-nitrosodiphenylamine	8270D	Approved	
Acid Compounds	PEO-022	6605	Pentachlorophenol	8270D	Approved	
Acid Compounds	PEO-022	6625	Phenol	8270D	Approved	
Base/Neutrals	PEO-121-2B	5095	Pyridine	8270D	Approved	
Low Level PAHs	PEO-259	5500	Acenaphthene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5505	Acenaphthylene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5555	Anthracene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5575	Benzo(a)anthracene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5580	Benzo(a)pyrene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5585	Benzo(b)fluoranthene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5590	Benzo(g,h,i)perylene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5600	Benzo(k)fluoranthene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5855	Chrysene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5895	Dibenzo(a,h)anthracene	8270D SIM	Approved	
Low Level PAHs	PEO-259	6265	Fluoranthene	8270D SIM	Approved	
Low Level PAHs	PEO-259	6270	Fluorene	8270D SIM	Approved	
Low Level PAHs	PEO-259	6315	Indeno(1,2,3-cd) pyrene	8270D SIM	Approved	
Low Level PAHs	PEO-259	5005	Naphthalene	8270D SIM	Approved	
Low Level PAHs	PEO-259	6615	Penanthrene	8270D SIM	Approved	
Low Level PAHs	PEO-259	6665	Pyrene	8270D SIM	Approved	
			2-Methylnaphthalene	8270D SIM	Approved	
2,3,7,8-Tetrachlorodibenzo-p-dioxin	38186	9618	2,3,7,8-TCDD	8290	Approved	
Dioxin	PEO-258	9519	1,2,3,4,6,7,8,9-OCDD	8290	Approved	
Dioxin	PEO-258	9516	1,2,3,4,6,7,8,9-OCDF	8290	Approved	
Dioxin	PEO-258	9426	1,2,3,4,6,7,8-Hpcdd	8290	Approved	
Dioxin	PEO-258	9420	1,2,3,4,6,7,8-Hpcdf	8290	Approved	
Dioxin	PEO-258	9423	1,2,3,4,7,8,9-Hpcdf	8290	Approved	
Dioxin	PEO-258	9453	1,2,3,4,7,8-Hxcdd	8290	Approved	
Dioxin	PEO-258	9471	1,2,3,4,7,8-Hxcdf	8290	Approved	
Dioxin	PEO-258	9456	1,2,3,6,7,8-Hxcdd	8290	Approved	
Dioxin	PEO-258	9474	1,2,3,6,7,8-Hxcdf	8290	Approved	
Dioxin	PEO-258	9459	1,2,3,7,8,9-Hxcdd	8290	Approved	
Dioxin	PEO-258	9477	1,2,3,7,8,9-Hxcdf	8290	Approved	
Dioxin	PEO-258	9540	1,2,3,7,8-Pecdd	8290	Approved	
Dioxin	PEO-258	9543	1,2,3,7,8-Pecdf	8290	Approved	
Dioxin	PEO-258	9480	2,3,4,6,7,8-Hxcdf	8290	Approved	
Dioxin	PEO-258	9549	2,3,4,7,8-Pecdf	8290	Approved	
Dioxin	PEO-258	9606	2,3,7,8-TCDD	8290	Approved	
Dioxin	PEO-258	9612	2,3,7,8-TCDF	8290	Approved	
Dioxin	PEO-258	9438	Hpcdd, total	8290	Approved	
Dioxin	PEO-258	9444	Hpcdf, total	8290	Approved	
Dioxin	PEO-258	9468	Hxcdd, total	8290	Approved	
Dioxin	PEO-258	9483	Hxcdf, total	8290	Approved	
Dioxin	PEO-258	9556	PCDD + PCDF, total	8290	Approved	
Dioxin	PEO-258	9991	PCDD, total	8290	Approved	
Dioxin	PEO-258	9993	PCDF, total	8290	Approved	
Dioxin	PEO-258	9555	Pecdd, total	8290	Approved	
Dioxin	PEO-258	9552	Pecdf, total	8290	Approved	
Dioxin	PEO-258	9609	TCDD, total	8290	Approved	
Dioxin	PEO-258	9615	TCDF, total	8290	Approved	
WP Carbamates	38156	7710	3-Hydroxycarbofuran	8321A	Approved	

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

Lab Name :		APPL, Inc.			
City/State :		Clovis, CA			
PartName	PartNumber	NELACCCode	AnalyteName	EPA Method	PT results
WP Carbamates	38156	7010	Aldicarb	8321A	Approved
WP Carbamates	38156	7015	Aldicarb sulfone	8321A	Approved
WP Carbamates	38156	7020	Aldicarb sulfoxide	8321A	Approved
NPTA			Barban	8321A	Approved
NPTA			Bromacil	8321A	Approved
WP Carbamates	38156	7195	Carbaryl	8321A	Approved
WP Carbamates	38156	7205	Carbofuran	8321A	Approved
NPTA			Chloroxuron	8321A	Approved
WP Carbamates	38156	7505	Diuron	8321A	Approved
NPTA			Linuron	8321A	Approved
WP Carbamates	38156	7800	Methiocarb	8321A	Approved
WP Carbamates	38156	7805	Methomyl	8321A	Approved
WP Carbamates	38156	7940	Oxamyl	8321A	Approved
WP Carbamates	38156	8075	Propham	8321A	Approved
WP Carbamates	38156	8080	Propoxur (Baygon)	8321A	Approved
CWA Nitroaromatics in Water	38172	6885	1,3,5-Trinitrobenzene	8330A	Approved
CWA Nitroaromatics in Water	38172	6160	1,3-Dinitrobenzene	8330A	Approved
CWA Nitroaromatics in Water	38172	9651	2,4,6-Trinitrotoluene	8330A	Approved
CWA Nitroaromatics in Water	38172	6185	2,4-Dinitrotoluene	8330A	Approved
CWA Nitroaromatics in Water	38172	6190	2,6-Dinitrotoluene	8330A	Approved
CWA Nitroaromatics in Water	38172	9303	2-Amino-4,6-dinitrotoluene	8330A	Approved
CWA Nitroaromatics in Water	38172	9507	2-Nitrotoluene	8330A	Approved
CWA Nitroaromatics in Water	38172	9510	3-Nitrotoluene	8330A	Approved
CWA Nitroaromatics in Water	38172	9306	4-Amino-2,6-dinitrotoluene	8330A	Approved
CWA Nitroaromatics in Water	38172	9513	4-Nitrotoluene	8330A	Approved
CWA Nitroaromatics in Water	38172	9522	HMX	8330A	Approved
CWA Nitroaromatics in Water	38172	5015	Nitrobenzene	8330A	Approved
NPTA			Nitroglycerin	8330A	Approved
NPTA			PETN	8330A	Approved
NPTA			PGDN	8330A	Approved
NPTA			Picric Acid	8330A	Approved
CWA Nitroaromatics in Water	38172	9432	RDX	8330A	Approved
CWA Nitroaromatics in Water	38172	6415	Tetryl	8330A	Approved
CWA Nitroaromatics in Water	38172	6885	1,3,5-Trinitrobenzene	8330B	Approved
CWA Nitroaromatics in Water	38172	6160	1,3-Dinitrobenzene	8330B	Approved
CWA Nitroaromatics in Water	38172	9651	2,4,6-Trinitrotoluene	8330B	Approved
CWA Nitroaromatics in Water	38172	6185	2,4-Dinitrotoluene	8330B	Approved
CWA Nitroaromatics in Water	38172	6190	2,6-Dinitrotoluene	8330B	Approved
CWA Nitroaromatics in Water	38172	9303	2-Amino-4,6-dinitrotoluene	8330B	Approved
CWA Nitroaromatics in Water	38172	9507	2-Nitrotoluene	8330B	Approved
CWA Nitroaromatics in Water	38172	9510	3-Nitrotoluene	8330B	Approved
CWA Nitroaromatics in Water	38172	9306	4-Amino-2,6-dinitrotoluene	8330B	Approved
CWA Nitroaromatics in Water	38172	9513	4-Nitrotoluene	8330B	Approved
CWA Nitroaromatics in Water	38172	9522	HMX	8330B	Approved
CWA Nitroaromatics in Water	38172	5015	Nitrobenzene	8330B	Approved
NPTA			Nitroglycerin	8330B	Approved
NPTA			PGDN	8330B	Approved
NPTA			Picric Acid	8330B	Approved
CWA Nitroaromatics in Water	38172	9432	RDX	8330B	Approved
CWA Nitroaromatics in Water	38172	6415	Tetryl	8330B	Approved
Low Level Nit/Nit	PEO-251	6885	1,3,5-Trinitrobenzene (1,3,5-TNB)	8330B	Approved
Low Level Nit/Nit	PEO-251	6160	1,3-Dinitrobenzene (1,3-DNB)	8330B	Approved
Low Level Nit/Nit	PEO-251	9651	2,4,6-Trinitrotoluene (2,4,6-TNT)	8330B	Approved
Low Level Nit/Nit	PEO-251	6185	2,4-Dinitrotoluene (2,4-DNT)	8330B	Approved
Low Level Nit/Nit	PEO-251	6190	2,6-Dinitrotoluene (2,6-DNT)	8330B	Approved
Low Level Nit/Nit	PEO-251	9303	2-Amino-4,6-dinitrotoluene (2am-dnt)	8330B	Approved
Low Level Nit/Nit	PEO-251	9507	2-Nitrotoluene	8330B	Approved
Low Level Nit/Nit	PEO-251	9510	3-Nitrotoluene	8330B	Approved
Low Level Nit/Nit	PEO-251	9306	4-Amino-2,6-dinitrotoluene (4am-dnt)	8330B	Approved
Low Level Nit/Nit	PEO-251	9513	4-Nitrotoluene	8330B	Approved
Low Level Nit/Nit	PEO-251	9522	HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)	8330B	Approved
Low Level Nit/Nit	PEO-251	5015	Nitrobenzene	8330B	Approved
Low Level Nit/Nit	PEO-251	6485	Nitroglycerin	8330B	Approved
Low Level Nit/Nit	PEO-251	9432	RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine)	8330B	Approved
Low Level Nit/Nit	PEO-251	6415	Tetryl (Methyl-2,4,6-trinitrophenylnitramine)	8330B	Approved
Low Level Nit/Nit	PEO-252	9558	PETN	8330B	Approved
WP Cyanide, Total & Amenable	55132	1645	Total Cyanide	9010B	Approved
WP Cyanide, Total & Amenable	55132	1645	Total Cyanide	9010C & 9014	Approved
WP pH @ 25C	55061	1900	pH	9040B	Approved
WP pH @ 25C	55061	1900	pH	9040C	Approved
WP & DMRQA Nutrients	55035	1810	Nitrate as N	9056	Approved
WP & DMRQA Nutrients	55035	1870	Orthophosphate as P	9056	Approved
WP Nitrate & Nitrite	55130	1810	Nitrate as N	9056	Approved
WP Nitrate & Nitrite	55130	1820	Nitrite + Nitrate as N	9056	Approved

**Accredited Analytes/Methods  
WP Proficiency Testing Summary**

<b>Lab Name :</b>		<b>APPL, Inc.</b>				
<b>City/State :</b>		<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT results</b>	
WP Nitrate & Nitrite	55130	1840	Nitrite as N	9056	Approved	
SWA Anions	55131	1540	Bromide	9056	Approved	
WP Minerals #1	55144	1575	Chloride	9056	Approved	
WP Minerals #2	55145	1730	Fluoride	9056	Approved	
WP Minerals #2	55145	2000	Sulfate	9056	Approved	
WP & DMRQA Nutrients	55035	1810	Nitrate as N	9056A	Approved	
WP & DMRQA Nutrients	55035	1870	Orthophosphate as P	9056A	Approved	
WP Nitrate & Nitrite	55130	1810	Nitrate as N	9056A	Approved	
WP Nitrate & Nitrite	55130	1820	Nitrite + Nitrate as N	9056A	Approved	
WP Nitrate & Nitrite	55130	1840	Nitrite as N	9056A	Approved	
SWA Anions	55131	1540	Bromide	9056A	Approved	
WP Minerals #1	55144	1575	Chloride	9056A	Approved	
WP Minerals #2	55145	1730	Fluoride	9056A	Approved	
WP Minerals #2	55145	2000	Sulfate	9056A	Approved	
WP & DMRQA Demands	55055	2040	Total Organic Carbon	9060	Approved	
CWA UV 254 Absorbance/DOC	55088	1710	Dissolved Organic Carbon	9060	Approved	
WP & DMRQA Demands	55055	2040	Total Organic Carbon	9060A	Approved	
CWA UV 254 Absorbance/DOC	55088	1710	Dissolved Organic Carbon	9060A	Approved	
<del>Fluoride</del>	<del>4420</del>	<del>1730</del>	<del>Fluoride</del>	<del>9214</del>	Approved	
WP Minerals #2	55145	1505	Total Alkalinity (CaCO3)	SM 2320B	Approved	
Minerals	4050	1610	Conductivity	SM 2510B	Approved	
WP Conductance @ 25C	55026	1610	Specific Conductance	SM 2510B	Approved	
Solids (Total Solids, TSS & TDS)	55085	1955	Total Dissolved Solids (TDS)	SM 2540C	Approved	
WP Minerals #1	55144	1955	Total Dissolved Solids @ 180C	SM 2540C	Approved	
Sulphide	55042	2005	Sulphide	SM 4500-S2F	Approved	
Minerals	PEI-257	2005	Sulfide	SM 4500-S2F	Approved	
WP & DMRQA Demands	55055	2040	Total Organic Carbon	SM 5310B	Approved	
CWA UV 254 Absorbance/DOC	55088	1710	Dissolved Organic Carbon	SM 5310B	Approved	
Miscellaneous Analytes	PEI-029	1860	Oil & Grease	SM 5520B	Approved	
Total Petroleum Hydrocarbons (TPH) in Water	642	1935	TPH (Gravimetric)	SM 5520BF	Approved	
WP MBAS	55083	2025	MBAS	SM 5540C	Approved	
MBAS	55106	2025	MBAS	SM 5540C	Approved	
NPTA			Ethane, Ethene, Methane	RSK175	Approved	
Solids	4030	1960	Total Suspended Solids	SM 2540D	Approved	
Solids (Total Solids, TSS & TDS)	55085	1960	Non-Filterable Residue (TSS)	SM 2540D	Approved	

**Accredited Analytes/Methods**

**WS Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
WS Minerals Mix #2	55123	1955	Total Filterable Residue	160.1	Approved
SDWA Solids (Total Solids, TSS & TDS)	55161	1955	Total Dissolved Solids	160.1	Approved
WS Chromium VI	55112	1045	Chromium VI	218.6	Approved
WS Inorganic Disinfection By-Products	55010	1540	Bromide	300.0	Approved
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1730	Fluoride	300.0	Approved
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1820	Nitrate and Nitrite as N	300.0	Approved
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1810	Nitrate as N	300.0	Approved
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1840	Nitrite as N	300.0	Approved
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1870	Orthophosphate as P	300.0	Approved
WS Sulphate/TOC	55070	2000	Sulfate	300.0	Approved
WS Minerals Mix #1	55122	1575	Chloride	300.0	Approved
WS Perchlorate	55099	1895	Perchlorate	314.0	Approved
SDWA Nutrients	55165	1515	Ammonia as N	350.1	Approved
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1820	Nitrate and Nitrite as N	353.2	Approved
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1810	Nitrate as N	353.2	Approved
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1840	Nitrite as N	353.2	Approved
WS Perchlorate	55099	1895	Perchlorate	6850	Approved
WS pH @ 25C	55016	1900	pH @ 25	9040C	Approved
WS Minerals Mix #1	55122	1505	Alkalinity	SM 2320B	Approved
WS Minerals Mix #2	55123	1955	Total Filterable Residue	SM 2540C	Approved
SDWA Solids (Total Solids, TSS, & TDS)	55161	1955	Total Dissolved Solids	SM 2540C	Approved
WS Sulphate/TOC	55070	2040	TOC	SM 5310B	Approved
WS UV 254 Absorbance/DOC	55098	1710	Dissolved Organic Carbon (DOC)	SM 5310B	Approved
WS MBAS	55106	2025	MBAS	SM 5540C	Approved
Solids	5150	1960	Total Suspended Solids	SM 2540D	Approved
SDWA Solids (Total Solids, TSS, & TDS)	55161	1960	Non-Filterable Residue (TSS)	SM 2540D	Approved
Trace Metals	5070	1095	Mercury	EPA 245.1	Approved
WS Trace Elements Amp1	55012	1095	Mercury	EPA 245.1	Approved

## Accredited Analytes/Methods

### UST: Water Proficiency Testing Summary

<b>Lab Name :</b>		<b>APPL, Inc.</b>			
<b>City/State :</b>		<b>Clovis, CA</b>			
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
Petroleum Hydrocarbons in Water	PEO-010	102	Gasoline Range Organics, C6-C10	EPA 8015B	Approved
Petroleum Hydrocarbons in Water	PEO-010	9408	Gasoline Range Organics, C6-C10	EPA 8015C	Approved
Petroleum Hydrocarbons in Water	PEO-010	9408	Gasoline Range Organics, C6-C10	EPA 8015D	Approved
Petroleum Hydrocarbons in Wastewater	PEO-011	9369	Diesel Range Organics (DRO)	EPA 8015B	Approved
Petroleum Hydrocarbons in Wastewater	PEO-011	9369	Diesel range organics, C10-C28	EPA 8015B	Approved
GRO/BTEX in Water	PEO-114AK	4375	Benzene	EPA 8260B	Approved
GRO/BTEX in Water	PEO-114AK	4765	Ethylbenzene	EPA 8260B	Approved
GRO/BTEX in Water	PEO-114AK	5240	m+p-Xylene	EPA 8260B	Approved
GRO/BTEX in Water	PEO-114AK	5000	MTBE	EPA 8260B	Approved
GRO/BTEX in Water	PEO-114AK	5250	o-Xylene	EPA 8260B	Approved
GRO/BTEX in Water	PEO-114AK	5140	Toluene	EPA 8260B	Approved
GRO/BTEX in Water	PEO-114AK	5260	Xylene, total	EPA 8260B	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
PCB Congeners in Soil	SPE-068	9070	2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180)	1668A	Approved
PCB Congeners in Soil	SPE-068	9025	2,2',3,4,4',5'-Hexachlorobiphenyl (PCB 138)	1668A	Approved
PCB Congeners in Soil	SPE-068	9040	2,2',4,4',5,5'-Hexachlorobiphenyl (PCB 153)	1668A	Approved
PCB Congeners in Soil	SPE-068	8980	2,2',4,5,5'-Pentachlorobiphenyl (PCB 101)	1668A	Approved
PCB Congeners in Soil	SPE-068	8955	2,2',5,5'-Tetrachlorobiphenyl (PCB 52)	1668A	Approved
PCB Congeners in Soil	SPE-068	9085	2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189)	1668A	Approved
PCB Congeners in Soil	SPE-068	9050	2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156)	1668A	Approved
PCB Congeners in Soil	SPE-068	9045	2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157)	1668A	Approved
PCB Congeners in Soil	SPE-068	8985	2,3,3',4,4'-Pentachlorobiphenyl (PCB 105)	1668A	Approved
PCB Congeners in Soil	SPE-068	9055	2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167)	1668A	Approved
PCB Congeners in Soil	SPE-068	9005	2,3,4,4',5-Pentachlorobiphenyl (PCB 114)	1668A	Approved
PCB Congeners in Soil	SPE-068	8995	2,3',4,4',5-Pentachlorobiphenyl (PCB 118)	1668A	Approved
PCB Congeners in Soil	SPE-068	9000	2,3',4,4',5'-Pentachlorobiphenyl (PCB 123)	1668A	Approved
PCB Congeners in Soil	SPE-068	8936	2,4,4'-Trichlorobiphenyl (PCB 28)	1668A	Approved
PCB Congeners in Soil	SPE-068	9060	3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169)	1668A	Approved
PCB Congeners in Soil	SPE-068	9015	3,3',4,4',5-Pentachlorobiphenyl (PCB 126)	1668A	Approved
PCB Congeners in Soil	SPE-068	8965	3,3',4,4'-Tetrachlorobiphenyl (PCB 77)	1668A	Approved
PCB Congeners in Soil	SPE-068	8970	3,4,4',5-Tetrachlorobiphenyl (PCB 81)	1668A	Approved
PCB Congeners in Soil	SPE-068	9025	PCB (129)+(138)+(163)	1668A	Approved
PCB Congeners in Soil	SPE-068	9040	PCB (153)+(168)	1668A	Approved
PCB Congeners in Soil	SPE-068	9046	PCB (156)+(157)	1668A	Approved
PCB Congeners in Soil	SPE-068	9070	PCB (180)+(193)	1668A	Approved
PCB Congeners in Soil	SPE-068	8936	PCB (20)+(28)	1668A	Approved
PCB Congeners in Soil	SPE-068	8980	PCB (90)+(101)+(113)	1668A	Approved
PCB Congeners in Soil	SPE-068	8870	PCBs, total	1668A	Approved
RCRA Anions	55141	1540	Bromide (Br)	300.0	Approved
RCRA Anions	55141	1575	Chloride (Cl)	300.0	Approved
RCRA Anions	55141	1730	Fluoride (F)	300.0	Approved
RCRA Anions	55141	1810	Nitrate as N (NO3- as N)	300.0	Approved
RCRA Anions	55141	1870	Phosphate as P (PO43- as P)	300.0	Approved
RCRA Anions	55141	2000	Sulfate (SO42-)	300.0	Approved
RCRA Hexavalent Chromium	55104	1045	Chromium VI	3060A	Approved
RCRA Perchlorate	55143	1895	Perchlorate	314.0	Approved
RCRA Nutrients	55142	1515	Ammonia as N	350.1	Approved
RCRA Nutrients	55142	1795	Total Kjeldhal Nitrogen	351.2	Approved
RCRA Anions	55141	1810	Nitrate as N (NO3 as N)	353.2	Approved
RCRA Metals in Soil #2	55103	1000	Aluminum	6010B	Approved
RCRA Metals in Soil #1	55102	1005	Antimony	6010B	Approved
TCLP Metals	SPE-005	1005	Antimony, Sb	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1005	Antimony, Sb	6010B	Approved
RCRA Metals in Soil #1	55102	1010	Arsenic	6010B	Approved
TCLP Metals	SPE-005	1010	Arsenic, As	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1010	Arsenic, As	6010B	Approved
RCRA Metals in Soil #1	55102	1015	Barium	6010B	Approved
TCLP Metals	SPE-005	1015	Barium, Ba	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1015	Barium, Ba	6010B	Approved
RCRA Metals in Soil #1	55102	1020	Beryllium	6010B	Approved
TCLP Metals	SPE-005	1020	Beryllium, Be	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1020	Beryllium, Be	6010B	Approved
RCRA Metals in Soil #1	55102	1025	Boron	6010B	Approved
RCRA Metals in Soil #1	55102	1030	Cadmium	6010B	Approved
TCLP Metals	SPE-005	1030	Cadmium, Cd	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1030	Cadmium, Cd	6010B	Approved
RCRA Metals in Soil #2	55103	1035	Calcium	6010B	Approved
RCRA Metals in Soil #1	55102	1040	Chromium	6010B	Approved
TCLP Metals	SPE-005	1040	Chromium, Cr (total)	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1040	Chromium, Cr (total)	6010B	Approved
RCRA Metals in Soil #1	55102	1050	Cobalt	6010B	Approved
TCLP Metals	SPE-005	1050	Cobalt, Co	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1050	Cobalt, Co	6010B	Approved
RCRA Metals in Soil #1	55102	1055	Copper	6010B	Approved
TCLP Metals	SPE-005	1055	Copper, Cu	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1055	Copper, Cu	6010B	Approved
RCRA Metals in Soil #2	55103	1070	Iron	6010B	Approved
RCRA Metals in Soil #1	55102	1075	Lead	6010B	Approved
TCLP Metals	SPE-005	1075	Lead, Pb	6010B	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
TCLP Metals in Soil - CA WET	SPE-006	1075	Lead, Pb	6010B	Approved
RCRA Metals in Soil #2	55103	1085	Magnesium	6010B	Approved
RCRA Metals in Soil #1	55102	1090	Manganese	6010B	Approved
RCRA Metals in Soil #1	55102	1100	Molybdenum	6010B	Approved
TCLP Metals	SPE-005	1100	Molybdenum, Mo	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1100	Molybdenum, Mo	6010B	Approved
RCRA Metals in Soil #1	55102	1105	Nickel	6010B	Approved
TCLP Metals	SPE-005	1105	Nickel, Ni	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1105	Nickel, Ni	6010B	Approved
RCRA Metals in Soil #2	55103	1125	Potassium	6010B	Approved
RCRA Metals in Soil #1	55102	1140	Selenium	6010B	Approved
TCLP Metals	SPE-005	1140	Selenium, Se	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1140	Selenium, Se	6010B	Approved
RCRA Metals in Soil #1	55102	1150	Silver	6010B	Approved
TCLP Metals	SPE-005	1150	Silver, Ag	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1150	Silver, Ag	6010B	Approved
RCRA Metals in Soil #2	55103	1155	Sodium	6010B	Approved
RCRA Metals in Soil #1	55102	1160	Strontium	6010B	Approved
RCRA Metals in Soil #1	55102	1165	Thallium	6010B	Approved
TCLP Metals	SPE-005	1165	Thallium, Tl	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1165	Thallium, Tl	6010B	Approved
RCRA Metals in Soil #1	55102	1175	Tin	6010B	Approved
RCRA Metals in Soil #1	55102	1180	Titanium	6010B	Approved
RCRA Nutrients	55142	1910	Total Phosphorus	6010B	Approved
RCRA Metals in Soil #1	55102	1185	Vanadium	6010B	Approved
TCLP Metals	SPE-005	1185	Vanadium, V	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1185	Vanadium, V	6010B	Approved
RCRA Metals in Soil #1	55102	1190	Zinc	6010B	Approved
TCLP Metals	SPE-005	1190	Zinc, Zn	6010B	Approved
TCLP Metals in Soil - CA WET	SPE-006	1190	Zinc, Zn	6010B	Approved
RCRA Metals in Soil #2	55103	1000	Aluminum	6010C	Approved
RCRA Metals in Soil #1	55102	1005	Antimony	6010C	Approved
RCRA Metals in Soil #1	55102	1010	Arsenic	6010C	Approved
RCRA Metals in Soil #1	55102	1015	Barium	6010C	Approved
RCRA Metals in Soil #1	55102	1020	Beryllium	6010C	Approved
RCRA Metals in Soil #1	55102	1025	Boron	6010C	Approved
RCRA Metals in Soil #1	55102	1030	Cadmium	6010C	Approved
RCRA Metals in Soil #2	55103	1035	Calcium	6010C	Approved
RCRA Metals in Soil #1	55102	1040	Chromium	6010C	Approved
RCRA Metals in Soil #1	55102	1050	Cobalt	6010C	Approved
RCRA Metals in Soil #1	55102	1055	Copper	6010C	Approved
RCRA Metals in Soil #2	55103	1070	Iron	6010C	Approved
RCRA Metals in Soil #1	55102	1075	Lead	6010C	Approved
RCRA Metals in Soil #2	55103	1085	Magnesium	6010C	Approved
RCRA Metals in Soil #1	55102	1090	Manganese	6010C	Approved
RCRA Metals in Soil #1	55102	1100	Molybdenum	6010C	Approved
RCRA Metals in Soil #1	55102	1105	Nickel	6010C	Approved
RCRA Metals in Soil #2	55103	1125	Potassium	6010C	Approved
RCRA Metals in Soil #1	55102	1140	Selenium	6010C	Approved
RCRA Metals in Soil #1	55102	1150	Silver	6010C	Approved
RCRA Metals in Soil #2	55103	1155	Sodium	6010C	Approved
RCRA Metals in Soil #1	55102	1160	Strontium	6010C	Approved
RCRA Metals in Soil #1	55102	1165	Thallium	6010C	Approved
RCRA Metals in Soil #1	55102	1175	Tin	6010C	Approved
RCRA Metals in Soil #1	55102	1180	Titanium	6010C	Approved
			Total Phosphorus	6010C	Approved
RCRA Metals in Soil #1	55102	1185	Vanadium	6010C	Approved
RCRA Metals in Soil #1	55102	1190	Zinc	6010C	Approved
NPTA			Zirconium	6010C	Approved
RCRA Metals in Soil #2	55103	1000	Aluminum	6020	Approved
RCRA Metals in Soil #1	55102	1005	Antimony	6020	Approved
RCRA Metals in Soil #1	55102	1010	Arsenic	6020	Approved
RCRA Metals in Soil #1	55102	1015	Barium	6020	Approved
RCRA Metals in Soil #1	55102	1020	Beryllium	6020	Approved
RCRA Metals in Soil #1	55102	1025	Boron	6020	Approved
RCRA Metals in Soil #1	55102	1030	Cadmium	6020	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
RCRA Metals in Soil #2	55103	1035	Calcium	6020	Approved
RCRA Metals in Soil #1	55102	1040	Chromium	6020	Approved
RCRA Metals in Soil #1	55102	1050	Cobalt	6020	Approved
RCRA Metals in Soil #1	55102	1055	Copper	6020	Approved
RCRA Metals in Soil #2	55103	1070	Iron	6020	Approved
RCRA Metals in Soil #1	55102	1075	Lead	6020	Approved
RCRA Metals in Soil #2	55103	1085	Magnesium	6020	Approved
RCRA Metals in Soil #1	55102	1090	Manganese	6020	Approved
RCRA Metals in Soil #1	55102	1100	Molybdenum	6020	Approved
RCRA Metals in Soil #1	55102	1105	Nickel	6020	Approved
RCRA Metals in Soil #2	55103	1125	Potassium	6020	Approved
RCRA Metals in Soil #1	55102	1140	Selenium	6020	Approved
RCRA Metals in Soil #1	55102	1150	Silver	6020	Approved
RCRA Metals in Soil #2	55103	1155	Sodium	6020	Approved
RCRA Metals in Soil #1	55102	1160	Strontium	6020	Approved
RCRA Metals in Soil #1	55102	1165	Thallium	6020	Approved
RCRA Metals in Soil #1	55102	1175	Tin	6020	Approved
RCRA Metals in Soil #1	55102	1180	Titanium	6020	Approved
RCRA Metals in Soil #1	55102	1185	Vanadium	6020	Approved
RCRA Metals in Soil #1	55102	1190	Zinc	6020	Approved
NPTA			Zirconium	6020	Approved
RCRA Metals in Soil #2	55103	1000	Aluminum	6020A	Approved
RCRA Metals in Soil #1	55102	1005	Antimony	6020A	Approved
RCRA Metals in Soil #1	55102	1010	Arsenic	6020A	Approved
RCRA Metals in Soil #1	55102	1015	Barium	6020A	Approved
RCRA Metals in Soil #1	55102	1020	Beryllium	6020A	Approved
RCRA Metals in Soil #1	55102	1025	Boron	6020A	Approved
RCRA Metals in Soil #1	55102	1030	Cadmium	6020A	Approved
RCRA Metals in Soil #2	55103	1035	Calcium	6020A	Approved
RCRA Metals in Soil #1	55102	1040	Chromium	6020A	Approved
RCRA Metals in Soil #1	55102	1050	Cobalt	6020A	Approved
RCRA Metals in Soil #1	55102	1055	Copper	6020A	Approved
RCRA Metals in Soil #2	55103	1070	Iron	6020A	Approved
RCRA Metals in Soil #1	55102	1075	Lead	6020A	Approved
RCRA Metals in Soil #2	55103	1085	Magnesium	6020A	Approved
RCRA Metals in Soil #1	55102	1090	Manganese	6020A	Approved
RCRA Metals in Soil #1	55102	1100	Molybdenum	6020A	Approved
RCRA Metals in Soil #1	55102	1105	Nickel	6020A	Approved
RCRA Metals in Soil #2	55103	1125	Potassium	6020A	Approved
RCRA Metals in Soil #1	55102	1140	Selenium	6020A	Approved
RCRA Metals in Soil #1	55102	1150	Silver	6020A	Approved
RCRA Metals in Soil #2	55103	1155	Sodium	6020A	Approved
RCRA Metals in Soil #1	55102	1160	Strontium	6020A	Approved
RCRA Metals in Soil #1	55102	1165	Thallium	6020A	Approved
RCRA Metals in Soil #1	55102	1175	Tin	6020A	Approved
RCRA Metals in Soil #1	55102	1180	Titanium	6020A	Approved
RCRA Metals in Soil #1	55102	1185	Vanadium	6020A	Approved
RCRA Metals in Soil #1	55102	1190	Zinc	6020A	Approved
NPTA			Zirconium	6020A	Approved
RCRA Perchlorate	55143	1895	Perchlorate	6850	Approved
RCRA Hexavalent Chromium	55104	1045	Chromium VI	7196A	Approved
RCRA Hexavalent Chromium	55104	1045	Chromium VI	7199	Approved
TCLP Metals	SPE-005	1095	Mercury, Hg	7470A	Approved
TCLP Metals in Soil - CA WET	SPE-006	1095	Mercury, Hg	7470A	Approved
RCRA Metals in Soil #1	55102	1095	Mercury	7471B	Approved
Petroleum Hydrocarbons in Soil	SPE-007	9369	Diesel Range Organics C10-C28	8015B	Approved
Petroleum Hydrocarbons in Soil	SPE-007	9369	Diesel Range Organics C10-C28	8015C	Approved
Petroleum Hydrocarbons in Soil	SPE-007	9369	Diesel Range Organics C10-C28	8015D	Approved
Petroleum Hydrocarbons in Soil	SPE-008	101	Gasoline Range Organics, C6-C10	8015B	Approved
Petroleum Hydrocarbons in Soil	SPE-008	101	Total Purgeable Hydrocarbons	8015B	Approved
Petroleum Hydrocarbons in Soil	SPE-008	9408	Gasoline Range Organics, C6-C10	8015C	Approved
Petroleum Hydrocarbons in Soil	SPE-008	99990	Total Purgeable Hydrocarbons	8015C	Approved
Petroleum Hydrocarbons in Soil	SPE-008	9408	Gasoline Range Organics, C6-C10	8015D	Approved
Petroleum Hydrocarbons in Soil	SPE-008	99990	Total Purgeable Hydrocarbons	8015D	Approved
Toxaphene in Soil	38066	8250	Toxaphene	8081A	Approved
Chlorinated Pesticides in Soil	38101	7355	4,4'-DDD	8081A	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
Chlorinated Pesticides in Soil	38101	7360	4,4'-DDE	8081A	Approved
Chlorinated Pesticides in Soil	38101	7365	4,4'-DDT	8081A	Approved
Chlorinated Pesticides in Soil	38101	7110	a-BHC	8081A	Approved
Chlorinated Pesticides in Soil	38101	7240	a-Chlordane	8081A	Approved
Chlorinated Pesticides in Soil	38101	7025	Aldrin	8081A	Approved
Chlorinated Pesticides in Soil	38101	7115	b-BHC	8081A	Approved
Chlorinated Pesticides in Soil	38101	7105	d-BHC	8081A	Approved
Chlorinated Pesticides in Soil	38101	7470	Dieldrin	8081A	Approved
Chlorinated Pesticides in Soil	38101	7510	Endosulfan I	8081A	Approved
Chlorinated Pesticides in Soil	38101	7515	Endosulfan II	8081A	Approved
Chlorinated Pesticides in Soil	38101	7520	Endosulfan sulfate	8081A	Approved
Chlorinated Pesticides in Soil	38101	7540	Endrin	8081A	Approved
Chlorinated Pesticides in Soil	38101	7530	Endrin aldehyde	8081A	Approved
Chlorinated Pesticides in Soil	38101	7535	Endrin ketone	8081A	Approved
Chlorinated Pesticides in Soil	38101	7120	g-BHC (Lindane)	8081A	Approved
Chlorinated Pesticides in Soil	38101	7245	g-Chlordane	8081A	Approved
Chlorinated Pesticides in Soil	38101	7685	Heptachlor	8081A	Approved
Chlorinated Pesticides in Soil	38101	7690	Heptachlor epoxide	8081A	Approved
Chlorinated Pesticides in Soil	38101	7810	Methoxychlor	8081A	Approved
Chlordane in Soil	38141	7250	Chlordane	8081A	Approved
Toxaphene in Soil	38066	8250	Toxaphene	8081B	Approved
Chlorinated Pesticides in Soil	38101	7355	4,4'-DDD	8081B	Approved
Chlorinated Pesticides in Soil	38101	7360	4,4'-DDE	8081B	Approved
Chlorinated Pesticides in Soil	38101	7365	4,4'-DDT	8081B	Approved
Chlorinated Pesticides in Soil	38101	7110	a-BHC	8081B	Approved
Chlorinated Pesticides in Soil	38101	7240	a-Chlordane	8081B	Approved
Chlorinated Pesticides in Soil	38101	7025	Aldrin	8081B	Approved
Chlorinated Pesticides in Soil	38101	7115	b-BHC	8081B	Approved
Chlorinated Pesticides in Soil	38101	7105	d-BHC	8081B	Approved
Chlorinated Pesticides in Soil	38101	7470	Dieldrin	8081B	Approved
Chlorinated Pesticides in Soil	38101	7510	Endosulfan I	8081B	Approved
Chlorinated Pesticides in Soil	38101	7515	Endosulfan II	8081B	Approved
Chlorinated Pesticides in Soil	38101	7520	Endosulfan sulfate	8081B	Approved
Chlorinated Pesticides in Soil	38101	7540	Endrin	8081B	Approved
Chlorinated Pesticides in Soil	38101	7530	Endrin aldehyde	8081B	Approved
Chlorinated Pesticides in Soil	38101	7535	Endrin ketone	8081B	Approved
Chlorinated Pesticides in Soil	38101	7120	g-BHC (Lindane)	8081B	Approved
Chlorinated Pesticides in Soil	38101	7245	g-Chlordane	8081B	Approved
Chlorinated Pesticides in Soil	38101	7685	Heptachlor	8081B	Approved
Chlorinated Pesticides in Soil	38101	7690	Heptachlor epoxide	8081B	Approved
Chlorinated Pesticides in Soil	38101	7810	Methoxychlor	8081B	Approved
Chlordane in Soil	38141	7250	Chlordane	8081B	Approved
PCBs in Transformer Oil #2	38092	8880	PCB in Oil 1016	8082	Approved
PCBs in Transformer Oil #2	38092	8895	PCB in Oil 1242	8082	Approved
PCBs in Transformer Oil #2	38092	8905	PCB in Oil 1254	8082	Approved
PCBs in Transformer Oil #2	38092	8910	PCB in Oil 1260	8082	Approved
PCBs in Transformer Oil #2	38095	8880	PCB in Oil 1016	8082	Approved
PCBs in Transformer Oil #2	38095	8895	PCB in Oil 1242	8082	Approved
PCBs in Transformer Oil #2	38095	8905	PCB in Oil 1254	8082	Approved
PCBs in Transformer Oil #2	38095	8910	PCB in Oil 1260	8082	Approved
Aroclor in Soil	38142	8880	Aroclor 1016	8082	Approved
Aroclor in Soil	38142	8885	Aroclor 1221	8082	Approved
Aroclor in Soil	38142	8890	Aroclor 1232	8082	Approved
Aroclor in Soil	38142	8895	Aroclor 1242	8082	Approved
Aroclor in Soil	38142	8900	Aroclor 1248	8082	Approved
Aroclor in Soil	38142	8905	Aroclor 1254	8082	Approved
Aroclor in Soil	38142	8910	Aroclor 1260	8082	Approved
PCB in Soil	SPE-010	8912	Aroclor 1016/1242	8082	Approved
PCB in Soil	SPE-010	8880	Aroclor-1016 (PCB-1016)	8082	Approved
PCB in Soil	SPE-010	8885	Aroclor-1221 (PCB-1221)	8082	Approved
PCB in Soil	SPE-010	8890	Aroclor-1232 (PCB-1232)	8082	Approved
PCB in Soil	SPE-010	8895	Aroclor-1242 (PCB-1242)	8082	Approved
PCB in Soil	SPE-010	8900	Aroclor-1248 (PCB-1248)	8082	Approved
PCB in Soil	SPE-010	8905	Aroclor-1254 (PCB-1254)	8082	Approved
PCB in Soil	SPE-010	8910	Aroclor-1260 (PCB-1260)	8082	Approved
PCB in Soil	SPE-010	8912	Aroclor 1016/1242	8082	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
PCB in Soil	SPE-010	8880	Aroclor-1016 (PCB-1016)	8082	Approved
PCB in Soil	SPE-010	8885	Aroclor-1221 (PCB-1221)	8082	Approved
PCB in Soil	SPE-010	8890	Aroclor-1232 (PCB-1232)	8082	Approved
PCB in Soil	SPE-010	8895	Aroclor-1242 (PCB-1242)	8082	Approved
PCB in Soil	SPE-010	8900	Aroclor-1248 (PCB-1248)	8082	Approved
PCB in Soil	SPE-010	8905	Aroclor-1254 (PCB-1254)	8082	Approved
PCB in Soil	SPE-010	8910	Aroclor-1260 (PCB-1260)	8082	Approved
PCBs in Transformer Oil #2	38092	8880	PCB in Oil 1016	8082A	Approved
PCBs in Transformer Oil #2	38092	8895	PCB in Oil 1242	8082A	Approved
PCBs in Transformer Oil #2	38092	8905	PCB in Oil 1254	8082A	Approved
PCBs in Transformer Oil #2	38092	8910	PCB in Oil 1260	8082A	Approved
PCBs in Transformer Oil #2	38095	8880	PCB in Oil 1016	8082A	Approved
PCBs in Transformer Oil #2	38095	8895	PCB in Oil 1242	8082A	Approved
PCBs in Transformer Oil #2	38095	8905	PCB in Oil 1254	8082A	Approved
PCBs in Transformer Oil #2	38095	8910	PCB in Oil 1260	8082A	Approved
Aroclor in Soil	38142	8880	Aroclor 1016	8082A	Approved
Aroclor in Soil	38142	8885	Aroclor 1221	8082A	Approved
Aroclor in Soil	38142	8890	Aroclor 1232	8082A	Approved
Aroclor in Soil	38142	8895	Aroclor 1242	8082A	Approved
Aroclor in Soil	38142	8900	Aroclor 1248	8082A	Approved
Aroclor in Soil	38142	8905	Aroclor 1254	8082A	Approved
Aroclor in Soil	38142	8910	Aroclor 1260	8082A	Approved
PCB in Soil	SPE-010	8912	Aroclor 1016/1242	8082A	Approved
PCB in Soil	SPE-010	8880	Aroclor-1016 (PCB-1016)	8082A	Approved
PCB in Soil	SPE-010	8885	Aroclor-1221 (PCB-1221)	8082A	Approved
PCB in Soil	SPE-010	8890	Aroclor-1232 (PCB-1232)	8082A	Approved
PCB in Soil	SPE-010	8895	Aroclor-1242 (PCB-1242)	8082A	Approved
PCB in Soil	SPE-010	8900	Aroclor-1248 (PCB-1248)	8082A	Approved
PCB in Soil	SPE-010	8905	Aroclor-1254 (PCB-1254)	8082A	Approved
PCB in Soil	SPE-010	8910	Aroclor-1260 (PCB-1260)	8082A	Approved
PCB in Soil	SPE-010	8912	Aroclor 1016/1242	8082A	Approved
PCB in Soil	SPE-010	8880	Aroclor-1016 (PCB-1016)	8082A	Approved
PCB in Soil	SPE-010	8885	Aroclor-1221 (PCB-1221)	8082A	Approved
PCB in Soil	SPE-010	8890	Aroclor-1232 (PCB-1232)	8082A	Approved
PCB in Soil	SPE-010	8895	Aroclor-1242 (PCB-1242)	8082A	Approved
PCB in Soil	SPE-010	8900	Aroclor-1248 (PCB-1248)	8082A	Approved
PCB in Soil	SPE-010	8905	Aroclor-1254 (PCB-1254)	8082A	Approved
PCB in Soil	SPE-010	8910	Aroclor-1260 (PCB-1260)	8082A	Approved
OrganoPhosphorus Pesticides	38151	7075	Azinphosmethyl	8141A	Approved
OrganoPhosphorus Pesticides	38151	7390	Demeton, (Mix of Isomers O:S)	8141A	Approved
OrganoPhosphorus Pesticides	38151	7410	Diazinon	8141A	Approved
OrganoPhosphorus Pesticides	38151	8625	Disulfoton	8141A	Approved
OrganoPhosphorus Pesticides	38151	8110	Fenchlorphos (Ronnel)	8141A	Approved
OrganoPhosphorus Pesticides	38151	7770	Malathion	8141A	Approved
OrganoPhosphorus Pesticides	38151	7955	Parathion ethyl	8141A	Approved
OrganoPhosphorus Pesticides	38151	7825	Parathion methyl	8141A	Approved
OrganoPhosphorus Pesticides	38151	7985	Phorate	8141A	Approved
OrganoPhosphorus Pesticides	38151	8200	Tetrachlorvinphos (Stirophos)	8141A	Approved
OrganoPhosphorus Pesticides	38151	7075	Azinphosmethyl	8141B	Approved
OrganoPhosphorus Pesticides	38151	7390	Demeton, (Mix of Isomers O:S)	8141B	Approved
OrganoPhosphorus Pesticides	38151	7410	Diazinon	8141B	Approved
OrganoPhosphorus Pesticides	38151	8625	Disulfoton	8141B	Approved
OrganoPhosphorus Pesticides	38151	8110	Fenchlorphos (Ronnel)	8141B	Approved
OrganoPhosphorus Pesticides	38151	7770	Malathion	8141B	Approved
OrganoPhosphorus Pesticides	38151	7955	Parathion ethyl	8141B	Approved
OrganoPhosphorus Pesticides	38151	7825	Parathion methyl	8141B	Approved
OrganoPhosphorus Pesticides	38151	7985	Phorate	8141B	Approved
OrganoPhosphorus Pesticides	38151	8200	Tetrachlorvinphos (Stirophos)	8141B	Approved
Herbicide Acids in Soil	38146	8655	2,4,5-T	8151A	Approved
Herbicide Acids in Soil	38146	8650	2,4,5-TP	8151A	Approved
Herbicide Acids in Soil	38146	8545	2,4-D	8151A	Approved
Herbicide Acids in Soil	38146	8560	2,4-DB	8151A	Approved
Herbicide Acids in Soil	38146	8555	Dalapon	8151A	Approved
Herbicide Acids in Soil	38146	8595	Dicamba	8151A	Approved
Herbicide Acids in Soil	38146	8620	Dinoseb	8151A	Approved
Herbicide Acids in Soil	38146	6605	Pentachlorophenol	8151A	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
NPTA			Dichlorprop (2,4-DP)	8151A	Approved
NPTA			MCPA	8151A	Approved
NPTA			MSPP	8151A	Approved
Volatiles in Soil	38084	5105	1,1,1,2-Tetrachloroethane	8260B	Approved
Volatiles in Soil	38084	5160	1,1,1-Trichloroethane	8260B	Approved
Volatiles in Soil	38084	5110	1,1,2,2-Tetrachloroethane	8260B	Approved
Volatiles in Soil	38084	5165	1,1,2-Trichloroethane	8260B	Approved
Volatiles in Soil	38084	4630	1,1-Dichloroethane	8260B	Approved
Volatiles in Soil	38084	4640	1,1-Dichloroethene	8260B	Approved
Volatiles in Soil	38084	4670	1,1-Dichloropropene	8260B	Approved
Volatiles in Soil	38084	5150	1,2,3-Trichlorobenzene	8260B	Approved
Volatiles in Soil	38084	5180	1,2,3-Trichloropropane	8260B	Approved
Volatiles in Soil	38084	5155	1,2,4-Trichlorobenzene	8260B	Approved
Volatiles in Soil	38084	5210	1,2,4-Trimethylbenzene	8260B	Approved
Volatiles in Soil	38084	4570	1,2-Dibromo-3-chloropropane	8260B	Approved
Volatiles in Soil	38084	4585	1,2-Dibromoethane	8260B	Approved
Volatiles in Soil	38084	4610	1,2-Dichlorobenzene	8260B	Approved
Volatiles in Soil	38084	4635	1,2-Dichloroethane	8260B	Approved
Volatiles in Soil	38084	4655	1,2-Dichloropropane	8260B	Approved
Volatiles in Soil	38084	5215	1,3,5-Trimethylbenzene	8260B	Approved
Volatiles in Soil	38084	4615	1,3-Dichlorobenzene	8260B	Approved
Volatiles in Soil	38084	4660	1,3-Dichloropropane	8260B	Approved
Volatiles in Soil	38084	4620	1,4-Dichlorobenzene	8260B	Approved
Volatiles in Soil	38084	4665	2,2-Dichloropropane	8260B	Approved
Volatiles in Soil	38084	4535	2-Chlorotoluene	8260B	Approved
Volatiles in Soil	38084	4540	4-Chlorotoluene	8260B	Approved
Volatiles in Soil	38084	4995	4-Methyl-2-pentanone	8260B	Approved
Volatiles in Soil	38084	4375	Benzene	8260B	Approved
Volatiles in Soil	38084	4385	Bromobenzene	8260B	Approved
Volatiles in Soil	38084	4390	Bromochloromethane	8260B	Approved
Volatiles in Soil	38084	4395	Bromodichloromethane	8260B	Approved
Volatiles in Soil	38084	4400	Bromoform	8260B	Approved
Volatiles in Soil	38084	4950	Bromomethane	8260B	Approved
Volatiles in Soil	38084	4450	Carbon disulphide	8260B	Approved
Volatiles in Soil	38084	4455	Carbon tetrachloride	8260B	Approved
Volatiles in Soil	38084	4475	Chlorobenzene	8260B	Approved
Volatiles in Soil	38084	4485	Chloroethane	8260B	Approved
Volatiles in Soil	38084	4505	Chloroform	8260B	Approved
Volatiles in Soil	38084	4960	Chloromethane	8260B	Approved
Volatiles in Soil	38084	4645	cis-1,2-Dichloroethene	8260B	Approved
Volatiles in Soil	38084	4680	cis-1,3-Dichloropropene	8260B	Approved
Volatiles in Soil	38084	4575	Dibromochloromethane	8260B	Approved
Volatiles in Soil	38084	4595	Dibromomethane	8260B	Approved
Volatiles in Soil	38084	4625	Dichlorodifluoromethane	8260B	Approved
Volatiles in Soil	38084	4765	Ethyl benzene	8260B	Approved
Volatiles in Soil	38084	4835	Hexachlorobutadiene	8260B	Approved
Volatiles in Soil	38084	4840	Hexachloroethane	8260B	Approved
Volatiles in Soil	38084	4900	Isopropylbenzene	8260B	Approved
Volatiles in Soil	38084	5000	Methyl tert-butyl ether (MTBE)	8260B	Approved
Volatiles in Soil	38084	4975	Methylene chloride	8260B	Approved
Volatiles in Soil	38084	5005	Naphthalene	8260B	Approved
Volatiles in Soil	38084	4435	n-Butyl benzene	8260B	Approved
Volatiles in Soil	38084	5090	n-Propylbenzene	8260B	Approved
Volatiles in Soil	38084	4910	p-Isopropyl toluene	8260B	Approved
Volatiles in Soil	38084	4440	sec-Butyl benzene	8260B	Approved
Volatiles in Soil	38084	5100	Styrene	8260B	Approved
Volatiles in Soil	38084	4445	tert-Butyl benzene	8260B	Approved
Volatiles in Soil	38084	5140	Toluene	8260B	Approved
Volatiles in Soil	38084	5260	Total Xylenes	8260B	Approved
Volatiles in Soil	38084	4700	trans-1,2-Dichloroethene	8260B	Approved
Volatiles in Soil	38084	5170	Trichloroethene	8260B	Approved
Volatiles in Soil	38084	5175	Trichlorofluoromethane	8260B	Approved
Volatiles in Soil	38084	5235	Vinyl chloride	8260B	Approved
RCRA BTEX & MTBE	38161	4375	Benzene	8260B	Approved
RCRA BTEX & MTBE	38161	4765	Ethyl benzene	8260B	Approved
RCRA BTEX & MTBE	38161	5140	Toluene	8260B	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
RCRA BTEX & MTBE	38161	5000	Methyl tert-butyl ether (MTBE)	8260B	Approved
RCRA BTEX & MTBE	38161	5260	Total Xylenes	8260B	Approved
RCRA Ketones in Soil	38167	4410	2-Butanone (Methyl ethyl ketone)	8260B	Approved
RCRA Ketones in Soil	38167	4860	2-Hexanone	8260B	Approved
RCRA Ketones in Soil	38167	4995	4-Methyl-2-pentanone	8260B	Approved
RCRA Ketones in Soil	38167	4315	Acetone	8260B	Approved
RCRA Oxygenates	38169	5185	1,1,2-Trichlorotrifluoroethane	8260B	Approved
RCRA Oxygenates	38169	4770	Ethyl tert-butyl ether	8260B	Approved
RCRA Oxygenates	38169	9375	Isopropyl ether	8260B	Approved
RCRA Oxygenates	38169	5000	Methyl tert-butyl ether (MTBE)	8260B	Approved
RCRA Oxygenates	38169	5090	n-Propylbenzene	8260B	Approved
RCRA Oxygenates	38169	4370	tert-Amyl methyl ether	8260B	Approved
RCRA Oxygenates	38169	4420	tert-Butyl alcohol (t-Butanol)	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5105	1,1,1,2-Tetrachloroethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5160	1,1,1-Trichloroethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5110	1,1,2,2-Tetrachloroethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5165	1,1,2-Trichloroethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4630	1,1-Dichloroethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4640	1,1-Dichloroethene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5180	1,2,3-Trichloropropane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5155	1,2,4-Trichlorobenzene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4570	1,2-Dibromo-3-chloropropane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4585	1,2-Dibromoethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4610	1,2-Dichlorobenzene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4635	1,2-Dichloroethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4655	1,2-Dichloropropane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4615	1,3-Dichlorobenzene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4620	1,4-Dichlorobenzene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4410	2-Butanone (Methyl ethyl ketone)	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4860	2-Hexanone	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4995	4-Methyl-2-pentanone	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4315	Acetone	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4375	Benzene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4385	Bromobenzene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4395	Bromodichloromethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4400	Bromoform	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4950	Bromomethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4455	Carbon tetrachloride	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4475	Chlorobenzene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4485	Chloroethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4505	Chloroform	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4960	Chloromethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4645	cis-1,2-Dichloroethene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4680	cis-1,3-Dichloropropene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4575	Dibromochloromethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4595	Dibromomethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4625	Dichlorodifluoromethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4765	Ethyl benzene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4900	Isopropylbenzene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5000	Methyl tert-butyl ether (MTBE)	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4975	Methylene chloride	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5005	Naphthalene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5100	Styrene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5115	Tetrachloroethene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5140	Toluene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4700	trans-1,2-Dichloroethene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	4685	trans-1,3-Dichloropropene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5170	Trichloroethene	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5175	Trichlorofluoromethane	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5235	Vinyl chloride	8260B	Approved
RCRA Medium Level Volatiles in Soil	38199	5260	Xylenes, total	8260B	Approved
GRO/BTEX in Soil	SPE-025AK	4375	Benzene	8260B	Approved
GRO/BTEX in Soil	SPE-025AK	4765	Ethylbenzene	8260B	Approved
GRO/BTEX in Soil	SPE-025AK	5240	m+p-Xylene	8260B	Approved
GRO/BTEX in Soil	SPE-025AK	5000	MTBE	8260B	Approved
GRO/BTEX in Soil	SPE-025AK	5250	o-Xylene	8260B	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
GRO/BTEX in Soil	SPE-025AK	5140	Toluene	8260B	Approved
GRO/BTEX in Soil	SPE-025AK	5260	Xylene, total	8260B	Approved
NPTA			Cyclohexane	8260B	Approved
NPTA			Methyl Acetate	8260B	Approved
NPTA			Methylcyclohexane	8260B	Approved
NPTA			m&p Xylenes	8260B	Approved
NPTA			o-Xylene	8260B	Approved
NPTA			p-isopropyltoluene	8260B	Approved
NPTA			Vinyl Acetate	8260B	Approved
Volatiles in Soil	38084	5105	1,1,1,2-Tetrachloroethane	8260C	Approved
Volatiles in Soil	38084	5160	1,1,1-Trichloroethane	8260C	Approved
Volatiles in Soil	38084	5110	1,1,2,2-Tetrachloroethane	8260C	Approved
Volatiles in Soil	38084	5165	1,1,2-Trichloroethane	8260C	Approved
Volatiles in Soil	38084	4630	1,1-Dichloroethane	8260C	Approved
Volatiles in Soil	38084	4640	1,1-Dichloroethene	8260C	Approved
Volatiles in Soil	38084	4670	1,1-Dichloropropene	8260C	Approved
Volatiles in Soil	38084	5150	1,2,3-Trichlorobenzene	8260C	Approved
Volatiles in Soil	38084	5180	1,2,3-Trichloropropane	8260C	Approved
Volatiles in Soil	38084	5155	1,2,4-Trichlorobenzene	8260C	Approved
Volatiles in Soil	38084	5210	1,2,4-Trimethylbenzene	8260C	Approved
Volatiles in Soil	38084	4570	1,2-Dibromo-3-chloropropane	8260C	Approved
Volatiles in Soil	38084	4585	1,2-Dibromoethane	8260C	Approved
Volatiles in Soil	38084	4610	1,2-Dichlorobenzene	8260C	Approved
Volatiles in Soil	38084	4635	1,2-Dichloroethane	8260C	Approved
Volatiles in Soil	38084	4655	1,2-Dichloropropane	8260C	Approved
Volatiles in Soil	38084	5215	1,3,5-Trimethylbenzene	8260C	Approved
Volatiles in Soil	38084	4615	1,3-Dichlorobenzene	8260C	Approved
Volatiles in Soil	38084	4660	1,3-Dichloropropane	8260C	Approved
Volatiles in Soil	38084	4620	1,4-Dichlorobenzene	8260C	Approved
Volatiles in Soil	38084	4665	2,2-Dichloropropane	8260C	Approved
Volatiles in Soil	38084	4535	2-Chlorotoluene	8260C	Approved
Volatiles in Soil	38084	4540	4-Chlorotoluene	8260C	Approved
Volatiles in Soil	38084	4995	4-Methyl-2-pentanone	8260C	Approved
Volatiles in Soil	38084	4375	Benzene	8260C	Approved
Volatiles in Soil	38084	4385	Bromobenzene	8260C	Approved
Volatiles in Soil	38084	4390	Bromochloromethane	8260C	Approved
Volatiles in Soil	38084	4395	Bromodichloromethane	8260C	Approved
Volatiles in Soil	38084	4400	Bromoform	8260C	Approved
Volatiles in Soil	38084	4950	Bromomethane	8260C	Approved
Volatiles in Soil	38084	4450	Carbon disulphide	8260C	Approved
Volatiles in Soil	38084	4455	Carbon tetrachloride	8260C	Approved
Volatiles in Soil	38084	4475	Chlorobenzene	8260C	Approved
Volatiles in Soil	38084	4485	Chloroethane	8260C	Approved
Volatiles in Soil	38084	4505	Chloroform	8260C	Approved
Volatiles in Soil	38084	4960	Chloromethane	8260C	Approved
Volatiles in Soil	38084	4645	cis-1,2-Dichloroethene	8260C	Approved
Volatiles in Soil	38084	4680	cis-1,3-Dichloropropene	8260C	Approved
Volatiles in Soil	38084	4575	Dibromochloromethane	8260C	Approved
Volatiles in Soil	38084	4595	Dibromomethane	8260C	Approved
Volatiles in Soil	38084	4625	Dichlorodifluoromethane	8260C	Approved
Volatiles in Soil	38084	4765	Ethyl benzene	8260C	Approved
Volatiles in Soil	38084	4835	Hexachlorobutadiene	8260C	Approved
Volatiles in Soil	38084	4840	Hexachloroethane	8260C	Approved
Volatiles in Soil	38084	4900	Isopropylbenzene	8260C	Approved
Volatiles in Soil	38084	5000	Methyl tert-butyl ether (MTBE)	8260C	Approved
Volatiles in Soil	38084	4975	Methylene chloride	8260C	Approved
Volatiles in Soil	38084	5005	Naphthalene	8260C	Approved
Volatiles in Soil	38084	4435	n-Butyl benzene	8260C	Approved
Volatiles in Soil	38084	5090	n-Propylbenzene	8260C	Approved
Volatiles in Soil	38084	4910	p-Isopropyl toluene	8260C	Approved
Volatiles in Soil	38084	4440	sec-Butyl benzene	8260C	Approved
Volatiles in Soil	38084	5100	Styrene	8260C	Approved
Volatiles in Soil	38084	4445	tert-Butyl benzene	8260C	Approved
Volatiles in Soil	38084	5140	Toluene	8260C	Approved
Volatiles in Soil	38084	5260	Total Xylenes	8260C	Approved
Volatiles in Soil	38084	4700	trans-1,2-Dichloroethene	8260C	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
Volatiles in Soil	38084	5170	Trichloroethene	8260C	Approved
Volatiles in Soil	38084	5175	Trichlorofluoromethane	8260C	Approved
Volatiles in Soil	38084	5235	Vinyl chloride	8260C	Approved
RCRA BTEX & MTBE	38161	4375	Benzene	8260C	Approved
RCRA BTEX & MTBE	38161	4765	Ethyl benzene	8260C	Approved
RCRA BTEX & MTBE	38161	5140	Toluene	8260C	Approved
RCRA BTEX & MTBE	38161	5000	Methyl tert-butyl ether (MTBE)	8260C	Approved
RCRA BTEX & MTBE	38161	5260	Total Xylenes	8260C	Approved
RCRA Ketones in Soil	38167	4410	2-Butanone (Methyl ethyl ketone)	8260C	Approved
RCRA Ketones in Soil	38167	4860	2-Hexanone	8260C	Approved
RCRA Ketones in Soil	38167	4995	4-Methyl-2-pentanone	8260C	Approved
RCRA Ketones in Soil	38167	4315	Acetone	8260C	Approved
RCRA Oxygenates	38169	5185	1,1,2-Trichlorotrifluoroethane	8260C	Approved
RCRA Oxygenates	38169	4770	Ethyl tert-butyl ether	8260C	Approved
RCRA Oxygenates	38169	9375	Isopropyl ether	8260C	Approved
RCRA Oxygenates	38169	5000	Methyl tert-butyl ether (MTBE)	8260C	Approved
RCRA Oxygenates	38169	5090	n-Propylbenzene	8260C	Approved
RCRA Oxygenates	38169	4370	tert-Amyl methyl ether	8260C	Approved
RCRA Oxygenates	38169	4420	tert-Butyl alcohol (t-Butanol)	8260C	Approved
NPTA			Cyclohexane	8260C	Approved
NPTA			Methyl Acetate	8260C	Approved
NPTA			Methylcyclohexane	8260C	Approved
NPTA			m&p Xylenes	8260C	Approved
NPTA			o-Xylene	8260C	Approved
NPTA			p-isopropyltoluene	8260C	Approved
NPTA			Vinyl Acetate	8260C	Approved
Acenaphthylene in Soils	SPE-003	5505	Acenaphthylene	8270C	Approved
BNAs in Soil	SPE-003	5155	1,2,4-Trichlorobenzene	8270C	Approved
BNAs in Soil	SPE-003	4610	1,2-Dichlorobenzene	8270C	Approved
BNAs in Soil	SPE-003	4615	1,3-Dichlorobenzene	8270C	Approved
BNAs in Soil	SPE-003	4620	1,4-Dichlorobenzene	8270C	Approved
BNAs in Soil	SPE-003	6835	2,4,5-Trichlorophenol	8270C	Approved
BNAs in Soil	SPE-003	6840	2,4,6-Trichlorophenol	8270C	Approved
BNAs in Soil	SPE-003	6000	2,4-Dichlorophenol	8270C	Approved
BNAs in Soil	SPE-003	6130	2,4-Dimethylphenol	8270C	Approved
BNAs in Soil	SPE-003	6175	2,4-Dinitrophenol	8270C	Approved
BNAs in Soil	SPE-003	6185	2,4-Dinitrotoluene (2,4-DNT)	8270C	Approved
BNAs in Soil	SPE-003	6005	2,6-Dichlorophenol	8270C	Approved
BNAs in Soil	SPE-003	6190	2,6-Dinitrotoluene (2,6-DNT)	8270C	Approved
BNAs in Soil	SPE-003	5795	2-Chloronaphthalene	8270C	Approved
BNAs in Soil	SPE-003	5800	2-Chlorophenol	8270C	Approved
BNAs in Soil	SPE-003	6360	2-Methyl-4,6-dinitrophenol	8270C	Approved
BNAs in Soil	SPE-003	6385	2-Methylnaphthalene	8270C	Approved
BNAs in Soil	SPE-003	6400	2-Methylphenol (o-Cresol)	8270C	Approved
BNAs in Soil	SPE-003	6460	2-Nitroaniline	8270C	Approved
BNAs in Soil	SPE-003	6490	2-Nitrophenol	8270C	Approved
BNAs in Soil	SPE-003	5945	3,3'-Dichlorobenzidine	8270C	Approved
BNAs in Soil	SPE-003	6410	3+4-Methylphenol (m+p-Cresol)	8270C	Approved
BNAs in Soil	SPE-003	6405	3-Methylphenol (m-Cresol)	8270C	Approved
BNAs in Soil	SPE-003	6465	3-Nitroaniline	8270C	Approved
BNAs in Soil	SPE-003	5660	4-Bromophenyl phenyl ether	8270C	Approved
BNAs in Soil	SPE-003	5700	4-Chloro-3-methylphenol	8270C	Approved
BNAs in Soil	SPE-003	5745	4-Chloroaniline	8270C	Approved
BNAs in Soil	SPE-003	5825	4-Chlorophenyl phenylether	8270C	Approved
BNAs in Soil	SPE-003	6410	4-Methylphenol (p-Cresol)	8270C	Approved
BNAs in Soil	SPE-003	6470	4-Nitroaniline	8270C	Approved
BNAs in Soil	SPE-003	6500	4-Nitrophenol	8270C	Approved
BNAs in Soil	SPE-003	5500	Acenaphthene	8270C	Approved
BNAs in Soil	SPE-003	5505	Acenaphthylene	8270C	Approved
BNAs in Soil	SPE-003	5545	Aniline	8270C	Approved
BNAs in Soil	SPE-003	5555	Anthracene	8270C	Approved
BNAs in Soil	SPE-003	5595	Benzidine	8270C	Approved
BNAs in Soil	SPE-003	5575	Benzo(a)anthracene	8270C	Approved
BNAs in Soil	SPE-003	5580	Benzo(a)pyrene	8270C	Approved
BNAs in Soil	SPE-003	5585	Benzo(b)fluoranthene	8270C	Approved
BNAs in Soil	SPE-003	5590	Benzo(g,h,i)perylene	8270C	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
BNAs in Soil	SPE-003	5600	Benzo(k)fluoranthene	8270C	Approved
BNAs in Soil	SPE-003	5610	Benzoic acid	8270C	Approved
BNAs in Soil	SPE-003	5630	Benzyl alcohol	8270C	Approved
BNAs in Soil	SPE-003	5760	bis(2-Chloroethoxy)methane	8270C	Approved
BNAs in Soil	SPE-003	5765	bis(2-Chloroethyl) ether	8270C	Approved
BNAs in Soil	SPE-003	5780	bis(2-Chloroisopropyl) ether	8270C	Approved
BNAs in Soil	SPE-003	6255	bis(2-Ethylhexyl) phthalate (DEHP)	8270C	Approved
BNAs in Soil	SPE-003	5670	Butyl benzyl phthalate	8270C	Approved
BNAs in Soil	SPE-003	5680	Carbazole	8270C	Approved
BNAs in Soil	SPE-003	5855	Chrysene	8270C	Approved
BNAs in Soil	SPE-003	5895	Dibenz(a,h) anthracene	8270C	Approved
BNAs in Soil	SPE-003	5905	Dibenzofuran	8270C	Approved
BNAs in Soil	SPE-003	6070	Diethyl phthalate	8270C	Approved
BNAs in Soil	SPE-003	6135	Dimethyl phthalate	8270C	Approved
BNAs in Soil	SPE-003	5925	Di-n-butyl phthalate	8270C	Approved
BNAs in Soil	SPE-003	6200	Di-n-octyl phthalate	8270C	Approved
BNAs in Soil	SPE-003	6265	Fluoranthene	8270C	Approved
BNAs in Soil	SPE-003	6270	Fluorene	8270C	Approved
BNAs in Soil	SPE-003	6275	Hexachlorobenzene	8270C	Approved
BNAs in Soil	SPE-003	4835	Hexachlorobutadiene	8270C	Approved
BNAs in Soil	SPE-003	6285	Hexachlorocyclopentadiene	8270C	Approved
BNAs in Soil	SPE-003	4840	Hexachloroethane	8270C	Approved
BNAs in Soil	SPE-003	6315	Indeno(1,2,3-cd) pyrene	8270C	Approved
BNAs in Soil	SPE-003	6320	Isophorone	8270C	Approved
BNAs in Soil	SPE-003	5005	Naphthalene	8270C	Approved
BNAs in Soil	SPE-003	5015	Nitrobenzene	8270C	Approved
BNAs in Soil	SPE-003	6530	n-Nitrosodimethylamine	8270C	Approved
BNAs in Soil	SPE-003	6545	n-Nitroso-di-n-propylamine	8270C	Approved
BNAs in Soil	SPE-003	6535	n-Nitrosodiphenylamine	8270C	Approved
BNAs in Soil	SPE-003	6605	Pentachlorophenol	8270C	Approved
BNAs in Soil	SPE-003	6615	Phenanthrene	8270C	Approved
BNAs in Soil	SPE-003	6625	Phenol	8270C	Approved
BNAs in Soil	SPE-003	6665	Pyrene	8270C	Approved
BNAs in Soil	SPE-003	5095	Pyridine	8270C	Approved
Low-Level PAHs in Soil	722	6665	Pyrene	8270CSIM	Approved
PAHs - Solids	SPE-017	5005	Naphthalene	8270CSIM	Approved
PAHs - Solids	SPE-017	5500	Acenaphthene	8270CSIM	Approved
PAHs - Solids	SPE-017	5505	Acenaphthylene	8270CSIM	Approved
PAHs - Solids	SPE-017	5555	Anthracene	8270CSIM	Approved
PAHs - Solids	SPE-017	5575	Benzo(a)anthracene	8270CSIM	Approved
PAHs - Solids	SPE-017	5580	Benzo(a)pyrene	8270CSIM	Approved
PAHs - Solids	SPE-017	5585	Benzo(b)fluoranthene	8270CSIM	Approved
PAHs - Solids	SPE-017	5590	Benzo(g,h,i)perylene	8270CSIM	Approved
PAHs - Solids	SPE-017	5600	Benzo(k)fluoranthene	8270CSIM	Approved
PAHs - Solids	SPE-017	5855	Chrysene	8270CSIM	Approved
PAHs - Solids	SPE-017	5895	Dibenzo(a,h)anthracene	8270CSIM	Approved
PAHs - Solids	SPE-017	6265	Fluoranthene	8270CSIM	Approved
PAHs - Solids	SPE-017	6270	Fluorene	8270CSIM	Approved
PAHs - Solids	SPE-017	6315	Indeno(1,2,3-cd) pyrene	8270CSIM	Approved
PAHs - Solids	SPE-017	6385	2-Methylnaphthalene	8270CSIM	Approved
PAHs - Solids	SPE-017	6615	Phenanthrene	8270CSIM	Approved
PAHs - Solids	SPE-017	6665	Pyrene	8270CSIM	Approved
BNAs in Soil	SPE-003	5155	1,2,4-Trichlorobenzene	8270D	Approved
BNAs in Soil	SPE-003	4610	1,2-Dichlorobenzene	8270D	Approved
BNAs in Soil	SPE-003	4615	1,3-Dichlorobenzene	8270D	Approved
BNAs in Soil	SPE-003	4620	1,4-Dichlorobenzene	8270D	Approved
BNAs in Soil	SPE-003	6835	2,4,5-Trichlorophenol	8270D	Approved
BNAs in Soil	SPE-003	6840	2,4,6-Trichlorophenol	8270D	Approved
BNAs in Soil	SPE-003	6000	2,4-Dichlorophenol	8270D	Approved
BNAs in Soil	SPE-003	6130	2,4-Dimethylphenol	8270D	Approved
BNAs in Soil	SPE-003	6175	2,4-Dinitrophenol	8270D	Approved
BNAs in Soil	SPE-003	6185	2,4-Dinitrotoluene (2,4-DNT)	8270D	Approved
BNAs in Soil	SPE-003	6005	2,6-Dichlorophenol	8270D	Approved
BNAs in Soil	SPE-003	6190	2,6-Dinitrotoluene (2,6-DNT)	8270D	Approved
BNAs in Soil	SPE-003	5795	2-Chloronaphthalene	8270D	Approved
BNAs in Soil	SPE-003	5800	2-Chlorophenol	8270D	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
BNAs in Soil	SPE-003	6360	2-Methyl-4,6-dinitrophenol	8270D	Approved
BNAs in Soil	SPE-003	6385	2-Methylnaphthalene	8270D	Approved
BNAs in Soil	SPE-003	6400	2-Methylphenol (o-Cresol)	8270D	Approved
BNAs in Soil	SPE-003	6460	2-Nitroaniline	8270D	Approved
BNAs in Soil	SPE-003	6490	2-Nitrophenol	8270D	Approved
BNAs in Soil	SPE-003	5945	3,3'-Dichlorobenzidine	8270D	Approved
BNAs in Soil	SPE-003	6410	3+4-Methylphenol (m+p-Cresol)	8270D	Approved
BNAs in Soil	SPE-003	6405	3-Methylphenol (m-Cresol)	8270D	Approved
BNAs in Soil	SPE-003	6465	3-Nitroaniline	8270D	Approved
BNAs in Soil	SPE-003	5660	4-Bromophenyl phenyl ether	8270D	Approved
BNAs in Soil	SPE-003	5700	4-Chloro-3-methylphenol	8270D	Approved
BNAs in Soil	SPE-003	5745	4-Chloroaniline	8270D	Approved
BNAs in Soil	SPE-003	5825	4-Chlorophenyl phenylether	8270D	Approved
BNAs in Soil	SPE-003	6410	4-Methylphenol (p-Cresol)	8270D	Approved
BNAs in Soil	SPE-003	6470	4-Nitroaniline	8270D	Approved
BNAs in Soil	SPE-003	6500	4-Nitrophenol	8270D	Approved
BNAs in Soil	SPE-003	5500	Acenaphthene	8270D	Approved
BNAs in Soil	SPE-003	5505	Acenaphthylene	8270D	Approved
BNAs in Soil	SPE-003	5545	Aniline	8270D	Approved
BNAs in Soil	SPE-003	5555	Anthracene	8270D	Approved
BNAs in Soil	SPE-003	5595	Benzidine	8270D	Approved
BNAs in Soil	SPE-003	5575	Benzo(a)anthracene	8270D	Approved
BNAs in Soil	SPE-003	5580	Benzo(a)pyrene	8270D	Approved
BNAs in Soil	SPE-003	5585	Benzo(b)fluoranthene	8270D	Approved
BNAs in Soil	SPE-003	5590	Benzo(g,h,i)perylene	8270D	Approved
BNAs in Soil	SPE-003	5600	Benzo(k)fluoranthene	8270D	Approved
BNAs in Soil	SPE-003	5610	Benzoic acid	8270D	Approved
BNAs in Soil	SPE-003	5630	Benzyl alcohol	8270D	Approved
BNAs in Soil	SPE-003	5760	bis(2-Chloroethoxy)methane	8270D	Approved
BNAs in Soil	SPE-003	5765	bis(2-Chloroethyl) ether	8270D	Approved
BNAs in Soil	SPE-003	5780	bis(2-Chloroisopropyl) ether	8270D	Approved
BNAs in Soil	SPE-003	6255	bis(2-Ethylhexyl) phthalate (DEHP)	8270D	Approved
BNAs in Soil	SPE-003	5670	Butyl benzyl phthalate	8270D	Approved
BNAs in Soil	SPE-003	5680	Carbazole	8270D	Approved
BNAs in Soil	SPE-003	5855	Chrysene	8270D	Approved
BNAs in Soil	SPE-003	5895	Dibenz(a,h) anthracene	8270D	Approved
BNAs in Soil	SPE-003	5905	Dibenzofuran	8270D	Approved
BNAs in Soil	SPE-003	6070	Diethyl phthalate	8270D	Approved
BNAs in Soil	SPE-003	6135	Dimethyl phthalate	8270D	Approved
BNAs in Soil	SPE-003	5925	Di-n-butyl phthalate	8270D	Approved
BNAs in Soil	SPE-003	6200	Di-n-octyl phthalate	8270D	Approved
BNAs in Soil	SPE-003	6265	Fluoranthene	8270D	Approved
BNAs in Soil	SPE-003	6270	Fluorene	8270D	Approved
BNAs in Soil	SPE-003	6275	Hexachlorobenzene	8270D	Approved
BNAs in Soil	SPE-003	4835	Hexachlorobutadiene	8270D	Approved
BNAs in Soil	SPE-003	6285	Hexachlorocyclopentadiene	8270D	Approved
BNAs in Soil	SPE-003	4840	Hexachloroethane	8270D	Approved
BNAs in Soil	SPE-003	6315	Indeno(1,2,3-cd) pyrene	8270D	Approved
BNAs in Soil	SPE-003	6320	Isophorone	8270D	Approved
BNAs in Soil	SPE-003	5005	Naphthalene	8270D	Approved
BNAs in Soil	SPE-003	5015	Nitrobenzene	8270D	Approved
BNAs in Soil	SPE-003	6530	n-Nitrosodimethylamine	8270D	Approved
BNAs in Soil	SPE-003	6545	n-Nitroso-di-n-propylamine	8270D	Approved
BNAs in Soil	SPE-003	6535	n-Nitrosodiphenylamine	8270D	Approved
BNAs in Soil	SPE-003	6605	Pentachlorophenol	8270D	Approved
BNAs in Soil	SPE-003	6615	Phenanthrene	8270D	Approved
BNAs in Soil	SPE-003	6625	Phenol	8270D	Approved
BNAs in Soil	SPE-003	6665	Pyrene	8270D	Approved
BNAs in Soil	SPE-003	5095	Pyridine	8270D	Approved
PAHs - Solids	SPE-017	5005	Naphthalene	8270DSIM	Approved
PAHs - Solids	SPE-017	5500	Acenaphthene	8270DSIM	Approved
PAHs - Solids	SPE-017	5505	Acenaphthylene	8270DSIM	Approved
PAHs - Solids	SPE-017	5555	Anthracene	8270DSIM	Approved
PAHs - Solids	SPE-017	5575	Benzo(a)anthracene	8270DSIM	Approved
PAHs - Solids	SPE-017	5580	Benzo(a)pyrene	8270DSIM	Approved
PAHs - Solids	SPE-017	5585	Benzo(b)fluoranthene	8270DSIM	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
PAHs - Solids	SPE-017	5590	Benzo(g,h,i)perylene	8270DSIM	Approved
PAHs - Solids	SPE-017	5600	Benzo(k)fluoranthene	8270DSIM	Approved
PAHs - Solids	SPE-017	5855	Chrysene	8270DSIM	Approved
PAHs - Solids	SPE-017	5895	Dibenzo(a,h)anthracene	8270DSIM	Approved
PAHs - Solids	SPE-017	6265	Fluoranthene	8270DSIM	Approved
PAHs - Solids	SPE-017	6270	Fluorene	8270DSIM	Approved
PAHs - Solids	SPE-017	6315	Indeno(1,2,3-cd) pyrene	8270DSIM	Approved
PAHs - Solids	SPE-017	6385	2-Methylnaphthalene	8270DSIM	Approved
PAHs - Solids	SPE-017	6615	Phenanthrene	8270DSIM	Approved
PAHs - Solids	SPE-017	6665	Pyrene	8270DSIM	Approved
Dioxins and Furans in Soil	SPE-016	9612	2,3,7,8-TCDD	8290	Approved
Dioxins and Furans in Soil	SPE-016	9606	PCDD + PCDF, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9992	PCDD, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9615	TCDD, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9519	1,2,3,4,6,7,8,9-OCDD	8290	Approved
Dioxins and Furans in Soil	SPE-016	9516	1,2,3,4,6,7,8,9-OCDF	8290	Approved
Dioxins and Furans in Soil	SPE-016	9426	1,2,3,4,6,7,8-Hpccd	8290	Approved
Dioxins and Furans in Soil	SPE-016	9420	1,2,3,4,6,7,8-Hpcdf	8290	Approved
Dioxins and Furans in Soil	SPE-016	9423	1,2,3,4,7,8,9-Hpcdf	8290	Approved
Dioxins and Furans in Soil	SPE-016	9453	1,2,3,4,7,8-Hxcd	8290	Approved
Dioxins and Furans in Soil	SPE-016	9471	1,2,3,4,7,8-Hxcdf	8290	Approved
Dioxins and Furans in Soil	SPE-016	9456	1,2,3,6,7,8-Hxcd	8290	Approved
Dioxins and Furans in Soil	SPE-016	9474	1,2,3,6,7,8-Hxcdf	8290	Approved
Dioxins and Furans in Soil	SPE-016	9459	1,2,3,7,8,9-Hxcd	8290	Approved
Dioxins and Furans in Soil	SPE-016	9477	1,2,3,7,8,9-Hxcdf	8290	Approved
Dioxins and Furans in Soil	SPE-016	9540	1,2,3,7,8-Pecdd	8290	Approved
Dioxins and Furans in Soil	SPE-016	9543	1,2,3,7,8-Pecdf	8290	Approved
Dioxins and Furans in Soil	SPE-016	9480	2,3,4,6,7,8-Hxcdf	8290	Approved
Dioxins and Furans in Soil	SPE-016	9549	2,3,4,7,8-Pecdf	8290	Approved
Dioxins and Furans in Soil	SPE-016	9606	2,3,7,8-TCDD	8290	Approved
Dioxins and Furans in Soil	SPE-016	9989	2,3,7,8-TCDF	8290	Approved
Dioxins and Furans in Soil	SPE-016	9438	Hpcdd, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9444	Hpcdf, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9468	Hxcd, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9483	Hxcdf, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9992	PCDD + PCDF, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9991	PCDD, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9993	PCDF, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9555	Pecdd, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9552	Pecdf, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9989	TCDD, total	8290	Approved
Dioxins and Furans in Soil	SPE-016	9991	TCDF, total	8290	Approved
RCRA Carbamates	38158	7710	3-Hydroxycarbofuran	8321A	Approved
RCRA Carbamates	38158	7010	Aldicarb	8321A	Approved
RCRA Carbamates	38158	7015	Aldicarb sulfone	8321A	Approved
RCRA Carbamates	38158	7020	Aldicarb sulfoxide	8321A	Approved
RCRA Carbamates	38158	8080	Baygon (Propoxur)	8321A	Approved
RCRA Carbamates	38158	7195	Carbaryl	8321A	Approved
RCRA Carbamates	38158	7205	Carbofuran	8321A	Approved
RCRA Carbamates	38158	9384	Dioxacarb	8321A	Approved
RCRA Carbamates	38158	7505	Diuron	8321A	Approved
RCRA Carbamates	38158	7800	Methiocarb	8321A	Approved
RCRA Carbamates	38158	7805	Methomyl	8321A	Approved
RCRA Carbamates	38158	8025	Promecarb	8321A	Approved
RCRA Nitroaromatics in Soil	38155	6885	1,3,5-Trinitrobenzene	8330	Approved
RCRA Nitroaromatics in Soil	38155	6160	1,3-Dinitrobenzene	8330	Approved
RCRA Nitroaromatics in Soil	38155	9651	2,4,6-Trinitrotoluene	8330	Approved
RCRA Nitroaromatics in Soil	38155	6185	2,4-Dinitrotoluene	8330	Approved
RCRA Nitroaromatics in Soil	38155	6190	2,6-Dinitrotoluene	8330	Approved
RCRA Nitroaromatics in Soil	38155	9303	2-Amino-4,6-dinitrotoluene	8330	Approved
RCRA Nitroaromatics in Soil	38155	9507	2-Nitrotoluene	8330	Approved
RCRA Nitroaromatics in Soil	38155	9510	3-Nitrotoluene	8330	Approved
RCRA Nitroaromatics in Soil	38155	9306	4-Amino-2,6-dinitrotoluene	8330	Approved
RCRA Nitroaromatics in Soil	38155	9513	4-Nitrotoluene	8330	Approved
RCRA Nitroaromatics in Soil	38155	9522	HMX	8330	Approved
RCRA Nitroaromatics in Soil	38155	5015	Nitrobenzene	8330	Approved

**Accredited Analytes/Methods**  
**SOIL Proficiency Testing Summary**

<b>Lab Name :</b>	<b>APPL, Inc.</b>				
<b>City/State :</b>	<b>Clovis, CA</b>				
<b>PartName</b>	<b>PartNumber</b>	<b>NELACCode</b>	<b>AnalyteName</b>	<b>EPA Method</b>	<b>PT Results</b>
NPTA			Nitroglycerin	8330	Approved
NPTA			PGDN	8330	Approved
NPTA			Picric Acid	8330	Approved
NPTA			PETN	8330	Approved
RCRA Nitroaromatics in Soil	38155	9432	RDX	8330	Approved
RCRA Nitroaromatics in Soil	38155	6415	Tetryl	8330	Approved
RCRA Nitroaromatics in Soil	38155	6885	1,3,5-Trinitrobenzene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	6160	1,3-Dinitrobenzene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	9651	2,4,6-Trinitrotoluene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	6185	2,4-Dinitrotoluene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	6190	2,6-Dinitrotoluene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	9303	2-Amino-4,6-dinitrotoluene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	9507	2-Nitrotoluene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	9510	3-Nitrotoluene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	9306	4-Amino-2,6-dinitrotoluene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	9513	4-Nitrotoluene	8330A	Approved
RCRA Nitroaromatics in Soil	38155	9522	HMX	8330A	Approved
RCRA Nitroaromatics in Soil	38155	5015	Nitrobenzene	8330A	Approved
NPTA			Nitroglycerin	8330A	Approved
NPTA			PGDN	8330A	Approved
NPTA			Picric Acid	8330A	Approved
NPTA			PETN	8330A	Approved
RCRA Nitroaromatics in Soil	38155	9432	RDX	8330A	Approved
RCRA Nitroaromatics in Soil	38155	6415	Tetryl	8330A	Approved
RCRA Nitroaromatics in Soil	38155	6885	1,3,5-Trinitrobenzene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	6160	1,3-Dinitrobenzene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	9651	2,4,6-Trinitrotoluene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	9185	2,4-Dinitrotoluene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	6190	2,6-Dinitrotoluene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	9303	2-Amino-4,6-dinitrotoluene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	9507	2-Nitrotoluene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	9510	3-Nitrotoluene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	9306	4-Amino-2,6-dinitrotoluene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	9513	4-Nitrotoluene	8330B	Approved
RCRA Nitroaromatics in Soil	38155	9522	HMX	8330B	Approved
RCRA Nitroaromatics in Soil	38155	5015	Nitrobenzene	8330B	Approved
NPTA			Nitroglycerin	8330B	Approved
NPTA			PGDN	8330B	Approved
NPTA			Picric Acid	8330B	Approved
NPTA			PETN	8330B	Approved
RCRA Nitroaromatics in Soil	38155	9432	RDX	8330B	Approved
RCRA Nitroaromatics in Soil	38155	6415	Tetryl	8330B	Approved
RCRA Cyanide	55105	1645	Cyanide	9010B	Approved
RCRA Cyanide	55105	1645	Cyanide	9010C	Approved
RCRA Cyanide	55105	1645	Cyanide	9014	Approved
RCRA Corrosivity - pH Determination	55127	1625	Corrosivity	9045C	Approved
RCRA Corrosivity - pH Determination	55127	1625	Corrosivity	9045D	Approved
RCRA Anions	55141	1541	Bromide (Br)	9056	Approved
RCRA Anions	55141	1576	Chloride (Cl)	9056	Approved
RCRA Anions	55141	1731	Fluoride (F)	9056	Approved
RCRA Anions	55141	1811	Nitrate as N (NO3- as N)	9056	Approved
RCRA Anions	55141	1871	Phosphate as P (PO43- as P)	9056	Approved
RCRA Anions	55141	2001	Sulfate (SO42-)	9056	Approved
RCRA Anions	55141	1540	Bromide (Br)	9056A	Approved
RCRA Anions	55141	1575	Chloride (Cl)	9056A	Approved
RCRA Anions	55141	1730	Fluoride (F)	9056A	Approved
RCRA Anions	55141	1810	Nitrate as N (NO3- as N)	9056A	Approved
RCRA Anions	55141	1870	Phosphate as P (PO43- as P)	9056A	Approved
RCRA Anions	55141	2000	Sulfate (SO42-)	9056A	Approved
RCRA Nutrients	55142	2040	TOC	Walkley Black	Approved
Nutrients	PEO-014	2040	TOC	Walkley Black	Approved



## ANSI-ASQ National Accreditation Board/AClass

October 18, 2011

**VIA EMAIL**

Diane Anderson  
APPL, Inc.  
908 N. Temperance Avenue  
Clovis, CA 93611

**Re: Extension for DoD ELAP accreditation**

Dear Diane Anderson:

This letter is to inform you that your accreditation for DoD ELAP will expire on October 23, 2011. We have granted you an extension of 60 days from the expiration date on your certificate and scope of accreditation. If you have any questions or concerns regarding this matter, please feel free to give me a call at 703-836-0025 x-203.

Regards,

A handwritten signature in black ink that reads "Keith Greenaway".

Keith Greenaway  
Vice President





# ANSI-ASQ National Accreditation Board

## SCOPE OF DoD-ELAP ACCREDITATION

### APPL, Inc.

908 N. Temperance Avenue, Clovis, CA 93611  
 Diane Anderson Phone: 559-275-2175

### TESTING

Valid to: October 23, 2011

Certificate Number: ADE-1410

#### I. Environmental

MATRIX	SPECIFIC TEST or GROUP of ANALYTES	SPECIFICATION OR STANDARD METHOD (all SW846 unless specified)	* KEY EQUIPMENT OR TECHNOLOGY USED
Water / Wastewater	Acid Digestion for Metals Analysis	3010A	
Solid / Solid Waste	Acid digestion for Metals Analysis	3050B	
Water / Wastewater	Mercury Digestion and Analysis	245.1 / 7470A	AAS
Solid / Solid Waste	Mercury Digestion and Analysis	7471B	AAS
Water / Wastewater	Microwave assisted Acid Digestion for Metals Analysis	3015	Microwave
Solid / Solid Waste	Microwave assisted Acid Digestion for Metals Analysis	3051A	Microwave
Water / Wastewater	Purge and Trap for Aqueous Samples	5030B / 5030C	
Solid / Solid Waste	Closed-system purge and trap extraction for VOA analysis	5035 / 5035A	
Water / Wastewater	Separatory Funnel Extraction	3510C	
Solid / Solid Waste	Ultrasonic Extraction	3550B	Ultrasonic waterbath
Solid / Solid Waste	Soxhlet Extraction	3540C	Soxhlet Extractors

<b>MATRIX</b>	<b>SPECIFIC TEST or GROUP of ANALYTES</b>	<b>SPECIFICATION OR STANDARD METHOD (all SW846 unless specified)</b>	<b>* KEY EQUIPMENT OR TECHNOLOGY USED</b>
Water / Wastewater	Liquid-Liquid Extraction	3520C	Liquid-Liquid Extractor
Water / Wastewater / Solid / Solid Waste	Silica gel cleanup	3630C	
Solid / Solid Waste	Incremental sampling	8330B, Appendix A	Puck mill grinder
Water / Wastewater / Solid / Solid Waste	Sulfur cleanup	3660B	
Water / Wastewater / Solid / Solid Waste	Sulfuric acid – permanganate cleanup	3665A	
Water / Wastewater / Solid / Solid Waste	Gel permeation cleanup	3640A	
Solid / Solid Waste	TCLP extraction	1311	Rotary Tumbler
Solid / Solid Waste	SPLP extraction	1312	Rotary Tumbler
Solid / Solid Waste	Waste Extraction Test (WET)	CCR Chapter 11, Article 5, Appendix II	Rotary Tumbler
Water / Wastewater	Total Dissolved Solids	160.1 / 2540C	Gravimetric
Water / Wastewater	Total Suspended Solids	160.2 / 2540D	Gravimetric
Water / Wastewater	Anion analysis	300.0 / 9056 / 9056A	Dionex Ion Chromatography
Solid / Solid Waste	Anion analysis	9056 / 9056A	Dionex Ion Chromatography
Water / Wastewater / Solid / Solid Waste	Perchlorate analysis	314.0	Dionex Ion Chromatography
Water / Wastewater / Solid / Solid Waste	Ammonia	350.1	Lachat Flow Injection Analysis
Water / Wastewater / Solid / Solid Waste	TKN	351.2	Lachat Flow Injection Analysis
Water / Wastewater / Solid / Solid Waste	Nitrate / Nitrite	353.2	Lachat Flow Injection Analysis
Water / Wastewater / Solid / Solid Waste	Sulfide	376.1	Titrimetric
Water	Fluoride	9214	Ion Selective Electrode

<b>MATRIX</b>	<b>SPECIFIC TEST or GROUP of ANALYTES</b>	<b>SPECIFICATION OR STANDARD METHOD (all SW846 unless specified)</b>	<b>* KEY EQUIPMENT OR TECHNOLOGY USED</b>
Drinking Water / Water / Wastewater / Solid / Solid Waste	PCB Congeners	1668	High Resolution GC/MS
Water / Wastewater / Solid / Solid Waste	Perchlorate	6850	HPLC/Electrospray Ionization/MS
Water / Wastewater	Oil & Grease	1664A	Gravimetric
Water / Wastewater	Oil & Grease	5520B	Gravimetric
Water / Wastewater	TRPH	5520BF	Gravimetric
Water / Wastewater / Solid / Solid Waste	Total Metals	6010B / 6010C	ICP
Water / Wastewater / Solid / Solid Waste	Total Metals	6020 / 6020A	ICP/MS
Water / Wastewater / Solid / Solid Waste	Hexavalent Chromium	7196A	UV/Vis
Solid / Solid Waste	Alkaline digestion of Hexavalent Chromium	3060A	
Water / Wastewater	Hexavalent Chromium	218.6 / 7199	Dionex Ion Chromatography
Water / Wastewater / Solid / Solid Waste	Total Cyanide Distillation	9010B / 9010C	Midi-Distillation unit
Water / Wastewater / Solid / Solid Waste	Total Cyanide Analysis	9014	UV/Vis
Water / Wastewater	Corrosivity - pH	9040B	Ion Selective Electrode
Solid / Solid Waste	Corrosivity - pH	9045C / 9045D	Ion Selective Electrode
Water / Wastewater / Solid / Solid Waste	Chlorinated & Brominated Hydrocarbons	8011	GC/ECD
Water / Wastewater / Solid / Solid Waste	DRO/GRO	8015B/C/D	GC/FID
Water / Wastewater / Solid / Solid Waste	BTEX	8021B	GC/PID
Water / Solid	OP Pesticides	614 / 8141A / 8141B	GC/ECD
Water / Waste Water	OP Pesticides	614	GC/ECD

MATRIX	SPECIFIC TEST or GROUP of ANALYTES	SPECIFICATION OR STANDARD METHOD (all SW846 unless specified)	* KEY EQUIPMENT OR TECHNOLOGY USED
Water / Waste Water	OCL Pesticides	608	GC/ECD
Water / Wastewater / Solid / Solid Waste	OCL Pesticides	8081A / 8081B	GC/ECD
Water / Waste Water	PCB	608	GC/ECD
Water / Wastewater / Solid / Solid Waste	PCB	8082 / 8082A	GC/ECD
Water / Waste Water	Herbicides	615	GC/ECD
Water / Wastewater / Solid / Solid Waste	Herbicides	8151A	GC/ECD
Water / Wastewater / Solid / Solid Waste	VOA	8260B / 8260C	GC/MS
Water / Wastewater / Solid / Solid Waste	PAH	8270 SIM	GC/MS
Water / Waste Water	Semi-VOA	625	GC/MS
Water / Wastewater / Solid / Solid Waste	Semi-VOA	8270C / 8270D	GC/MS
Water / Wastewater / Solid / Solid Waste	Dioxins	8290	HRGC/HRMS
Water / Wastewater / Solid / Solid Waste	Nitroaromatics & Nitramines & Nitroguanidine	8330A / 8330B / 8321A&B	HPLC
Water / Wastewater / Solid / Solid Waste	Carbamates	8321A / 8321B	HPLC
Solid / Solid Waste	Ignitability	1030	

**Notes:**

- \* = As Applicable
- This scope is part of and must be included with the Certificate of Accreditation No. ADE- 1410



\_\_\_\_\_  
Vice President



## ANSI-ASQ National Accreditation Board/AClass

January 20, 2010

Diane Anderson / Frances Lediaev  
APPL Labs  
908 N. Temperance Avenue  
Clovis, CA 93611

Dear Diane and Frances,

We have reviewed the materials submitted by your laboratory and can confirm that they have provided sufficient documentation indicating all requirements of the DoD QSM have been met for the new analyte as you have requested. We can therefore recommend that any formal analyte list for method 8330A/8330B pertinent to APPL Labs could be expanded by the addition of propylene glycol dinitrate [PGDN] at this time.

We understand that there is no current commercial PT testing for this analyte, so it will not be in the "DoD-approved PT" listing that we publish, but that does not deny our verification of the competence review that has been favorable for this analyte.

The addition of this analyte to the existing, accredited method falls within the allowable additions to the method and does not require a new method listing in the current scope of accreditation.

Please let us know if we can assist you any further in this matter.

Best wishes.

Bill Hirt, Ph.D.

Bill Hirt, Ph.D.  
ANSI/ASQ National Accreditation Board / AClass  
Director of Accreditation



DoD ELAP -- PT Performance Summary Review -- WP ALL

Lab Name :		APPL, Inc.					
City/State :		Clovis, CA					
PT Provider Used :		ERA, Absolute, RTC, APG					
PartName	PartNumber	NELACCode	AnalyteName	EPAMethod#	PT results - Pass/Acceptable	Results	
pH	4060	1900	pH	EPA 150.2	Pass		
WP pH @ 25°C	55061	1900	pH	EPA 150.2	Pass		
Solids (Total Solids, TSS, & TDS)	55085	1955	Total Dissolved Solids (TDS)	EPA 160.1	Pass		
WP Minerals #1	55144	1955	Total Dissolved Solids @ 180°C	EPA 160.1	Pass		
Solids	4030	1705	Total Dissolved Solids at 180C	EPA 160.1	Pass		
Solids (Total Solids, TSS, & TDS)	55085	1960	Non-Filterable Residue (TSS)	EPA 160.2	Pass		
Solids	4030	1960	Total Suspended Solids	EPA 160.2	Pass		
Oil & Grease	4120	1860	Oil & Grease	EPA 1664A	Pass		
Oil & Grease - n-Hexadecane & Stearic acid	55084	1860	Oil & Grease	EPA 1664A	Pass		
PCB Congeners in Water	PEO-403	9070	2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9025	2,2',3,4,4',5'-Hexachlorobiphenyl (PCB 138)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9040	2,2',4,4',5,5'-Hexachlorobiphenyl (PCB 153)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8980	2,2',4,5,5'-Pentachlorobiphenyl (PCB 101)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8955	2,2',5,5'-Tetrachlorobiphenyl (PCB 52)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9085	2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9050	2,3,3',4,4',5-Hexachlorobiphenyl (PCB 156)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9045	2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8985	2,3,3',4,4'-Pentachlorobiphenyl (PCB 105)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9055	2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9005	2,3,4,4',5-Pentachlorobiphenyl (PCB 114)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8995	2,3',4,4',5-Pentachlorobiphenyl (PCB 118)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9000	2,3',4,4',5'-Pentachlorobiphenyl (PCB 123)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8936	2,4,4'-Trichlorobiphenyl (PCB 28)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9060	3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9015	3,3',4,4',5-Pentachlorobiphenyl (PCB 126)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8965	3,3',4,4'-Tetrachlorobiphenyl (PCB 77)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8970	3,4,4',5-Tetrachlorobiphenyl (PCB 81)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9025	PCB (129)+(138)+(163)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9040	PCB (153)+(168)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9046	PCB (166)+(157)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	9070	PCB (180)+(193)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8936	PCB (20)+(28)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8980	PCB (90)+(101)+(113)	EPA 1668	Pass		
PCB Congeners in Water	PEO-403	8870	PCBs, total	EPA 1668	Pass		
Bromide	4850	1540	Bromide	EPA 300.0	Pass		
CWA Anions	55131	1540	Bromide (Br)	EPA 300.0	Pass		
Minerals	4050	1575	Chloride	EPA 300.0	Pass		
WP Minerals #1	55144	1575	Chloride	EPA 300.0	Pass		
Fluoride	4420	1730	Fluoride	EPA 300.0	Pass		
WP Minerals #2	55145	1730	Fluoride	EPA 300.0	Pass		
WP & DMRQA Nutrients	55035	1810	Nitrate as N	EPA 300.0	Pass		
WP Nitrate & Nitrite	55130	1810	Nitrate as N	EPA 300.0	Pass		
Nutrients	4020	1810	Nitrate Nitrogen as N	EPA 300.0	Pass		
Nitrate-Nitrite as N	4770	1820	Nitrate-Nitrite as N	EPA 300.0	Pass		
WP Nitrate & Nitrite	55130	1820	Nitrite + Nitrate as N	EPA 300.0	Pass		
Nitrite as N	4780	1840	Nitrite as N	EPA 300.0	Pass		
WP Nitrate & Nitrite	55130	1840	Nitrite as N	EPA 300.0	Pass		
Nutrients	4020	1870	Orthophosphate as P	EPA 300.0	Pass		
WP & DMRQA Nutrients	55035	1870	Orthophosphate as P	EPA 300.0	Pass		
Minerals	4050	2000	Sulfate	EPA 300.0	Pass		
WP Minerals #2	55145	2000	Sulfate	EPA 300.0	Pass		
Miscellaneous Analytes	PEI-051	1540	Bromide	EPA 300.0	Pass		
Minerals	PEI-051	1575	Chloride	EPA 300.0	Pass		
Minerals	PEI-051	1730	Fluoride	EPA 300.0	Pass		
Nutrients	PEI-051	1805	Nitrate as N	EPA 300.0	Pass		
Nutrients	PEI-051	1820	Nitrate+nitrite as N	EPA 300.0	Pass		
Nutrients	PEI-051	1840	Nitrite as N	EPA 300.0	Pass		
Nutrients	PEI-051	1870	Orthophosphate as P	EPA 300.0	Pass		
Minerals	PEI-051	2000	Sulfate	EPA 300.0	Pass		
WP Perchlorate	55116	1895	Perchlorate	EPA 314.0	Pass		
Fluoride	4420	1730	Fluoride	EPA 340.2	Pass		
WP Minerals #2	55145	1730	Fluoride	EPA 340.2	Pass		
WP & DMRQA Nutrients	55035	1515	Ammonia as N	EPA 350.1	Pass		
Nutrients	4020	1515	Ammonia Nitrogen as N	EPA 350.1	Pass		
Nutrients	4020	1795	Total Kjeldahl Nitrogen	EPA 351.2	Pass		
WP & DMRQA Nutrients #2	55064	1795	Total Kjeldahl Nitrogen	EPA 351.2	Pass		
WP & DMRQA Nutrients	55035	1810	Nitrate as N	EPA 353.2	Pass		
WP Nitrate & Nitrite	55130	1810	Nitrate as N	EPA 353.2	Pass		
Nutrients	4020	1810	Nitrate Nitrogen as N	EPA 353.2	Pass		
Nitrate-Nitrite as N	4770	1820	Nitrate-Nitrite as N	EPA 353.2	Pass		
WP Nitrate & Nitrite	55130	1820	Nitrite + Nitrate as N	EPA 353.2	Pass		
Nitrite as N	4780	1840	Nitrite as N	EPA 353.2	Pass		
WP Nitrate & Nitrite	55130	1840	Nitrite as N	EPA 353.2	Pass		
Sulfide	4900	2005	Sulfide	EPA 376.1	Pass		
Sulphide	55042	2005	Sulphide	EPA 376.1	Pass		
MBAS	4430	2025	MBAS	EPA 425.1	Pass		
Trace Metals	4070	1000	Aluminum	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1000	Aluminum	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1000	Aluminum	EPA 6010B	Pass		
Trace Metals 1	PEI-034-1	1000	Aluminum, Al	EPA 6010B	Pass		
Trace Metals	4070	1005	Antimony	EPA 6010B	Pass		
WP Trace Elements	55025	1005	Antimony	EPA 6010B	Pass		
Trace Metals 2	PEI-034-2	1005	Antimony, Sb	EPA 6010B	Pass		

Trace Metals	4070	1010	Arsenic	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1010	Arsenic	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1010	Arsenic	EPA 6010B	Pass		
Trace Metals 1	PEI-034-1	1010	Arsenic, As	EPA 6010B	Pass		
WP Trace Elements	55025	1015	Barium	EPA 6010B	Pass		
Trace Metals	586	1015	Barium	EPA 6010B	Pass		
Trace Metals	4070	1020	Beryllium	EPA 6010B	Pass		
WP Trace Elements	55025	1020	Beryllium	EPA 6010B	Pass		
Trace Metals 1	PEI-034-1	1020	Beryllium, Be	EPA 6010B	Pass		
Trace Metals	4070	1025	Boron	EPA 6010B	Pass		
WP Trace Elements	55025	1025	Boron	EPA 6010B	Pass		
WP Trace Elements	55025	1025	Boron	EPA 6010B	Pass		
Trace Metals 2	PEI-034-2	1025	Boron, B	EPA 6010B	Pass		
Trace Metals	4070	1030	Cadmium	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1030	Cadmium	EPA 6010B	Pass		
WP Minerals #1	55144	1035	Calcium	EPA 6010B	Pass		
WP Minerals #1	55144	1550	Calcium Hardness (CaCO3)	EPA 6010B	Pass		
Trace Metals	4070	1040	Chromium	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1040	Chromium	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1050	Cobalt	EPA 6010B	Pass		
Trace Metals	586	1050	Cobalt	EPA 6010B	Pass		
Trace Metals	4070	1055	Copper	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1055	Copper	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1055	Copper	EPA 6010B	Pass		
Trace Metals	4070	1070	Iron	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1070	Iron	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1070	Iron	EPA 6010B	Pass		
Trace Metals	4070	1075	Lead	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1075	Lead	EPA 6010B	Pass		
WP Minerals #1	55144	1085	Magnesium	EPA 6010B	Pass		
Trace Metals	4070	1090	Manganese	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1090	Manganese	EPA 6010B	Pass		
Trace Metals 1	PEI-034-1	1090	Manganese, Mn	EPA 6010B	Pass		
Trace Metals	4070	1100	Molybdenum	EPA 6010B	Pass		
WP Trace Elements	55025	1100	Molybdenum	EPA 6010B	Pass		
WP Trace Elements	55025	1100	Molybdenum	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1105	Nickel	EPA 6010B	Pass		
Trace Metals	586	1105	Nickel	EPA 6010B	Pass		
WP Minerals #2	55145	1125	Potassium	EPA 6010B	Pass		
Trace Metals	4070	1140	Selenium	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1140	Selenium	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1140	Selenium	EPA 6010B	Pass		
Trace Metals 1	PEI-034-1	1140	Selenium, Se	EPA 6010B	Pass		
Trace Metals	4070	1150	Silver	EPA 6010B	Pass		
WP Trace Elements	55025	1150	Silver	EPA 6010B	Pass		
WP Trace Elements	55025	1150	Silver	EPA 6010B	Pass		
Trace Metals 2	PEI-034-2	1150	Silver, Ag	EPA 6010B	Pass		
WP Minerals #2	55145	1155	Sodium	EPA 6010B	Pass		
Trace Metals	4070	1160	Strontium	EPA 6010B	Pass		
WP Trace Elements	55025	1160	Strontium	EPA 6010B	Pass		
WP Trace Elements	55025	1160	Strontium	EPA 6010B	Pass		
Trace Metals 2	PEI-034-2	1160	Strontium, Sr	EPA 6010B	Pass		
Trace Metals	4070	1165	Thallium	EPA 6010B	Pass		
WP Trace Elements	55025	1165	Thallium	EPA 6010B	Pass		
WP Trace Elements	55025	1165	Thallium	EPA 6010B	Pass		
Trace Metals	4070	1175	Tin	EPA 6010B	Pass		
WP Tin	55095	1175	Tin	EPA 6010B	Pass		
Barium & Tin	PEI-034-5	1175	Tin, Sn	EPA 6010B	Pass		
Trace Metals	4070	1180	Titanium	EPA 6010B	Pass		
WP Trace Elements	55025	1180	Titanium	EPA 6010B	Pass		
WP Trace Elements	55025	1180	Titanium	EPA 6010B	Pass		
Trace Metals 2	PEI-034-2	1180	Titanium, Ti	EPA 6010B	Pass		
WP Minerals #1	55144	1755	Total Hardness (CaCO3)	EPA 6010B	Pass		
Trace Metals	4070	1185	Vanadium	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1185	Vanadium	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1185	Vanadium	EPA 6010B	Pass		
Trace Metals	4070	1190	Zinc	EPA 6010B	Pass		
WP & DMRQA Trace Elements	55024	1190	Zinc	EPA 6010B	Pass		
Trace Metals	4070	1000	Aluminum	EPA 6020	Pass		
Trace Metals	4070	1005	Antimony	EPA 6020	Pass		
WP Trace Elements	55025	1005	Antimony	EPA 6020	Pass		
Trace Metals	4070	1010	Arsenic	EPA 6020	Pass		
WP & DMRQA Trace Elements	55024	1010	Arsenic	EPA 6020	Pass		
Trace Metals	4070	1015	Barium	EPA 6020	Pass		
Trace Metals	4070	1020	Beryllium	EPA 6020	Pass		
WP Trace Elements	55025	1020	Beryllium	EPA 6020	Pass		
Trace Metals	4070	1025	Boron	EPA 6020	Pass		
Trace Metals	586	1025	Boron	EPA 6020	Pass		
Trace Metals	PEI-034	1025	Boron, B	EPA 6020	Pass		
Trace Metals	4070	1030	Cadmium	EPA 6020	Pass		
WP & DMRQA Trace Elements	55024	1030	Cadmium	EPA 6020	Pass		
Trace Metals	4070	1040	Chromium	EPA 6020	Pass		
Trace Metals	4070	1050	Cobalt	EPA 6020	Pass		
WP & DMRQA Trace Elements	55024	1050	Cobalt	EPA 6020	Pass		
Trace Metals	4070	1055	Copper	EPA 6020	Pass		
WP & DMRQA Trace Elements	55024	1055	Copper	EPA 6020	Pass		
WP & DMRQA Trace Elements	55024	1070	Iron	EPA 6020	Pass		
Trace Metals	586	1070	Iron	EPA 6020	Pass		
Trace Metals	4070	1075	Lead	EPA 6020	Pass		
WP & DMRQA Trace Elements	55024	1075	Lead	EPA 6020	Pass		
Trace Metals	4070	1090	Manganese	EPA 6020	Pass		

WP & DMRQA Trace Elements	55024	1090	Manganese	EPA 6020	Pass
Trace Metals	4070	1100	Molybdenum	EPA 6020	Pass
WP Trace Elements	55025	1100	Molybdenum	EPA 6020	Pass
Trace Metals	4070	1105	Nickel	EPA 6020	Pass
WP & DMRQA Trace Elements	55024	1105	Nickel	EPA 6020	Pass
Trace Metals	4070	1140	Selenium	EPA 6020	Pass
WP & DMRQA Trace Elements	55024	1140	Selenium	EPA 6020	Pass
Trace Metals	4070	1150	Silver	EPA 6020	Pass
Trace Metals	4070	1160	Strontium	EPA 6020	Pass
WP Trace Elements	55025	1160	Strontium	EPA 6020	Pass
Trace Metals	4070	1165	Thallium	EPA 6020	Pass
WP Trace Elements	55025	1165	Thallium	EPA 6020	Pass
Trace Metals	4070	1175	Tin	EPA 6020	Pass
WP Trace Elements	55025	1180	Titanium	EPA 6020	Pass
Trace Metals	4070	1185	Vanadium	EPA 6020	Pass
WP & DMRQA Trace Elements	55024	1185	Vanadium	EPA 6020	Pass
Trace Metals	4070	1190	Zinc	EPA 6020	Pass
WP & DMRQA Trace Elements	55024	1190	Zinc	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1000	Aluminum, Al	EPA 6020	Pass
Trace Metals 2	PEI-034-2	1005	Antimony, Sb	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1010	Arsenic, As	EPA 6020	Pass
Barium & Tin	PEI-034-5	1015	Barium, Ba	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1020	Beryllium, Be	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1030	Cadmium, Cd	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1040	Chromium, Cr (total)	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1050	Cobalt, Co	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1055	Copper, Cu	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1070	Iron, Fe	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1075	Lead, Pb	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1090	Manganese, Mn	EPA 6020	Pass
Trace Metals 2	PEI-034-2	1100	Molybdenum, Mo	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1105	Nickel, Ni	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1140	Selenium, Se	EPA 6020	Pass
Trace Metals 2	PEI-034-2	1150	Silver, Ag	EPA 6020	Pass
Barium & Tin	PEI-034-5	1175	Tin, Sn	EPA 6020	Pass
Trace Metals 2	PEI-034-2	1180	Titanium, Ti	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1185	Vanadium, V	EPA 6020	Pass
Trace Metals 1	PEI-034-1	1190	Zinc, Zn	EPA 6020	Pass
Pesticides (WP)	4460	7355	4,4'-DDD	EPA 608	Pass
WP Organochlorine Pesticides	38122	7355	4,4'-DDD	EPA 608	Pass
Pesticides (WP)	4460	7360	4,4'-DDE	EPA 608	Pass
WP Organochlorine Pesticides	38122	7360	4,4'-DDE	EPA 608	Pass
Pesticides (WP)	4460	7365	4,4'-DDT	EPA 608	Pass
WP Organochlorine Pesticides	38122	7365	4,4'-DDT	EPA 608	Pass
WP Organochlorine Pesticides	38122	7810	4,4'-Methoxychlor	EPA 608	Pass
WP Organochlorine Pesticides	38122	7110	a-BHC	EPA 608	Pass
WP Organochlorine Pesticides	38122	7240	a-Chlordane	EPA 608	Pass
Pesticides (WP)	4460	7025	Aldrin	EPA 608	Pass
WP Organochlorine Pesticides	38122	7025	Aldrin	EPA 608	Pass
Pesticides (NELAC)	4460	7110	alpha-BHC	EPA 608	Pass
Pesticides (NELAC)	4460	7240	alpha-Chlordane	EPA 608	Pass
WP PCBs in Water	38091	8880	Aroclor 1016	EPA 608	Pass
WP PCBs in Water	38094	8880	Aroclor 1016	EPA 608	Pass
WP PCBs in Water	832S	8880	Aroclor 1016	EPA 608	Pass
PCBs in Water	4130	8880	Aroclor 1016	EPA 608	Pass
PCBs in Oil	4140	8880	Aroclor 1016 in Oil	EPA 608	Pass
PCBs in Water	4130	8880	Aroclor 1016 Sample 1	EPA 608	Pass
PCBs in Water	4130	8880	Aroclor 1016 Sample 2	EPA 608	Pass
PCBs in Water	832S	8885	Aroclor 1221	EPA 608	Pass
WP PCBs in Water	38091	8885	Aroclor 1221	EPA 608	Pass
WP PCBs in Water	38094	8885	Aroclor 1221	EPA 608	Pass
PCBs in Water	4130	8885	Aroclor 1221	EPA 608	Pass
PCBs in Oil	4140	8885	Aroclor 1221 in Oil	EPA 608	Pass
WP PCBs in Water	38091	8890	Aroclor 1232	EPA 608	Pass
WP PCBs in Water	38094	8890	Aroclor 1232	EPA 608	Pass
WP PCBs in Water	832S	8890	Aroclor 1232	EPA 608	Pass
PCBs in Water	4130	8890	Aroclor 1232	EPA 608	Pass
PCBs in Oil	4140	8890	Aroclor 1232 in Oil	EPA 608	Pass
PCBs in Water	4130	8890	Aroclor 1232 Sample 1	EPA 608	Pass
PCBs in Water	4130	8890	Aroclor 1232 Sample 2	EPA 608	Pass
WP PCBs in Water	832S	8895	Aroclor 1242	EPA 608	Pass
WP PCBs in Water	38091	8895	Aroclor 1242	EPA 608	Pass
WP PCBs in Water	38094	8895	Aroclor 1242	EPA 608	Pass
PCBs in Water	4130	8895	Aroclor 1242	EPA 608	Pass
PCBs in Oil	4140	8895	Aroclor 1242 in Oil	EPA 608	Pass
PCBs in Water	4130	8895	Aroclor 1242 Sample 1	EPA 608	Pass
PCBs in Water	4130	8895	Aroclor 1242 Sample 2	EPA 608	Pass
WP PCBs in Water	38091	8900	Aroclor 1248	EPA 608	Pass
WP PCBs in Water	38094	8900	Aroclor 1248	EPA 608	Pass
PCBs in Oil	4140	8900	Aroclor 1248 in Oil	EPA 608	Pass
PCBs in Water	4130	8900	Aroclor 1248 Sample 1	EPA 608	Pass
PCBs in Water	4130	8900	Aroclor 1248 Sample 2	EPA 608	Pass
PCBs in Water	832S	8905	Aroclor 1254	EPA 608	Pass
WP PCBs in Water	38091	8905	Aroclor 1254	EPA 608	Pass
WP PCBs in Water	38094	8905	Aroclor 1254	EPA 608	Pass
PCBs in Water	4130	8905	Aroclor 1254	EPA 608	Pass
PCBs in Oil	4140	8905	Aroclor 1254 in Oil	EPA 608	Pass
PCBs in Water	4130	8905	Aroclor 1254 Sample 1	EPA 608	Pass
PCBs in Water	4130	8905	Aroclor 1254 Sample 2	EPA 608	Pass
WP PCBs in Water	38091	8910	Aroclor 1260	EPA 608	Pass
WP PCBs in Water	38094	8910	Aroclor 1260	EPA 608	Pass

WP PCBs in Water	832S	8910	Aroclor 1260	EPA 608	Pass		
PCBs in Water	4130	8910	Aroclor 1260	EPA 608	Pass		
PCBs in Oil	4140	8910	Aroclor 1260 in Oil	EPA 608	Pass		
PCBs in Water	4130	8910	Aroclor 1260 Sample 1	EPA 608	Pass		
PCBs in Water	4130	8910	Aroclor 1260 Sample 2	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7115	b-BHC	EPA 608	Pass		
Pesticides (NELAC)	4460	7115	beta-BHC	EPA 608	Pass		
WP Pesticide Amp 2	38046	7250	Chlordane (total)	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7105	d-BHC	EPA 608	Pass		
Pesticides (NELAC)	4460	7105	delta-BHC	EPA 608	Pass		
Pesticides (WP)	4460	7470	Dieldrin	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7470	Dieldrin	EPA 608	Pass		
Pesticides (NELAC)	4460	7510	Endosulfan I	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7510	Endosulfan I	EPA 608	Pass		
Pesticides (NELAC)	4460	7515	Endosulfan II	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7515	Endosulfan II	EPA 608	Pass		
Pesticides (NELAC)	4460	7520	Endosulfan sulfate	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7520	Endosulfan sulfate	EPA 608	Pass		
Pesticides (NELAC)	4460	7540	Endrin	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7540	Endrin	EPA 608	Pass		
Pesticides (NELAC)	4460	7530	Endrin aldehyde	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7530	Endrin aldehyde	EPA 608	Pass		
Pesticides (NELAC)	4460	7535	Endrin Ketone	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7535	Endrin ketone	EPA 608	Pass		
Pesticides (NELAC)	4460	7120	gamma-BHC (Lindane)	EPA 608	Pass		
Pesticides (NELAC)	4460	7245	gamms-Chlordane	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7120	g-BHC (Lindane)	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7245	g-Chlordane	EPA 608	Pass		
Pesticides (WP)	4460	7685	Heptachlor	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7685	Heptachlor	EPA 608	Pass		
Pesticides (WP)	4460	7690	Heptachlor epoxide	EPA 608	Pass		
WP Organochlorine Pesticides	38122	7690	Heptachlor epoxide	EPA 608	Pass		
Pesticides (NELAC)	4460	7810	Methoxychlor	EPA 608	Pass		
WP PCBs in Transformer Oil	38092	8880	PCB in Oil 1016 or 1242	EPA 608	Pass		
WP PCBs in Water	38094	8880	PCB in Oil 1016 or 1242	EPA 608	Pass		
WP PCBs in Transformer Oil	38092	8905	PCB in Oil 1254	EPA 608	Pass		
WP PCBs in Water	38094	8905	PCB in Oil 1254	EPA 608	Pass		
WP PCBs in Transformer Oil	38092	8910	PCB in Oil 1260	EPA 608	Pass		
WP PCBs in Water	38094	8910	PCB in Oil 1260	EPA 608	Pass		
Total Chlordane	4160	7250	Total Chlordane	EPA 608	Pass		
Toxaphene	4270	8250	Toxaphene	EPA 608	Pass		
WP Acrolein & Acrylonitrile	38123	8250	Toxaphene	EPA 608	Pass		
Herbicides	4440	8655	2,4,5-T	EPA 615	Pass		
WP Herbicide Acid Mix #2	38136	8655	2,4,5-T	EPA 615	Pass		
Herbicides	4440	8650	2,4,5-TP (Silvex)	EPA 615	Pass		
Herbicides	4440	8545	2,4-D	EPA 615	Pass		
WP Acrolein & Acrylonitrile	38123	8545	2,4-D (2,4-Dichlorophenoxyacetic acid)	EPA 615	Pass		
Herbicides	4440	8560	2,4-DB	EPA 615	Pass		
WP Herbicide Acid Mix #2	38136	8560	2,4-DB	EPA 615	Pass		
Herbicides	4440	8600	3,5-Dichlorobenzoic acid	EPA 615	Pass		
WP Herbicide Acid Mix #2	38136	8600	3,5-Dichlorobenzoic acid	EPA 615	Pass		
Herbicides	4440	6500	4-Nitrophenol	EPA 615	Pass		
WP Herbicide Acid Mix #2	38136	6500	4-Nitrophenol	EPA 615	Pass		
Herbicides	4440	8505	Acifluorfen	EPA 615	Pass		
WP Acrolein & Acrylonitrile	38123	8505	Acifluorfen	EPA 615	Pass		
Herbicides	4440	8530	Bentazon	EPA 615	Pass		
WP Herbicide Acid Mix #2	38136	8530	Bentazon	EPA 615	Pass		
Herbicides	4440	8540	Chloramben	EPA 615	Pass		
Herbicides	4440	8550	Dacthal diacid (DCPA)	EPA 615	Pass		
Herbicides	4440	8555	Dalapon	EPA 615	Pass		
WP Acrolein & Acrylonitrile	38123	8555	Dalapon	EPA 615	Pass		
Herbicides	4440	8595	Dicamba	EPA 615	Pass		
WP Acrolein & Acrylonitrile	38123	8595	Dicamba	EPA 615	Pass		
Herbicides	4440	8605	Dichloroprop	EPA 615	Pass		
WP Herbicide Acid Mix #2	38136	8605	Dichloroprop	EPA 615	Pass		
Herbicides	4440	8620	Dinoseb	EPA 615	Pass		
WP Acrolein & Acrylonitrile	38123	8620	Dinoseb (2-sec-Butyl-4,6-dinitrophenol)	EPA 615	Pass		
Herbicides	4440	7775	MCPA	EPA 615	Pass		
Herbicides	4440	7780	MCPP	EPA 615	Pass		
Herbicides	4440	6605	Pentachlorophenol	EPA 615	Pass		
WP Acrolein & Acrylonitrile	38123	6605	Pentachlorophenol	EPA 615	Pass		
Herbicides	4440	8645	Picloram	EPA 615	Pass		
WP Acrolein & Acrylonitrile	38123	8645	Picloram	EPA 615	Pass		
WP Acrolein & Acrylonitrile	38123	8650	Silvex (2,4,5-TP)	EPA 615	Pass		
Volatiles	4170	5105	1,1,1,2-Tetrachloroethane	EPA 624	Pass		
Volatiles in Non-Potable Water	38083	5105	1,1,1,2-Tetrachloroethane	EPA 624	Pass		
Volatiles	4170	5160	1,1,1-Trichloroethane	EPA 624	Pass		
Volatiles in Non-Potable Water	38083	5160	1,1,1-Trichloroethane	EPA 624	Pass		
Volatiles	4170	5110	1,1,2,2-Tetrachloroethane	EPA 624	Pass		
Volatiles in Non-Potable Water	38083	5110	1,1,2,2-Tetrachloroethane	EPA 624	Pass		
Volatiles	4170	5165	1,1,2-Trichloroethane	EPA 624	Pass		
Volatiles in Non-Potable Water	38083	5165	1,1,2-Trichloroethane	EPA 624	Pass		
WP Oxygenates	38157	5185	1,1,2-Trichlorotrifluoroethane	EPA 624	Pass		
Volatiles	4170	4630	1,1-Dichloroethane	EPA 624	Pass		
Volatiles in Non-Potable Water	38083	4630	1,1-Dichloroethane	EPA 624	Pass		
Volatiles	4170	4640	1,1-Dichloroethene	EPA 624	Pass		
Volatiles in Non-Potable Water	38083	4640	1,1-Dichloroethene	EPA 624	Pass		
Volatiles in Non-Potable Water	38083	4670	1,1-Dichloropropene	EPA 624	Pass		
Volatiles in Non-Potable Water	38083	5150	1,2,3-Trichlorobenzene	EPA 624	Pass		
Volatiles	4170	5180	1,2,3-Trichloropropane	EPA 624	Pass		
Volatiles in Non-Potable Water	38083	5180	1,2,3-Trichloropropane	EPA 624	Pass		

Volatiles in Non-Potable Water	38083	5210	1,2,4-Trimethylbenzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4570	1,2-Dibromo-3-chloropropane	EPA 624	Pass
Volatiles	4170	4585	1,2-Dibromoethane (EDB)	EPA 624	Pass
Volatile Aromatics	4450	4610	1,2-Dichlorobenzene	EPA 624	Pass
Volatiles	4170	4610	1,2-Dichlorobenzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4610	1,2-Dichlorobenzene	EPA 624	Pass
Volatiles	4170	4635	1,2-Dichloroethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4635	1,2-Dichloroethane	EPA 624	Pass
Volatiles	4170	4655	1,2-Dichloropropane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4655	1,2-Dichloropropane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5215	1,3,5-Trimethylbenzene	EPA 624	Pass
Volatile Aromatics	4450	4615	1,3-Dichlorobenzene	EPA 624	Pass
Volatiles	4170	4615	1,3-Dichlorobenzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4615	1,3-Dichlorobenzene	EPA 624	Pass
Volatile Aromatics	4450	4620	1,4-Dichlorobenzene	EPA 624	Pass
Volatiles	4170	4620	1,4-Dichlorobenzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4620	1,4-Dichlorobenzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4665	2,2-Dichloropropane	EPA 624	Pass
Volatiles	4170	4410	2-Butanone (Methyl ethyl ketone)	EPA 624	Pass
WP Ketones	38134	4410	2-Butanone	EPA 624	Pass
Volatiles	4170	4500	2-Chloroethyl vinyl ether	EPA 624	Pass
WP 2-Chloroethyl vinyl ether	38128	4500	2-Chloroethyl vinyl ether	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4535	2-Chlorotoluene	EPA 624	Pass
Volatiles	4170	4860	2-Hexanone	EPA 624	Pass
WP Ketones	38134	4860	2-Hexanone	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4540	4-Chlorotoluene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4995	4-Methyl-2-pentanone	EPA 624	Pass
WP Ketones	38134	4995	4-Methyl-2-pentanone	EPA 624	Pass
Volatiles	4170	4995	4-Methyl-2-pentanone (MIBK)	EPA 624	Pass
Volatiles	4170	4315	Acetone	EPA 624	Pass
WP Ketones	38134	4315	Acetone	EPA 624	Pass
Volatiles	4170	4325	Acrolein	EPA 624	Pass
WP Acrolein & Acrylonitrile	38123	4325	Acrolein	EPA 624	Pass
Volatiles	4170	4340	Acrylonitrile	EPA 624	Pass
WP Acrolein & Acrylonitrile	38123	4340	Acrylonitrile	EPA 624	Pass
CWA BTEX & MTBE	38166	4375	Benzene	EPA 624	Pass
Volatile Aromatics	4450	4375	Benzene	EPA 624	Pass
Volatiles	4170	4375	Benzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4375	Benzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4385	Bromobenzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4390	Bromochloromethane	EPA 624	Pass
Volatiles	4170	4395	Bromodichloromethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4395	Bromodichloromethane	EPA 624	Pass
Volatiles	4170	4400	Bromoform	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4400	Bromoform	EPA 624	Pass
Volatiles	4170	4950	Bromomethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4950	Bromomethane	EPA 624	Pass
Volatiles	4170	4450	Carbon disulfide	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4450	Carbon disulfide	EPA 624	Pass
Volatiles	4170	4455	Carbon tetrachloride	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4455	Carbon tetrachloride	EPA 624	Pass
Volatiles	4170	4475	Chlorobenzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4475	Chlorobenzene	EPA 624	Pass
Volatiles	4170	4485	Chloroethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4485	Chloroethane	EPA 624	Pass
Volatiles	4170	4505	Chloroform	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4505	Chloroform	EPA 624	Pass
Volatiles	4170	4960	Chloromethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4960	Chloromethane	EPA 624	Pass
Volatiles	4170	4645	cis-1,2-Dichloroethene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4645	cis-1,2-Dichloroethene	EPA 624	Pass
Volatiles	4170	4680	cis-1,3-Dichloropropene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4680	cis-1,3-Dichloropropene	EPA 624	Pass
Volatiles	4170	4575	Dibromochloromethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4575	Dibromochloromethane	EPA 624	Pass
Volatiles	4170	4595	Dibromomethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4595	Dibromomethane	EPA 624	Pass
Volatiles	4170	4625	Dichlorodifluoromethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4625	Dichlorodifluoromethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4765	Ethyl benzene	EPA 624	Pass
CWA BTEX & MTBE	38166	4765	Ethylbenzene	EPA 624	Pass
Volatile Aromatics	4450	4765	Ethylbenzene	EPA 624	Pass
Volatiles	4170	4765	Ethylbenzene	EPA 624	Pass
Volatiles	4170	4835	Hexachlorobutadiene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4835	Hexachlorobutadiene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4840	Hexachloroethane	EPA 624	Pass
WP Oxygenates	38157	9375	Isopropyl ether (DIPE)	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4900	Isopropylbenzene	EPA 624	Pass
CWA BTEX & MTBE	38166	5000	Methyl tert-butyl ether (MTBE)	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5000	Methyl tert-butyl ether (MTBE)	EPA 624	Pass
WP Oxygenates	38157	5000	Methyl tert-butyl ether (MTBE)	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4975	Methylene chloride	EPA 624	Pass
Volatiles	4170	4975	Methylene chloride (Dichloromethane)	EPA 624	Pass
Volatiles	4170	5000	Methyl-t-butylether (MTBE)	EPA 624	Pass
Volatiles	4170	5005	Naphthalene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5005	Naphthalene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4435	n-Butyl benzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5090	n-Propylbenzene	EPA 624	Pass
WP Oxygenates	38157	5090	n-Propylbenzene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4910	p-Isopropyl toluene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4440	sec-Butyl benzene	EPA 624	Pass

Volatiles	4170	5100	Styrene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5100	Styrene	EPA 624	Pass
WP Oxygenates	38157	4370	tert-Amyl methyl ether (TAME)	EPA 624	Pass
WP Oxygenates	38157	4420	tert-Butyl alcohol (t-Butanol)	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4445	tert-Butyl benzene	EPA 624	Pass
WP Oxygenates	38157	4770	tert-Butyl ethyl ether (ETBE)	EPA 624	Pass
Volatiles	4170	5115	Tetrachloroethene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5115	Tetrachloroethene	EPA 624	Pass
CWA BTEX & MTBE	38166	5140	Toluene	EPA 624	Pass
Volatile Aromatics	4450	5140	Toluene	EPA 624	Pass
Volatiles	4170	5140	Toluene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5140	Toluene	EPA 624	Pass
CWA BTEX & MTBE	38166	5260	Total Xylenes	EPA 624	Pass
Volatile Aromatics	4450	5260	Total Xylenes	EPA 624	Pass
Volatiles	4170	5260	Total Xylenes	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5260	Total Xylenes	EPA 624	Pass
Volatiles	4170	4700	trans-1,2-Dichloroethene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4700	trans-1,2-Dichloroethene	EPA 624	Pass
Volatiles	4170	4685	trans-1,3-Dichloropropene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	4685	trans-1,3-Dichloropropene	EPA 624	Pass
Volatiles	4170	5170	Trichloroethene	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5170	Trichloroethene	EPA 624	Pass
Volatiles	4170	5175	Trichlorofluoromethane	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5175	Trichlorofluoromethane	EPA 624	Pass
Volatiles	4170	5225	Vinyl acetate	EPA 624	Pass
Volatiles	4170	5235	Vinyl Chloride	EPA 624	Pass
Volatiles in Non-Potable Water	38083	5235	Vinyl chloride	EPA 624	Pass
Base Neutral Extractables	4200	6715	1,2,4,5-Tetrachlorobenzene	EPA 625	Pass
Base Neutral Extractables	4200	5155	1,2,4-Trichlorobenzene	EPA 625	Pass
WP Base/Neutrals	711	5155	1,2,4-Trichlorobenzene	EPA 625	Pass
Base Neutral Extractables	4200	4610	1,2-Dichlorobenzene	EPA 625	Pass
WP Base/Neutrals	711	4610	1,2-Dichlorobenzene	EPA 625	Pass
Base Neutral Extractables	4200	4615	1,3-Dichlorobenzene	EPA 625	Pass
WP Base/Neutrals	711	4615	1,3-Dichlorobenzene	EPA 625	Pass
Base Neutral Extractables	4200	4620	1,4-Dichlorobenzene	EPA 625	Pass
WP Base/Neutrals	711	4620	1,4-Dichlorobenzene	EPA 625	Pass
Acid Extractables	4190	6735	2,3,4,6-Tetrachlorophenol	EPA 625	Pass
Acids	712	6735	2,3,4,6-Tetrachlorophenol	EPA 625	Pass
Acid Extractables	4190	6835	2,4,5-Trichlorophenol	EPA 625	Pass
Acids	712	6835	2,4,5-Trichlorophenol	EPA 625	Pass
Acids	712	6840	2,4,6-Trichlorophenol	EPA 625	Pass
Acid Extractables	4190	6840	2,4,6-Trichlorophenol	EPA 625	Pass
Acid Extractables	4190	6000	2,4-Dichlorophenol	EPA 625	Pass
Acids	712	6000	2,4-Dichlorophenol	EPA 625	Pass
Acid Extractables	4190	6130	2,4-Dimethylphenol	EPA 625	Pass
Acids	712	6130	2,4-Dimethylphenol	EPA 625	Pass
Acid Extractables	4190	6175	2,4-Dinitrophenol	EPA 625	Pass
Acids	712	6175	2,4-Dinitrophenol	EPA 625	Pass
WP Base/Neutrals	711	6185	2,4-Dinitrotoluene	EPA 625	Pass
Base Neutral Extractables	4200	6185	2,4-Dinitrotoluene (2,4-DNT)	EPA 625	Pass
Acid Extractables	4190	6005	2,6-Dichlorophenol	EPA 625	Pass
Acids	712	6005	2,6-Dichlorophenol	EPA 625	Pass
WP Base/Neutrals	711	6190	2,6-Dinitrotoluene	EPA 625	Pass
Base Neutral Extractables	4200	6190	2,6-Dinitrotoluene (2,6-DNT)	EPA 625	Pass
Base Neutral Extractables	4200	5795	2-Chloronaphthalene	EPA 625	Pass
WP Base/Neutrals	711	5795	2-Chloronaphthalene	EPA 625	Pass
Acid Extractables	4190	5800	2-Chlorophenol	EPA 625	Pass
Acids	712	5800	2-Chlorophenol	EPA 625	Pass
Acid Extractables	4190	6360	2-Methyl-4,6-Dinitrophenol	EPA 625	Pass
Base Neutral Extractables	4200	6385	2-Methylnaphthalene	EPA 625	Pass
WP Base/Neutrals	711	6385	2-Methylnaphthalene	EPA 625	Pass
Acid Extractables	4190	6400	2-Methylphenol	EPA 625	Pass
Acids	712	6400	2-Methylphenol	EPA 625	Pass
WP Base/Neutrals	711	6460	2-Nitroaniline	EPA 625	Pass
Base Neutral Extractables	4200	6460	2-Nitroaniline	EPA 625	Pass
Acid Extractables	4190	6490	2-Nitrophenol	EPA 625	Pass
Acids	712	6490	2-Nitrophenol	EPA 625	Pass
Acid Extractables	4190	6410	3 & 4-Methylphenol	EPA 625	Pass
Base Neutral Extractables	4200	5945	3,3'-Dichlorobenzidine	EPA 625	Pass
WP Base/Neutrals	711	5945	3,3'-Dichlorobenzidine	EPA 625	Pass
Acid Extractables	4190	6405	3-Methylphenol	EPA 625	Pass
Base Neutral Extractables	4200	6465	3-Nitroaniline	EPA 625	Pass
WP Base/Neutrals	711	6465	3-Nitroaniline	EPA 625	Pass
Acids	712	6360	4,6-Dinitro-2-methylphenol	EPA 625	Pass
Base Neutral Extractables	4200	5660	4-Bromophenyl phenyl ether	EPA 625	Pass
WP Base/Neutrals	711	5660	4-Bromophenyl-phenylether	EPA 625	Pass
Acid Extractables	4190	5700	4-Chloro-3-methylphenol	EPA 625	Pass
Acids	712	5700	4-Chloro-3-methylphenol	EPA 625	Pass
Base Neutral Extractables	4200	5745	4-Chloroaniline	EPA 625	Pass
WP Base/Neutrals	711	5745	4-Chloroaniline	EPA 625	Pass
Base Neutral Extractables	4200	5825	4-Chlorophenyl-phenylether	EPA 625	Pass
WP Base/Neutrals	711	5825	4-Chlorophenyl-phenylether	EPA 625	Pass
Acids	712	6410	4-Methylphenol	EPA 625	Pass
Base Neutral Extractables	4200	6470	4-Nitroaniline	EPA 625	Pass
WP Base/Neutrals	711	6470	4-Nitroaniline	EPA 625	Pass
Acid Extractables	4190	6500	4-Nitrophenol	EPA 625	Pass
Acids	712	6500	4-Nitrophenol	EPA 625	Pass
Base Neutral Extractables	4200	5500	Acenaphthene	EPA 625	Pass
PAH-GC & GCMS	4880	5500	Acenaphthene	EPA 625	Pass
WP Base/Neutrals	711	5500	Acenaphthene	EPA 625	Pass
Base Neutral Extractables	4200	5505	Acenaphthylene	EPA 625	Pass

PAH-GC & GCMS	4880	5505	Acenaphthylene	EPA 625	Pass		
WP Base/Neutrals	711	5505	Acenaphthylene	EPA 625	Pass		
Base Neutral Extractables	4200	5545	Aniline	EPA 625	Pass		
WP Base/Neutrals	711	5545	Aniline	EPA 625	Pass		
Base Neutral Extractables	4200	5555	Anthracene	EPA 625	Pass		
PAH-GC & GCMS	4880	5555	Anthracene	EPA 625	Pass		
WP Base/Neutrals	711	5555	Anthracene	EPA 625	Pass		
Base Neutral Extractables	4200	5595	Benzidine	EPA 625	Pass		
WP Base/Neutrals	711	5595	Benzidine	EPA 625	Pass		
Base Neutral Extractables	4200	5575	Benzo(a)anthracene	EPA 625	Pass		
PAH-GC & GCMS	4880	5575	Benzo(a)anthracene	EPA 625	Pass		
WP Base/Neutrals	711	5575	Benzo(a)anthracene	EPA 625	Pass		
Base Neutral Extractables	4200	5580	Benzo(a)pyrene	EPA 625	Pass		
PAH-GC & GCMS	4880	5580	Benzo(a)pyrene	EPA 625	Pass		
WP Base/Neutrals	711	5580	Benzo(a)pyrene	EPA 625	Pass		
Base Neutral Extractables	4200	5585	Benzo(b)fluoranthene	EPA 625	Pass		
PAH-GC & GCMS	4880	5585	Benzo(b)fluoranthene	EPA 625	Pass		
WP Base/Neutrals	711	5585	Benzo(b)fluoranthene	EPA 625	Pass		
Base Neutral Extractables	4200	5590	Benzo(g,h,i)perylene	EPA 625	Pass		
PAH-GC & GCMS	4880	5590	Benzo(g,h,i)perylene	EPA 625	Pass		
WP Base/Neutrals	711	5590	Benzo(g,h,i)perylene	EPA 625	Pass		
Base Neutral Extractables	4200	5600	Benzo(k)fluoranthene	EPA 625	Pass		
PAH-GC & GCMS	4880	5600	Benzo(k)fluoranthene	EPA 625	Pass		
WP Base/Neutrals	711	5600	Benzo(k)fluoranthene	EPA 625	Pass		
Acid Extractables	4190	5610	Benzoic Acid	EPA 625	Pass		
Acids	712	5610	Benzoic acid	EPA 625	Pass		
Base Neutral Extractables	4200	5630	Benzyl alcohol	EPA 625	Pass		
WP Base/Neutrals	711	5630	Benzyl alcohol	EPA 625	Pass		
Base Neutral Extractables	4200	5670	Benzyl butyl phthalate	EPA 625	Pass		
Base Neutral Extractables	4200	5760	bis(2-Chloroethoxy) methane	EPA 625	Pass		
WP Base/Neutrals	711	5760	bis(2-Chloroethoxy) methane	EPA 625	Pass		
Base Neutral Extractables	4200	5765	bis(2-Chloroethyl) ether	EPA 625	Pass		
WP Base/Neutrals	711	5765	bis(2-Chloroethyl) ether	EPA 625	Pass		
Base Neutrals Extractables	4200	5780	bis(2-Chloroisopropyl) ether	EPA 625	Pass		
WP Base/Neutrals	711	5780	bis(2-Chloroisopropyl) ether	EPA 625	Pass		
Base Neutral Extractables	4200	6255	bis(2-Ethylhexyl) phthalate	EPA 625	Pass		
WP Base/Neutrals	711	6255	bis(2-Ethylhexyl) phthalate	EPA 625	Pass		
WP Base/Neutrals	711	5670	Butylbenzylphthalate	EPA 625	Pass		
Base Neutral Extractables	4200	5680	Carbazole	EPA 625	Pass		
WP Base/Neutrals	711	5680	Carbazole	EPA 625	Pass		
Base Neutral Extractables	4200	5855	Chrysene	EPA 625	Pass		
PAH-GC & GCMS	4880	5855	Chrysene	EPA 625	Pass		
WP Base/Neutrals	711	5855	Chrysene	EPA 625	Pass		
Base Neutrals Extractables	4200	5895	Dibenz(a,h) anthracene	EPA 625	Pass		
PAH-GC & GCMS	4880	5895	Dibenz(a,h) anthracene	EPA 625	Pass		
WP Base/Neutrals	711	5895	Dibenz(a,h) anthracene	EPA 625	Pass		
Base Neutral Extractables	4200	5905	Dibenzofuran	EPA 625	Pass		
WP Base/Neutrals	711	5905	Dibenzofuran	EPA 625	Pass		
Base Neutral Extractables	4200	6070	Diethyl phthalate	EPA 625	Pass		
WP Base/Neutrals	711	6070	Diethylphthalate	EPA 625	Pass		
Base Neutral Extractables	4200	6135	Dimethyl phthalate	EPA 625	Pass		
WP Base/Neutrals	711	6135	Dimethyl phthalate	EPA 625	Pass		
Base Neutral Extractables	4200	5925	Di-n-butylphthalate	EPA 625	Pass		
WP Base/Neutrals	711	5925	Di-n-butylphthalate	EPA 625	Pass		
Base Neutral Extractables	4200	6200	Di-n-octylphthalate	EPA 625	Pass		
WP Base/Neutrals	711	6200	Di-n-octylphthalate	EPA 625	Pass		
Base Neutral Extractables	4200	6265	Fluoranthene	EPA 625	Pass		
PAH-GC & GCMS	4880	6265	Fluoranthene	EPA 625	Pass		
WP Base/Neutrals	711	6265	Fluoranthene	EPA 625	Pass		
Base Neutral Extractables	4200	6270	Fluorene	EPA 625	Pass		
PAH-GC & GCMS	4880	6270	Fluorene	EPA 625	Pass		
WP Base/Neutrals	711	6270	Fluorene	EPA 625	Pass		
Base Neutral Extractables	4200	6275	Hexachlorobenzene	EPA 625	Pass		
WP Base/Neutrals	711	6275	Hexachlorobenzene	EPA 625	Pass		
Base Neutral Extractables	4200	4835	Hexachlorobutadiene	EPA 625	Pass		
WP Base/Neutrals	711	4835	Hexachlorobutadiene	EPA 625	Pass		
Base Neutral Extractables	4200	6285	Hexachlorocyclopentadiene	EPA 625	Pass		
WP Base/Neutrals	711	6285	Hexachlorocyclopentadiene	EPA 625	Pass		
Base Neutral Extractables	4200	4840	Hexachloroethane	EPA 625	Pass		
WP Base/Neutrals	711	4840	Hexachloroethane	EPA 625	Pass		
Base Neutral Extractables	4200	6315	Indeno (1,2,3-cd) pyrene	EPA 625	Pass		
PAH-GC & GCMS	4880	6315	Indeno (1,2,3-cd) pyrene	EPA 625	Pass		
WP Base/Neutrals	711	6315	Indeno (1,2,3-cd) pyrene	EPA 625	Pass		
WP Base/Neutrals	711	6320	Isophorone	EPA 625	Pass		
Base Neutral Extractables	4200	6320	Isophorone	EPA 625	Pass		
Base Neutral Extractables	4200	5005	Naphthalene	EPA 625	Pass		
PAH-GC & GCMS	4880	5005	Naphthalene	EPA 625	Pass		
WP Base/Neutrals	711	5005	Naphthalene	EPA 625	Pass		
WP Base/Neutrals	711	5015	Nitrobenzene	EPA 625	Pass		
Base Neutral Extractables	4200	5015	Nitrobenzene (NB)	EPA 625	Pass		
Base Neutral Extractables	4200	6530	N-nitrosodimethylamine	EPA 625	Pass		
WP Base/Neutrals	711	6530	N-Nitrosodimethylamine	EPA 625	Pass		
Base Neutral Extractables	4200	6545	N-Nitroso-di-n-propylamine	EPA 625	Pass		
WP Base/Neutrals	711	6545	N-Nitroso-di-n-propylamine	EPA 625	Pass		
Base Neutral Extractables	4200	6535	N-nitrosodiphenylamine	EPA 625	Pass		
WP Base/Neutrals	711	6535	N-Nitrosodiphenylamine	EPA 625	Pass		
Acid Extractables	4190	6605	Pentachlorophenol	EPA 625	Pass		
Acids	712	6605	Pentachlorophenol	EPA 625	Pass		
Acid Extractables	4190	6605	Pentachlorophenol	EPA 625	Pass		
Base Neutral Extractables	4200	6615	Phenanthrene	EPA 625	Pass		
PAH-GC & GCMS	4880	6615	Phenanthrene	EPA 625	Pass		

WP Base/Neutrals	711	6615	Phenanthrene	EPA 625	Pass	
Acid Extractables	4190	6625	Phenol	EPA 625	Pass	
Acids	712	6625	Phenol	EPA 625	Pass	
Base Neutral Extractables	4200	6665	Pyrene	EPA 625	Pass	
PAH-GC & GCMS	4880	6665	Pyrene	EPA 625	Pass	
WP Base/Neutrals	711	6665	Pyrene	EPA 625	Pass	
Base Neutral Extractables	4200	5095	Pyridine	EPA 625	Pass	
WP Base/Neutrals	711	5095	Pyridine	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5500	Acenaphthene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5505	Acenaphthylene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5555	Anthracene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5575	Benzo(a)anthracene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5580	Benzo(a)pyrene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5585	Benzo(b)fluoranthene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5601	Benzo(b+k)fluoranthene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5590	Benzo(g,h,i)perylene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5600	Benzo(k)fluoranthene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5855	Chrysene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5895	Dibenz(a,h) anthracene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	6265	Fluoranthene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	6270	Fluorene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	6315	Indeno (1,2,3-cd) pyrene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	5005	Naphthalene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	6615	Phenanthrene	EPA 625	Pass	
Base/Neutrals 1	PEO-121-1	6665	Pyrene	EPA 625	Pass	
WP Perchlorate	55116	1895	Perchlorate	EPA 6850	Pass	
WP Hexavalent Chromium	55096	1045	Chromium VI	EPA 7196A	Pass	
Hexavalent Chromium	4180	1045	Chromium, Hexavalent	EPA 7196A	Pass	
WP Hexavalent Chromium	55096	1045	Chromium VI	EPA 7199	Pass	
Hexavalent Chromium	4180	1045	Chromium, Hexavalent	EPA 7199	Pass	
Trace Metals	4070	1095	Mercury	EPA 7470A	Pass	
WP & DMRQA Trace Elements	55024	1095	Mercury	EPA 7470A	Pass	
Trace Metals 1	PEI-034-1	1095	Mercury, Hg	EPA 7470A	Pass	
PT Diesel Fuel #2 in Water	38114	9369	#2 Fuel Oil (Diesel)	EPA 8015B	Pass	
Diesel Range Organics (DRO)	4830	9369	Diesel Range Organics (DRO)	EPA 8015B	Pass	
Gasoline Range Organics (GRO)	4840	9408	Gasoline Range Organics	EPA 8015B	Pass	
PT Unleaded Gasoline in Water	38116	9408	Unleaded Gasoline 93 Octane	EPA 8015B	Pass	
BTEX	4230	4375	Benzene	EPA 8021B	Pass	
BTEX & MTBE in Water	643	4375	Benzene	EPA 8021B	Pass	
BTEX	4230	4765	Ethylbenzene	EPA 8021B	Pass	
BTEX & MTBE in Water	643	4765	Ethylbenzene	EPA 8021B	Pass	
BTEX	4230	5000	Methyl-t-butylether (MTBE)	EPA 8021B	Pass	
BTEX & MTBE in Water	643	5000	tert-Butyl methyl ether (MTBE)	EPA 8021B	Pass	
BTEX	4230	5140	Toluene	EPA 8021B	Pass	
BTEX & MTBE in Water	643	5140	Toluene	EPA 8021B	Pass	
BTEX	4230	5260	Total Xylenes	EPA 8021B	Pass	
BTEX & MTBE in Water	643	5260	Xylenes, total	EPA 8021B	Pass	
Pesticides (WP)	4460	7355	4,4'-DDD	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7355	4,4'-DDD	EPA 8081A	Pass	
Pesticides (WP)	4460	7360	4,4'-DDE	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7360	4,4'-DDE	EPA 8081A	Pass	
Pesticides (WP)	4460	7365	4,4'-DDT	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7365	4,4'-DDT	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7810	4,4'-Methoxychlor	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7110	a-BHC	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7240	a-Chlordane	EPA 8081A	Pass	
Pesticides (WP)	4460	7025	Aldrin	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7025	Aldrin	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7110	alpha-BHC	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7240	alpha-Chlordane	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7115	b-BHC	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7115	beta-BHC	EPA 8081A	Pass	
WP Pesticide Amp 3	38047	7250	Chlordane (total)	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7105	d-BHC	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7105	delta-BHC	EPA 8081A	Pass	
Pesticides (WP)	4460	7470	Dieldrin	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7470	Dieldrin	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7510	Endosulfan I	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7515	Endosulfan II	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7515	Endosulfan II	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7520	Endosulfan sulfate	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7520	Endosulfan sulfate	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7540	Endrin	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7540	Endrin	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7530	Endrin aldehyde	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7530	Endrin aldehyde	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7535	Endrin Ketone	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7535	Endrin ketone	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7120	gamma-BHC (Lindane)	EPA 8081A	Pass	
Pesticides (NELAC)	4470	7120	gamma-BHC (Lindane)	EPA 8081A	Pass	
Pesticides (NELAC)	4470	7245	gamma-Chlordane	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7245	gamms-Chlordane	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7120	g-BHC (Lindane)	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7245	g-Chlordane	EPA 8081A	Pass	
Pesticides (WP)	4460	7685	Heptachlor	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7685	Heptachlor	EPA 8081A	Pass	
Pesticides (WP)	4460	7690	Heptachlor epoxide	EPA 8081A	Pass	
WP Organochlorine Pesticides	38122	7690	Heptachlor epoxide	EPA 8081A	Pass	
Pesticides (NELAC)	4460	7810	Methoxychlor	EPA 8081A	Pass	
Total Chlordane	4160	7250	Total Chlordane	EPA 8081A	Pass	
Toxaphene	4270	8250	Toxaphene	EPA 8081A	Pass	

WP Acrolein & Acrylonitrile	38123	8250	Toxaphene	EPA 8081A	Pass
WP PCBs in Water	38091	8880	Aroclor 1016	EPA 8082	Pass
WP PCBs in Water	38094	8880	Aroclor 1016	EPA 8082	Pass
WP PCBs in Water	832S	8880	Aroclor 1016	EPA 8082	Pass
PCBs in Oil	4140	8880	Aroclor 1016 in Oil	EPA 8082	Pass
PCBs in Water	4130	8880	Aroclor 1016 Sample 1	EPA 8082	Pass
PCBs in Water	4130	8880	Aroclor 1016 Sample 2	EPA 8082	Pass
PCBs in Water	PEO-020	8912	Aroclor 1016/1242	EPA 8082	Pass
PCBs in Water	832S	8885	Aroclor 1221	EPA 8082	Pass
WP PCBs in Water	38091	8885	Aroclor 1221	EPA 8082	Pass
WP PCBs in Water	38094	8885	Aroclor 1221	EPA 8082	Pass
PCBs in Oil	4140	8885	Aroclor 1221 in Oil	EPA 8082	Pass
WP PCBs in Water	38091	8890	Aroclor 1232	EPA 8082	Pass
WP PCBs in Water	38094	8890	Aroclor 1232	EPA 8082	Pass
WP PCBs in Water	832S	8890	Aroclor 1232	EPA 8082	Pass
PCBs in Oil	4140	8890	Aroclor 1232 in Oil	EPA 8082	Pass
PCBs in Water	4130	8890	Aroclor 1232 Sample 1	EPA 8082	Pass
WP PCBs in Water	832S	8895	Aroclor 1242	EPA 8082	Pass
WP PCBs in Water	38091	8895	Aroclor 1242	EPA 8082	Pass
WP PCBs in Water	38094	8895	Aroclor 1242	EPA 8082	Pass
PCBs in Oil	4140	8895	Aroclor 1242 in Oil	EPA 8082	Pass
PCBs in Water	4130	8895	Aroclor 1242 Sample 1	EPA 8082	Pass
PCBs in Water	4130	8895	Aroclor 1242 Sample 2	EPA 8082	Pass
WP PCBs in Water	38091	8900	Aroclor 1248	EPA 8082	Pass
WP PCBs in Water	38094	8900	Aroclor 1248	EPA 8082	Pass
PCBs in Oil	4140	8900	Aroclor 1248 in Oil	EPA 8082	Pass
PCBs in Water	4130	8900	Aroclor 1248 Sample 1	EPA 8082	Pass
PCBs in Water	4130	8900	Aroclor 1248 Sample 2	EPA 8082	Pass
WP PCBs in Water	38091	8905	Aroclor 1254	EPA 8082	Pass
WP PCBs in Water	38094	8905	Aroclor 1254	EPA 8082	Pass
PCBs in Oil	4140	8905	Aroclor 1254 in Oil	EPA 8082	Pass
PCBs in Water	4130	8905	Aroclor 1254 Sample 1	EPA 8082	Pass
PCBs in Water	4130	8905	Aroclor 1254 Sample 2	EPA 8082	Pass
WP PCBs in Water	38091	8910	Aroclor 1260	EPA 8082	Pass
WP PCBs in Water	38094	8910	Aroclor 1260	EPA 8082	Pass
WP PCBs in Water	832S	8910	Aroclor 1260	EPA 8082	Pass
PCBs in Water	4130	8910	Aroclor 1260 Sample 1	EPA 8082	Pass
PCBs in Water	4130	8910	Aroclor 1260 Sample 2	EPA 8082	Pass
PCBs in Water	PEO-020	8880	Aroclor-1016 (PCB-1016)	EPA 8082	Pass
PCBs in Water	PEO-020	8885	Aroclor-1221 (PCB-1221)	EPA 8082	Pass
PCBs in Water	PEO-020	8890	Aroclor-1232 (PCB-1232)	EPA 8082	Pass
PCBs in Water	PEO-020	8895	Aroclor-1242 (PCB-1242)	EPA 8082	Pass
PCBs in Water	PEO-020	8900	Aroclor-1248 (PCB-1248)	EPA 8082	Pass
PCBs in Water	PEO-020	8905	Aroclor-1254 (PCB-1254)	EPA 8082	Pass
PCBs in Water	PEO-020	8910	Aroclor-1260 (PCB-1260)	EPA 8082	Pass
WP PCBs in Transformer Oil	38092	8880	PCB in Oil 1016 or 1242	EPA 8082	Pass
WP PCBs in Water	38094	8880	PCB in Oil 1016 or 1242	EPA 8082	Pass
WP PCBs in Transformer Oil	38092	8905	PCB in Oil 1254	EPA 8082	Pass
WP PCBs in Water	38094	8905	PCB in Oil 1254	EPA 8082	Pass
WP PCBs in Transformer Oil	38092	8910	PCB in Oil 1260	EPA 8082	Pass
WP PCBs in Water	38094	8910	PCB in Oil 1260	EPA 8082	Pass
OP Pesticides/Herbicides	4810	7075	Azinphos-methyl	EPA 8141A	Pass
WP Organophosphorous Pesticides	38135	7075	Azinphosmethyl (Guthion)	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7300	Chlorpyrifos	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7390	Demeton O&S	EPA 8141A	Pass
WP Organophosphorous Pesticides	38135	7390	Demeton, (Mix of Isomers O:S [35%:56%])	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7410	Diazinon	EPA 8141A	Pass
WP Organophosphorous Pesticides	38135	7410	Diazinon	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	8610	Dichlorvos (DDVP)	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7475	Dimethoate	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	8625	Disulfoton	EPA 8141A	Pass
WP Organophosphorous Pesticides	38135	8625	Disulfoton	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7565	Ethion	EPA 8141A	Pass
WP Organophosphorous Pesticides	38135	7565	Ethion	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7570	Ethoprop	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7580	Famphur	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7770	Malathion	EPA 8141A	Pass
WP Organophosphorous Pesticides	38135	7770	Malathion	EPA 8141A	Pass
WP Organophosphorous Pesticides	38135	7955	Parathion ethyl	EPA 8141A	Pass
WP Organophosphorous Pesticides	38135	7825	Parathion methyl	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7955	Parathion, ethyl	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7825	Parathion, methyl	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	7985	Phorate	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	8000	Phosmet	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	8110	Ronnel	EPA 8141A	Pass
OP Pesticides/Herbicides	4810	8200	Stirophos (Tetrachlorvinphos)	EPA 8141A	Pass
Herbicides	4440	8655	2,4,5-T	EPA 8151A	Pass
WP Herbicide Acid Mix #2	38136	8655	2,4,5-T	EPA 8151A	Pass
Herbicides	4440	8650	2,4,5-TP (Silvex)	EPA 8151A	Pass
Herbicides	4440	8545	2,4-D	EPA 8151A	Pass
WP Acrolein & Acrylonitrile	38123	8545	2,4-D (2,4-Dichlorophenoxyacetic acid)	EPA 8151A	Pass
Herbicides	4440	8560	2,4-DB	EPA 8151A	Pass
WP Herbicide Acid Mix #2	38136	8560	2,4-DB	EPA 8151A	Pass
Herbicides	4440	8600	3,5-Dichlorobenzoic acid	EPA 8151A	Pass
WP Herbicide Acid Mix #2	38136	8600	3,5-Dichlorobenzoic acid	EPA 8151A	Pass
Herbicides	4440	6500	4-Nitrophenol	EPA 8151A	Pass
WP Herbicide Acid Mix #2	38136	6500	4-Nitrophenol	EPA 8151A	Pass
Herbicides	4440	8505	Acifluorfen	EPA 8151A	Pass
WP Acrolein & Acrylonitrile	38123	8505	Acifluorfen	EPA 8151A	Pass
Herbicides	4440	8530	Bentazon	EPA 8151A	Pass
WP Herbicide Acid Mix #2	38136	8530	Bentazon	EPA 8151A	Pass

Herbicides	4440	8540	Chloramben	EPA 8151A	Pass	
Herbicides	4440	8550	Daclhal diacid (DCPA)	EPA 8151A	Pass	
Herbicides	4440	8555	Dalapon	EPA 8151A	Pass	
WP Acrolein & Acrylonitrile	38123	8555	Dalapon	EPA 8151A	Pass	
Herbicides	4440	8595	Dicamba	EPA 8151A	Pass	
WP Acrolein & Acrylonitrile	38123	8595	Dicamba	EPA 8151A	Pass	
Herbicides	4440	8605	Dichloroprop	EPA 8151A	Pass	
WP Herbicide Acid Mix #2	38136	8605	Dichloroprop	EPA 8151A	Pass	
Herbicides	4440	8620	Dinoseb	EPA 8151A	Pass	
WP Acrolein & Acrylonitrile	38123	8620	Dinoseb (2-sec-Butyl-4,6-dinitrophenol)	EPA 8151A	Pass	
Herbicides	4440	7775	MCPA	EPA 8151A	Pass	
Herbicides	4440	7780	MCPP	EPA 8151A	Pass	
Herbicides	4440	6605	Pentachlorophenol	EPA 8151A	Pass	
WP Acrolein & Acrylonitrile	38123	6605	Pentachlorophenol	EPA 8151A	Pass	
Herbicides	4440	8645	Picloram	EPA 8151A	Pass	
WP Acrolein & Acrylonitrile	38123	8645	Picloram	EPA 8151A	Pass	
WP Acrolein & Acrylonitrile	38123	8650	Silvex (2,4,5-TP)	EPA 8151A	Pass	
Volatile Organic Compounds 3B	PEO-120-3B	5105	1,1,1,2-Tetrachloroethane	EPA 8260B	Pass	
Volatiles	4170	5105	1,1,1,2-Tetrachloroethane	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5105	1,1,1,2-Tetrachloroethane	EPA 8260B	Pass	
Volatile Organic Compounds 2	PEO-120-2	5160	1,1,1-Trichloroethane	EPA 8260B	Pass	
Volatiles	4170	5160	1,1,1-Trichloroethane	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5160	1,1,1-Trichloroethane	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	5110	1,1,2,2-Tetrachloroethane	EPA 8260B	Pass	
Volatiles	4170	5110	1,1,2,2-Tetrachloroethane	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5110	1,1,2,2-Tetrachloroethane	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	5165	1,1,2-Trichloroethane	EPA 8260B	Pass	
Volatiles	4170	5165	1,1,2-Trichloroethane	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5165	1,1,2-Trichloroethane	EPA 8260B	Pass	
WP Oxygenates	38157	5185	1,1,2-Trichlorotrifluoroethane	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	4630	1,1-Dichloroethane	EPA 8260B	Pass	
Volatiles	4170	4630	1,1-Dichloroethane	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4630	1,1-Dichloroethane	EPA 8260B	Pass	
Volatiles	4170	4640	1,1-Dichloroethene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4640	1,1-Dichloroethene	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	4640	1,1-Dichloroethylene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4670	1,1-Dichloropropene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5150	1,2,3-Trichlorobenzene	EPA 8260B	Pass	
Volatile Organic Compounds 3B	PEO-120-3B	5180	1,2,3-Trichloropropane	EPA 8260B	Pass	
Volatiles	4170	5180	1,2,3-Trichloropropane	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5180	1,2,3-Trichloropropane	EPA 8260B	Pass	
Volatiles	4170	5155	1,2,4-Trichlorobenzene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5155	1,2,4-Trichlorobenzene	EPA 8260B	Pass	
Volatile Organic Compounds 1	PEO-120-1	5210	1,2,4-Trimethylbenzene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5210	1,2,4-Trimethylbenzene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4570	1,2-Dibromo-3-chloropropane	EPA 8260B	Pass	
Volatile Organic Compounds 3B	PEO-120-3B	4570	1,2-Dibromo-3-chloropropane (DBCP)	EPA 8260B	Pass	
Volatiles	4170	4570	1,2-Dibromo-3-chloropropane (DBCP)	EPA 8260B	Pass	
Volatiles	4170	4585	1,2-Dibromoethane (EDB)	EPA 8260B	Pass	
Volatile Organic Compounds 3B	PEO-120-3B	4585	1,2-Dibromoethane (EDB, Ethylene dibromide)	EPA 8260B	Pass	
Volatile Aromatics	4450	4610	1,2-Dichlorobenzene	EPA 8260B	Pass	
Volatile Organic Compounds 1	PEO-120-1	4610	1,2-Dichlorobenzene	EPA 8260B	Pass	
Volatiles	4170	4610	1,2-Dichlorobenzene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4610	1,2-Dichlorobenzene	EPA 8260B	Pass	
Volatile Organic Compounds 2	PEO-120-2	4635	1,2-Dichloroethane	EPA 8260B	Pass	
Volatiles	4170	4635	1,2-Dichloroethane	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4635	1,2-Dichloroethane	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	4655	1,2-Dichloropropane	EPA 8260B	Pass	
Volatiles	4170	4655	1,2-Dichloropropane	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4655	1,2-Dichloropropane	EPA 8260B	Pass	
Volatile Organic Compounds 1	PEO-120-1	5215	1,3,5-Trimethylbenzene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5215	1,3,5-Trimethylbenzene	EPA 8260B	Pass	
Volatile Aromatics	4450	4615	1,3-Dichlorobenzene	EPA 8260B	Pass	
Volatile Organic Compounds 1	PEO-120-1	4615	1,3-Dichlorobenzene	EPA 8260B	Pass	
Volatiles	4170	4615	1,3-Dichlorobenzene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4615	1,3-Dichlorobenzene	EPA 8260B	Pass	
Volatile Aromatics	4450	4620	1,4-Dichlorobenzene	EPA 8260B	Pass	
Volatile Organic Compounds 1	PEO-120-1	4620	1,4-Dichlorobenzene	EPA 8260B	Pass	
Volatiles	4170	4620	1,4-Dichlorobenzene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4620	1,4-Dichlorobenzene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4665	2,2-Dichloropropane	EPA 8260B	Pass	
WP Ketones	38134	4410	2-Butanone	EPA 8260B	Pass	
Volatiles	4170	4410	2-Butanone (Methyl ethyl ketone)	EPA 8260B	Pass	
Volatile Organic Compounds 3B	PEO-120-3B	4410	2-Butanone (Methyl ethyl ketone, MEK)	EPA 8260B	Pass	
Volatile Organic Compounds 3B	PEO-120-3B	4500	2-Chloroethyl vinyl ether	EPA 8260B	Pass	
Volatiles	4170	4500	2-Chloroethyl vinyl ether	EPA 8260B	Pass	
WP 2-Chloroethyl vinyl ether	38128	4500	2-Chloroethyl vinyl ether	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4535	2-Chlorotoluene	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	4860	2-Hexanone	EPA 8260B	Pass	
Volatiles	4170	4860	2-Hexanone	EPA 8260B	Pass	
WP Ketones	38134	4860	2-Hexanone	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4540	4-Chlorotoluene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4995	4-Methyl-2-pentanone	EPA 8260B	Pass	
WP Ketones	38134	4995	4-Methyl-2-pentanone	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	4995	4-Methyl-2-pentanone (MIBK)	EPA 8260B	Pass	
Volatiles	4170	4995	4-Methyl-2-pentanone (MIBK)	EPA 8260B	Pass	
Volatile Organic Compounds 3B	PEO-120-3B	4315	Acetone	EPA 8260B	Pass	
Volatiles	4170	4315	Acetone	EPA 8260B	Pass	
WP Ketones	38134	4315	Acetone	EPA 8260B	Pass	
Volatile Organic Compounds 3B	PEO-120-3B	4320	Acetonitrile	EPA 8260B	Pass	
Volatiles	4170	4325	Acrolein	EPA 8260B	Pass	

WP Acrolein & Acrylonitrile	38123	4325	Acrolein	EPA 8260B	Pass
Volatile Organic Compounds 3B	PEO-120-3B	4325	Acrolein (Propenal)	EPA 8260B	Pass
Volatile Organic Compounds 3B	PEO-120-3B	4340	Acrylonitrile	EPA 8260B	Pass
Volatiles	4170	4340	Acrylonitrile	EPA 8260B	Pass
WP Acrolein & Acrylonitrile	38123	4340	Acrylonitrile	EPA 8260B	Pass
CWA BTEX & MTBE	38166	4375	Benzene	EPA 8260B	Pass
Volatile Aromatics	4450	4375	Benzene	EPA 8260B	Pass
Volatile Organic Compounds 1	PEO-120-1	4375	Benzene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4375	Benzene	EPA 8260B	Pass
Volatiles	4170	4375	Beznene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4385	Bromobenzene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4390	Bromochloromethane	EPA 8260B	Pass
Volatile Organic Compounds 2	PEO-120-2	4395	Bromodichloromethane	EPA 8260B	Pass
Volatiles	4170	4395	Bromodichloromethane	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4395	Bromodichloromethane	EPA 8260B	Pass
Volatile Organic Compounds 2	PEO-120-2	4400	Bromoform	EPA 8260B	Pass
Volatiles	4170	4400	Bromoform	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4400	Bromoform	EPA 8260B	Pass
Volatiles	4170	4950	Bromomethane	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4950	Bromomethane	EPA 8260B	Pass
Volatiles	4170	4450	Carbon disulfide	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4450	Carbon disulfide	EPA 8260B	Pass
Volatile Organic Compounds 2	PEO-120-2	4455	Carbon tetrachloride	EPA 8260B	Pass
Volatiles	4170	4455	Carbon tetrachloride	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4455	Carbon tetrachloride	EPA 8260B	Pass
Volatile Organic Compounds 2	PEO-120-2	4475	Chlorobenzene	EPA 8260B	Pass
Volatiles	4170	4475	Chlorobenzene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4475	Chlorobenzene	EPA 8260B	Pass
Volatile Organic Compounds 3A	PEO-120-3A	4485	Chloroethane	EPA 8260B	Pass
Volatiles	4170	4485	Chloroethane	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4485	Chloroethane	EPA 8260B	Pass
Volatile Organic Compounds 2	PEO-120-2	4505	Chloroform	EPA 8260B	Pass
Volatiles	4170	4505	Chloroform	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4505	Chloroform	EPA 8260B	Pass
Volatiles	4170	4960	Chloromethane	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4960	Chloromethane	EPA 8260B	Pass
Volatiles	4170	4645	cis-1,2-Dichloroethene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4645	cis-1,2-Dichloroethene	EPA 8260B	Pass
Volatile Organic Compounds 3A	PEO-120-3A	4645	cis-1,2-Dichloroethylene	EPA 8260B	Pass
Volatile Organic Compounds 3A	PEO-120-3A	4680	cis-1,3-Dichloropropene	EPA 8260B	Pass
Volatiles	4170	4680	cis-1,3-Dichloropropene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4680	cis-1,3-Dichloropropene	EPA 8260B	Pass
Volatile Organic Compounds 2	PEO-120-2	4575	Dibromochloromethane	EPA 8260B	Pass
Volatiles	4170	4575	Dibromochloromethane	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4575	Dibromochloromethane	EPA 8260B	Pass
Volatile Organic Compounds 3B	PEO-120-3B	4595	Dibromomethane	EPA 8260B	Pass
Volatiles	4170	4595	Dibromomethane	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4595	Dibromomethane	EPA 8260B	Pass
Volatiles	4170	4625	Dichlorodifluoromethane	EPA 8260B	Pass
Volatile Organic Compounds 3B	PEO-120-3B	4625	Dichlorodifluoromethane	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4625	Dichlorodifluoromethane	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4765	Ethyl benzene	EPA 8260B	Pass
CWA BTEX & MTBE	38166	4765	Ethylbenzene	EPA 8260B	Pass
Volatile Aromatics	4450	4765	Ethylbenzene	EPA 8260B	Pass
Volatile Organic Compounds 1	PEO-120-1	4765	Ethylbenzene	EPA 8260B	Pass
Volatiles	4170	4765	Ethylbenzene	EPA 8260B	Pass
Volatiles	4170	4835	Hexachlorobutadiene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4835	Hexachlorobutadiene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4840	Hexachloroethane	EPA 8260B	Pass
WP Oxygenates	38157	9375	Isopropyl ether (DIPE)	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4900	Isopropylbenzene	EPA 8260B	Pass
Volatile Organic Compounds 1	PEO-120-1	5240	m+p-Xylene	EPA 8260B	Pass
Volatile Organic Compounds 3A	PEO-120-3A	4950	Methyl bromide (Bromomethane)	EPA 8260B	Pass
Volatile Organic Compounds 3A	PEO-120-3A	4960	Methyl chloride (Chloromethane)	EPA 8260B	Pass
CWA BTEX & MTBE	38166	5000	Methyl tert-butyl ether (MTBE)	EPA 8260B	Pass
Volatile Organic Compounds 1	PEO-120-1	5000	Methyl tert-butyl ether (MTBE)	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	5000	Methyl tert-butyl ether (MTBE)	EPA 8260B	Pass
WP Oxygenates	38157	5000	Methyl tert-butyl ether (MTBE)	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4975	Methylene chloride	EPA 8260B	Pass
Volatile Organic Compounds 2	PEO-120-2	4975	Methylene chloride (Dichloromethane)	EPA 8260B	Pass
Volatiles	4170	4975	Methylene chloride (Dichloromethane)	EPA 8260B	Pass
Volatiles	4170	5000	Methyl-t-butylether (MTBE)	EPA 8260B	Pass
Volatile Organic Compounds 1	PEO-120-1	5005	Naphthalene	EPA 8260B	Pass
Volatiles	4170	5005	Naphthalene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	5005	Naphthalene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4435	n-Butyl benzene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	5090	n-Propylbenzene	EPA 8260B	Pass
WP Oxygenates	38157	5090	n-Propylbenzene	EPA 8260B	Pass
Volatile Organic Compounds 1	PEO-120-1	5250	o-Xylene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4910	p-Isopropyl toluene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4440	sec-Butyl benzene	EPA 8260B	Pass
Volatile Organic Compounds 3A	PEO-120-3A	5100	Styrene	EPA 8260B	Pass
Volatiles	4170	5100	Styrene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	5100	Styrene	EPA 8260B	Pass
WP Oxygenates	38157	4370	tert-Amyl methyl ether (TAME)	EPA 8260B	Pass
WP Oxygenates	38157	4420	tert-Butyl alcohol (t-Butanol)	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	4445	tert-Butyl benzene	EPA 8260B	Pass
WP Oxygenates	38157	4770	tert-Butyl ethyl ether (ETBE)	EPA 8260B	Pass
Volatiles	4170	5115	Tetrachloroethene	EPA 8260B	Pass
Volatiles in Non-Potable Water	38083	5115	Tetrachloroethene	EPA 8260B	Pass
Volatile Organic Compounds 2	PEO-120-2	5115	Tetrachloroethylene (Perchloroethylene)	EPA 8260B	Pass

CWA BTEX & MTBE	38166	5140	Toluene	EPA 8260B	Pass	
Volatile Aromatics	4450	5140	Toluene	EPA 8260B	Pass	
Volatile Organic Compounds 1	PEO-120-1	5140	Toluene	EPA 8260B	Pass	
Volatiles	4170	5140	Toluene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5140	Toluene	EPA 8260B	Pass	
CWA BTEX & MTBE	38166	5260	Total Xylenes	EPA 8260B	Pass	
Volatile Aromatics	4450	5260	Total Xylenes	EPA 8260B	Pass	
Volatiles	4170	5260	Total Xylenes	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5260	Total Xylenes	EPA 8260B	Pass	
Volatiles	4170	4700	trans-1,2-Dichloroethene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4700	trans-1,2-Dichloroethene	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	4700	trans-1,2-Dichloroethylene	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	4685	trans-1,3-Dichloropropene	EPA 8260B	Pass	
Volatiles	4170	4685	trans-1,3-Dichloropropene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	4685	trans-1,3-Dichloropropene	EPA 8260B	Pass	
Volatiles	4170	5170	Trichloroethene	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5170	Trichloroethene	EPA 8260B	Pass	
Volatile Organic Compounds 2	PEO-120-2	5170	Trichloroethene (Trichloroethylene)	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	5175	Trichlorofluoromethane	EPA 8260B	Pass	
Volatiles	4170	5175	Trichlorofluoromethane	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5175	Trichlorofluoromethane	EPA 8260B	Pass	
Volatile Organic Compounds 3B	PEO-120-3B	5225	Vinyl acetate	EPA 8260B	Pass	
Volatiles	4170	5225	Vinyl acetate	EPA 8260B	Pass	
Volatile Organic Compounds 3A	PEO-120-3A	5235	Vinyl chloride	EPA 8260B	Pass	
Volatiles	4170	5235	Vinyl chloride	EPA 8260B	Pass	
Volatiles in Non-Potable Water	38083	5235	Vinyl chloride	EPA 8260B	Pass	
Volatile Organic Compounds 1	PEO-120-1	5260	Xylene, total	EPA 8260B	Pass	
Base Neutral Extractables	4200	6715	1,2,4,5-Tetrachlorobenzene	EPA 8270C	Pass	
Base Neutral Extractables	4200	5155	1,2,4-Trichlorobenzene	EPA 8270C	Pass	
WP Base/Neutrals	711	5155	1,2,4-Trichlorobenzene	EPA 8270C	Pass	
Base Neutral Extractables	4200	4610	1,2-Dichlorobenzene	EPA 8270C	Pass	
WP Base/Neutrals	711	4610	1,2-Dichlorobenzene	EPA 8270C	Pass	
Base Neutral Extractables	4200	4615	1,3-Dichlorobenzene	EPA 8270C	Pass	
WP Base/Neutrals	711	4615	1,3-Dichlorobenzene	EPA 8270C	Pass	
Base Neutral Extractables	4200	4620	1,4-Dichlorobenzene	EPA 8270C	Pass	
WP Base/Neutrals	711	4620	1,4-Dichlorobenzene	EPA 8270C	Pass	
Acid Extractables	4190	6735	2,3,4,6-Tetrachlorophenol	EPA 8270C	Pass	
Acids	712	6735	2,3,4,6-Tetrachlorophenol	EPA 8270C	Pass	
Acid Extractables	4190	6835	2,4,5-Trichlorophenol	EPA 8270C	Pass	
Acids	712	6835	2,4,5-Trichlorophenol	EPA 8270C	Pass	
Acids	712	6840	2,4,6-Trichlorophenol	EPA 8270C	Pass	
Acid Extractables	4190	6840	2,4,6-Trichlorophenol	EPA 8270C	Pass	
Acid Extractables	4190	6000	2,4-Dichlorophenol	EPA 8270C	Pass	
Acids	712	6000	2,4-Dichlorophenol	EPA 8270C	Pass	
Acid Extractables	4190	6130	2,4-Dimethylphenol	EPA 8270C	Pass	
Acids	712	6130	2,4-Dimethylphenol	EPA 8270C	Pass	
Acid Extractables	4190	6175	2,4-Dinitrophenol	EPA 8270C	Pass	
Acids	712	6175	2,4-Dinitrophenol	EPA 8270C	Pass	
WP Base/Neutrals	711	6185	2,4-Dinitrotoluene	EPA 8270C	Pass	
Base Neutral Extractables	4200	6185	2,4-Dinitrotoluene (2,4-DNT)	EPA 8270C	Pass	
Acid Extractables	4190	6005	2,6-Dichlorophenol	EPA 8270C	Pass	
Acids	712	6005	2,6-Dichlorophenol	EPA 8270C	Pass	
WP Base/Neutrals	711	6190	2,6-Dinitrotoluene	EPA 8270C	Pass	
Base Neutral Extractables	4200	6190	2,6-Dinitrotoluene (2,6-DNT)	EPA 8270C	Pass	
Base Neutral Extractables	4200	5795	2-Chloronaphthalene	EPA 8270C	Pass	
WP Base/Neutrals	711	5795	2-Chloronaphthalene	EPA 8270C	Pass	
Acid Extractables	4190	5800	2-Chlorophenol	EPA 8270C	Pass	
Acids	712	5800	2-Chlorophenol	EPA 8270C	Pass	
Acid Extractables	4190	6360	2-Methyl-4,6-Dinitrophenol	EPA 8270C	Pass	
Base Neutral Extractables	4200	6385	2-Methylnaphthalene	EPA 8270C	Pass	
WP Base/Neutrals	711	6385	2-Methylnaphthalene	EPA 8270C	Pass	
Acid Extractables	4190	6400	2-Methylphenol	EPA 8270C	Pass	
Acids	712	6400	2-Methylphenol	EPA 8270C	Pass	
WP Base/Neutrals	711	6460	2-Nitroaniline	EPA 8270C	Pass	
Base Neutral Extractables	4200	6460	2-Nitroaniline	EPA 8270C	Pass	
Acid Extractables	4190	6490	2-Nitrophenol	EPA 8270C	Pass	
Acids	712	6490	2-Nitrophenol	EPA 8270C	Pass	
Acid Extractables	4190	6410	3 & 4-Methylphenol	EPA 8270C	Pass	
Base Neutral Extractables	4200	5945	3,3'-Dichlorobenzidine	EPA 8270C	Pass	
WP Base/Neutrals	711	5945	3,3'-Dichlorobenzidine	EPA 8270C	Pass	
Acid Extractables	4190	6405	3-Methylphenol	EPA 8270C	Pass	
Base Neutral Extractables	4200	6465	3-Nitroaniline	EPA 8270C	Pass	
WP Base/Neutrals	711	6465	3-Nitroaniline	EPA 8270C	Pass	
Acids	712	6360	4,6-Dinitro-2-methylphenol	EPA 8270C	Pass	
Base Neutral Extractables	4200	5660	4-Bromophenyl phenyl ether	EPA 8270C	Pass	
WP Base/Neutrals	711	5660	4-Bromophenyl-phenylether	EPA 8270C	Pass	
Acid Extractables	4190	5700	4-Chloro-3-methylphenol	EPA 8270C	Pass	
Acids	712	5700	4-Chloro-3-methylphenol	EPA 8270C	Pass	
Base Neutral Extractables	4200	5745	4-Chloroaniline	EPA 8270C	Pass	
WP Base/Neutrals	711	5745	4-Chloroaniline	EPA 8270C	Pass	
Base Neutral Extractables	4200	5825	4-Chlorophenyl-phenylether	EPA 8270C	Pass	
WP Base/Neutrals	711	5825	4-Chlorophenyl-phenylether	EPA 8270C	Pass	
Acids	712	6410	4-Methylphenol	EPA 8270C	Pass	
Base Neutral Extractables	4200	6470	4-Nitroaniline	EPA 8270C	Pass	
WP Base/Neutrals	711	6470	4-Nitroaniline	EPA 8270C	Pass	
Acid Extractables	4190	6500	4-Nitrophenol	EPA 8270C	Pass	
Acids	712	6500	4-Nitrophenol	EPA 8270C	Pass	
Base Neutral Extractables	4200	5500	Acenaphthene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5500	Acenaphthene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	5500	Acenaphthene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5500	Acenaphthene	EPA 8270C	Pass	

WP Base/Neutrals	711	5500	Acenaphthene	EPA 8270C	Pass	
Base Neutral Extractables	4200	5505	Acenaphthylene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5505	Acenaphthylene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	5505	Acenaphthylene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5505	Acenaphthylene	EPA 8270C	Pass	
WP Base/Neutrals	711	5505	Acenaphthylene	EPA 8270C	Pass	
Base Neutral Extractables	4200	5545	Aniline	EPA 8270C	Pass	
WP Base/Neutrals	711	5545	Aniline	EPA 8270C	Pass	
Base Neutral Extractables	4200	5555	Anthracene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5555	Anthracene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	5555	Anthracene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5555	Anthracene	EPA 8270C	Pass	
WP Base/Neutrals	711	5555	Anthracene	EPA 8270C	Pass	
Base Neutral Extractables	4200	5595	Benzidine	EPA 8270C	Pass	
WP Base/Neutrals	711	5595	Benzidine	EPA 8270C	Pass	
Base Neutral Extractables	4200	5575	Benzo(a)anthracene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5575	Benzo(a)anthracene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	5575	Benzo(a)anthracene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5575	Benzo(a)anthracene	EPA 8270C	Pass	
WP Base/Neutrals	711	5575	Benzo(a)anthracene	EPA 8270C	Pass	
Base Neutral Extractables	4200	5580	Benzo(a)pyrene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5580	Benzo(a)pyrene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5580	Benzo(a)pyrene	EPA 8270C	Pass	
WP Base/Neutrals	711	5580	Benzo(a)pyrene	EPA 8270C	Pass	
Base Neutral Extractables	4200	5585	Benzo(b)fluoranthene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5585	Benzo(b)fluoranthene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	5585	Benzo(b)fluoranthene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5585	Benzo(b)fluoranthene	EPA 8270C	Pass	
WP Base/Neutrals	711	5585	Benzo(b)fluoranthene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5601	Benzo(b+k)fluoranthene	EPA 8270C	Pass	
Base Neutral Extractables	4200	5590	Benzo(g,h,i)perylene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5590	Benzo(g,h,i)perylene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	5590	Benzo(g,h,i)perylene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5590	Benzo(g,h,i)perylene	EPA 8270C	Pass	
WP Base/Neutrals	711	5590	Benzo(g,h,i)perylene	EPA 8270C	Pass	
Base Neutral Extractables	4200	5600	Benzo(k)fluoranthene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5600	Benzo(k)fluoranthene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	5600	Benzo(k)fluoranthene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5600	Benzo(k)fluoranthene	EPA 8270C	Pass	
WP Base/Neutrals	711	5600	Benzo(k)fluoranthene	EPA 8270C	Pass	
Acid Extractables	4190	5610	Benzoic Acid	EPA 8270C	Pass	
Acids	712	5610	Benzoic acid	EPA 8270C	Pass	
Base Neutral Extractables	4200	5630	Benzyl alcohol	EPA 8270C	Pass	
WP Base/Neutrals	711	5630	Benzyl alcohol	EPA 8270C	Pass	
Base Neutral Extractables	4200	5670	Benzyl butyl phthalate	EPA 8270C	Pass	
Base Neutral Extractables	4200	5760	bis(2-Chloroethoxy) methane	EPA 8270C	Pass	
WP Base/Neutrals	711	5760	bis(2-Chloroethoxy) methane	EPA 8270C	Pass	
Base Neutral Extractables	4200	5765	bis(2-Chloroethyl) ether	EPA 8270C	Pass	
WP Base/Neutrals	711	5765	bis(2-Chloroethyl) ether	EPA 8270C	Pass	
Base Neutrals Extractables	4200	5780	bis(2-Chloroisopropyl) ether	EPA 8270C	Pass	
WP Base/Neutrals	711	5780	bis(2-Chloroisopropyl) ether	EPA 8270C	Pass	
Base Neutral Extractables	4200	6255	bis(2-Ethylhexyl) phthalate	EPA 8270C	Pass	
WP Base/Neutrals	711	6255	bis(2-Ethylhexyl) phthalate	EPA 8270C	Pass	
WP Base/Neutrals	711	5670	Butylbenzylphthalate	EPA 8270C	Pass	
Base Neutral Extractables	4200	5680	Carbazole	EPA 8270C	Pass	
WP Base/Neutrals	711	5680	Carbazole	EPA 8270C	Pass	
Base Neutral Extractables	4200	5855	Chrysene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5855	Chrysene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	5855	Chrysene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5855	Chrysene	EPA 8270C	Pass	
WP Base/Neutrals	711	5855	Chrysene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	5895	Dibenz(a,h) anthracene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	5895	Dibenz(a,h) anthracene	EPA 8270C	Pass	
WP Base/Neutrals	711	5895	Dibenz(a,h) anthracene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	5895	Dibenz(a,h) anthracene	EPA 8270C	Pass	
Base Neutral Extractables	4200	5905	Dibenzofuran	EPA 8270C	Pass	
WP Base/Neutrals	711	5905	Dibenzofuran	EPA 8270C	Pass	
Base Neutral Extractables	4200	5895	Dibenz(a,h) anthracene	EPA 8270C	Pass	
Base Neutral Extractables	4200	6070	Diethyl phthalate	EPA 8270C	Pass	
WP Base/Neutrals	711	6070	Diethylphthalate	EPA 8270C	Pass	
Base Neutral Extractables	4200	6135	Dimethyl phthalate	EPA 8270C	Pass	
WP Base/Neutrals	711	6135	Dimethyl phthalate	EPA 8270C	Pass	
Base Neutral Extractables	4200	5925	Di-n-butylphthalate	EPA 8270C	Pass	
WP Base/Neutrals	711	5925	Di-n-butylphthalate	EPA 8270C	Pass	
Base Neutral Extractables	4200	6200	Di-n-octylphthalate	EPA 8270C	Pass	
WP Base/Neutrals	711	6200	Di-n-octylphthalate	EPA 8270C	Pass	
Base Neutral Extractables	4200	6265	Fluoranthene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	6265	Fluoranthene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	6265	Fluoranthene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	6265	Fluoranthene	EPA 8270C	Pass	
WP Base/Neutrals	711	6265	Fluoranthene	EPA 8270C	Pass	
Base Neutral Extractables	4200	6270	Fluorene	EPA 8270C	Pass	
Base/Neutrals 1	PEO-121-1	6270	Fluorene	EPA 8270C	Pass	
CWA Low Level PAH Mix	38010	6270	Fluorene	EPA 8270C	Pass	
PAH-GC & GCMS	4880	6270	Fluorene	EPA 8270C	Pass	
WP Base/Neutrals	711	6270	Fluorene	EPA 8270C	Pass	
Base Neutral Extractables	4200	6275	Hexachlorobenzene	EPA 8270C	Pass	
WP Base/Neutrals	711	6275	Hexachlorobenzene	EPA 8270C	Pass	
Base Neutral Extractables	4200	4835	Hexachlorobutadiene	EPA 8270C	Pass	
WP Base/Neutrals	711	4835	Hexachlorobutadiene	EPA 8270C	Pass	
Base Neutral Extractables	4200	6285	Hexachlorocyclopentadiene	EPA 8270C	Pass	

WP Base/Neutrals	711	6295	Hexachlorocyclopentadiene	EPA 8270C	Pass
Base Neutral Extractables	4200	4840	Hexachloroethane	EPA 8270C	Pass
WP Base/Neutrals	711	4840	Hexachloroethane	EPA 8270C	Pass
CWA Low Level PAH Mix	38010	6315	Indeno (1,2,3,cd) pyrene	EPA 8270C	Pass
Base Neutral Extractables	4200	6315	Indeno (1,2,3-cd) pyrene	EPA 8270C	Pass
PAH-GC & GCMS	4880	6315	Indeno (1,2,3-cd) pyrene	EPA 8270C	Pass
Base/Neutrals 1	PEO-121-1	6315	Indeno (1,2,3-cd) pyrene	EPA 8270C	Pass
WP Base/Neutrals	711	6315	Indeno (1,2,3-cd) pyrene	EPA 8270C	Pass
WP Base/Neutrals	711	6320	Isophorone	EPA 8270C	Pass
Base Neutral Extractables	4200	6320	Isophorone	EPA 8270C	Pass
Base Neutral Extractables	4200	5005	Naphthalene	EPA 8270C	Pass
Base/Neutrals 1	PEO-121-1	5005	Naphthalene	EPA 8270C	Pass
CWA Low Level PAH Mix	38010	5005	Naphthalene	EPA 8270C	Pass
PAH-GC & GCMS	4880	5005	Naphthalene	EPA 8270C	Pass
WP Base/Neutrals	711	5005	Naphthalene	EPA 8270C	Pass
WP Base/Neutrals	711	5015	Nitrobenzene	EPA 8270C	Pass
Base Neutral Extractables	4200	5015	Nitrobenzene (NB)	EPA 8270C	Pass
Base Neutral Extractables	4200	6530	N-nitrosodimethylamine	EPA 8270C	Pass
WP Base/Neutrals	711	6530	N-Nitrosodimethylamine	EPA 8270C	Pass
Base Neutral Extractables	4200	6545	N-Nitroso-di-n-propylamine	EPA 8270C	Pass
WP Base/Neutrals	711	6545	N-Nitroso-di-n-propylamine	EPA 8270C	Pass
Base Neutral Extractables	4200	6535	N-nitrosodiphenylamine	EPA 8270C	Pass
WP Base/Neutrals	711	6535	N-Nitrosodiphenylamine	EPA 8270C	Pass
Acid Extractables	4190	6605	Pentachlorophenol	EPA 8270C	Pass
Acids	712	6605	Pentachlorophenol	EPA 8270C	Pass
Base Neutral Extractables	4200	6615	Phenanthrene	EPA 8270C	Pass
Base/Neutrals 1	PEO-121-1	6615	Phenanthrene	EPA 8270C	Pass
CWA Low Level PAH Mix	38010	6615	Phenanthrene	EPA 8270C	Pass
PAH-GC & GCMS	4880	6615	Phenanthrene	EPA 8270C	Pass
WP Base/Neutrals	711	6615	Phenanthrene	EPA 8270C	Pass
Acid Extractables	4190	6625	Phenol	EPA 8270C	Pass
Acids	712	6625	Phenol	EPA 8270C	Pass
Base Neutral Extractables	4200	6665	Pyrene	EPA 8270C	Pass
Base/Neutrals 1	PEO-121-1	6665	Pyrene	EPA 8270C	Pass
CWA Low Level PAH Mix	38010	6665	Pyrene	EPA 8270C	Pass
PAH-GC & GCMS	4880	6665	Pyrene	EPA 8270C	Pass
WP Base/Neutrals	711	6665	Pyrene	EPA 8270C	Pass
Base Neutral Extractables	4200	5095	Pyridine	EPA 8270C	Pass
WP Base/Neutrals	711	5095	Pyridine	EPA 8270C	Pass
Base Neutral Extractables	4200	6715	1,2,4,5-Tetrachlorobenzene	EPA 8270D	Pass
Base Neutral Extractables	4200	5155	1,2,4-Trichlorobenzene	EPA 8270D	Pass
WP Base/Neutrals	711	5155	1,2,4-Trichlorobenzene	EPA 8270D	Pass
WP Base/Neutrals	711	4610	1,2-Dichlorobenzene	EPA 8270D	Pass
Base Neutral Extractables	4200	4610	1,2-Dichlorobenzene	EPA 8270D	Pass
WP Base/Neutrals	711	4615	1,3-Dichlorobenzene	EPA 8270D	Pass
Base Neutral Extractables	4200	4615	1,3-Dichlorobenzene	EPA 8270D	Pass
WP Base/Neutrals	711	4620	1,4-Dichlorobenzene	EPA 8270D	Pass
Base Neutral Extractables	4200	4620	1,4-Dichlorobenzene	EPA 8270D	Pass
Acids	712	6735	2,3,4,6-Tetrachlorophenol	EPA 8270D	Pass
Acid Extractables	4190	6735	2,3,4,6-Tetrachlorophenol	EPA 8270D	Pass
Acids	712	6835	2,4,5-Trichlorophenol	EPA 8270D	Pass
Acid Extractables	4190	6835	2,4,5-Trichlorophenol	EPA 8270D	Pass
Acids	712	6840	2,4,6-Trichlorophenol	EPA 8270D	Pass
Acid Extractables	4190	6840	2,4,6-Trichlorophenol	EPA 8270D	Pass
Acids	712	6000	2,4-Dichlorophenol	EPA 8270D	Pass
Acid Extractables	4190	6000	2,4-Dichlorophenol	EPA 8270D	Pass
Acids	712	6130	2,4-Dimethylphenol	EPA 8270D	Pass
Acid Extractables	4190	6130	2,4-Dimethylphenol	EPA 8270D	Pass
Acids	712	6175	2,4-Dinitrophenol	EPA 8270D	Pass
Acid Extractables	4190	6175	2,4-Dinitrophenol	EPA 8270D	Pass
WP Base/Neutrals	711	6185	2,4-Dinitrotoluene	EPA 8270D	Pass
Base Neutral Extractables	4200	6185	2,4-Dinitrotoluene (2,4-DNT)	EPA 8270D	Pass
Acids	712	6005	2,6-Dichlorophenol	EPA 8270D	Pass
Acid Extractables	4190	6005	2,6-Dichlorophenol	EPA 8270D	Pass
WP Base/Neutrals	711	6190	2,6-Dinitrotoluene	EPA 8270D	Pass
Base Neutral Extractables	4200	6190	2,6-Dinitrotoluene (2,6-DNT)	EPA 8270D	Pass
WP Base/Neutrals	711	5795	2-Chloronaphthalene	EPA 8270D	Pass
Base Neutral Extractables	4200	5795	2-Chloronaphthalene	EPA 8270D	Pass
Acids	712	5800	2-Chlorophenol	EPA 8270D	Pass
Acid Extractables	4190	5800	2-Chlorophenol	EPA 8270D	Pass
Acid Extractables	4190	6360	2-Methyl-4,6-Dinitrophenol	EPA 8270D	Pass
WP Base/Neutrals	711	6385	2-Methylnaphthalene	EPA 8270D	Pass
Base Neutral Extractables	4200	6385	2-Methylnaphthalene	EPA 8270D	Pass
Acids	712	6400	2-Methylphenol	EPA 8270D	Pass
Acid Extractables	4190	6400	2-Methylphenol	EPA 8270D	Pass
WP Base/Neutrals	711	6460	2-Nitroaniline	EPA 8270D	Pass
Base Neutral Extractables	4200	6460	2-Nitroaniline	EPA 8270D	Pass
Acids	712	6490	2-Nitrophenol	EPA 8270D	Pass
Acid Extractables	4190	6490	2-Nitrophenol	EPA 8270D	Pass
WP Base/Neutrals	711	5945	3,3'-Dichlorobenzidine	EPA 8270D	Pass
Base Neutral Extractables	4200	5945	3,3'-Dichlorobenzidine	EPA 8270D	Pass
Acid Extractables	4190	6405	3-Methylphenol	EPA 8270D	Pass
WP Base/Neutrals	711	6465	3-Nitroaniline	EPA 8270D	Pass
Base Neutral Extractables	4200	6465	3-Nitroaniline	EPA 8270D	Pass
Acids	712	6360	4,6-Dinitro-2-methylphenol	EPA 8270D	Pass
Base Neutral Extractables	4200	5660	4-Bromophenyl phenylether	EPA 8270D	Pass
WP Base/Neutrals	711	5660	4-Bromophenyl-phenylether	EPA 8270D	Pass
Acids	712	5700	4-Chloro-3-methylphenol	EPA 8270D	Pass
Acid Extractables	4190	5700	4-Chloro-3-methylphenol	EPA 8270D	Pass
WP Base/Neutrals	711	5745	4-Chloroaniline	EPA 8270D	Pass
Base Neutral Extractables	4200	5745	4-Chloroaniline	EPA 8270D	Pass

WP Base/Neutrals	711	5825	4-Chlorophenyl-phenylether	EPA 8270D	Pass
Base Neutral Extractables	4200	5825	4-Chlorophenyl-phenylether	EPA 8270D	Pass
Acids	712	6410	4-Methylphenol	EPA 8270D	Pass
Acid Extractables	4190	6410	4-Methylphenol	EPA 8270D	Pass
WP Base/Neutrals	711	6470	4-Nitroaniline	EPA 8270D	Pass
Base Neutral Extractables	4200	6470	4-Nitroaniline	EPA 8270D	Pass
Acids	712	6500	4-Nitrophenol	EPA 8270D	Pass
Acid Extractables	4190	6500	4-Nitrophenol	EPA 8270D	Pass
WP Base/Neutrals	711	5500	Acenaphthene	EPA 8270D	Pass
Base Neutral Extractables	4200	5500	Acenaphthene	EPA 8270D	Pass
WP Base/Neutrals	711	5505	Acenaphthylene	EPA 8270D	Pass
Base Neutral Extractables	4200	5505	Acenaphthylene	EPA 8270D	Pass
WP Base/Neutrals	711	5545	Aniline	EPA 8270D	Pass
Base Neutral Extractables	4200	5545	Aniline	EPA 8270D	Pass
WP Base/Neutrals	711	5555	Anthracene	EPA 8270D	Pass
Base Neutral Extractables	4200	5555	Anthracene	EPA 8270D	Pass
WP Base/Neutrals	711	5595	Benzidine	EPA 8270D	Pass
Base Neutral Extractables	4200	5595	Benzidine	EPA 8270D	Pass
WP Base/Neutrals	711	5575	Benzo(a)anthracene	EPA 8270D	Pass
Base Neutral Extractables	4200	5575	Benzo(a)anthracene	EPA 8270D	Pass
WP Base/Neutrals	711	5580	Benzo(a)pyrene	EPA 8270D	Pass
Base Neutral Extractables	4200	5580	Benzo(a)pyrene	EPA 8270D	Pass
WP Base/Neutrals	711	5585	Benzo(b)fluoranthene	EPA 8270D	Pass
Base Neutral Extractables	4200	5585	Benzo(b)fluoranthene	EPA 8270D	Pass
WP Base/Neutrals	711	5590	Benzo(g,h,i)perylene	EPA 8270D	Pass
Base Neutral Extractables	4200	5590	Benzo(g,h,i)perylene	EPA 8270D	Pass
WP Base/Neutrals	711	5600	Benzo(k)fluoranthene	EPA 8270D	Pass
Base Neutral Extractables	4200	5600	Benzo(k)fluoranthene	EPA 8270D	Pass
Acids	712	5610	Benzoic acid	EPA 8270D	Pass
Acid Extractables	4190	5610	Benzoic acid	EPA 8270D	Pass
WP Base/Neutrals	711	5630	Benzyl alcohol	EPA 8270D	Pass
Base Neutral Extractables	4200	5630	Benzyl alcohol	EPA 8270D	Pass
Base Neutral Extractables	4200	5670	Benzyl butyl phthalate	EPA 8270D	Pass
WP Base/Neutrals	711	5760	bis(2-Chloroethoxy) methane	EPA 8270D	Pass
Base Neutral Extractables	4200	5760	bis(2-Chloroethoxy) methane	EPA 8270D	Pass
Base Neutral Extractables	4200	5765	bis(2-Chloroethyl) ether	EPA 8270D	Pass
WP Base/Neutrals	711	5765	bis(2-Chloroethyl) ether	EPA 8270D	Pass
WP Base/Neutrals	711	5780	bis(2-Chloroisopropyl) ether	EPA 8270D	Pass
Base Neutral Extractables	4200	5780	bis(2-Chloroisopropyl) ether	EPA 8270D	Pass
WP Base/Neutrals	711	6255	bis(2-Ethylhexyl) phthalate	EPA 8270D	Pass
Base Neutral Extractables	4200	6255	bis(2-Ethylhexyl) phthalate	EPA 8270D	Pass
WP Base/Neutrals	711	5670	Butylbenzylphthalate	EPA 8270D	Pass
WP Base/Neutrals	711	5680	Carbazole	EPA 8270D	Pass
Base Neutral Extractables	4200	5680	Carbazole	EPA 8270D	Pass
WP Base/Neutrals	711	5855	Chrysene	EPA 8270D	Pass
Base Neutral Extractables	4200	5855	Chrysene	EPA 8270D	Pass
WP Base/Neutrals	711	5895	Dibenz(a,h) anthracene	EPA 8270D	Pass
Base Neutral Extractables	4200	5895	Dibenz(a,h) anthracene	EPA 8270D	Pass
Base Neutral Extractables	4200	5905	Dibenzofuran	EPA 8270D	Pass
Base Neutral Extractables	4200	5895	Dibenz(a,h) anthracene	EPA 8270D	Pass
Base Neutral Extractables	4200	6070	Diethyl phthalate	EPA 8270D	Pass
WP Base/Neutrals	711	6070	Diethylphthalate	EPA 8270D	Pass
WP Base/Neutrals	711	6135	Dimethyl phthalate	EPA 8270D	Pass
Base Neutral Extractables	4200	6135	Dimethyl phthalate	EPA 8270D	Pass
WP Base/Neutrals	711	5925	Di-n-butylphthalate	EPA 8270D	Pass
Base Neutral Extractables	4200	5925	Di-n-butylphthalate	EPA 8270D	Pass
WP Base/Neutrals	711	6200	Di-n-octylphthalate	EPA 8270D	Pass
Base Neutral Extractables	4200	6200	Di-n-octylphthalate	EPA 8270D	Pass
Base Neutral Extractables	4200	6265	Fluoranthene	EPA 8270D	Pass
WP Base/Neutrals	711	6265	Fluoranthene	EPA 8270D	Pass
WP Base/Neutrals	711	6270	Fluorene	EPA 8270D	Pass
Base Neutral Extractables	4200	6270	Fluorene	EPA 8270D	Pass
WP Base/Neutrals	711	6275	Hexachlorobenzene	EPA 8270D	Pass
Base Neutral Extractables	4200	6275	Hexachlorobenzene	EPA 8270D	Pass
WP Base/Neutrals	711	4835	Hexachlorobutadiene	EPA 8270D	Pass
Base Neutral Extractables	4200	4835	Hexachlorobutadiene	EPA 8270D	Pass
WP Base/Neutrals	711	6285	Hexachlorocyclopentadiene	EPA 8270D	Pass
Base Neutral Extractables	4200	6285	Hexachlorocyclopentadiene	EPA 8270D	Pass
Base Neutral Extractables	4200	4840	Hexachloroethane	EPA 8270D	Pass
WP Base/Neutrals	711	4840	Hexachloroethane	EPA 8270D	Pass
WP Base/Neutrals	711	6315	Indeno (1,2,3-cd) pyrene	EPA 8270D	Pass
Base Neutral Extractables	4200	6315	Indeno (1,2,3-cd) pyrene	EPA 8270D	Pass
WP Base/Neutrals	711	6320	Isophorone	EPA 8270D	Pass
Base Neutral Extractables	4200	6320	Isophorone	EPA 8270D	Pass
WP Base/Neutrals	711	5005	Naphthalene	EPA 8270D	Pass
Base Neutral Extractables	4200	5005	Naphthalene	EPA 8270D	Pass
WP Base/Neutrals	711	5015	Nitrobenzene	EPA 8270D	Pass
Base Neutral Extractables	4200	5015	Nitrobenzene (NB)	EPA 8270D	Pass
WP Base/Neutrals	711	6530	N-Nitrosodimethylamine	EPA 8270D	Pass
Base Neutral Extractables	4200	6530	N-nitrosodimethylamine	EPA 8270D	Pass
WP Base/Neutrals	711	6545	N-Nitroso-di-n-propylamine	EPA 8270D	Pass
Base Neutral Extractables	4200	6545	N-Nitroso-di-n-propylamine	EPA 8270D	Pass
WP Base/Neutrals	711	6535	N-Nitrosodiphenylamine	EPA 8270D	Pass
Base Neutral Extractables	4200	6535	N-nitrosodiphenylamine	EPA 8270D	Pass
Acids	712	6605	Pentachlorophenol	EPA 8270D	Pass
Acid Extractables	4190	6605	Pentachlorophenol	EPA 8270D	Pass
WP Base/Neutrals	711	6615	Phenanthrene	EPA 8270D	Pass
Base Neutral Extractables	4200	6615	Phenanthrene	EPA 8270D	Pass
Acids	712	6625	Phenol	EPA 8270D	Pass
Acid Extractables	4190	6625	Phenol	EPA 8270D	Pass
WP Base/Neutrals	711	6665	Pyrene	EPA 8270D	Pass

Base Neutral Extractables	4200	6665	Pyrene	EPA 8270D	Pass
WP Base/Neutrals	711	5095	Pyridine	EPA 8270D	Pass
Base Neutral Extractables	4200	5095	Pyridine	EPA 8270D	Pass
Dioxin	PEO-258	9420	1,2,3,4,6,7,8-HpCDF	EPA 8290	Pass
2,3,7,8-Tetrachlorodibenzo-p-dioxin	38186	9618	2,3,7,8-Tetrachlorodibenzo-p-dioxin	EPA 8290	Pass
WP Carbamates	38156	7205	Carbofuran	EPA 8321A	Pass
WP Carbamates	38156	7505	Diuron	EPA 8321A	Pass
WP Carbamates	38156	7750	Methomyl	EPA 8321A	Pass
WP Carbamates	38156	7940	Oxamyl	EPA 8321A	Pass
WP Carbamates	38156	8075	Propham	EPA 8321A	Pass
Herbicides	PEO-094	8620	Dinoseb (2-sec-butyl-4,6-dinitrophenol, DNBP)	EPA 8321A	Pass
CWA Nitroaromatics in Water	38172	6885	1,3,5-Trinitrobenzene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	6160	1,3-Dinitrobenzene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	9651	2,4,6-Trinitrotoluene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	6185	2,4-Dinitrotoluene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	6190	2,6-Dinitrotoluene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	9303	2-Amino-4,6-dinitrotoluene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	9507	2-Nitrotoluene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	9510	3-Nitrotoluene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	9306	4-Amino-2,6-dinitrotoluene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	9513	4-Nitrotoluene	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	9522	HMX	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	9432	RDX	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	6415	Tetryl	EPA 8330	Pass
CWA Nitroaromatics in Water	38172	6885	1,3,5-Trinitrobenzene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	6885	1,3,5-Trinitrobenzene (1,3,5-TNB)	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	6160	1,3-Dinitrobenzene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	6160	1,3-Dinitrobenzene (1,3-DNB)	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	9651	2,4,6-Trinitrotoluene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	9651	2,4,6-Trinitrotoluene (2,4,6-TNT)	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	6185	2,4-Dinitrotoluene (2,4-DNT)	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	6190	2,6-Dinitrotoluene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	6190	2,6-Dinitrotoluene (2,6-DNT)	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	9303	2-Amino-4,6-dinitrotoluene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	9303	2-Amino-4,6-dinitrotoluene (2am-dnt)	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	9507	2-Nitrotoluene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	9507	2-Nitrotoluene	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	9510	3-Nitrotoluene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	9510	3-Nitrotoluene	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	9306	4-Amino-2,6-dinitrotoluene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	9306	4-Amino-2,6-dinitrotoluene (4-am-dnt)	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	9513	4-Nitrotoluene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	9513	4-Nitrotoluene	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	9522	HMX	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	9522	HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	5015	Nitrobenzene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	5015	Nitrobenzene	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	6485	Nitroglycerin	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	9432	RDX	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	9432	RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine)	EPA 8330A	Pass
CWA Nitroaromatics in Water	38172	6415	Tetryl	EPA 8330A	Pass
Low Level Ni/Nil	PEO-251	6415	Tetryl (Methyl-2,4,6-trinitrophenylnitramine)	EPA 8330A	Pass
Total Cyanide	4090	1645	Total Cyanide	EPA 9010B	Pass
Total Cyanide	PEI-031	1645	Total cyanide	EPA 9010B	Pass
Total Cyanide	4090	1645	Total Cyanide	EPA 9014	Pass
CWA Anions	55131	1540	Bromide (Br)	EPA 9056	Pass
WP Minerals #1	55144	1575	Chloride	EPA 9056	Pass
Fluoride	4420	1730	Fluoride	EPA 9056	Pass
WP Minerals #2	55145	1730	Fluoride	EPA 9056	Pass
WP & DMRQA Nutrients	55035	1810	Nitrate as N	EPA 9056	Pass
Nutrients	4020	1810	Nitrate Nitrogen as N	EPA 9056	Pass
Nitrate-Nitrite as N	4770	1820	Nitrate-Nitrite as N	EPA 9056	Pass
Nitrite as N	4780	1840	Nitrite as N	EPA 9056	Pass
Nutrients	4020	1870	Orthophosphate as P	EPA 9056	Pass
WP & DMRQA Nutrients	55035	1870	Orthophosphate as P	EPA 9056	Pass
Miscellaneous Analytes	PEI-051	1540	Bromide	EPA 9056	Pass
Minerals	PEI-051	1575	Chloride	EPA 9056	Pass
Minerals	PEI-051	1730	Fluoride	EPA 9056	Pass
Nutrients	PEI-051	1805	Nitrate as N	EPA 9056	Pass
Nutrients	PEI-051	1820	Nitrate+nitrite as N	EPA 9056	Pass
Nutrients	PEI-051	1840	Nitrite as N	EPA 9056	Pass
Nutrients	PEI-051	1870	Orthophosphate as P	EPA 9056	Pass
Minerals	PEI-051	2000	Sulfate	EPA 9056	Pass
Demand	4010	2040	Total organic carbon (TOC)	EPA 9060	Pass
Demands	PEI-026	2040	Total organic carbon (TOC)	EPA 9060	Pass
Fluoride	4420	1730	Fluoride	EPA 9214	Pass
Minerals	4050	1505	Alkalinity as CaCO3	SM 2320B	Pass
Solids (Total Solids, TSS, & TDS)	55085	1955	Total Dissolved Solids (TDS)	SM 2540C	Pass
Solids	4030	1705	Total Dissolved Solids at 180C	SM 2540C	Pass
Solids	4030	1960	Total Suspended Solids	SM 2540D	Pass
CWA UV 254 Absorbance/ DOC	55088	1710	Dissolved Organic Carbon	SM 5310B	Pass
Demand	4010	2040	Total Organic Carbon	SM 5310B	Pass
WP & DMRQA Demands	55055	2040	Total Organic Carbon	SM 5310B	Pass
Demands	PEI-026	2040	Total organic carbon (TOC)	SM 5310B	Pass
Oil & Grease	4120	1860	Oil & Grease	SM 5520B	Pass
MBAS	4430	2025	MBAS	SM 5540C	Pass
WP MBAS	55083	2025	MBAS	SM 5540C	Pass

DoD ELAP -- PT Performance Summary Review -- WS ALL

PartName	PartNumber	NELACCode	AnalyteName	EPAMethod#	PT results - Pass/Acceptable Results
Lab Name :	APPL, Inc.				
City/State :	Clovis, CA				
PT Provider Used :	ERA, Absolute, RTC, APG				
WS Chromium VI	55112	1045	Chromium VI	EPA 218.6	Pass
Trace Metals	5070	1095	Mercury	EPA 245.1	Pass
WS Trace Elements	55012	1095	Total Mercury	EPA 245.1	Pass
WS Inorganic Disinfection By-Products	55010	1540	Bromide	EPA 300.0	Pass
Minerals	5080	1575	Chloride	EPA 300.0	Pass
WS Minerals Mix #1	55122	1575	Chloride	EPA 300.0	Pass
Nutrients	5140	1730	Fluoride	EPA 300.0	Pass
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1730	Fluoride	EPA 300.0	Pass
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1820	Nitrate and Nitrite as N	EPA 300.0	Pass
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1810	Nitrate as N	EPA 300.0	Pass
Nutrients	5140	1810	Nitrate Nitrogen as N	EPA 300.0	Pass
Nitrate+Nitrite as N	5860	1820	Nitrate+Nitrite as N	EPA 300.0	Pass
Nutrients	5140	1840	Nitrite as N	EPA 300.0	Pass
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1840	Nitrite as N	EPA 300.0	Pass
Nutrients	5140	1870	Orthophosphate as P	EPA 300.0	Pass
Minerals	5080	2000	Sulfate	EPA 300.0	Pass
WS Sulphate/TOC	55070	2000	Sulfate	EPA 300.0	Pass
Perchlorate	5610	1895	Perchlorate	EPA 314.0	Pass
WS Perchlorate	55099	1895	Perchlorate	EPA 314.0	Pass
Nutrients	5140	1730	Fluoride	EPA 340.2	Pass
SDWA Nutrients	55165	1515	Ammonia as N	EPA 350.1	Pass
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1820	Nitrate and Nitrite as N	EPA 353.2	Pass
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1810	Nitrate as N	EPA 353.2	Pass
Nutrients	5140	1810	Nitrate Nitrogen as N	EPA 353.2	Pass
Nitrate+Nitrite as N	5860	1820	Nitrate+Nitrite as N	EPA 353.2	Pass
Nutrients	5140	1840	Nitrite as N	EPA 353.2	Pass
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1840	Nitrite as N	EPA 353.2	Pass
WS NO3-, NO2-, F, PO4-3, and NO3- & NO2- as N	55011	1870	Orthophosphate as P	EPA 353.2	Pass
Nutrients	5140	1870	Orthophosphate as P	EPA 353.2	Pass
SDWA Nutrients	55165	1910	Total Phosphorus	EPA 365.2	Pass
MBAS	5470	2025	MBAS	EPA 425.1	Pass
Perchlorate	5610	1895	Perchlorate	EPA 6850	Pass
WS Perchlorate	55099	1895	Perchlorate	EPA 6850	Pass
pH	5060	1900	pH	EPA 9040B	Pass
UV 254/DOC	5480	1710	Dissolved Organic Carbon (DOC)	EPA 9060	Pass
Total Organic Carbon (TOC)	5250	2040	Total Organic Carbon	EPA 9060	Pass
Nutrients	5140	1730	Fluoride	EPA 9214	Pass
Minerals	5080	1505	Alkalinity	SM 2320B	Pass
Minerals	5080	1955	Total Dissolved Solids	SM 2540C	Pass
SDWA Solids (Total Solids, TSS, & TDS)	55161	1955	Total Dissolved Solids	SM 2540C	Pass
Solids	5150	1705	Total Dissolved Solids	SM 2540C	Pass
SDWA Solids (Total Solids, TSS, & TDS)	55161	1960	Non-Filterable Residue (TSS)	SM 2540D	Pass
Solids	5150	1960	Total Suspended Solids	SM 2540D	Pass
MBAS	5470	2025	MBAS	SM 5540C	Pass
WS MBAS	55106	2025	MBAS	SM 5540C	Pass

DoD ELAP -- PT Performance Summary Review -- SOIL						
Lab Name :		APPL, Inc.				
City/State :		Clovis, CA				
PT Provider Used :		ERA, RTC, Absolute, APG				
PartName	PartNumber	NELACCCode	AnalyteName	EPAMethod#	PT results - Pass/Acceptable Results	
Oil & Grease - n-Hexadecane & Stearic acid	55084	1860	Oil & Grease	EPA 1664A	Pass	
PCB Congeners in Soil	SPE-068	9070	2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9025	2,2',3,4,4',5'-Hexachlorobiphenyl (PCB 138)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9040	2,2',4,4',5,5'-Hexachlorobiphenyl (PCB 153)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8980	2,2',4,5,5'-Pentachlorobiphenyl (PCB 101)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8955	2,2',5,5'-Tetrachlorobiphenyl (PCB 52)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9085	2,3,3',4,4',5,5'-Heptachlorobiphenyl (PCB 189)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9050	2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 156)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9045	2,3,3',4,4',5'-Hexachlorobiphenyl (PCB 157)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8985	2,3,3',4,4',5'-Pentachlorobiphenyl (PCB 105)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9055	2,3',4,4',5,5'-Hexachlorobiphenyl (PCB 167)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9005	2,3,4,4',5-Pentachlorobiphenyl (PCB 114)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8995	2,3,4,4',5-Pentachlorobiphenyl (PCB 118)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9000	2,3,4,4',5'-Pentachlorobiphenyl (PCB 123)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8936	2,4,4'-Trichlorobiphenyl (PCB 28)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9060	3,3',4,4',5,5'-Hexachlorobiphenyl (PCB 169)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9015	3,3',4,4',5-Pentachlorobiphenyl (PCB 126)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8965	3,3',4,4'-Tetrachlorobiphenyl (PCB 77)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8970	3,4,4',5-Tetrachlorobiphenyl (PCB 81)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9025	PCB (129)+(138)+(163)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9040	PCB (153)+(168)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9046	PCB (166)+(157)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	9070	PCB (180)+(193)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8936	PCB (20)+(28)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8980	PCB (90)+(101)+(113)	EPA 1668	Pass	
PCB Congeners in Soil	SPE-068	8870	PCBs, total	EPA 1668	Pass	
RCRA Anions	55141	1540	Bromide	EPA 300.0	Pass	
RCRA Anions	55141	1575	Chloride	EPA 300.0	Pass	
RCRA Anions	55141	1730	Fluoride	EPA 300.0	Pass	
RCRA Anions	55141	1810	Nitrate as N	EPA 300.0	Pass	
RCRA Anions	55141	1870	Phosphate as P	EPA 300.0	Pass	
RCRA Anions	55141	2000	Sulfate	EPA 300.0	Pass	
RCRA Hexavalent Chromium	55104	1045	Chromium IV	EPA 3060A	Pass	
Hexavalent Chromium in Soil	4120	1045	Chromium, Hexavalent	EPA 3060A	Pass	
RCRA Perchlorate	38151	1885	Perchlorate	EPA 314.0	Pass	
RCRA Nutrients	55142	1515	Ammonia as N	EPA 350.1	Pass	
Nutrients in Soil	4170	1515	Ammonia Nitrogen as N	EPA 350.1	Pass	
Nutrients in Soil	4170	1795	Total Kjeldahl Nitrogen	EPA 351.2	Pass	
RCRA Nutrients	55142	1795	Total Kjeldahl Nitrogen	EPA 351.2	Pass	
RCRA Metals In Soil #2	55103	1000	Aluminum	EPA 6010B	Pass	
TCLP Metals	PT-TCLPMET-SOIL	1005	Antimony	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1005	Antimony	EPA 6010B	Pass	
TCLP Metals in Soil	4180	1005	Antimony, Sb	EPA 6010B	Pass	
TCLP Metals in Soil - CA WET	SPE-006	1005	Antimony, Sb	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1010	Arsenic	EPA 6010B	Pass	
TCLP Metals in Soil	4180	1010	Arsenic, As	EPA 6010B	Pass	
TCLP Metals	PT-TCLPMET-SOIL	1015	Barium	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1015	Barium	EPA 6010B	Pass	
TCLP Metals in Soil	4180	1015	Barium, Ba	EPA 6010B	Pass	
TCLP Metals	PT-TCLPMET-SOIL	1020	Beryllium	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1020	Beryllium	EPA 6010B	Pass	
TCLP Metals in Soil - CA WET	SPE-006	1020	Beryllium, Be	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1025	Boron	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1030	Cadmium	EPA 6010B	Pass	
TCLP Metals in Soil	4180	1030	Cadmium, Cd	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1030	Cadmium	EPA 6010B	Pass	
RCRA Metals in Soil #2	55103	1035	Calcium	EPA 6010B	Pass	
RCRA Metals In Soil #2	55103	1035	Calcium	EPA 6010B	Pass	
TCLP Metals	PT-TCLPMET-SOIL	1040	Chromium	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1040	Chromium	EPA 6010B	Pass	
TCLP Metals in Soil	4180	1040	Chromium, Cr (total)	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1050	Cobalt	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1055	Copper	EPA 6010B	Pass	
TCLP Metals in Soil - CA WET	SPE-006	1055	Copper, Cu	EPA 6010B	Pass	
RCRA Metals In Soil #2	55103	1070	Iron	EPA 6010B	Pass	
TCLP Metals	PT-TCLPMET-SOIL	1075	Lead	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1075	Lead	EPA 6010B	Pass	
TCLP Metals in Soil	4180	1075	Lead, Pb	EPA 6010B	Pass	
RCRA Metals in Soil #2	55103	1085	Magnesium	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1090	Manganese	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1100	Molybdenum	EPA 6010B	Pass	
TCLP Metals in Soil - CA WET	SPE-006	1100	Molybdenum, Mo	EPA 6010B	Pass	
TCLP Metals	PT-TCLPMET-SOIL	1105	Nickel	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1105	Nickel	EPA 6010B	Pass	
TCLP Metals in Soil	4180	1105	Nickel, Ni	EPA 6010B	Pass	
RCRA Metals in Soil #2	55103	1125	Potassium	EPA 6010B	Pass	
TCLP Metals	PT-TCLPMET-SOIL	1140	Selenium	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1140	Selenium	EPA 6010B	Pass	
TCLP Metals in Soil	4180	1140	Selenium, Se	EPA 6010B	Pass	
TCLP Metals	PT-TCLPMET-SOIL	1150	Silver	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1150	Silver	EPA 6010B	Pass	
TCLP Metals in Soil	4180	1150	Silver, Ag	EPA 6010B	Pass	
RCRA Metals in Soil #2	55103	1155	Sodium	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1160	Strontium	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1165	Thallium	EPA 6010B	Pass	
TCLP Metals in Soil - CA WET	SPE-006	1165	Thallium, Tl	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1175	Tin	EPA 6010B	Pass	
RCRA Metals in Soil #1	55102	1180	Titanium	EPA 6010B	Pass	
RCRA Nutrients	55142	1910	Total Phosphorus	EPA 6010B	Pass	
Nutrients in Soil	4170	1910	Total Phosphorus as P	EPA 6010B	Pass	

RCRA Metals in Soil #1	55102	1185	Vanadium	EPA 6010B	Pass
TCLP Metals in Soil - CA WET	SPE-006	1185	Vanadium, V	EPA 6010B	Pass
TCLP Metals	PT-TCLPMET-SOIL	1190	Zinc	EPA 6010B	Pass
RCRA Metals in Soil #1	55102	1190	Zinc	EPA 6010B	Pass
TCLP Metals in Soil	4180	1190	Zinc, Zn	EPA 6010B	Pass
RCRA Metals in Soil #2	55103	1000	Aluminum	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1005	Antimony	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1015	Barium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1020	Beryllium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1025	Boron	EPA 6020	Pass
RCRA Metals in Soil #2	55103	1035	Calcium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1040	Chromium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1050	Cobalt	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1055	Copper	EPA 6020	Pass
RCRA Metals in Soil #2	55103	1070	Iron	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1075	Lead	EPA 6020	Pass
RCRA Metals in Soil #2	55103	1085	Magnesium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1090	Manganese	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1100	Molybdenum	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1105	Nickel	EPA 6020	Pass
RCRA Metals in Soil #2	55103	1125	Potassium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1140	Selenium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1150	Silver	EPA 6020	Pass
RCRA Metals in Soil #2	55103	1155	Sodium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1160	Strontium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1165	Thallium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1175	Tin	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1180	Titanium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1185	Vanadium	EPA 6020	Pass
RCRA Metals in Soil #1	55102	1190	Zinc	EPA 6020	Pass
RCRA Perchlorate	55143	1895	Perchlorate	EPA 6850	Pass
RCRA Hexavalent Chromium	55104	1045	Chromium VI	EPA 7196A	Pass
Hexavalent Chromium in Soil	4120	1045	Chromium, Hexavalent	EPA 7196A	Pass
RCRA Hexavalent Chromium	55104	1045	Chromium VI	EPA 7199	Pass
Hexavalent Chromium in Soil	4120	1045	Chromium, Hexavalent	EPA 7199	Pass
TCLP Metals	PT-TCLPMET-SOIL	1095	Mercury	EPA 7470A	Pass
TCLP Metals in Soil	4180	1095	Mercury	EPA 7470A	Pass
RCRA Metals in Soil #1	55102	1095	Mercury	EPA 7471A	Pass
RCRA Metals in Soil #1	55102	1095	Mercury	EPA 7471B	Pass
Diesel Fuel #2 in Soil	38115	9369	#2 Fuel Oil (Diesel)	EPA 8015B	Pass
PT Diesel Fuel #2 in Water	38114	9369	#2 Fuel Oil (Diesel)	EPA 8015B	Pass
93 Octane Gasoline in Soil	38117	9408	93 Octane Gasoline in Soil	EPA 8015B	Pass
PT Unleaded Gasoline in Water	38116	9408	Unleaded Gasoline 93 Octane	EPA 8015B	Pass
RCRA BTEX & MTBE	38161	4375	Benzene	EPA 8021B	Pass
RCRA BTEX & MTBE	38161	4765	Ethyl benzene	EPA 8021B	Pass
RCRA BTEX & MTBE	38161	5000	Methyl tert-butyl ether (MTBE)	EPA 8021B	Pass
RCRA BTEX & MTBE	38161	5140	Toluene	EPA 8021B	Pass
RCRA BTEX & MTBE	38161	5260	Total Xylenes	EPA 8021B	Pass
Chlorinated Pesticides in Soil	38101	7355	4,4'-DDD	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7360	4,4'-DDE	EPA 8081A	Pass
Pesticides in Soil	14221	7360	4,4'-DDE	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7365	4,4'-DDT	EPA 8081A	Pass
Pesticides in Soil	14222	7365	4,4'-DDT	EPA 8081A	Pass
Pesticides in Soil	14220	7355	4,4'-DDD	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7110	a-BHC	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7240	a-Chlordane	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7025	Aldrin	EPA 8081A	Pass
Pesticides in Soil	14223	7025	Aldrin	EPA 8081A	Pass
Pesticides in Soil	14224	7110	alpha-BHC	EPA 8081A	Pass
Pesticides in Soil	14225	7240	alpha-Chlordane	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7115	b-BHC	EPA 8081A	Pass
Pesticides in Soil	14226	7115	beta-BHC	EPA 8081A	Pass
Chlordane in Soil	38141	7250	Chlordane	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7105	d-BHC	EPA 8081A	Pass
Pesticides in Soil	14227	7105	delta-BHC	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7470	Dieldrin	EPA 8081A	Pass
Pesticides in Soil	14228	7470	Dieldrin	EPA 8081A	Pass
Pesticides in Soil	14229	7510	Endosulfan I	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7515	Endosulfan II	EPA 8081A	Pass
Pesticides in Soil	14230	7515	Endosulfan II	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7520	Endosulfan sulfate	EPA 8081A	Pass
Pesticides in Soil	14231	7520	Endosulfan sulfate	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7540	Endrin	EPA 8081A	Pass
Pesticides in Soil	14232	7540	Endrin	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7530	Endrin aldehyde	EPA 8081A	Pass
Pesticides in Soil	14233	7530	Endrin aldehyde	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7535	Endrin ketone	EPA 8081A	Pass
Pesticides in Soil	14234	7535	Endrin ketone	EPA 8081A	Pass
Pesticides in Soil	14235	7120	gamma-BHC (Lindane)	EPA 8081A	Pass
Pesticides in Soil	14236	7245	gamma-Chlordane	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7120	g-BHC (Lindane)	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7685	Heptachlor	EPA 8081A	Pass
Pesticides in Soil	14237	7685	Heptachlor	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7690	Heptachlor epoxide	EPA 8081A	Pass
Pesticides in Soil	14238	7690	Heptachlor epoxide	EPA 8081A	Pass
Chlorinated Pesticides in Soil	38101	7810	Methoxychlor	EPA 8081A	Pass
Pesticides in Soil	14239	7810	Methoxychlor	EPA 8081A	Pass
Total Chlordane in Soil	4240	7250	Total Chlordane	EPA 8081A	Pass
Toxaphene in Soil	38066	8250	Toxaphene	EPA 8081A	Pass
Toxaphene in Soil	4230	8250	Toxaphene	EPA 8081A	Pass
Aroclor in Soil	38142	8880	Aroclor 1016	EPA 8082	Pass
WP PCBs in Water	38091	8880	Aroclor 1016	EPA 8082	Pass
WP PCBs in Water	38094	8880	Aroclor 1016	EPA 8082	Pass
Aroclor in Soil	38142	8885	Aroclor 1221	EPA 8082	Pass
WP PCBs in Water	38091	8885	Aroclor 1221	EPA 8082	Pass
WP PCBs in Water	38094	8885	Aroclor 1221	EPA 8082	Pass
Aroclor in Soil	38142	8890	Aroclor 1232	EPA 8082	Pass
WP PCBs in Water	38091	8890	Aroclor 1232	EPA 8082	Pass

WP PCBs in Water	38094	8890	Aroclor 1232	EPA 8082	Pass
Aroclor in Soil	38142	8895	Aroclor 1242	EPA 8082	Pass
WP PCBs in Water	38091	8895	Aroclor 1242	EPA 8082	Pass
WP PCBs in Water	38094	8895	Aroclor 1242	EPA 8082	Pass
Aroclor in Soil	38142	8900	Aroclor 1248	EPA 8082	Pass
WP PCBs in Water	38091	8900	Aroclor 1248	EPA 8082	Pass
WP PCBs in Water	38094	8900	Aroclor 1248	EPA 8082	Pass
Aroclor in Soil	38142	8905	Aroclor 1254	EPA 8082	Pass
WP PCBs in Water	38091	8905	Aroclor 1254	EPA 8082	Pass
WP PCBs in Water	38094	8905	Aroclor 1254	EPA 8082	Pass
Aroclor in Soil	38142	8910	Aroclor 1260	EPA 8082	Pass
WP PCBs in Water	38091	8910	Aroclor 1260	EPA 8082	Pass
WP PCBs in Water	38094	8910	Aroclor 1260	EPA 8082	Pass
PCB in Soil	SPE-010	8912	Aroclor 1016/1242	EPA 8082	Pass
PCB in Soil	SPE-010	8880	Aroclor-1016 (PCB-1016)	EPA 8082	Pass
PCB in Soil	SPE-010	8885	Aroclor-1221 (PCB-1221)	EPA 8082	Pass
PCB in Soil	SPE-010	8890	Aroclor-1232 (PCB-1232)	EPA 8082	Pass
PCB in Soil	SPE-010	8895	Aroclor-1242 (PCB-1242)	EPA 8082	Pass
PCB in Soil	SPE-010	8900	Aroclor-1248 (PCB-1248)	EPA 8082	Pass
PCB in Soil	SPE-010	8905	Aroclor-1254 (PCB-1254)	EPA 8082	Pass
PCB in Soil	SPE-010	8910	Aroclor-1260 (PCB-1260)	EPA 8082	Pass
OrganoPhosphorus Pesticides	38151	7075	Azinphosmethyl	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	7075	Azinphos-methyl	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	7300	Chlorpyrifos	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	7390	Demeton O&S	EPA 8141A	Pass
OrganoPhosphorus Pesticides	38151	7390	Demeton, (Mix of Isomers O,S)	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	7410	Diazinon	EPA 8141A	Pass
OrganoPhosphorus Pesticides	38151	7410	Diazinon	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	8610	Dichlorvos (DDVP)	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	8625	Disulfoton	EPA 8141A	Pass
OrganoPhosphorus Pesticides	38151	8625	Disulfoton	EPA 8141A	Pass
OrganoPhosphorus Pesticides	38151	8110	Fenclorophos (Ronnel)	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	7770	Malathion	EPA 8141A	Pass
OrganoPhosphorus Pesticides	38151	7770	Malathion	EPA 8141A	Pass
OrganoPhosphorus Pesticides	38151	7825	Parathion methyl	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	7955	Parathion, ethyl	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	7825	Parathion, methyl	EPA 8141A	Pass
OrganoPhosphorus Pesticides	38151	7985	Phorate	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	8110	Ronnel	EPA 8141A	Pass
OP/NP Pesticides in Soil	4280	8200	Stirophos (Tetrachlorvinphos)	EPA 8141A	Pass
OrganoPhosphorus Pesticides	38151	8200	Tetrachlorvinphos (Stirophos)	EPA 8141A	Pass
Herbicide Acids in Soil	38146	8655	2,4,5-T	EPA 8151A	Pass
Herbicide Acids in Soil	38146	8650	2,4,5-TP	EPA 8151A	Pass
Herbicide Acids in Soil	38146	8545	2,4-D	EPA 8151A	Pass
Herbicide Acids in Soil	38146	8560	2,4-DB	EPA 8151A	Pass
Herbicides in Soil	4250	8600	3,5-Dichlorobenzoic acid	EPA 8151A	Pass
Herbicides in Soil	4250	8505	Acifluorfen	EPA 8151A	Pass
Herbicides in Soil	4250	8530	Bentazon	EPA 8151A	Pass
Herbicides in Soil	4250	8540	Chloramben	EPA 8151A	Pass
Herbicides in Soil	4250	8550	Dacihal diacid (DCPA)	EPA 8151A	Pass
Herbicide Acids in Soil	38146	8555	Dalapon	EPA 8151A	Pass
Herbicide Acids in Soil	38146	8595	Dicamba	EPA 8151A	Pass
Herbicide Acids in Soil	38146	8620	Dinoseb	EPA 8151A	Pass
Herbicide Acids in Soil	38146	6605	Pentachlorophenol	EPA 8151A	Pass
Herbicides in Soil	4250	6605	Pentachlorophenol	EPA 8151A	Pass
Herbicides in Soil	4250	8645	Picloram	EPA 8151A	Pass
RCRA Medium Level Volatiles in Soil	38199	5105	1,1,1,2-Tetrachloroethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5105	1,1,1,2-Tetrachloroethane	EPA 8260B	Pass
Volatiles in Soil	38084	5105	1,1,1,2-Tetrachloroethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5160	1,1,1-Trichloroethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5160	1,1,1-Trichloroethane	EPA 8260B	Pass
Volatiles in Soil	38084	5160	1,1,1-Trichloroethane	EPA 8260B	Pass
Volatiles in Soil	4200	5160	1,1,1-Trichloroethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5110	1,1,2,2-Tetrachloroethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5110	1,1,2,2-Tetrachloroethane	EPA 8260B	Pass
Volatiles in Soil	38084	5110	1,1,2,2-Tetrachloroethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5165	1,1,2-Trichloroethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5165	1,1,2-Trichloroethane	EPA 8260B	Pass
Volatiles in Soil	38084	5165	1,1,2-Trichloroethane	EPA 8260B	Pass
Volatiles in Soil	4200	5165	1,1,2-Trichloroethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4630	1,1-Dichloroethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4630	1,1-Dichloroethane	EPA 8260B	Pass
Volatiles in Soil	38084	4630	1,1-Dichloroethane	EPA 8260B	Pass
Volatiles in Soil	4200	4630	1,1-Dichloroethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4640	1,1-Dichloroethene	EPA 8260B	Pass
Volatiles in Soil	38084	4640	1,1-Dichloroethene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4640	1,1-Dichloroethylene	EPA 8260B	Pass
Volatiles in Soil	38084	4670	1,1-Dichloropropene	EPA 8260B	Pass
Volatiles in Soil	38084	5150	1,2,3-Trichlorobenzene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5180	1,2,3-Trichloropropane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5180	1,2,3-Trichloropropane	EPA 8260B	Pass
Volatiles in Soil	38084	5180	1,2,3-Trichloropropane	EPA 8260B	Pass
Volatiles in Soil	4200	5180	1,2,3-Trichloropropane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5155	1,2,4-Trichlorobenzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5155	1,2,4-Trichlorobenzene	EPA 8260B	Pass
Volatiles in Soil	4200	5155	1,2,4-Trichlorobenzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5210	1,2,4-Trimethylbenzene	EPA 8260B	Pass
Volatiles in Soil	38084	5210	1,2,4-Trimethylbenzene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4570	1,2-Dibromo-3-chloropropane	EPA 8260B	Pass
Volatiles in Soil	38084	4570	1,2-Dibromo-3-chloropropane	EPA 8260B	Pass
Volatiles in Soil	4200	4570	1,2-Dibromo-3-chloropropane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4570	1,2-Dibromo-3-chloropropane (DBCP)	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4585	1,2-Dibromoethane	EPA 8260B	Pass
Volatiles in Soil	38084	4585	1,2-Dibromoethane	EPA 8260B	Pass
Volatiles in Soil	4200	4585	1,2-Dibromoethane (EDB)	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4585	1,2-Dibromoethane (EDB, Ethylene dibromide)	EPA 8260B	Pass
Volatiles in Soil	4200	4655	1,2-Dichloropropane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4610	1,2-Dichlorobenzene	EPA 8260B	Pass

VOAs in Soil - Medium Level	SPE-002-H	4610	1,2-Dichlorobenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4610	1,2-Dichlorobenzene	EPA 8260B	Pass
Volatiles in Soil	4200	4610	1,2-Dichlorobenzene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4635	1,2-Dichloroethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4635	1,2-Dichloroethane	EPA 8260B	Pass
Volatiles in Soil	38084	4635	1,2-Dichloroethane	EPA 8260B	Pass
Volatiles in Soil	4200	4635	1,2-Dichloroethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4655	1,2-Dichloropropane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4655	1,2-Dichloropropane	EPA 8260B	Pass
Volatiles in Soil	38084	4655	1,2-Dichloropropane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5215	1,3,5-Trimethylbenzene	EPA 8260B	Pass
Volatiles in Soil	38084	5215	1,3,5-Trimethylbenzene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4615	1,3-Dichlorobenzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4615	1,3-Dichlorobenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4615	1,3-Dichlorobenzene	EPA 8260B	Pass
Volatiles in Soil	4200	4615	1,3-Dichlorobenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4660	1,3-Dichloropropane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4620	1,4-Dichlorobenzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4620	1,4-Dichlorobenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4620	1,4-Dichlorobenzene	EPA 8260B	Pass
Volatiles in Soil	4200	4620	1,4-Dichlorobenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4665	2,2-Dichloropropane	EPA 8260B	Pass
RCRA Ketones in Soil	38167	4410	2-Butanone (Methyl ethyl ketone)	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4410	2-Butanone (Methyl ethyl ketone)	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4410	2-Butanone (Methyl ethyl ketone, MEK)	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4500	2-Chloroethyl vinyl ether	EPA 8260B	Pass
Volatiles in Soil	4200	4500	2-Chloroethylvinylether	EPA 8260B	Pass
Volatiles in Soil	38084	4535	2-Chlorotoluene	EPA 8260B	Pass
RCRA Ketones in Soil	38167	4860	2-Hexanone	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4860	2-Hexanone	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4860	2-Hexanone	EPA 8260B	Pass
Volatiles in Soil	4200	4860	2-Hexanone	EPA 8260B	Pass
Volatiles in Soil	38084	4540	4-Chlorotoluene	EPA 8260B	Pass
RCRA Ketones in Soil	38167	4995	4-Methyl-2-pentanone	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4995	4-Methyl-2-pentanone	EPA 8260B	Pass
Volatiles in Soil	38084	4995	4-Methyl-2-pentanone	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4995	4-Methyl-2-pentanone (MIBK)	EPA 8260B	Pass
Volatiles in Soil	4200	4995	4-Methyl-2-pentanone (MIBK)	EPA 8260B	Pass
RCRA Ketones in Soil	38167	4315	Acetone	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4315	Acetone	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4315	Acetone	EPA 8260B	Pass
Volatiles in Soil	4200	4320	Acetonitrile	EPA 8260B	Pass
Volatiles in Soil	4200	4325	Acrolein	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4325	Acrolein (Propenal)	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4375	Benzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4375	Benzene	EPA 8260B	Pass
Volatiles in Soil	38084	4375	Benzene	EPA 8260B	Pass
Volatiles in Soil	4200	4375	Benzene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4385	Bromobenzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4385	Bromobenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4385	Bromobenzene	EPA 8260B	Pass
Volatiles in Soil	4200	4385	Bromobenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4390	Bromochloromethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4395	Bromodichloromethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4395	Bromodichloromethane	EPA 8260B	Pass
Volatiles in Soil	38084	4395	Bromodichloromethane	EPA 8260B	Pass
Volatiles in Soil	4200	4395	Bromodichloromethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4400	Bromoform	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4400	Bromoform	EPA 8260B	Pass
Volatiles in Soil	38084	4400	Bromoform	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	49504	Bromomethane	EPA 8260B	Pass
Volatiles in Soil	38084	4950	Bromomethane	EPA 8260B	Pass
Volatiles in Soil	4200	4950	Bromomethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4450	Carbon disulfide	EPA 8260B	Pass
Volatiles in Soil	4200	4450	Carbon disulfide	EPA 8260B	Pass
Volatiles in Soil	38084	4450	Carbon disulfide	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4455	Carbon tetrachloride	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4455	Carbon tetrachloride	EPA 8260B	Pass
Volatiles in Soil	38084	4455	Carbon tetrachloride	EPA 8260B	Pass
Volatiles in Soil	4200	4455	Carbon tetrachloride	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4475	Chlorobenzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4475	Chlorobenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4475	Chlorobenzene	EPA 8260B	Pass
Volatiles in Soil	4200	4475	Chlorobenzene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4485	Chloroethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4485	Chloroethane	EPA 8260B	Pass
Volatiles in Soil	38084	4485	Chloroethane	EPA 8260B	Pass
Volatiles in Soil	4200	4485	Chloroethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4505	Chloroform	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4505	Chloroform	EPA 8260B	Pass
Volatiles in Soil	38084	4505	Chloroform	EPA 8260B	Pass
Volatiles in Soil	4200	4505	Chloroform	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4960	Chloromethane	EPA 8260B	Pass
Volatiles in Soil	38084	4960	Chloromethane	EPA 8260B	Pass
Volatiles in Soil	4200	4960	Chloromethane	EPA 8260B	Pass
Volatiles in Soil	4200	4645	cis-1,2-Dichloroethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4645	cis-1,2-Dichloroethane	EPA 8260B	Pass
Volatiles in Soil	38084	4645	cis-1,2-Dichloroethylene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4645	cis-1,2-Dichloroethylene	EPA 8260B	Pass
Volatiles in Soil	4200	4680	cis-1,2-Dichloropropene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4680	cis-1,3-Dichloropropene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4680	cis-1,3-Dichloropropene	EPA 8260B	Pass
Volatiles in Soil	38084	4680	cis-1,3-Dichloropropene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4575	Dibromochloromethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4575	Dibromochloromethane	EPA 8260B	Pass
Volatiles in Soil	38084	4575	Dibromochloromethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4595	Dibromomethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4595	Dibromomethane	EPA 8260B	Pass

Volatiles in Soil	38084	4595	Dibromomethane	EPA 8260B	Pass
Volatiles in Soil	4200	4595	Dibromomethane	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4625	Dichlorodifluoromethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4625	Dichlorodifluoromethane	EPA 8260B	Pass
Volatiles in Soil	38084	4625	Dichlorodifluoromethane	EPA 8260B	Pass
Volatiles in Soil	4200	4625	Dichlorodifluoromethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	9375	Di-isopropylether (DIPE)	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4765	Ethyl benzene	EPA 8260B	Pass
Volatiles in Soil	38084	4765	Ethyl benzene	EPA 8260B	Pass
RCRA Oxygenates	38169	4770	Ethyl tert-butyl ether	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4765	Ethylbenzene	EPA 8260B	Pass
Volatiles in Soil	4200	4765	Ethylbenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4835	Hexachlorobutadiene	EPA 8260B	Pass
Volatiles in Soil	4200	4835	Hexachlorobutadiene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4840	Hexachloroethane	EPA 8260B	Pass
Volatiles in Soil	38084	4840	Hexachloroethane	EPA 8260B	Pass
RCRA Oxygenates	38169	9375	Isopropyl ether	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4900	Isopropylbenzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4900	Isopropylbenzene	EPA 8260B	Pass
Volatiles in Soil	38084	4900	Isopropylbenzene	EPA 8260B	Pass
Volatiles in Soil	4200	4900	Isopropylbenzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5240	m+p-Xylene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4950	Methyl bromide (Bromomethane)	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4960	Methyl chloride (Chloromethane)	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5000	Methyl tert-butyl ether (MTBE)	EPA 8260B	Pass
RCRA Oxygenates	38169	5000	Methyl tert-butyl ether (MTBE)	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5000	Methyl tert-butyl ether (MTBE)	EPA 8260B	Pass
Volatiles in Soil	38084	5000	Methyl tert-butyl ether (MTBE)	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4975	Methylene chloride	EPA 8260B	Pass
Volatiles in Soil	38084	4975	Methylene chloride	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4975	Methylene chloride (Dichloromethane)	EPA 8260B	Pass
Volatiles in Soil	4200	4975	Methylene chloride (Dichloromethane)	EPA 8260B	Pass
Volatiles in Soil	4200	5000	Methyl-t-butylether (MTBE)	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5005	Naphthalene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5005	Naphthalene	EPA 8260B	Pass
Volatiles in Soil	38084	5005	Naphthalene	EPA 8260B	Pass
Volatiles in Soil	38084	4435	n-Butyl benzene	EPA 8260B	Pass
RCRA Oxygenates	38169	5090	n-Propylbenzene	EPA 8260B	Pass
Volatiles in Soil	38084	5090	n-Propylbenzene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5250	o-Xylene	EPA 8260B	Pass
Volatiles in Soil	38084	4910	p-Isopropyl toluene	EPA 8260B	Pass
Volatiles in Soil	38084	4440	sec-Butyl benzene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5100	Styrene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5100	Styrene	EPA 8260B	Pass
Volatiles in Soil	38084	5100	Styrene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4370	T-amylmethyl ether (TAME)	EPA 8260B	Pass
RCRA Oxygenates	38169	4370	tert-Amyl methyl ether	EPA 8260B	Pass
RCRA Oxygenates	38169	4420	tert-Butyl alcohol (t-Butanol)	EPA 8260B	Pass
Volatiles in Soil	38084	4445	tert-Butyl benzene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5115	Tetrachloroethene	EPA 8260B	Pass
Volatiles in Soil	38084	5115	Tetrachloroethene	EPA 8260B	Pass
Volatiles in Soil	4200	5115	Tetrachloroethene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5115	Tetrachloroethylene (Perchloroethylene)	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5140	Toluene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5140	Toluene	EPA 8260B	Pass
Volatiles in Soil	38084	5140	Toluene	EPA 8260B	Pass
Volatiles in Soil	4200	5140	Toluene	EPA 8260B	Pass
Volatiles in Soil	4200	4260	Total Xylenes	EPA 8260B	Pass
Volatiles in Soil	38084	5260	Total Xylenes	EPA 8260B	Pass
Volatiles in Soil	4200	5260	Total Xylenes	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4700	trans-1,2-Dichloroethene	EPA 8260B	Pass
Volatiles in Soil	38084	4700	trans-1,2-Dichloroethene	EPA 8260B	Pass
Volatiles in Soil	4200	4700	trans-1,2-Dichloroethene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4700	trans-1,2-Dichloroethylene	EPA 8260B	Pass
Volatiles in Soil	4200	4685	trans-1,3-Dichloropropene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	4685	trans-1,3-Dichloropropene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	4685	trans-1,3-Dichloropropene	EPA 8260B	Pass
Volatiles in Soil	38084	4685	trans-1,3-Dichloropropene	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5170	Trichloroethene	EPA 8260B	Pass
Volatiles in Soil	38084	5170	Trichloroethene	EPA 8260B	Pass
Volatiles in Soil	4200	5170	Trichloroethene	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5170	Trichloroethene (Trichloroethylene)	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5175	Trichlorofluoromethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5175	Trichlorofluoromethane	EPA 8260B	Pass
Volatiles in Soil	38084	5175	Trichlorofluoromethane	EPA 8260B	Pass
Volatiles in Soil	4200	5175	Trichlorofluoromethane	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5225	Vinyl acetate	EPA 8260B	Pass
Volatiles in Soil	4200	5225	Vinyl acetate	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5235	Vinyl chloride	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5235	Vinyl chloride	EPA 8260B	Pass
Volatiles in Soil	38084	5235	Vinyl chloride	EPA 8260B	Pass
Volatiles in Soil	4200	5235	Vinyl Chloride	EPA 8260B	Pass
VOAs in Soil - Medium Level	SPE-002-H	5260	Xylene, total	EPA 8260B	Pass
RCRA Medium Level Volatiles in Soil	38199	5260	Xylenes, total	EPA 8260B	Pass
RCRA Semi-Volatiles in Soil	38068	5155	1,2,4-Trichlorobenzene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	4610	1,2-Dichlorobenzene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	4610	1,2-Dichlorobenzene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	4615	1,3-Dichlorobenzene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	4615	1,3-Dichlorobenzene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	4620	1,4-Dichlorobenzene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	4620	1,4-Dichlorobenzene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6735	2,3,4,6-Tetrachlorophenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6835	2,4,5-Trichlorophenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6835	2,4,5-Trichlorophenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6840	2,4,6-Trichlorophenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6840	2,4,6-Trichlorophenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6000	2,4-Dichlorophenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6000	2,4-Dichlorophenol	EPA 8270C	Pass

Base Neutrals and Acids in Soil	4260	6130	2,4-Dimethylphenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6130	2,4-Dimethylphenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6175	2,4-Dinitrophenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6175	2,4-Dinitrophenol	EPA 8270C	Pass
RCRA PAH's	38171	6185	2,4-Dinitrotoluene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6185	2,4-Dinitrotoluene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6185	2,4-Dinitrotoluene (2,4-DNT)	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6005	2,6-Dichlorophenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6005	2,6-Dichlorophenol	EPA 8270C	Pass
RCRA PAH's	38171	6190	2,6-Dinitrotoluene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6190	2,6-Dinitrotoluene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5795	2-Chloronaphthalene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5800	2-Chlorophenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5800	2-Chlorophenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6360	2-Methyl-4,6-Dinitrophenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6385	2-Methylnaphthalene	EPA 8270C	Pass
RCRA PAH's	38171	6385	2-Methylnaphthalene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6385	2-Methylnaphthalene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6400	2-Methylphenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6460	2-Nitroaniline	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6490	2-Nitrophenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6490	2-Nitrophenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5945	3,3'-Dichlorobenzidine	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5945	3,3'-Dichlorobenzidine	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6405	3-Methylphenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6465	3-Nitroaniline	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6465	3-Nitroaniline	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6360	4,6-Dinitro-2-methylphenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5660	4-Bromophenyl phenyl ether	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5660	4-Bromophenyl phenyl ether	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5700	4-Chloro-3-methylphenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5700	4-Chloro-3-methylphenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5745	4-Chloroaniline	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5745	4-Chloroaniline	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5825	4-Chlorophenyl phenyl ether	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5825	4-Chlorophenyl-phenylether	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6410	4-Methylphenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6470	4-Nitroaniline	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6470	4-Nitroaniline	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6500	4-Nitrophenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6500	4-Nitrophenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5500	Acenaphthene	EPA 8270C	Pass
RCRA PAH's	38171	5500	Acenaphthene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5500	Acenaphthene	EPA 8270C	Pass
Acenaphthylene in Soils	SPE-003	5505	Acenaphthylene	EPA 8270C	Pass
RCRA PAH's	38171	5505	Acenaphthylene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5505	Acenaphthylene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5545	Aniline	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5555	Anthracene	EPA 8270C	Pass
RCRA PAH's	38171	5555	Anthracene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5555	Anthracene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5575	Benzo(a)anthracene	EPA 8270C	Pass
RCRA PAH's	38171	5575	Benzo(a)anthracene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5575	Benzo(a)anthracene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5580	Benzo(a)pyrene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5585	Benzo(b)fluoranthene	EPA 8270C	Pass
RCRA PAH's	38171	5585	Benzo(b)fluoranthene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5585	Benzo(b)fluoranthene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5590	Benzo(g,h,i)perylene	EPA 8270C	Pass
RCRA PAH's	38171	5590	Benzo(g,h,i)perylene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5590	Benzo(g,h,i)perylene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5600	Benzo(k)fluoranthene	EPA 8270C	Pass
RCRA PAH's	38171	5600	Benzo(k)fluoranthene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5600	Benzo(k)fluoranthene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5610	Benzoic Acid	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5630	Benzyl alcohol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5630	Benzyl alcohol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5670	Benzyl butyl phthalate	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5670	Benzyl butyl phthalate	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5760	bis(2-Chloroethoxy) methane	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5760	bis(2-Chloroethoxy) methane	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5765	bis(2-Chloroethyl) ether	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5765	bis(2-Chloroethyl) ether	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5780	bis(2-Chloroisopropyl) ether	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5780	bis(2-Chloroisopropyl) ether	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6255	bis(2-Ethylhexyl) phthalate	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6065	bis(2-Ethylhexyl) phthalate	EPA 8270C	Pass
Base Neutrals and Acids in Soil	14260	5680	Carbazole	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5680	Carbazole	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5855	Chrysene	EPA 8270C	Pass
RCRA PAH's	38171	5855	Chrysene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5855	Chrysene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5895	Dibenzo(a,h)anthracene	EPA 8270C	Pass
RCRA PAH's	38171	5895	Dibenzo(a,h)anthracene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5895	Dibenzo(a,h)anthracene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5905	Dibenzofuran	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5905	Dibenzofuran	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6070	Diethyl phthalate	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6070	Diethyl phthalate	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6135	Dimethyl phthalate	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6135	Dimethyl phthalate	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5925	Di-n-butyl phthalate	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5925	Di-n-butylphthalate	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6200	Di-n-octyl phthalate	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6200	Di-n-octylphthalate	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6265	Fluoranthene	EPA 8270C	Pass
RCRA PAH's	38171	6265	Fluoranthene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6265	Fluoranthene	EPA 8270C	Pass

Base Neutrals and Acids in Soil	4260	6270	Fluorene	EPA 8270C	Pass
RCRA PAH's	38171	6270	Fluorene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6270	Fluorene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6275	Hexachlorobenzene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	4835	Hexachlorobutadiene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	4835	Hexachlorobutadiene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6285	Hexachlorocyclopentadiene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6285	Hexachlorocyclopentadiene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	4840	Hexachloroethane	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	4840	Hexachloroethane	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6315	Indeno(1,2,3-cd)pyrene	EPA 8270C	Pass
RCRA PAH's	38171	6315	Indeno(1,2,3-cd)pyrene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6315	Indeno(1,2,3-cd)pyrene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6320	Isophorone	EPA 8270C	Pass
RCRA PAH's	38171	6320	Isophorone	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6320	Isophorone	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6410	m/p-Cresol	EPA 8270C	Pass
RCRA PAH's	38171	5005	Naphthalene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5005	Naphthalene	EPA 8270C	Pass
RCRA PAH's	38171	5015	Nitrobenzene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5015	Nitrobenzene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	5015	Nitrobenzene (NB)	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6530	N-nitrosodimethylamine	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6530	N-Nitrosodimethylamine	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6545	N-nitrosodi-n-propylamine	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6545	N-Nitrosodi-n-propylamine	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6535	N-nitrosodiphenylamine	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6535	N-Nitrosodiphenylamine	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6400	o-Cresol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6605	Pentachlorophenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6615	Phenanthrene	EPA 8270C	Pass
RCRA PAH's	38171	6615	Phenanthrene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6615	Phenanthrene	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6625	Phenol	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6625	Phenol	EPA 8270C	Pass
Base Neutrals and Acids in Soil	4260	6665	Pyrene	EPA 8270C	Pass
RCRA PAH's	38171	6665	Pyrene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	6665	Pyrene	EPA 8270C	Pass
RCRA Semi-Volatiles in Soil	38068	5095	Pyridine	EPA 8270C	Pass
BNAs in Soil	SPE-003	5155	1,2,4-Trichlorobenzene	EPA 8270C	Pass
BNAs in Soil	SPE-003	4610	1,2-Dichlorobenzene	EPA 8270C	Pass
BNAs in Soil	SPE-003	4615	1,3-Dichlorobenzene	EPA 8270C	Pass
BNAs in Soil	SPE-003	4620	1,4-Dichlorobenzene	EPA 8270C	Pass
BNAs in Soil	SPE-003	6835	2,4,5-Trichlorophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6840	2,4,6-Trichlorophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6000	2,4-Dichlorophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6130	2,4-Dimethylphenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6175	2,4-Dinitrophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6185	2,4-Dinitrotoluene (2,4-DNT)	EPA 8270C	Pass
BNAs in Soil	SPE-003	6005	2,6-Dichlorophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6190	2,6-Dinitrotoluene (2,6-DNT)	EPA 8270C	Pass
BNAs in Soil	SPE-003	5795	2-Chloronaphthalene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5800	2-Chlorophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6360	2-Methyl-4,6-dinitrophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6385	2-Methylnaphthalene	EPA 8270C	Pass
BNAs in Soil	SPE-003	6400	2-Methylphenol (o-Cresol)	EPA 8270C	Pass
BNAs in Soil	SPE-003	6460	2-Nitroaniline	EPA 8270C	Pass
BNAs in Soil	SPE-003	6490	2-Nitrophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	5945	3,3'-Dichlorobenzidine	EPA 8270C	Pass
BNAs in Soil	SPE-003	6410	3+4-Methylphenol (m+p-Cresol)	EPA 8270C	Pass
BNAs in Soil	SPE-003	6405	3-Methylphenol (m-Cresol)	EPA 8270C	Pass
BNAs in Soil	SPE-003	6465	3-Nitroaniline	EPA 8270C	Pass
BNAs in Soil	SPE-003	5860	4-Bromophenyl phenyl ether	EPA 8270C	Pass
BNAs in Soil	SPE-003	5700	4-Chloro-3-methylphenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	5745	4-Chloroaniline	EPA 8270C	Pass
BNAs in Soil	SPE-003	5825	4-Chlorophenyl phenylether	EPA 8270C	Pass
BNAs in Soil	SPE-003	6410	4-Methylphenol (p-Cresol)	EPA 8270C	Pass
BNAs in Soil	SPE-003	6470	4-Nitroaniline	EPA 8270C	Pass
BNAs in Soil	SPE-003	6500	4-Nitrophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	5500	Acenaphthene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5505	Acenaphthylene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5545	Aniline	EPA 8270C	Pass
BNAs in Soil	SPE-003	5555	Anthracene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5595	Benzidine	EPA 8270C	Pass
BNAs in Soil	SPE-003	5575	Benzo(a)anthracene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5580	Benzo(a)pyrene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5585	Benzo(b)fluoranthene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5590	Benzo(g,h,i)perylene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5600	Benzo(k)fluoranthene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5610	Benzoic acid	EPA 8270C	Pass
BNAs in Soil	SPE-003	5630	Benzyl alcohol	EPA 8270C	Pass
BNAs in Soil	SPE-003	5760	bis(2-Chloroethoxy)methane	EPA 8270C	Pass
BNAs in Soil	SPE-003	5765	bis(2-Chloroethyl) ether	EPA 8270C	Pass
BNAs in Soil	SPE-003	5780	bis(2-Chloroisopropyl) ether	EPA 8270C	Pass
BNAs in Soil	SPE-003	6255	bis(2-Ethylhexyl) phthalate (DEHP)	EPA 8270C	Pass
BNAs in Soil	SPE-003	5670	Butyl benzyl phthalate	EPA 8270C	Pass
BNAs in Soil	SPE-003	5680	Carbazole	EPA 8270C	Pass
BNAs in Soil	SPE-003	5855	Chrysene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5895	Dibenz(a,h) anthracene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5905	Dibenzofuran	EPA 8270C	Pass
BNAs in Soil	SPE-003	6070	Diethyl phthalate	EPA 8270C	Pass
BNAs in Soil	SPE-003	6135	Dimethyl phthalate	EPA 8270C	Pass
BNAs in Soil	SPE-003	5925	Di-n-butyl phthalate	EPA 8270C	Pass
BNAs in Soil	SPE-003	6200	Di-n-octyl phthalate	EPA 8270C	Pass
BNAs in Soil	SPE-003	6265	Fluoranthene	EPA 8270C	Pass
BNAs in Soil	SPE-003	6270	Fluorene	EPA 8270C	Pass
BNAs in Soil	SPE-003	6275	Hexachlorobenzene	EPA 8270C	Pass
BNAs in Soil	SPE-003	4835	Hexachlorobutadiene	EPA 8270C	Pass

BNAs in Soil	SPE-003	6285	Hexachlorocyclopentadiene	EPA 8270C	Pass
BNAs in Soil	SPE-003	4840	Hexachloroethane	EPA 8270C	Pass
BNAs in Soil	SPE-003	6315	Indeno(1,2,3-cd) pyrene	EPA 8270C	Pass
BNAs in Soil	SPE-003	6320	Isophorone	EPA 8270C	Pass
BNAs in Soil	SPE-003	5005	Naphthalene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5015	Nitrobenzene	EPA 8270C	Pass
BNAs in Soil	SPE-003	6530	n-Nitrosodimethylamine	EPA 8270C	Pass
BNAs in Soil	SPE-003	6545	n-Nitroso-di-n-propylamine	EPA 8270C	Pass
BNAs in Soil	SPE-003	6535	n-Nitrosodiphenylamine	EPA 8270C	Pass
BNAs in Soil	SPE-003	6605	Pentachlorophenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6615	Phenanthrene	EPA 8270C	Pass
BNAs in Soil	SPE-003	6625	Phenol	EPA 8270C	Pass
BNAs in Soil	SPE-003	6665	Pyrene	EPA 8270C	Pass
BNAs in Soil	SPE-003	5095	Pyridine	EPA 8270C	Pass
Base/Neutrals and Acids in Soil	727	5155	1,2,4-Trichlorobenzene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	4610	1,2-Dichlorobenzene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	4615	1,3-Dichlorobenzene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	4620	1,4-Dichlorobenzene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6835	2,4,5-Trichlorophenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6840	2,4,6-Trichlorophenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6000	2,4-Dichlorophenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6130	2,4-Dimethylphenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6175	2,4-Dinitrophenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6185	2,4-Dinitrotoluene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6005	2,6-Dichlorophenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6190	2,6-Dinitrotoluene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5795	2-Chloronaphthalene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5800	2-Chlorophenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6385	2-Methylnaphthalene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6400	2-Methylphenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6460	2-Nitroaniline	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6490	2-Nitrophenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6410	3&4-Methylphenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5945	3,3-Dichlorobenzidine	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6465	3-Nitroaniline	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6360	4,6-Dinitro-2-methylphenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5660	4-Bromophenyl-phenylether	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5700	4-Chloro-3-methylphenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5745	4-Chloroaniline	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5825	4-Chlorophenyl-phenylether	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6470	4-Nitroaniline	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6500	4-Nitrophenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5500	Acenaphthene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5505	Acenaphthylene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5545	Aniline	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5555	Anthracene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5575	Benzo(a)anthracene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5580	Benzo(a)pyrene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5585	Benzo(b)fluoranthene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5590	Benzo(g,h,i)perylene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5600	Benzo(k)fluoranthene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5610	Benzoic acid	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5630	Benzyl alcohol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5760	bis(2-Chloroethoxy)methane	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5765	bis(2-Chloroethyl)ether	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5780	bis(2-Chloroisopropyl)ether	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6255	bis(2-Ethylhexyl)phthalate	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5670	Butylbenzylphthalate	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5855	Chrysene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5895	Dibenz(a,h)anthracene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5905	Dibenzofuran	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6070	Diethylphthalate	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6135	Dimethylphthalate	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5925	Di-n-butylphthalate	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6200	Di-n-octylphthalate	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6265	Fluoranthene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6270	Fluorene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6275	Hexachlorobenzene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	4835	Hexachlorobutadiene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6285	Hexachlorocyclopentadiene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	4840	Hexachloroethane	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6315	Indeno(1,2,3-cd)pyrene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6320	Isophorone	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5005	Naphthalene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5015	Nitrobenzene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6530	N-Nitrosodimethylamine	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6545	N-Nitroso-di-n-propylamine	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6535	N-Nitrosodiphenylamine	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6605	Pentachlorophenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6615	Phenanthrene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6625	Phenol	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	6665	Pyrene	EPA 8270D	Pass
Base/Neutrals and Acids in Soil	727	5095	Pyridine	EPA 8270D	Pass
Low-Level PAHs in Soil	722	5500	Acenaphthene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5505	Acenaphthylene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5555	Anthracene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5575	Benzo(a)anthracene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5580	Benzo(a)pyrene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5585	Benzo(b)fluoranthene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5590	Benzo(g,h,i)perylene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5600	Benzo(k)fluoranthene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5855	Chrysene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5895	Dibenz(a,h)anthracene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	6265	Fluoranthene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	6270	Fluorene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	6315	Indeno(1,2,3-cd)pyrene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	5005	Naphthalene	EPA 8270DSIM	Pass
Low-Level PAHs in Soil	722	6615	Phenanthrene	EPA 8270DSIM	Pass

Low-Level PAHs in Soil					
Dioxin	SPE-016	6665	Pyrene	EPA 8270DSIM	Pass
Dioxin	SPE-016	9519	1,2,3,4,6,7,8,9-OCDD	EPA 8290	Pass
Dioxin	SPE-016	9516	1,2,3,4,6,7,8,9-OCDF	EPA 8290	Pass
Dioxin	SPE-016	9426	1,2,3,4,6,7,8-Hpccdf	EPA 8290	Pass
Dioxin	SPE-016	9420	1,2,3,4,6,7,8-Hpccdf	EPA 8290	Pass
Dioxin	SPE-016	9423	1,2,3,4,7,8,9-Hpccdf	EPA 8290	Pass
Dioxin	SPE-016	9453	1,2,3,4,7,8-Hxcccdf	EPA 8290	Pass
Dioxin	SPE-016	9471	1,2,3,4,7,8-Hxcccdf	EPA 8290	Pass
Dioxin	SPE-016	9456	1,2,3,6,7,8-Hxcccdf	EPA 8290	Pass
Dioxin	SPE-016	9474	1,2,3,6,7,8-Hxcccdf	EPA 8290	Pass
Dioxin	SPE-016	9459	1,2,3,7,8,9-Hxcccdf	EPA 8290	Pass
Dioxin	SPE-016	9477	1,2,3,7,8,9-Hxcccdf	EPA 8290	Pass
Dioxin	SPE-016	9549	2,3,4,7,8-Pecdf	EPA 8290	Pass
Dioxin	SPE-016	9606	2,3,7,8-TCDD	EPA 8290	Pass
Dioxin	SPE-016	9612	2,3,7,8-TCDF	EPA 8290	Pass
Dioxin	SPE-016	9444	Hpccdf, total	EPA 8290	Pass
Dioxin	SPE-016	9483	Hxcccdf, total	EPA 8290	Pass
Dioxin	SPE-016	9606	PCDD + PCDF, total	EPA 8290	Pass
Dioxin	SPE-016	9993	PCDF, total	EPA 8290	Pass
Dioxin	SPE-016	9555	Pecdd, total	EPA 8290	Pass
Dioxin	SPE-016	9552	Pecdf, total	EPA 8290	Pass
Dioxin	SPE-016	9615	TCDD, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9540	1,2,3,7,8-Peccdf	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9543	1,2,3,7,8-Peccdf	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9480	2,3,4,6,7,8-Hxcccdf	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9438	Hpccdf, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9444	Hpccdf, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9468	Hxcccdf, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9483	Hxcccdf, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9992	PCDD + PCDF, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9991	PCDD, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9993	PCDF, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9555	Pecdd, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9552	Pecdf, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9989	TCDD, total	EPA 8290	Pass
Dioxins and Furans in Soil	SPE-016	9615	TCDF, total	EPA 8290	Pass
Herbicides in Soil	4250	8655	2,4,5-T	EPA 8321A	Pass
Herbicides in Soil	4250	8650	2,4,5-TP (silvex)	EPA 8321A	Pass
Herbicides in Soil	4250	8545	2,4-D	EPA 8321A	Pass
Herbicides in Soil	4250	8560	2,4-DB	EPA 8321A	Pass
RCRA Carbamates	38158	7710	3-Hydroxycarbofuran	EPA 8321A	Pass
RCRA Carbamates	38158	7015	Aldicarb sulfone	EPA 8321A	Pass
RCRA Carbamates	38158	7020	Aldicarb sulfonide	EPA 8321A	Pass
RCRA Carbamates	38158	8080	Baygon (Propoxur)	EPA 8321A	Pass
RCRA Carbamates	38158	7195	Carbaryl	EPA 8321A	Pass
RCRA Carbamates	38158	7205	Carbofuran	EPA 8321A	Pass
Herbicides in Soil	4250	8555	Dalapon	EPA 8321A	Pass
Herbicides in Soil	4250	8595	Dicamba	EPA 8321A	Pass
Herbicides in Soil	4250	8605	Dichloroprop	EPA 8321A	Pass
Herbicides in Soil	4250	8620	Dinoseb	EPA 8321A	Pass
RCRA Carbamates	38158	9384	Dioxacarb	EPA 8321A	Pass
RCRA Carbamates	38158	7505	Diuron	EPA 8321A	Pass
Herbicides in Soil	4250	7775	MCPA	EPA 8321A	Pass
Herbicides in Soil	4250	7780	MOPP	EPA 8321A	Pass
RCRA Carbamates	38158	7800	Methiocarb	EPA 8321A	Pass
RCRA Carbamates	38158	8025	Promecarb	EPA 8321A	Pass
Nitroaromatics/Nitroamines in Soil	4420	6885	1,3,5-Trinitrotoluene	EPA 8330	Pass
Nitroaromatics/Nitroamines in Soil	4420	9651	2,4,6-Trinitrotoluene	EPA 8330	Pass
Nitroaromatics/Nitroamines in Soil	4420	6185	2,4-Dinitrotoluene	EPA 8330	Pass
Nitroaromatics/Nitroamines in Soil	4420	6190	2,6-Dinitrotoluene	EPA 8330	Pass
Nitroaromatics/Nitroamines in Soil	4420	9306	4-Amino-2,6-dinitrotoluene	EPA 8330	Pass
Nitroaromatics/Nitroamines in Soil	4420	9513	4-Nitrotoluene	EPA 8330	Pass
Nitroaromatics/Nitroamines in Soil	4420	3740	HMX	EPA 8330	Pass
Nitroaromatics/Nitroamines in Soil	4420	6900	Nitrobenzene	EPA 8330	Pass
Nitroaromatics/Nitroamines in Soil	4420	3630	RDX	EPA 8330	Pass
Nitroaromatics/Nitroamines in Soil	4420	6415	Tetryl	EPA 8330	Pass
RCRA Nitroaromatics in Soil	38155	6885	1,3,5-Trinitrobenzene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	6160	1,3-Dinitrobenzene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	9651	2,4,6-Trinitrotoluene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	6185	2,4-Dinitrotoluene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	6190	2,6-Dinitrotoluene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	9303	2-Amino-4,6-dinitrotoluene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	9507	2-Nitrotoluene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	9510	3-Nitrotoluene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	9306	4-Amino-2,6-dinitrotoluene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	9513	4-Nitrotoluene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	9522	HMX	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	5015	Nitrobenzene	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	9432	RDX	EPA 8330A	Pass
RCRA Nitroaromatics in Soil	38155	6415	Tetryl	EPA 8330A	Pass
Nitroaromatics in Soil	38155	6885	1,3,5-Trinitrobenzene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	6160	1,3-Dinitrobenzene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	9651	2,4,6-Trinitrotoluene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	9185	2,4-Dinitrotoluene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	6190	2,6-Dinitrotoluene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	9303	2-Amino-4,6-dinitrotoluene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	9507	2-Nitrotoluene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	9510	3-Nitrotoluene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	9306	4-Amino-2,6-dinitrotoluene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	9513	4-Nitrotoluene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	9522	HMX	EPA 8330B	Pass
Nitroaromatics in Soil	38155	5015	Nitrobenzene	EPA 8330B	Pass
Nitroaromatics in Soil	38155	9432	RDX	EPA 8330B	Pass
Nitroaromatics in Soil	38155	6415	Tetryl	EPA 8330B	Pass
RCRA Cyanide	55105	1645	Cyanide	EPA 9010B	Pass
Cyanide in Soil	4130	1645	Total Cyanide	EPA 9010B	Pass
RCRA Cyanide	55105	1645	Cyanide	EPA 9014	Pass
Cyanide in Soil	4130	1645	Total Cyanide	EPA 9014	Pass

RCRA Corrosivity - pH Determination	55127	1625	Corrosivity	EPA 9045C	Pass
pH/Corrosivity in Soil	4140	1625	Corrosivity (pH)	EPA 9045C	Pass
RCRA Corrosivity - pH Determination	55127	1625	Corrosivity	EPA 9045D	Pass
Anions in Soil	4160	1540	Bromide	EPA 9056	Pass
RCRA Anions	55141	1540	Bromide (Br)	EPA 9056	Pass
Anions in Soil	4160	1575	Chloride	EPA 9056	Pass
RCRA Anions	55141	1575	Chloride (Cl)	EPA 9056	Pass
Anions in Soil	4160	1730	Fluoride	EPA 9056	Pass
RCRA Anions	55141	1730	Fluoride (F)	EPA 9056	Pass
RCRA Anions	55141	1810	Nitrate as N (NO3- as N)	EPA 9056	Pass
Anions in Soil	4160	1810	Nitrate Nitrogen as N	EPA 9056	Pass
Anions in Soil	4160	1870	Orthophosphate as P	EPA 9056	Pass
RCRA Anions	55141	1870	Phosphate as P (PO43- as P)	EPA 9056	Pass
Anions in Soil	4160	2000	Sulfate	EPA 9056	Pass
RCRA Anions	55141	2000	Sulfate (SO42-)	EPA 9056	Pass
Anions in Soil	SPE-013	1540	Bromide	EPA 9056A	Pass
Anions in Soil	SPE-013	1575	Chloride	EPA 9056A	Pass
Anions in Soil	SPE-013	1730	Fluoride	EPA 9056A	Pass
Anions in Soil	SPE-013	1810	Nitrate as N	EPA 9056A	Pass
Anions in Soil	SPE-013	1820	Nitrate+nitrite as N	EPA 9056A	Pass
Anions in Soil	SPE-013	1840	Nitrite as N	EPA 9056A	Pass
Anions in Soil	SPE-013	1870	Orthophosphate as P	EPA 9056A	Pass
Anions in Soil	SPE-013	2000	Sulfate	EPA 9056A	Pass