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Resource Conservation and Recovery Act Corrective Measures Study Report for SWMU 10 - ROCKEYE

Naval Surface Warfare Center Crane, Indiana

Contract Task Order 0256

March 2006

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Naval Facilities Engineering Command
Southern Division
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IN REPLY REFER TO
5090/S4.7.5
Ser RP3/5109
28 MAR 2005

U.S. Environmental Protection Agency, Region V
Waste, Pesticides, & Toxics Division
Waste Management Branch
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Dear Mr. Ramanauskas:

Crane Division, Naval Surface Warfare Center submits the Draft Corrective Measures Study (CMS) for Rockeye, Solid Waste Management Unit 10 as enclosure (1). Please note that this report was mailed to your office on March 23, 2005 without cover and is therefore, not included with this submittal. The permit required Certification Statement is provided as enclosure (2).

If you require any further information, my point of contact is Mr. Thomas J. Brent, Code RP3-TB, at 812-854-6160, email thomas.brent@navy.mil.

Sincerely,

Christine D Reeman

for JAMES M. HUNSICKER
Manager, Environmental Protection
By direction of the Commanding Officer

Enclosures: 1. Draft Rockeye Corrective Measures Study
2. Certification Statement

Copy to:
ADMINISTRATIVE RECORD
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I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Christine D. Freeman

SIGNATURE

for

Manager, Environmental Protection

TITLE

3/28/05

DATE

REVISION 0
MARCH 2006

RESOURCE CONSERVATION AND RECOVERY ACT CORRECTIVE MEASURES STUDY REPORT FOR SWMU 10 - ROCKEYE

NAVAL SURFACE WARFARE CENTER CRANE, INDIANA

COMPREHENSIVE LONG-TERM ENVIRONMENTAL ACTION NAVY (CLEAN) CONTRACT

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MARCH 2006

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ACRONYMS

§	Part
§§	Parts
µg/L	micrograms per liter
ABG	Ammunition Burning Ground
AHPA	Archaeological and Historic Preservation Act
ALPEC	Ammunition Loading and Production Engineering Center
ARARs	Application or Relative and Appropriate Requirements
AS/SVE	air sparging / soil vapor extraction
B&R	Brown and Root
BGEPA	Bald and Gold Eagle Protection Act
bgs	Below Ground Surface
CAA	Clean Air Act
CAAA	Crane Army Ammunition Activity
CAO	Corrective Action Objectives
CASCO	Central Ammunition Supply Control Office
CEC	cation exchange capacity
CFR	Code of Federal Regulations
CFS	Permanganate Feed System
CLEAN	Comprehensive Long-Term Environmental Action Navy
CMA	Develop Corrective Measures Alternatives
CMD	Corrective Measures Design
CMS	Corrective Measure Study
COA	Corrective Action Objective
COC	chemicals of concern
COPCs	chemicals of potential concern
CTO	Contract Task Order
CWA	Clean Water Act
DNT	dinitrotoluene
DOT	Department of Transportation
DPT	direct push technology
EDQL	Ecological Data Quality Level
EEQ	Ecological Effects Quotient
EMR	Environmental Monitoring Report

EO	Executive Order
ERA	Ecological Risk Assessment
ERDC	Engineering Research and Development Center
ESA	Endangered Species Conservation Act
fps	feet per second
ft/mi	feet per mile
ft/yr	feet per year
FWCA	Fish and Wildlife Coordination Act
GAC	granular activated carbon
gpm	gallons per minute
HHRA	Human Health Risk Assessment
HMX	octahydro-1,3,5,7-tetranitro-1,2,5,7-tetrazocine (which is cyclotetramethylene tetranitramine)
HSWA	Hazardous and Solid Waste Amendments
IAAQS	Indiana Ambient Air Quality Standards
IAS	Initial Assessment Study
IASL	Indiana Air Screening Level
IDEM	Indiana Department of Environmental Management
IDR	Land Disposal Restriction
IERA	Indiana Environmental Remediation Act
IESA	Indiana Non-game and Endangered Species Conservation Act
in/hr	inches per hour
in/yr	inches per year
IR	Installation Restoration
IRIS	Integrated Risk Information System
ISWMB	Indiana Solid Waste Management Board
IWPCB	Indiana Water Pollution Control Board
IWQS	Indiana Water Quality Standards
IWR	Indiana Wildlife Regulation
kg	kilograms
K_{oc}	organic carbon partition coefficient
LAEL	Lowest- Adverse-Effects Levels
LAP	load, assemble, and pack
LCV	lowest chronic value
LEL	Lowest-Effect Level
LOAEL	Lowest-Observed-Adverse-Effects Level

LUC	Land Use Control
MCL	Maximum Contamination Level
MCLG	Maximum Contamination Level Goal
MCS	Media Cleanup Standard
MF	Modifying Factor
mg	milligrams
mph	miles per hour
NAAQS	National Ambient Air Quality Standards
NACIP	Naval Assessment and Control of Installation Pollutants
NAD	Naval Ammunition Depot
NAVFAC	Naval Facilities Engineering Command
NCP	National Contingency Plan
NEESA	Naval Energy and Environmental Support Agency
NESHAP	National Emission Standards for Hazardous Air Pollutants
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No-Observed-Adverse-Effects Level
NPDES	National Pollution Discharge Elimination System
NPW	net present worth
NSWC	Naval Surface Warfare Center
NWSCC	Naval Weapons Support Center Crane
O&M	operations and maintenance
ORC	Ordnance Renovation Complex formerly known as Rockeye (e.g., SWMU 10)
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PEL	permissible exposure limit
PPE	personal protective equipment
ppm	parts per million
PRB	permeable reactive barrier
PRG	Primary Remediation Goal
RBC	Risk Base Concentration
RCRA	Resource Conservation and Recovery Act
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine
	(which is cyclo-trimethyl-trinitramine or "cyclonite")
RFA	RCRA Facility Assessment
RfD	Reference Dose
RFI	RCRA Facility Investigation

RISC	Risk Integrated System of Closure
ROI	radius of influence
SSL	Soil Screening Level
SVOC	semivolatile organic compound
SWDA	Safe Water Drinking Act
SWMU 10	Rockeye
SWMU 5	Old Burn Pit
SWMU 7	Old Rifle Range
SWMU 9	Pesticide Control/R-150 Tank Area
SWMU	solid waste management unit
TAL	Target Analyte List
TBC	To Be Considered
TNT	2,4,6-trinitrotoluene
TOC	total organic carbon
TSD	treatment, storage, or disposal
TSDF	treatment, storage, or disposal facility
U. S. ACE	U.S. Army Corps of Engineers
U.S. ACE WES	United States Army Corps of Engineers Waterways Experiment Station
U.S. ACE	U.S. Army Corps of Engineers
U.S. EPA	United States Environmental Protection Agency
U.S.	United States
UF	Uncertainty Factor
USCOE	U.S. Army Corps of Engineers
VOC	volatile organic compound
WES	Waterways Experiment Station

EXECUTIVE SUMMARY

This Resource Conservation and Recovery Act (RCRA) Corrective Measures Study (CMS) Report was prepared for the Rockeye Facility, which is designated acted as Solid Waste Management Unit (SWMU) 10 at the Naval Surface Warfare Center (NSWC) facility located in Crane, Indiana. The work was sponsored by the United States (U.S.) Navy, Naval Facilities Engineering Field Division South (NAVFAC EFD SOUTH) under Contract Task Order (CTO) 0256, for the Comprehensive Long-Term Environmental Action Navy (CLEAN) 3, Contract Number N62467-94-D-0888.

SITE DESCRIPTION

The Rockeye Facility is still an operational ammunition facility and not a RCRA storage, treatment, or disposal site. The site covers 10 acres located on a flattened ridge crest that separates the Sulphur Creek and Turkey Creek drainage basins in the north-central portion of the Base. The site is located on Highway 45, approximately 2 miles south of North Gate No. 1.

Operations at the site began in the mid-1950s as a press-loading operation for 3-inch projectiles using Composition A-3 explosive (RDX and wax). In 1967 and 1968, the munitions facility was converted to a case-filling operation for the production of the MK20 series antitank Rockeye cluster bomb. The Rockeye bomb is a 500-pound unit that contains 247 steel-cased bomblets, each holding a 0.4-pound blend of Octol Type II and Composition B high explosives.

As part of loading operations, the production facility generated a large volume of explosive-contaminated wastewater, which was collected in sumps surrounding the buildings at the site. The sumps were periodically pumped and the residue was trucked to the Ammunition Burning Ground for treatment. Prior to 1978, when the sumps became full of explosive-contaminated wastewater, the wastewater was discharged via drainage pathways to local intermittent tributaries located near the site. On the northern and eastern sides of the production facility, the wastewater was released to tributaries of Sulphur Creek, on the southern side, the wastewater was released to Turkey Creek watershed, and on the western side the wastewater was released to a tributary of Furst Creek. Discharges with TNT concentrations as high as 50 parts per million (ppm) were detected at these discharge points (US ACE WES, 1998).

In the spring of 1978, an activated carbon water treatment facility (Building 3044) was constructed to purify the wastewater for recycled usage. In addition to a water treatment system, a scrubber system to remove contaminated particulates was designed and installed. In the tray wash area of the production

facility, explosive-contaminated trays are steam cleaned. Before the scrubber was installed, emissions were discharged directly to the atmosphere outside the production buildings. With the installation of the pollution abatement equipment, the release of explosive-contaminated waters was eliminated.

The Rockeye Facility has recently been renamed the Ordnance Renovation Complex (ORC) to reflect the change in operations. Current operations include load, assemble, and pack (LAP) of cast-load explosive items, renovation and painting of projectiles, and disassembly/demilitarization of munitions. Building 3044 continues to be used for treatment of explosive-contaminated waters.

INTERIM MEASURE ACTIVITY

Based on the results of the Phase II Soil Characterization, NSWC Crane evaluated SWMU 10 to determine if the area would be amenable to accelerated cleanup action, otherwise know as interim measure (IM). SWMU 10 was identified for IM cleanup because of explosive-contaminated surface soil (Toltest, 2002).

From November 2000 through July 2001, approximately 1,300 tons of contaminated soil and rock were excavated near Building 2733. The soil contaminants included various explosives, metals, volatile organic compounds (VOCs), and semivolatile organic compounds (SVOCs) (Toltest, 2002). These soils were treated in a 5½-acre bioremediation complex and concentrations were reduced to less than the industrial and/or residential cleanup levels and then used as excavation backfill.

PHASE III RFI PROGRAM

Various investigations have been performed at SWMU 10 to characterize the site conditions, nature and extent, or contamination and to evaluate human health and ecological risk. Investigations showed that soils were contaminated with explosives and that groundwater was contaminated with explosives and metals.

A RFI Phase III Groundwater Characterization study (U.S. ACE WES, 1998) commenced at SWMU 10 in March 1991. This study included the installation of two borings and 83 monitoring wells. The two borings extended beneath the site into the Mississippian-age rocks to characterize the deeper lithologic units and the geologic structure by correlating identifiable and consistent geologic units across the site. The wells were installed and placed in locations that provided areal coverage and characterized subsurface hydrogeology.

The RFI Phase III Groundwater Characterization study included five rounds of groundwater sampling and analysis for RCRA Appendix IX parameters and explosives. All groundwater samples collected for metals analysis were field filtered. After three rounds of sampling results, it was concluded that groundwater samples collected during subsequent monitoring efforts would be analyzed for only metals, nitrogen compounds, cyanide/sulfide, and explosives constituents.

The historical investigations were used as the basis to develop the most recent investigation, which was the Phase III RFI (TtNUS, 2003). The objectives of this investigation were as follows:

- To estimate the nature and extent of contamination.
- To evaluate human health risks through a baseline risk assessment.
- Estimate risks to the environment through a screening level ecological risk assessment.
- To develop information necessary to conduct baseline human health risk assessments (HHRAs) and screening level ecological risk assessments (ERAs).

The Phase III RFI was designed to support any future RCRA Corrective Measures Study (CMS). That study, if required, would be conducted to identify and evaluate cleanup alternatives for the site.

NATURE AND EXTENT OF CONTAMINATION

Little contamination was found in SWMU 10 environmental media. The primary exceptions were groundwater contaminated with three inorganics (iron, manganese, and nickel) and three explosives [2-amino-4,6-dinitrotoluene (2-amino-4,6-DNT), 4-amino-2,6-dinitrotoluene (4-amino-4,6-DNT), RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine, which is also called cyclo-trimethyl-trinitramine or "cyclonite")].

Iron and manganese groundwater concentrations frequently exceed their respective media cleanup standards (MCSs). However, the site activities at SWMU 10 did not include these inorganics; therefore, it was determined that the bedrock is the source of the dissolved iron and manganese in groundwater. Additionally, all nickel groundwater concentrations were less than MCS for nickel. Therefore, alternatives for the cleanup of inorganics were not addressed in this Corrective Measures Study (CMS).

The explosive contamination groundwater is limited to an area that is centrally located in the northeast portion of SWMU 10.

HUMAN HEALTH RISK ASSESSMENT

For SWMU 10, the Phase III RFI report determined that no human health risk exists from contamination to surface water, sediment, surface soil, and subsurface soil. However, it was determined that there was human health risk associated with groundwater to construction workers from dermal exposure (manganese), to future residents from ingestion (explosives and metals), and from dermal contact (manganese). No risk to off-site receptors was found.

ECOLOGICAL RISK ASSESMENT

For SWMU 10, the Phase III RFI report determined that no ecological risk exists from contamination to surface water, sediment, and surface soil.

REMEDIAL ALTERNATIVES

Three corrective measures alternatives were developed, evaluated, and compared for the remediation of the SWMU 10 groundwater explosives plume. These alternatives are as follows:

Alternative 1: No Action. The No Action alternative maintains the site as is and is retained to provide a baseline for comparison to other alternatives. There would be no costs associated with Alternative 1.

Alternative 2: Natural Attenuation, Institutional Controls, and Monitoring. This alternative includes three major components: (1) natural attenuation, (2) institutional controls, and (3) monitoring. Natural attenuation would rely on naturally occurring processes such as biodegradation, dispersion and dilution through aquifer movement, and adsorption on soil particles to reduce the concentrations of explosives. Institutional controls would be developed during the Corrective Measures Design (CMD) that would consist of formulating and implementing site-specific controls that would restrict groundwater use. As part of institutional controls, annual site inspections would be conducted to verify and enforce the continued application of these controls. Monitoring would consist of regularly collecting groundwater and surface water samples and analyzing these for explosives to evaluate the progress of remediation and verify that no contaminant migration is occurring. Although currently available data is insufficient to accurately predict the timeframe required for natural attenuation to attain the Media Cleanup Standards (MCSs), preliminary estimations indicate that this timeframe would probably be somewhat greater than 100 years. The 30-year net present worth (NPW) of Alternative 2 would be $294,000.

Alternative 3: "Hot-Spots" Enhanced In-Situ Bioremediation, Natural Attenuation, Institutional Controls, and Monitoring. This alternative includes four major components: (1) enhanced in-situ

bioremediation of groundwater contamination "hot-spots" with injection of emulsified oil, (2) natural attenuation, (3) institutional controls, and (4) monitoring. Enhanced in-situ bioremediation of "hot-spots" would consist of installing and operating a groundwater recirculation system in each of two 100-foot in diameter areas centered on monitoring well cluster 10C55/10C55P2 ("Hot-Spot" No. 1) and monitoring well 10-17 ("Hot-Spot" No. 2) where the highest concentrations of explosives have been detected. Each groundwater recirculation system would be operated for approximately 2 to 3 weeks and used to introduce a total of 770 gallons of proprietary food-grade emulsified oil in the contaminated aquifer to enhance the biodegradation of explosives. The natural attenuation, institutional controls, and monitoring components of Alternative 3 would be identical to those of Alternative 2, except that some of the groundwater samples would be analyzed for additional parameters to evaluate the progress of the bioremediation process. As for Alternative 2, currently available data is insufficient to accurately predict the timeframe for Alternative 3 to attain the groundwater MCSs. However, it is anticipated that the addition of the "hot-spots" enhanced in-situ bioremediation component would substantially shorten that timeframe and that the MCSs would be met within somewhat less than 100 years. The 30-year NPW of Alternative 3 would be $472,000.

RECOMMENDED CORRECTIVE ACTION

Although groundwater explosives concentrations are expected to decrease below MCSs through natural attenuation, Alternative 1 would not be sufficiently protective of human health and the environment because it would not in the meantime prevent use of groundwater nor detect potential future contaminant migration, both of which could result in unacceptable human health and ecological risks. Alternative 2 is recommended for use at SWMU 10 because it provides the most cost effective remediation approach and would adequately control risks until groundwater explosives concentrations are acceptable. Timeframe for attainment of MCSs would be relatively long (over 100 years), but this is acceptable in the absence of current and projected future risks to human health and the environment. Alternative 3 would provide a slightly accelerated timeframe for attainment of MCSs (less than 100 years) and the same risk controls as Alternative 2, but at a significantly higher NPW of $472,000 as compared to $294,000 for Alternative 2.

1.0 INTRODUCTION

1.1 SCOPE AND OBJECTIVES

This Resource Conservation and Recovery Act (RCRA) Corrective Measures Study (CMS) Report was prepared for the Rockeye Facility, which is designated as Solid Waste Management Unit (SWMU) 10 at the Naval Surface Warfare Center (NSWC) facility located in Crane, Indiana. The work was sponsored by the United States (U.S.) Navy, Naval Facilities Engineering Field Division South (NAVFAC EFD SOUTH) under Contract Task Order (CTO) 0256, for the Comprehensive Long-Term Environmental Action Navy (CLEAN) 3, Contract Number N62467-94-D-0888.

This work is part of the Navy's Installation Restoration (IR) Program, which is designed to identify contamination of Navy and Marine Corps lands/facilities resulting from past activities and to institute corrective measures, as needed. There are typically four distinct phases in the IR Program. Phase 1 is the Preliminary Assessment [formerly known as the Initial Assessment Study (IAS)]. Phase II is a RCRA Facility Assessment (RFA) which augments the information collected in the Preliminary Assessment. Phase 3 is the RCRA Facility Investigation/Corrective Measures Study (RFI/CMS) which characterizes the contamination at a facility and develops options for remediation of the site. Phase 4 is the Corrective Measure Implementation which results in the control or cleanup of contamination at sites. This report has been prepared under Phase 3. The Indiana Department of Environmental Management (IDEM) is the lead oversight agency. However, under a work-sharing agreement, U.S. Environmental Protection Agency (U.S. EPA) Region 5 is responsible for the RI/CMS phase at SWMU 10.

This work was conducted in accordance with the requirements of the Indiana State RCRA Hazardous Waste Permit for the facility (IN5170023498), effective on January 13, 2000.

The corrective measure action and objectives of the CMS are as follows.

- Identify Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) criteria.

- Identify risk-based action levels which are protective of human health and the environment.

- Develop Corrective Action Objectives (CAOs), which identify chemicals of concern (COCs), potential receptors, pathways, and media cleanup standards (MCSs). The MCSs are based on chemical-specific ARARs, TBC criteria, and risk-based action levels.

- Identify and screen corrective measures technologies.

- Develop Corrective Measures Alternatives (CMAs).

- Conduct detailed analysis of CMAs.

The RFI Report for SWMUs 4 (McComish Gorge), 5 (Old Burn Pit), 9 (Pesticide Control/R-150 Tank Area), and 10 (Rockeye), Naval Surface Warfare Center, Crane Division, Crane, Indiana (TtNUS, 2005), presents the finding of the human health and ecological risk assessments.

1.2 ORGANIZATION OF CORRECTIVE MEASURES STUDY

The CMS consists of six sections. Section 1.0 is the introduction section. Section 2.0 provides a description of the current conditions for SWMU 10. Section 3.0 identifies the ARARs, TBC criteria, and CAOs for SWMU 10. Section 4.0 provides the identification and screening of corrective measure technologies for groundwater at SWMU 10. Sections 5.0 and 6.0 present the development and evaluation/comparative analysis of CMAs, respectively.

1.3 ACTIVITY BACKGROUND INFORMATION

1.3.1 Facility Location

SWMU 10 is located at NSWC Crane. NSWC Crane is located in the southern portion of Indiana, approximately 75 miles southwest of Indianapolis and 71 miles northwest of Louisville, Kentucky (Figure 1-1) immediately east of Crane Village and Burns City. NSWC Crane encompasses 62,463 acres (approximately 98 square miles); most of which is located in the northern portion of Martin County. Smaller portions are located in Greene, Daviess, and Lawrence Counties. NSWC Crane is located in a rural, sparsely populated area. Most of NSWC Crane is forested, and the surrounding area is wooded or farmed land.

1.3.2 Facility History

This section provides general information on the history of NSWC Crane and its activities.

1.3.2.1 History of Ownership and Operation

In 1940, Congress authorized construction of a Naval Ammunition Depot (NAD) in southern Indiana. The NAD Burns City was commissioned in late 1941. In 1943, NAD Burns City was renamed NAD Crane, and the Town of Crane was built to house the rapidly growing number of civil service employees. NAD Crane's overall mission was to load, prepare, renovate, receive, store, and issue ammunition to the fleet.

During World War II, NAD Crane's mission expanded to include pyrotechnics production, mine filling, rocket assembly, field storage, torpedo storage, and ordnance spare parts and mobile equipment storage. During the 1950s, several new departments were created, the Ammunition Loading and Production Engineering Center (ALPEC) were transferred to NSWC Crane, and the Central Ammunition Supply Control Office (CASCO) was established. NAD Crane supplied ammunition to the fleet during the Korean and Vietnam Conflicts. During the Southeast Asia crisis, the number of full-time employees at NAD Crane grew to 6,800.

In 1975, NAD Crane was designated Naval Weapons Support Center Crane (NWSCC). Its new mission was to provide support for ships, aircraft, equipment, shipboard weapons systems, and assigned ordnance items and to perform additional functions as directed.

In 1977, the Single Manager Concept was implemented. The Crane Army Ammunition Activity (CAAA) was created, and the Army assumed ordnance production, storage, and related responsibilities as a tenant organization. Other functions remained Navy, and currently the Navy retains ownership of all real estate and facilities at NSWC Crane. Responsibility for overall station safety, security, and environmental protection remains with the Commanding Officer, NSWC Crane. In 1992, the Facility was designated as NSWC Crane. Approximately 4,000 people are currently employed at NSWC Crane.

NSWC Crane provides naval support for equipment, shipboard weapons systems, and ordnance. In addition, NSWC Crane supports the CAAA with production and renovation of conventional ammunition and storage, shipment, demilitarization, and disposal of conventional ammunition.

1.3.2.2 History of Regulatory Actions

Following promulgation of the U.S. EPA RCRA hazardous waste regulatory program, NSWC Crane filed notification and application to operate as a RCRA hazardous waste treatment, storage, or disposal (TSD)

facility in October 1980. Interim status was granted subject to operating requirements and applicable technical standards found in Title 40 Code of Federal Regulations, Part 265 (40 CFR §265).

Corrective action programs established as part of the 1984 RCRA Hazardous and Solid Waste Amendments (HSWA) required NSWC Crane to address past releases of hazardous waste or hazardous constituents at SWMUs. Accordingly, NSWC Crane submitted a Hazardous Waste Management Report and a RCRA facility assessment (Kvale, 1992) was conducted to characterize the potential for releases of hazardous waste or constituents from approximately 100 potential SWMUs identified during the assessment.

On December 23, 1989, U.S. EPA issued the federal portion of the Final RCRA Part B permit for NSWC Crane to the U.S. Navy. U.S. EPA renewed the permit in 1995. IDEM now has responsibility for the Federal Corrective Action Program. IDEM renewed the Corrective Action Permit in October 18, 2001. However, ongoing corrective actions will continue under the U.S. EPA IDEM Work Sharing Agreement for Corrective Action Activities at the NSWC Crane.

1.3.3 Site Description and History

1.3.3.1 Site Description

The Rockeye Facility is still an operational ammunition facility and not a RCRA storage, treatment, or disposal site. The site covers 10 acres located on a flattened ridge crest that separates the Sulphur Creek and Turkey Creek drainage basins in the north-central portion of the Base. The site is located on Highway 45, approximately 2 miles south of North Gate No. 1. The site map for the SWMU is presented as Figure 1-2 and the 2003 aerial photograph of the site and vicinity is shown in Figure 1-3.

Operations at the site began in the mid-1950s as a press-loading operation for 3-inch projectiles using Composition A-3 explosive [RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine, which is also called cyclo-trimethyl-trinitramine or "cyclonite") and wax]. In 1967 and 1968, the munitions facility was converted to a case-filling operation for the production of the MK20 series antitank Rockeye cluster bomb. The Rockeye bomb is a 500-pound unit that contains 247 steel-cased bomblets, each holding a 0.4-pound blend of Octol Type II and Composition B high explosives. Octol Type II contains 70 percent HMX (octahydro-1,3,5,7-tetranitro-1,2,5,7-tetrazocine, which is also called cyclotetramethylene tetranitramine) and 30 percent TNT (2,4,6-trinitrotoluene). Composition B is 60 percent RDX, 39 percent TNT, and 1 percent wax. The wax is used as a desensitizer.

As part of loading operations, the production facility generated a large volume of explosive-contaminated wastewater, which was collected in sumps surrounding the buildings at the site (see Figure 1-2 for approximate sump locations). The sumps were periodically pumped and the residue was trucked to the Ammunition Burning Ground for treatment. Prior to 1978, when the sumps became full of explosive-contaminated wastewater, the wastewater was discharged via drainage pathways to local intermittent tributaries located near the site. On the northern and eastern sides of the production facility, the wastewater was released to tributaries of Sulphur Creek, on the southern side, the wastewater was released to Turkey Creek watershed, and on the western side the wastewater was released to a tributary of Furst Creek. Discharges with TNT concentrations as high as 50 parts per million (ppm) were detected at these discharge points (US ACE WES, 1998).

In the spring of 1978, an activated carbon water treatment facility (Building 3044) was constructed to purify the wastewater for recycled usage. In addition to a water treatment system, a scrubber system to remove contaminated particulates was designed and installed. In the tray wash area of the production facility, explosive-contaminated trays are steam cleaned. Before the scrubber was installed, emissions were discharged directly to the atmosphere outside the production buildings. With the installation of the pollution abatement equipment, the release of explosive-contaminated waters was eliminated.

The Rockeye Facility has recently been renamed the Ordnance Renovation Complex (ORC) to reflect the change in operations. Current operations include load, assemble, and pack (LAP) of cast-load explosive items, renovation and painting of projectiles, and disassembly/demilitarization of munitions. Building 3044 continues to be used for treatment of explosive-contaminated waters.

1.3.3.2 Land Usage

SWMU 10 is an active site with an operational ammunition facility and no waste disposal activities occur at this site. The SWMU is not a RCRA storage, treatment, or disposal site.

1.3.3.3 Corrective Action Stages

Based on the results of the Phase II Soil Characterization, NSWC Crane evaluated SWMU 10 to determine if the area would be amenable to accelerated cleanup action, otherwise know as interim measure (IM). SWMU 10 was identified for IM cleanup because of explosive-contaminated surface soil.

From March 1996 to June 1997, a 5½-acre bioremediation complex was constructed in the southwest quadrant of NSWC Crane near the Crane Landfill. Based upon the favorable results of pilot scale testing

and full scale operations at SWMU 12 Mine Fill A and SWMU 13 Mine Fill B, the bioremediation occurred at SWMU 10.

From November 2000 through July 2001 the following activities occurred at SWMU 10 near Building 2733 (Figure 1-4) (Toltest, 2002):

- Collection and analysis of 96 initial site characterization samples from 34 grids of potentially-impacted soil. Sampling in each grid consisted of two composite samples and one grab sample. The composite samples were collected from zero to 12 inches and from 24 to 36 inches.

- Of the 34 rids that were sampled, seven grids required excavation because the explosive content of the soils sampled exceeded industrial cleanup goals. Soil excavation was performed on the blast wall berm between Buildings 2733 and 2734 and adjacent to the west side of Building 2733.

- Approximately 1,300 tons of contaminated soil and approximately 20 tons of rock were excavated and then screened. During excavation, all oversized material was separated into soil clods that were mixed with gravel and large rock. The rejected soil that was mixed with gravel was re-screened several times to separate as much soil from the gravel as possible.

- Soil samples were collected from each grid during excavation activities to assist in determining the extent of excavation that was required. Field screening test kits were used to test the RDX levels for the in-process soil samples to provide quick field screening results. Post-excavation samples were collected following excavation and field screening to determine the levels of contaminants remaining in the soil. Twenty-two post-excavation samples, which included one composite and one grab sample from the base of each grid and one grab sample from each 20 feet of the side wall, were collected to ensure that the soil contamination levels were below SWMU-specific cleanup goals.

- Screened material was transported to the on-site Bioremediation Facility where treatment of the explosives-contaminated material through composting to degrade the explosive compounds to below the SWMU-specific cleanup goals occurred.

  - At the on-site Bioremediation Facility, organic amendments, which serve as a food source for the microorganism, were mixed with the contaminated soil to form the compost windrows. The bioremediation resulted in a greater volume of compost being generated than the original volume of soil excavated.

- Confirmatory sampling of treated material to ensure that the cleanup goals were achieved included:

  -- Fifteen samples plus quality control samples from each of the five windrows cross-sections for Windrows 203 through 208.
  -- Twelve samples from each of the four cross section of Windrow 202, and
  -- Three samples from the Control Windrow at one cross section..

- All treated materials met residential cleanup for explosives.

- Approximately 2,200 tons of treated soil compost was transported back to SWMU 10 for use as backfill in the excavation sites. Because compositing generates more compost than the original soil excavated, after backfilling the excavations, it was necessary to convert the temporary storage area at SWMU 10 into a permanent placement area for the excess compost.

In summary, at SWMU 10, the IM work included the identification (e.g., soil adjacent to Building 2733 and the berm wall between Buildings 2733 and 2734), excavation, and bioremediation of explosives contaminated soils. All excavated soils were successfully treated at the Bioremediation Facility to levels below residential cleanup goals and returned to SWMU 10 for use as backfill. The confirmatory sampling was utilized in the RFI Report human health and ecological risk assessments (TtNUS, 2005).

1.3.3.4 Preliminary Remedial Actions

From November 2000 through July 2001, IMs were conducted to remove approximately 1,300 tons of contaminated soil and rock near Building 2733 (Toltest, 2002).

1.3.3.5 Site Investigations

The following is a brief description of the historical data collection activities conducted at SWMU 10. A tabular summary of the previous investigations completed for the site is presented in Table 1-1. Historical sample locations are shown in Figure 1-4. Locations of soil and groundwater samples collected in the 2000/2001, the latest phase of sampling as well as some historical borings, are shown in Figure 1-5.

Various investigations were completed at the site from 1981 to 1987 as part of several multi-site investigations. The first investigation, the IAS, began in April 1981 in response to the Naval Assessment and Control of Installation Pollutants (NACIP) Program. The Naval Energy and Environmental Support

Agency (NEESA) completed the IAS in May 1983, with assistance from the Ordnance Environmental Support Agency and the U.S. Army Corps of Engineers Waterways Experiment Station (U.S. ACE WES). The intent of the IAS was to identify and assess sites posing a potential threat to human health and the environment from past hazardous materials operations.

A RFI Phase II Soil Characterization study was performed in 1990. The objective of this study was to determine soil conditions around the site and to identify and characterize the constituents that may have been released to the soil (U.S. ACE WES, 1998d). The investigation included the collection and analysis of surface and subsurface samples, predominantly in areas where wastewaters from the munitions production lines were released and would likely have made contact with the soil (e.g., sumps, open ditches, etc.). Thirteen soil borings were advanced at the SWMU, and 24 soil samples were collected from these borings.

A RFI Phase III Groundwater Characterization study (U.S. ACE WES, 1998) commenced at SWMU 10 in March 1991. This study included the installation of two borings and 83 monitoring wells. The two borings extended beneath the site into the Mississippian-age rocks to characterize the deeper lithologic units and the geologic structure by correlating identifiable and consistent geologic units across the site. The wells were installed and placed in locations that provided areal coverage and characterized subsurface hydrogeology. Also, the wells were completed at various depths to determine the vertical extent of contamination. These wells were installed at depths of 100 feet or less.

The RFI Phase III Groundwater Characterization study included five rounds of groundwater sampling and analysis for RCRA Appendix IX parameters and explosives. All groundwater samples collected for metals analysis were field filtered. After three rounds of sampling results, it was concluded that groundwater samples collected during subsequent monitoring efforts would be analyzed for only metals, nitrogen compounds, cyanide/sulfide, and explosives constituents.

The most recent investigation was the Phase III RFI (TtNUS, 2003). The objectives of this investigation were as follows:

- To estimate the nature and extent of contamination.
- To develop information necessary to conduct baseline human health risk assessments (HHRAs) and screening level ecological risk assessments (ERAs).
- To develop the HHRAs and ERAs.

1.4 PHYSICAL CHARACTERISTICS OF SWMU 10 STUDY AREA

The SWMU is approximately 10 acres in size and is located on a flattened ridge crest that separates Sulphur Creek and Turkey Creek in the north central portion of the Facility. The SWMU is located on Highway 45, approximately 2 miles south of North Gate No. 1. The site map for the SWMU is presented as Figure 1-5.

1.4.1 Climate and Meteorology

The climate in the region of NSWC Crane can be described as temperate (NOAA, 1988). Precipitation is distributed evenly throughout the year, and there is no pronounced wet or dry season for this region. Rainfall in the spring and summer is produced mostly from showers and thunderstorms. A peak rainfall of about 2½ inches in a 24-hour period can be expected about once a year. Snowfalls of 3 inches or more occur on an average of two or three times per winter season. The annual mean monthly distribution of rain and snow for the area is shown in Table 1-3. Annual rainfall total is about 40 inches per year (in/yr) with the highest mean monthly totals occurring in the late spring and in the early summer period of May through July. Snowfall averages about 23 inches a year, with most occurring in the winter months of December through February.

Mean monthly air temperatures for the region are shown in Table 1-2. Temperatures range from a minimum of 27.9°F in January to a maximum of 75.7°F in July. The mean annual temperature for the area is 52.6°F.

Relative humidity for the local area is generally highest in the early morning hours June through September, and generally ranges between 80 to 88 percent on average. The lowest values of relative humidity, historically, have occurred between March through October during the afternoon and evening hours, when values average between 54 and 58 percent.

Long-term climatological records (NOAA, 1988) for the area indicate that the monthly prevailing wind direction is southwest during the month of April through December, then shifts to the northwest during the months of January through March. The annual prevailing wind direction for the region is from the southwest. The annual average wind speed for the area is about 9.6 miles per hour (mph).

1.4.2 Topography

1.4.2.1 NSWC Crane

NSWC Crane is in the unglaciated area of the Crawford Uplands Physiographic Province. This province is a rugged, highly vegetated, dissected plateau bounded by the Mitchell Plain Physiographic Province to the east and the Wabash Lowland Physiographic Province to the west (Murphy and Wade, 1988). The Mitchell Plain is a low dissected limestone plateau characterized by sinkholes and karst topographic features. The boundary between the Crawford Upland and the Mitchell Plain is marked by the highly irregular, eastern facing Chester Escarpment. Springs, caverns, caves, and other solution weathering features can be found along this escarpment and on the eastern edge of the NSWC Crane facility. The boundary between the Crawford Upland and the Mitchell Plain near the western boundary of NSWC Crane is gradual (Murphy and Wade, 1988).

The terrain is predominantly rolling with moderately incised stream valleys throughout and occasional flat areas in the central and northern portions of NSWC Crane. The elevations across NSWC Crane range from about 500 feet above mean sea level (msl) at the southern drainageway to about 850 feet msl on the ridge in the west-central portion of the site. V-shaped drainageways in the north progress to 2,000-foot-wide floodplains in the south and rise to approximately 150 to 200 feet to the ridgelines (NEESA, 1983).

1.4.2.2 SWMU 10

The surface at SWMU 10 is relatively flat with elevations across SWMU 10 ranging from 810 to 830 feet msl. Outside of the SWMU boundary, the elevation drops off sharply to the northeast, east and south into deep gullies with elevation below 700 feet msl. Total relief in the area is approximately 200 ft.

1.4.3 Geology and Soils

1.4.3.1 NSWC Crane

The unconsolidated overburden deposits over the entire Crane facility are generally 0 to 10 feet thick on the ridge tops and 10 to 65 feet thick in the valley bottoms (Nohrstedt et al., 1998). These deposits generally consist of two types: Quaternary- and Pleistocene-age alluvial and colluvial deposits near the floodplains of streams and unconsolidated residual soil and loess on sides and tops of ridges. The U.S. Department of Agriculture (USDA) has classified soils of Martin County (McElrath, 1988). Thin residual soils on or near the tops of ridges are generally classified as Zanesville or Wellston silt loams. These residual soils are characterized as well-drained to moderately-drained. They have a brown organic silt

loam at the surface (typically about 8 inches thick) underlain by 42 to 48 inches of mottled tan, gray, and yellow clay with varying percentages of sand and silt. The Wells-Berks-Gilpin soil complex is found on all of the hillsides near the MGBG (McElrath, 1988). This soil complex forms on very steep to moderately steep slopes and is well drained. In a typical profile, 1 to 2 inches of dark gray to brown silt loam is found at the surface. The subsurface soil is composed of light to dark yellowish-brown, silty loam to silty clay loam. All soils in the Wells-Berks-Gilpin complex contain about 15 percent to 35 percent clay.

Bedrock underlying NSWC Crane consists of sedimentary rocks from the Lower Pennsylvanian-age Mansfield Formation (Raccoon Creek Group) and the underlying Upper Mississippian-age Stephensport and West Baden Groups. The Mansfield Formation (uppermost bedrock) consists primarily of alternating beds of shales (e.g., black carbonaceous shale and gray shale), sandstone, and siltstone, but also includes thin discontinuous coal seams and limestone lenses. This formation is typically about 110 feet thick or more at NSWC Crane (U.S. ACE WES, 1991). An erosional unconformity separates the Pennsylvanian strata above from the Stephensport strata below. Depending on the location at NSWC Crane, pre-Pennsylvanian erosion has removed a significant portion of the Stephensport strata. At these locations the paleovalleys were filled with shales and sandstones of Pennsylvanian age.

The Stephensport Group, generally 130 to 190 feet thick, includes a number of sandstone and limestone units including the Big Clifty Sandstone and the Beech Creek Limestone. The underlying West Baden Group also consists of limestone, shale, and sandstone units and is generally 60 to 140 feet thick.

The Upper Mississippian bedrock formations crop out near the bottom of the major stream channels in the MGBG area. The bedrock sideslopes and upland areas over most of NSWC Crane consist of Mansfield Formation, labeled as "Raccoon Creek Group and undifferentiated." The bedrock formations in the NSWC Crane area dip west-southwest at about 25 feet per mile.

1.4.3.2 SWMU 10

Extensive geologic and hydrogeologic investigations of the SWMU were performed by the U.S. ACE and is detailed in a report titled RCRA Facility Investigation, Phase III Groundwater Release Characterization, SWMU 10/15 Rockeye Facility, Naval Surface Warfare Center Crane, Indiana (U.S. ACE, August 1998). That investigation included the drilling and installation of over 100 monitoring wells in multiple geologic and hydrogeologic units of interest. No monitoring wells were installed during the Tetra Tech NUS (TtNUS) investigation performed in 2001. A summary of the findings of the U.S. ACE investigation that focuses on those issues that are critical to this RFI is included in the remainder of this section.

The SWMU is located on a high point overlying Pennsylvanian rocks that were modified by the cut and fill process for construction of the facility. Farther east, the area is dissected by Sulphur Creek, exposing Mississippian rocks in the stream valley. The subsurface materials encountered beneath the SWMU include fill, natural unconsolidated materials derived from the Pennsylvanian rocks, the Pennsylvanian bedrock, and Mississippian bedrock. A generalized hydrogeologic cross section is included in Figure 1-7.

The U.S. ACE subsurface investigation focused primarily on the upper 150 feet of material beneath the SWMU, which included those units most likely to become impacted by SWMU activities. The majority of wells installed at the SWMU were located above the continuous shale (defined as the basal shale) that was encountered in the Pennsylvanian bedrock at an approximate elevation of 725 ft msl. Five borings investigated the Mississippian bedrock below the Pennsylvanian basal shale.

The U.S. ACE investigation included the installation of wells in clusters and at solitary locations, and three hydrogelogic zones above the basal shale were defined and investigated. Those units were named the upper, middle, and lower aquifers. The monitoring wells defining theses three aquifers were generally grouped because they had relatively similar well screen elevations and potentiometric surface elevations.

Fill material was added to low areas on top of the ridge in the 1940s and was graded to make the ridgetop relatively flat. The fill exists predominantly in the eastern portion of the SWMU and is up to 13 feet thick. The fill consists predominantly of silty clay. In general, the fill directly overlies the natural unconsolidated materials in all areas.

The natural unconsolidated materials, which consist of residual soils derived from the Pennsylvanian bedrock, are generally less than 10 feet thick and consist predominantly of clay. Residual soils derived from the Mississippian have also been mapped along the valley sides of Sulphur Creek, located east of the SWMU.

The bedrock units beneath the SWMU consist of the Pennsylvanian units and the underlying Mississippian units. The Pennsylvanian consists of alternating units of shale,.sandstone, siltstone, and coal. The lithogolic units comprising the Pennsylvanian were found to be thin and laterally discontinuous, based on depositional environment; which prompted extensive mapping by the U.S. ACE. Ten depositional facies (defined as thin, laterally discontinuous units) were identified, mapped, and detailed by the U.S. ACE (1998).

Several of the sandstone facies mapped and identified by the Indiana Geological Survey (massive, cross bedded, and ripple bedded sandstone facies) were interpreted to be channel sandstones, and were

identified as sandstones A, B, and C (see Figure 1-8 for Isopach maps), and were labeled in order from the deepest A (therefore the oldest) to the shallowest C (the youngest). These sandstones were identified as potentially excellent aquifer material. Sandstone "A" occupies the eastern two-thirds of the SWMU, sandstone "B" occupies the north-central two-thirds of the SWMU, and sandstone "C" occupies the southeast corner of the SWMU.

An intermediate shale facies unit exists between the sandstone A and the overlying sandstone B and C units. The surface of the shale has been mapped and is shown on Figure 1-9. Of particular interest is the absence of shale in the northwest and northeast corners of the SWMU, as well as an isolated area in the western portion of the SWMU. The surface of the shale is also highest at the east side and southwest corners of the SWMU with an undulating slope to the north-northwest. The thickness of this shale is greatest in the southeast and southwest corners of the SWMU (greater than 20 feet thick, see Figure 1-10), and tapers to those areas where the shale is nonexistent.

A continuous basal shale exists within the Pennsylvanian bedrock underlying the SWMU. The basal shale is reported to range in thickness from 2 to 12 feet, and is defined as a persistent aquiclude by the U.S. ACE. The surface of this shale has also been mapped as shown on Figure 1-11. The shale is at its highest elevation in the eastern portion of the SWMU and follows an undulating slope toward the west, which is consistent with the reported westward regional dip of bedrock units in this area (U.S. WES, 1998).

The Pennsylvanian bedrock units underlying the basal shale have not been extensively investigated. An unconformity forms the contact between the Pennsylvanian bedrock and the underlying Mississippian units. The Mississippian geologic units underlying the unconformity are from youngest to oldest, the Hardinsburg shale, Golconda/Haney Limestone, Indian Springs shale, Big Clifty Sandstone, Beech Creek Limestone, Elwren shale, Sample Formation, and Beaver Bend Limestone.

1.4.4 Surface Water Hydrology

1.4.4.1 NSWC Crane

The surface drainage at NSWC Crane has formed a dense, dendritic pattern throughout the installation which flows generally to the south and southwest. Seven primary creeks in five drainage basins carry surface water off the installation, where it eventually drains into the East Fork of the White River and then to the Wabash River to the southwest. The seven creeks that drain NSWC Crane include Furst Creek,

Sulphur Creek, Little Sulphur Creek, Boggs Creek, Turkey Creek, Indian Creek, and Seed Tick Creek. Figure 1-3 shows the surface drainage features and the individual drainage basins at NSWC Crane.

Drainage Basin IV includes Boggs and Turkey Creeks, which are the primary drainageways for the installation and drain the majority of the area. The northern and northwestern sections (Basin I) are drained by Furst Creek, the eastern portion (Basin III) is drained by the Sulphur Creek complex, the extreme eastern portion (Basin II) is drained by Indian Creek, and the southwestern section (Basin V) is drained by Seed Tick Creek.

Also located within the installation are several small ponds and Lake Greenwood, an 800-acre man-made, spring-fed lake in the northwestern portion of the installation. Lake Greenwood is the main source of potable water at NSWC Crane and is also used for recreation (NEESA, 1983).

1.4.4.2 SWMU 10

Surface water runoff from SWMU 10 is to the northeast, southwest and southeast. Surface water runoff from the northern and eastern drainageways at the SWMU leads to a tributary of Sulphur Creek. Surface water runoff from the Area A drainageway, which is located west of the SWMU, leads to a tributary of Furst Creek (Figure 1-6). Surface water runoff from the southern side of the SWMU leads to Turkey Creek.

1.4.5 Hydrogeology

1.4.5.1 NSWC Crane

U.S. ACE WES (1998) discussed regional groundwater trends pertaining to the unglaciated southwestern portion of Indiana. In general, groundwater is contained in joint openings of limestone and sandstone aquifers. Surficial unconsolidated aquifers are thin and have limited potential as water supplies.

Aquifers beneath NSWC Crane are considered to be vertically isolated from each other by interlayered shale beds that act as aquitards. Groundwater recharge in the unconsolidated surficial materials occurs through rainfall infiltration at the ground surface. Groundwater recharge in the underlying bedrock units can occur where aquifer units crop out or from vertical downward migration through joint openings from overlying units.

Local variations in bedding thickness and composition, dip, aquifer and aquitard thicknesses, the presence or absence of fractures, incision by surface drainage, and karstic conditions cause local

groundwater movement at NSWC Crane to differ from regional trends. Where erosion resulting from surface drainage has cut through aquifer units, groundwater discharge occurs as springs and seeps. Springs and seeps are prevalent at contacts between aquitards and overlying aquifers. Groundwater flowing from springs and seeps into surface water can potentially re-enter the groundwater system as recharge to a lower aquifer outcropping downstream below aquitards.

In the eastern portion of NSWC Crane, U.S. ACE WES (1998) hypothesized that karstic conditions are present primarily in major drainage valleys where erosion has cut into permeable sandstones overlying easily dissolved limestone units. Rapid infiltration in the Big Clifty Sandstone has caused dissolution and weathering of the underlying Beech Creek Limestone. The result of this occurrence has been the creation of karst and collapse conditions along some of the major drainageways within the eastern part of NSWC Crane.

The upper soil materials on the top and sides of ridges are generally unsaturated. The upper most bedrock is composed of Lower Pennsylvanian-age Mansfield Formation, consisting of irregular beds and lenses of sandstone, siltstone, and shale. Because of the irregularities in the extent and thickness of each lithologic unit and the variability in the permeability and yield of groundwater for each well, it is difficult to divide the Pennsylvanian-age rocks into distinct aquifers or water-bearing units. In general, groundwater is likely moving along fractures, joints, and bedding planes and not through a porous matrix, as is commonly the case with unconsolidated deposits.

1.4.5.2 SWMU 10

Because the soil/fill material is mostly compacted clay and silt, the hydraulic conductivity of the surface materials are relatively low. Most precipitation (rainfall) exits the site as surface runoff. During periods of infiltration, the soil acts as a slow conduit for water and contaminant movement.

Three discrete aquifers were identified and monitored in the Pennsylvanian formation beneath SWMU10. Those aquifers were identified as the upper, middle, and lower aquifers. Monitoring wells were also installed into four other deeper geologic units in the Mississippian formation, including the Golconda/Haney Limestone, Beech Creek Limestone, Big Clifty Sandstone, and Sample Formation.

Groundwater is primarily present in the bedrock beneath SWMU 10. However, at one location, groundwater was encountered in fill at a depth less than 10 feet below ground surface (bgs). This is located in a topographic low point at the SWMU. No groundwater was found in the unconsolidated natural material at the site, as it is relatively thin (generally 10 feet) and comprised primarily of clay.

The upper aquifer, which is the shallow aquifer at the site, generally follows topography and flows from topographic high points to low areas. The channel Sandstone C unit occupies a portion of the upper aquifer in the southeastern corner of the facility. Groundwater in the upper aquifer appears to be unaffected by the presence of this unit. The Upper Aquifer is reported by U.S. ACE WES to drain vertically into Sandstone B of the middle aquifer, in the northeastern portion of the SWMU area. This belief is confirmed by comparison of potentiometric surface water elevations in middle aquifer wells that are more representative of the upper aquifer potentiometric surface, and the lack of shallow groundwater at the expected depth where upper aquifer groundwater should exist. The hydraulic gradient in the upper aquifer is about 0.04. A geometric mean of hydraulic conductivity values for this unit is 1.8×10^{-4} feet per second (fps). A seepage velocity for the Upper Aquifer was calculated to be 4.5×10^{3} feet per year (ft/yr).

The middle aquifer is defined by U.S. ACE as the water-yielding unit above the intermediate shale at an elevation of 770 feet upwards to about 790 feet. This aquifer corresponds fairly well with the Sandstone B unit. Wells outside of the mapped extent of the Sandstone B unit are typically dry, or have potentiometric surface elevations that are more representative of the overlying upper aquifer, implying a hydraulic connection in these areas. The potentiometric surface contour map of the middle aquifer is included in Figure 1-12. Groundwater in the middle Aquifer flows from the east and west to a trough, then in a southward direction at a gradient of 0.2. A geometric mean of hydraulic conductivity values for this unit is 1.59×10^{-4} fps.

In general, the surface of the groundwater table for the upper and middle Pennsylvanian aquifers roughly parallels the topographic surface. The middle and upper aquifers are hydraulically connected. They merge in the northeast portion of the SWMU. Because the two aquifers ultimately act as one with respect to groundwater flow and potential contaminant migration, historical groundwater data from the wells of both aquifers (upper and middle) were combined and referred to as the upper/middle Pennsylvanian aquifer.

The lower aquifer is defined as the water-yielding unit that lies above the basal shale at an elevation of 725 feet, and underlying the intermediate shale at an elevation of 770 feet. This aquifer is defined to be extensive beneath the site, with varying groundwater yield. Sandstone A occupies a portion of the lower aquifer. Wells installed in the lower aquifer outside of the limits of Sandstone A yielded similar potentiometric surface elevations as those wells located in Sandstone A, which supports a hydraulic connection across the entire lower aquifer. The potentiometric surface contour map of the lower aquifer is included in Figure 1-13. The potentiometric surface is highest in the southeast corner of the SWMU with groundwater in this unit flowing toward the north and southwest, at a gradient of about 0.02. A

geometric mean of hydraulic conductivity values for this unit is 6.08 x 10^{-4}fps. A seepage velocity for the lower aquifer was calculated to be 1.28x10^4 ft/yr.

The top of the lower aquifer is deep (about 50 bgs) beneath the SWMU, but is projected to intercept the gullies draining the site to the northeast and south. The erosional gullies on the south side and northeast slope of the site do not drain the lower aquifer until the actual lower aquifer sandstone is breached. No springs or seeps, which would indicate drainage of the aquifer to the ground surface have been identified on either the south or northeast side of the ridge. It is probable that near-surface residual clay soils prevent groundwater from contacting the free surface in the gully banks.

1.4.6 Water Supply

1.4.6.1 NSWC Crane

Seven primary creeks carry surface water off the installation and eventually drain into the East Fork or the While River, and then to the Wabash River to the southwest. The seven creeks that drain NSWC Crane are Furst Creek, Sulphur Creek, Little Sulphur Creek, Boggs Creek, Turkey Creek, Indian Creek, and Seed Tick Creek (Figure 1-1). Also located within the installation are several small ponds and Lake Greenwood, an 800-acre man-made, spring-fed lake in the northwestern portion of the installation. Lake Greenwood is the main source of drinking water at NSWC Crane and it is also used for recreation.

1.4.6.2 SWMU 10

Groundwater at the SWMU is not currently and is not anticipated to be used in the future as a potable drinking water source. Lake Greenwood is the source of potable water for NSWC Crane.

1.4.7 Surrounding Land Use

NSWC Crane is situated in a rural area of south-central Indiana. The surrounding communities that form the region are in a period of transition from an economic base of agriculture, mining, and quarrying to an economy built on manufacturing and service industries. The patterns of settlement, population statistics, and median income are similar throughout the region.

There is no state or local planning within the vicinity of NSWC Crane. The only zoning and land use regulations are found in the municipalities within the region. None of these municipalities are close enough to have an impact on NSWC Crane. None of the areas adjacent to NSWC Crane are zoned, and zoning is not anticipated in the near future. SWMU 10 is approximately 3 miles east of the nearest NSWC

Crane property boundary; however, SWMU 10 is bounded on the northwest by Highway 45. There are no known current or likely future land use or community actions under consideration or proposed at this time for the off-base land in the vicinity of SWMU 10. SWMU 10 is contained completely within NSWC Crane and likely future land use at areas surrounding the SWMU is expected to be limited to industrial uses.

1.4.8 Ecological Setting

1.4.8.1 Facility Location

A biological characterization of NSWC Crane, including a listing of plants and animals found at the facility, was presented in the Installation Assessment (Army, 1978) and the IAS (NEESA, 1983), and is summarized in the Environmental Monitoring Reports (EMRs) (Halliburton NUS, 1992a and 1992b). A list of the species that may inhabit NSWC Crane and are protected under the U.S. Endangered Species Act, Indiana Department of Natural Resources Heritage Data Center, or the U.S. Fish and Wildlife Service is summarized in the RCRA Facility Permit (U.S. EPA, 1995). The following paragraphs briefly summarize the environmental setting at the installation.

Eighty percent of NSWC Crane's 63,000 acres are classified as Central Hardwoods Forest of the United States (NEESA, 1983). In addition, some agricultural fields are in various stages of succession. Openings on dry upland sites contain almost pure stands of grasses with some clumps of woody plants such as persimmon, sassafras, and sumac. Wetter sites have river birch, willow, sycamore, and cottonwood. Hillside communities have mostly hickory, white and black oak, red maple, sugar maple, tulip poplar, ash, and beech (NEESA, 1983).

The great variety of habitats at NSWC Crane (i.e., many stages of forest succession, streams, ponds, Lake Greenwood, grassy open spaces) has lead to a high diversity of animal species (NEESA, 1983). Some of these species include (but are not limited to) mammals such as white-tailed deer, beaver, coyote, hawks, red fox, rabbits, raccoons, mice; birds such as ducks, geese, wild turkey, bobwhite quail, red-tailed hawks, and American robins; and various amphibians, reptiles, fish, and invertebrates.

The bird population includes a number of state or federal threatened, endangered, or species of special concern that use the site as their home range. These species include the bald eagle, osprey, sharp-shinned hawk, red-shouldered hawk, broad-winged hawk, black and white warbler, hooded warbler, and the worm-eating warbler (B&R, 1997). Also, the Indiana bat, a federal endangered species, is known to

forage at NSWC Crane. Because of the bat and its potential habitat, the cutting of trees is restricted to certain times during the year, and the cutting of shagbark hickory trees is prohibited.

1.4.8.2 SWMU 10

The SWMU consists of approximately 10 acres located on a flattened ridge that separates Sulphur and Boggs Creeks. No trees are located on the SWMU (Schuman, et al.) but nearby stands consist mainly of oaks and poplars. To the north of the site, pignut hickory and shagbark hickory (*Carya spp.*), black oak (*Quercus velutina*), chestnut oak and red oak (*Quercus spp.*), scarlet oak (*Quercus coccinea*), white oak (*Quercus alba*), and yellow poplar (*Liriodendron tulipifera.*) dominate the landscape. To the south, maple, white oak, black oak, pine, hickory, and yellow poplar are present.

The drainage ditches adjacent to the site ultimately lead to streams that discharge into either Sulphur Creek or Turkey Creek. In October 1997, a fish inventory was performed on Boggs, Furst, Turkey, Seed Tick, and Sulphur Creeks. Boggs Creek had 29 species, Turkey Creek had 16 species, Furst Creek had 20 species, and Lake Greenwood had 13 species. Boggs Creek has a small watershed; ponds within the watershed are stocked annually with largemouth bass (*Micropterus salmoides*), bluegill sunfish (*Leopomis macrochirus*), redear sunfish (*Etheostoma whipplei*), and golden shiners (*Notemigonus crysoleucus*). Also in this area, a single male Indiana bat, an endangered species, was captured along the Little Sulphur and Furst Creeks approximately 1.5 miles west of SWMU 10 (Brent, personal comm).

TABLE 1-1

SUMMARY OF HISTORICAL SITE INVESTIGATIONS
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA
PAGE 1 OF 2

INVESTIGATION (REPORT/REFERENCE)	EXTENT OF INVESTIGATION	RESULTS OF INVESTIGATION	
	SUMMARY	DETECTED PARAMETERS OF INTEREST	CONCLUSIONS
General Basewide Investigations[1] (1981-1987)	Installation of 2 monitoring wells in 1981. Physical soil testing was performed to define hydrogeological characteristics	NA	Geology consists of clay with lesser amounts of sand and silt. Soils at the site range from 0.5 ft to 17 feet bgs. The average depth to groundwater (upper aquifer) is approximately 17 feet bgs with fluctuations based on topography. groundwater in the area tends to flow toward the intermittent streams that drain the site. Drainage from the north goes to Sulfur Creek; the south to Turkey Creek; and the west to Furst Creek. groundwater flows mainly to the north/northeast.
	Installation of 22 wells located around the perimeter of the site. Quarterly/semiannual groundwater monitoring instituted to identify the presence or absence of contamination.	Explosives (2,4,6-TNT, 2,4-DNT, 2,6-DNT, and RDX)	The primary areas of surface contamination are around the sumps and drainageways. Explosives contamination was noted in the monitoring walls northeast of the site. The presence of explosives in walls 10-01and 10-02 indicates that surface streams are an important transport the mechanisms. On-site wells near surface streams streams contained explosives.
RFI Phase II Soils Release Characterization for SWMU 10/15 Rockeye, Naval Surface Warfare Center Crane, Crane, Indiana (U.S. ACE WES, 1998)	Installation of 13 soil borings and collection of 23 soil samples. Collect surface samples in 8 areas utilizing a 5 ft grid pattern. Sampling performed to determine whether a chemical release had occurred at the site (i.e., identify residual contaminant concentrations in soil).	Surface soil - SVOCs (aniline and N-nitrosodi-methylamine), PAHs, explosives (2,4-DNT, 2,6-DNT, 2,4,6-TNT, HMX, and RDX) and various inorganics (mainly Sb, As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Ni, Sn, and Zn) Subsurface Soil - VOCs (1,1,1-TCA, 1,1,2-TCA) and various inorganics (mainly Sb, As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Ni, and Zn)	The bedrock surface is irregular. The soil types are mainly clay with lesser amounts of sand and silt. Much of the soil encountered is fill and contained natural organic debris. Because of the clay soil type, most of the rainfall would tend to exit as runoff and not migrate downward to groundwater. groundwater flow is affected by the drainage divide. groundwater generally moves toward the creeks. Analytes of major concern are the explosives, which were found in the sumps, surface drainageways and surface soils. No pattern was noted for those VOCs detected at the site. Most of the SVOCs/PAHs were found in one sample at Area H (collected sample at Area H (collected from an air vent discharge are from one building). Inorganics in subsurface soil were found at levels representative of background. Inorganics were detected at concentrations above background in soil samples collected from drainageways. However, there is not sufficient information to determine whether these inorganics were a result of site activities. Detects of methylene chloride and phthalates are thought to be attributable to laboratory contamination.
Final Report RFI Phase III Ground Water Release Characterization Report, SWMU 10 Rockeye Facility, Naval Surface Warfare Center, Crane, Indiana (U.S. ACE WES, 1998b)	Drilling of 2 borings and installation of 83 monitoring wells. Cluster wells were located at 10C23 through 10C53 and 10C55. Borings were used only to determine the structure trends across the base. Monitoring wells were used to determine subsurface hydrogeology and vertical extent of constituents.	VOCs (benzene and chloroform), explosives (1,3,5-trinitrobenzene, amino-dinitrotoluenes 2,4,6-TNT, 2,4-DNT, 2,6-DNT, and RDX), PCBs (Aroclor-1254), pesticides (mainly DDD, DDE, DDT, alpha-chlordane, beta-BHC, dieldrin, endosulfan II, endrin, gamma-chlordane, heptachlor, heptachlor epoxide, and methoxy-chlor), dinoseb, inorganics (mainly, Al, SB, As, Be, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Ni, Se, Tl, Zn), cyanide, chloride, nitrate, and nitrite	Three discrete aquifers were identified: the upper, middle, and lower in the Pennsylvanian aged rock. Also, deeper aquifers in the Mississippian geologic unit were identified (Beech and Golconda aquifers). Benzene, Aroclor-1254, and low levels of pesticides and herbicides were found throughout the site. Many of these detected were found in 1991, but were not confirmed in later sampling. Explosives were found predominantly in the northeast wells; these detections confirm earlier studies. Inorganics were found in most wells in all three Pennsylvanian aquifers. Most inorganics were identified as statistically significant, especially in the upper aquifer. However, the presence of these inorganics are thought to be attributable to natural conditions of low pH produced by depositional conditions of the aquifer rock. Detects of acetone, methylene chloride, and phthalates are considered to be laboratory contaminants.

TABLE 1-1

SUMMARY OF HISTORICAL SITE INVESTIGATIONS
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

INVESTIGATION (REPORT/REFERENCE)	EXTENT OF INVESTIGATION	RESULTS OF INVESTIGATION	
	SUMMARY	DETECTED PARAMETERS OF INTEREST	CONCLUSIONS
Draft Resource Conservation and Recovery Act Facility Investigation Report for SWMUs 4 (McComish Gorge), 5 (Old Burn Pit), 9 (Pesticide Control/R-150 Tank Area), and 10 (Rockeye), Naval Surface Warfare Center, Crane Division, Crane, Indiana	Drilling of 10 borings were used to collect 20 surface/subsurface soil samples. Existing monitoring wells were utilized to collect 20 ground water samples. Twelve surface water/sediment samples were collected.	Explosives (2-amino-4,6-DNT, 4-amino-2,6-DNT, 2,6-DNT, and RDX) and inorganics (iron, manganese, and nickel) were detected in groundwater.	Proceed to CMS.

Al - aluminum.
As - arsenic.
Ba - barium.
Be - beryllium.
Cd - cadmium.
CMS - Corrective Measures Study.
CN - cyanide.
Co - cobalt.
Cr - chromium.
Cu - copper.
DNT - dinitrotoluene.
Fe - iron.
Hg - mercury.
Mn - manganese.
NA - Not applicable.
Ni - nickel.
PAHS - Polynuclear Aromatic Hydrocarbons.
Pb - lead.
PCBs - Polychlorinated Biphenyls.
RCRA - Resource Conservation and Recovery Act.
RFI - RCRA Facility Investigation.
Sb - antimony.
Se - selenium.
Sn - tin.
SVOCs - Semivolatile Organic Compounds.
Tl - thallium.
TNT - trinitrotoluene.
Va - vanadium.
VOCs - Voletile Organic Compounds.
Zn - zinc.

1 Includes, but is not limited to, Hydrogeologic Investigations at Waste Disposal Sites (U.S. ACE WES, 1982) and Navy Assessment and Control of Installation Pollutants, Confirmation Study (HMTC, June 1985).

TABLE 1-2

CLIMATOLOGICAL
MEAN MONTHLY TEMPERATURES[1]
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE,
CRANE, INDIANA

Month	Mean Monthly Temperature (°F)
January	27.9
February	30.6
March	40.3
April	52.0
May	62.5
June	71.7
July	75.7
August	73.6
September	66.8
October	55.3
November	42.0
December	31.8
Mean Annual	52.6

1 - Reference: National Oceanic and Atmospheric Administration (NOAA), 1988.

°F - degrees Fahrenheit.

TABLE 1-3

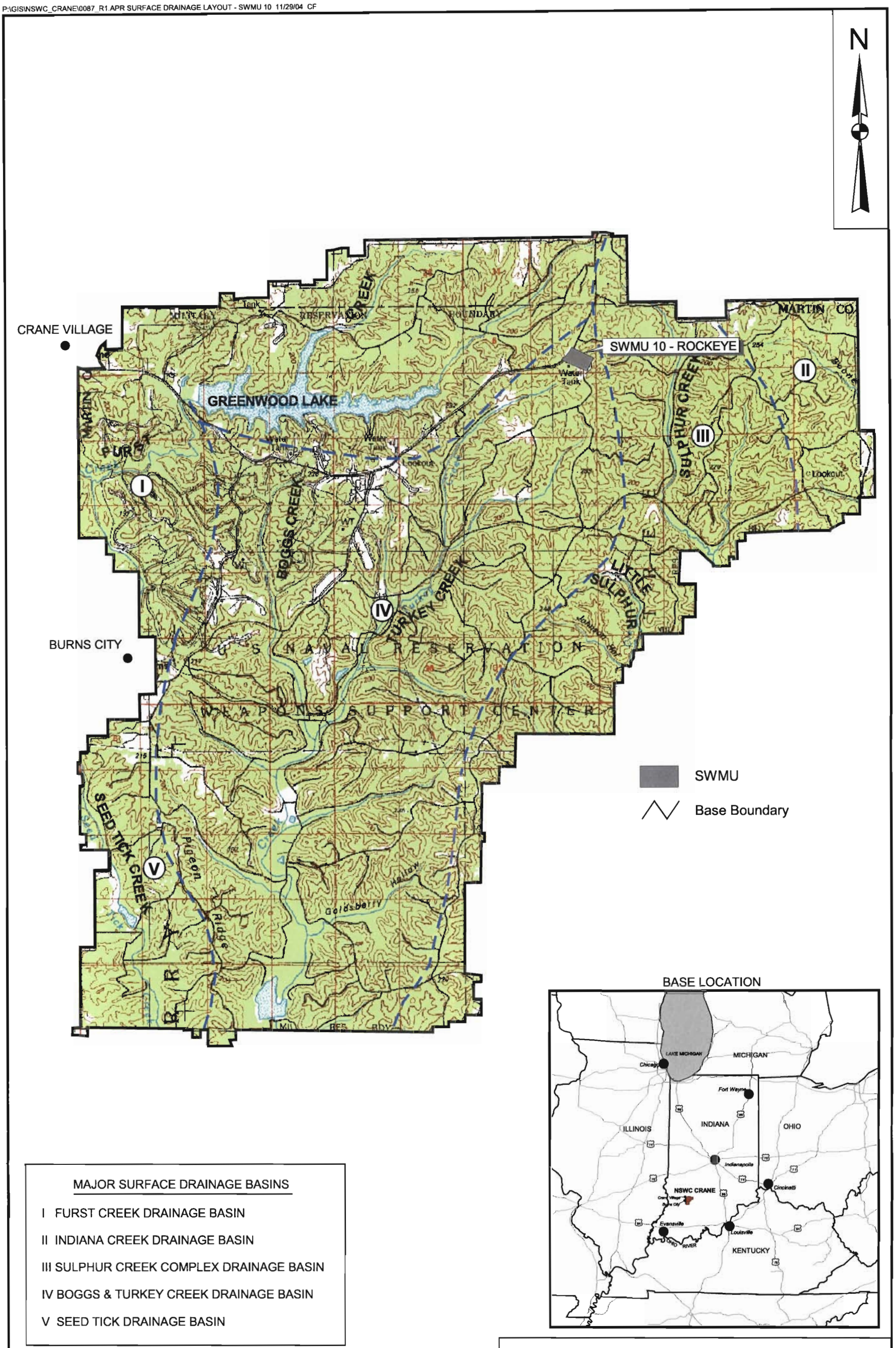
CLIMATOLOGICAL MEAN MONTHLY RAINFALL AND SNOWFALL AMOUNTS[1]
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Month	Mean Monthly Rainfall (inches)	Mean Monthly Snowfall (inches)
January	2.89	6.3
February	2.52	5.9
March	3.78	3.5
April	3.66	0.5
May	3.93	T[2]
June	4.06	0
July	3.89	0
August	3.28	0
September	3.11	0
October	2.68	T[1]
November	3.21	1.9
December	2.95	4.8
Annual	39.98	23.0

1 - Reference: National Oceanic and Atmospheric Administration (NOAA), 1988.

2 - indicates snowfall amounts less than 0.01 inch.

P:\GIS\NSWC_CRANE\0087_R1.APR SURFACE DRAINAGE LAYOUT - SWMU 10 11/29/04 CF



MAJOR SURFACE DRAINAGE BASINS

I FURST CREEK DRAINAGE BASIN

II INDIANA CREEK DRAINAGE BASIN

III SULPHUR CREEK COMPLEX DRAINAGE BASIN

IV BOGGS & TURKEY CREEK DRAINAGE BASIN

V SEED TICK DRAINAGE BASIN

SOURCE: "Initial Assessment Study of Naval Weapons Support Center Crane, Indiana." Naval Energy and Environment Support Activity, May 1983.

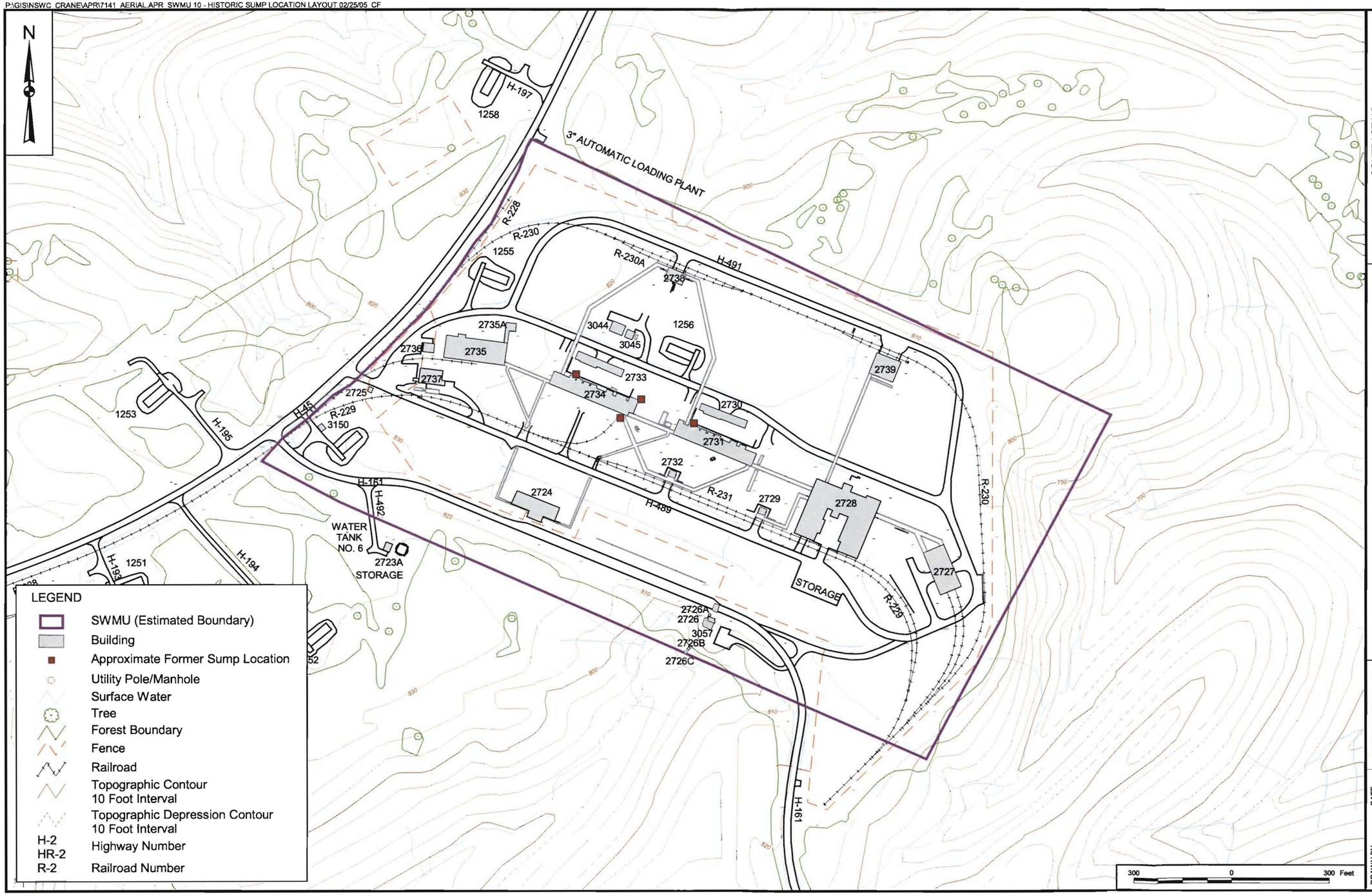
DRAWN BY	DATE
J. LAMEY	4/19/99
CHECKED BY	DATE
V. PLACHY	11/29/04
COST/SCHEDULE-AREA	
SCALE	
AS NOTED	

NAVFAC

SITE LOCATION AND SURFACE DRAINAGE BASINS
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

CONTRACT NUMBER N4267	
APPROVED BY	DATE
APPROVED BY	DATE
DRAWING NO. FIGURE 1 - 1	REV 0

P:\GIS\NSWC_CRANE\APR\7141_AERIAL.APR SWMU 10 - HISTORIC SUMP LOCATION LAYOUT 02/25/05 CF



CONTRACT NO. N4267

APPROVED BY ___ DATE ___

APPROVED BY ___ DATE ___

DRAWING NO. FIGURE 1 - 2

REV 0

SITE FEATURES
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

NAVFAC

DRAWN BY K. PEILA DATE 5/22/02

CHECKED BY V. PLACHY DATE 11/29/04

COST/SCHED-AREA

SCALE AS NOTED

DRAWN BY S. STROZ	DATE 3/10/06	2003 AERIAL PHOTOGRAPH CMS REPORT FOR SWMU 10 - ROCKEYE NSWC CRANE CRANE, INDIANA	CONTRACT NUMBER N4267
CHECKED BY G. ZIMMERMAN	DATE 3/09/06		APPROVED BY / DATE
COST/SCHEDULE-AREA			APPROVED BY / DATE
SCALE AS NOTED			DRAWING NO. FIGURE 1 - 3 / REV 0

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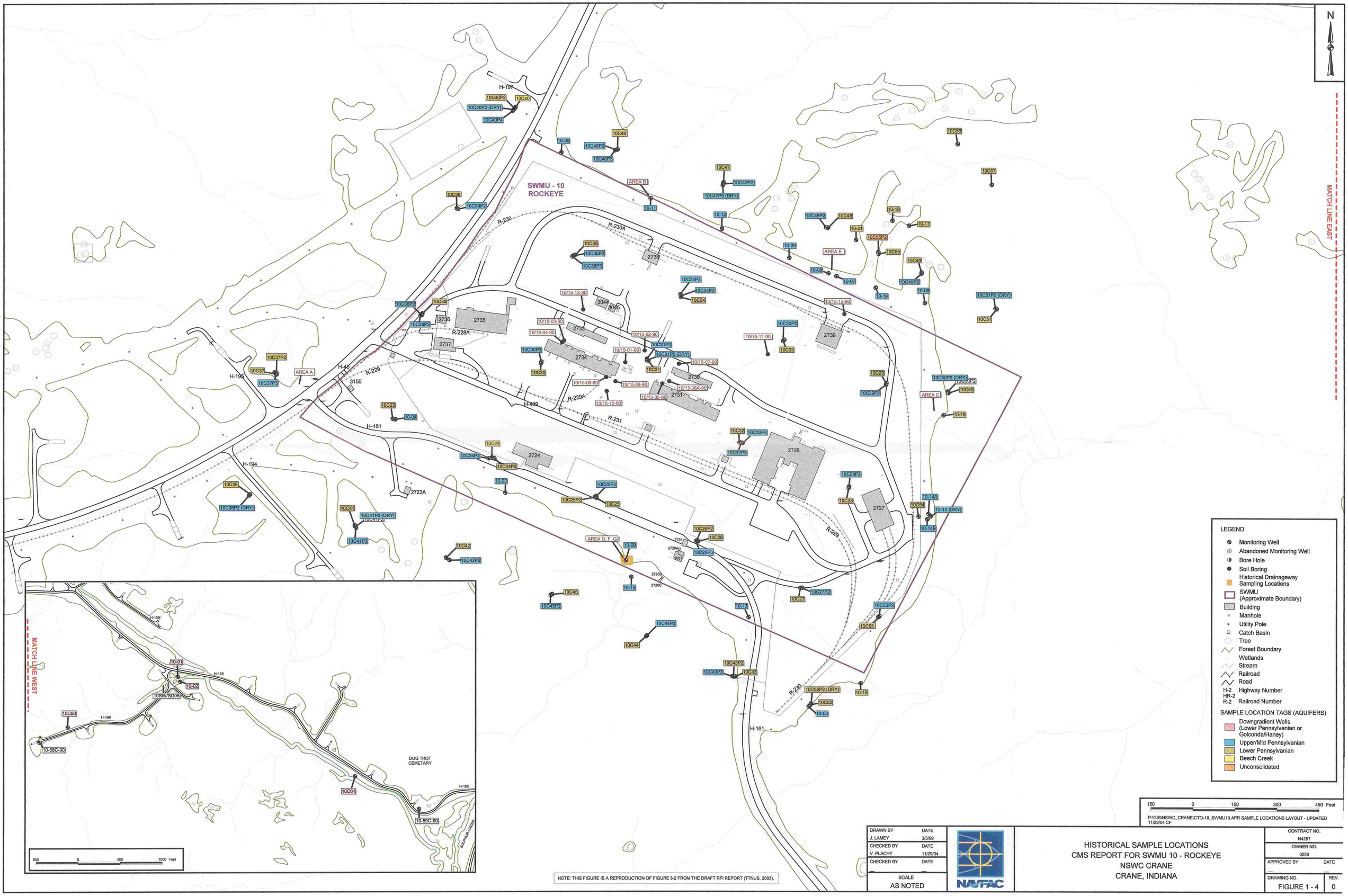


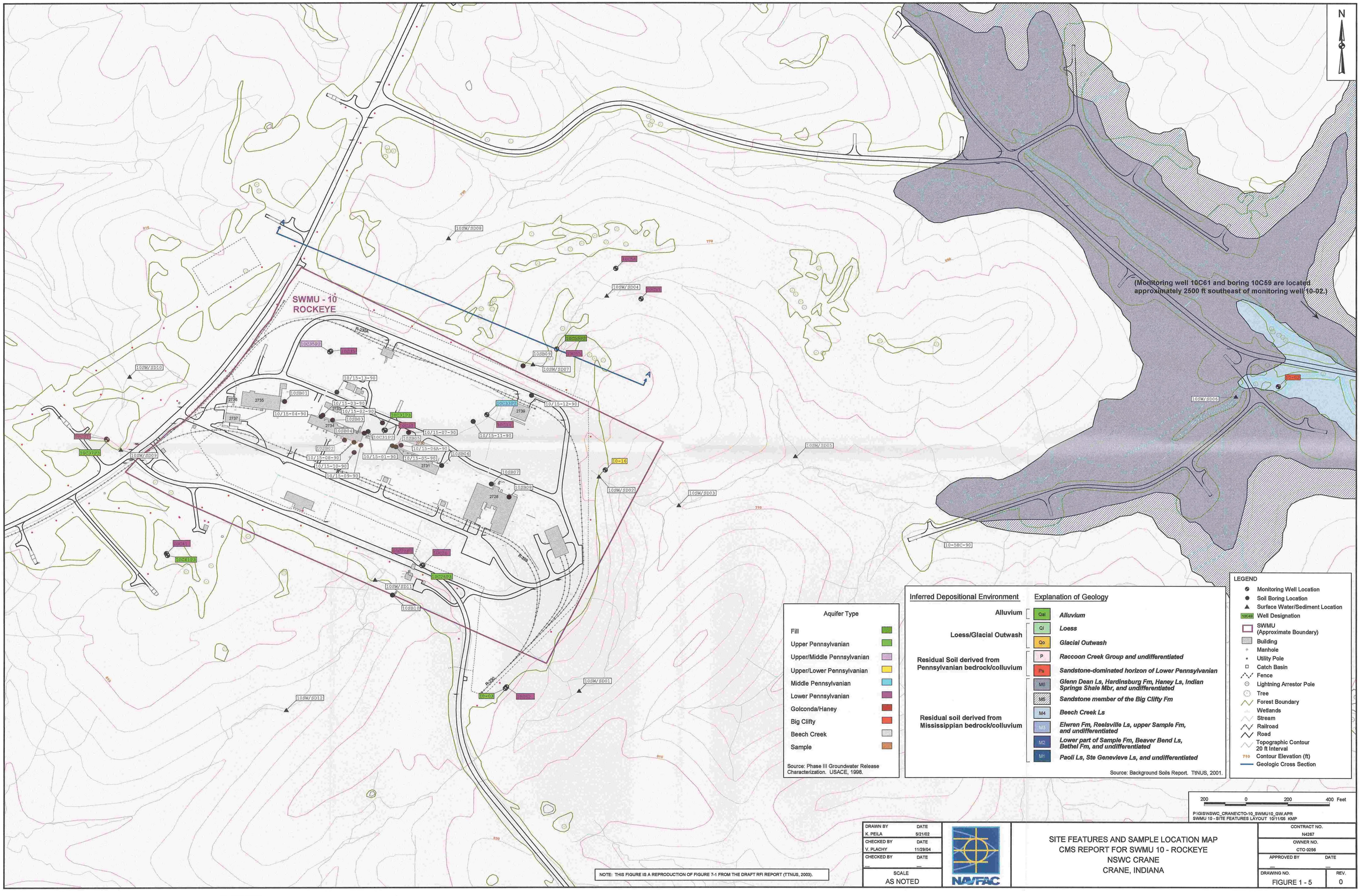
NOTE: THIS FIGURE IS A REPRODUCTION OF FIGURE 8-2 FROM THE DRAFT RFI REPORT (TTNUS, 2003).

DRAWN BY	DATE
J. LAMEY	3/5/99
CHECKED BY	DATE
V. PLACHY	11/29/04
CHECKED BY	DATE
SCALE	
AS NOTED	

NAVFAC

HISTORICAL SAMPLE LOCATIONS
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

CONTRACT NO.	
N4267	
OWNER NO.	
0256	
APPROVED BY	DATE
DRAWING NO.	REV.
FIGURE 1 - 4	0


N
SWMU - 10
ROCKEYE
(Monitoring well 10C61 and boring 10C59 are located approximately 2500 ft southeast of monitoring well 10-02.)
10SW/SD08
10SW/SD04
10SW/SD07
10SW/SD10
10SW/SD09
10SW/SD05
10SW/SD06
10SW/SD03
10SW/SD02
10SW/SD01
10SW/SD11
10SW/SD12
10SB01
10SB02
10SB03
10SB04
10SB05
10SB06
10SB07
10SB08
10SB09
10SB10
10/15-13-90
10/15-03-90
10/15-04-90
10/15-02-90
10/15-12-90
10/15-11-90
10/15-07-90
10/15-06A-90
10/15-05-90
10/15-01-90
10/15-08-90
10/15-10-90
10/15-09-90
10-16
10-02
10-58C-90
10C35P2
10C31P2
10C31P3
10C31P4
10C47P3
10C47P4
10C26P3
R-230A
R-230
2736
2735
2737
2734
2733
2731
2728
Aquifer Type
Fill
Upper Pennsylvanian
Upper/Middle Pennsylvanian
Upper/Lower Pennsylvanian
Middle Pennsylvanian
Lower Pennsylvanian
Golconda/Haney
Big Clifty
Beech Creek
Sample
Source: Phase III Groundwater Release Characterization. USACE, 1998.
Inferred Depositional Environment
Explanation of Geology
Alluvium
Qal
Alluvium
Loess/Glacial Outwash
Ql
Loess
Qo
Glacial Outwash
Residual Soil derived from Pennsylvanian bedrock/colluvium
P
Raccoon Creek Group and undifferentiated
Ps
Sandstone-dominated horizon of Lower Pennsylvanian
Residual soil derived from Mississippian bedrock/colluvium
M6
Glenn Dean Ls, Hardinsburg Fm, Haney Ls, Indian Springs Shale Mbr, and undifferentiated
M5
Sandstone member of the Big Clifty Fm
M4
Beech Creek Ls
M3
Elwren Fm, Reelsville Ls, upper Sample Fm, and undifferentiated
M2
Lower part of Sample Fm, Beaver Bend Ls, Bethel Fm, and undifferentiated
M1
Paoli Ls, Ste Genevieve Ls, and undifferentiated
Source: Background Soils Report. TtNUS, 2001.
LEGEND
Monitoring Well Location
Soil Boring Location
Surface Water/Sediment Location
10C48 Well Designation
SWMU (Approximate Boundary)
Building
Manhole
Utility Pole
Catch Basin
Fence
Lightning Arrestor Pole
Tree
Forest Boundary
Wetlands
Stream
Railroad
Road
Topographic Contour 20 ft Interval
710 Contour Elevation (ft)
Geologic Cross Section
200 0 200 400 Feet
P:\GIS\NSWC_CRANE\CTO-10_SWMU10_GW.APR
SWMU 10 - SITE FEATURES LAYOUT 10/11/05 KMP
NOTE: THIS FIGURE IS A REPRODUCTION OF FIGURE 7-1 FROM THE DRAFT RFI REPORT (TTNUS, 2003).
DRAWN BY K. PEILA DATE 5/21/02
CHECKED BY V. PLACHY DATE 11/29/04
CHECKED BY DATE
SCALE AS NOTED
NAVFAC
SITE FEATURES AND SAMPLE LOCATION MAP
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA
CONTRACT NO. N4267
OWNER NO. CTO 0256
APPROVED BY DATE
DRAWING NO. FIGURE 1 - 5
REV. 0

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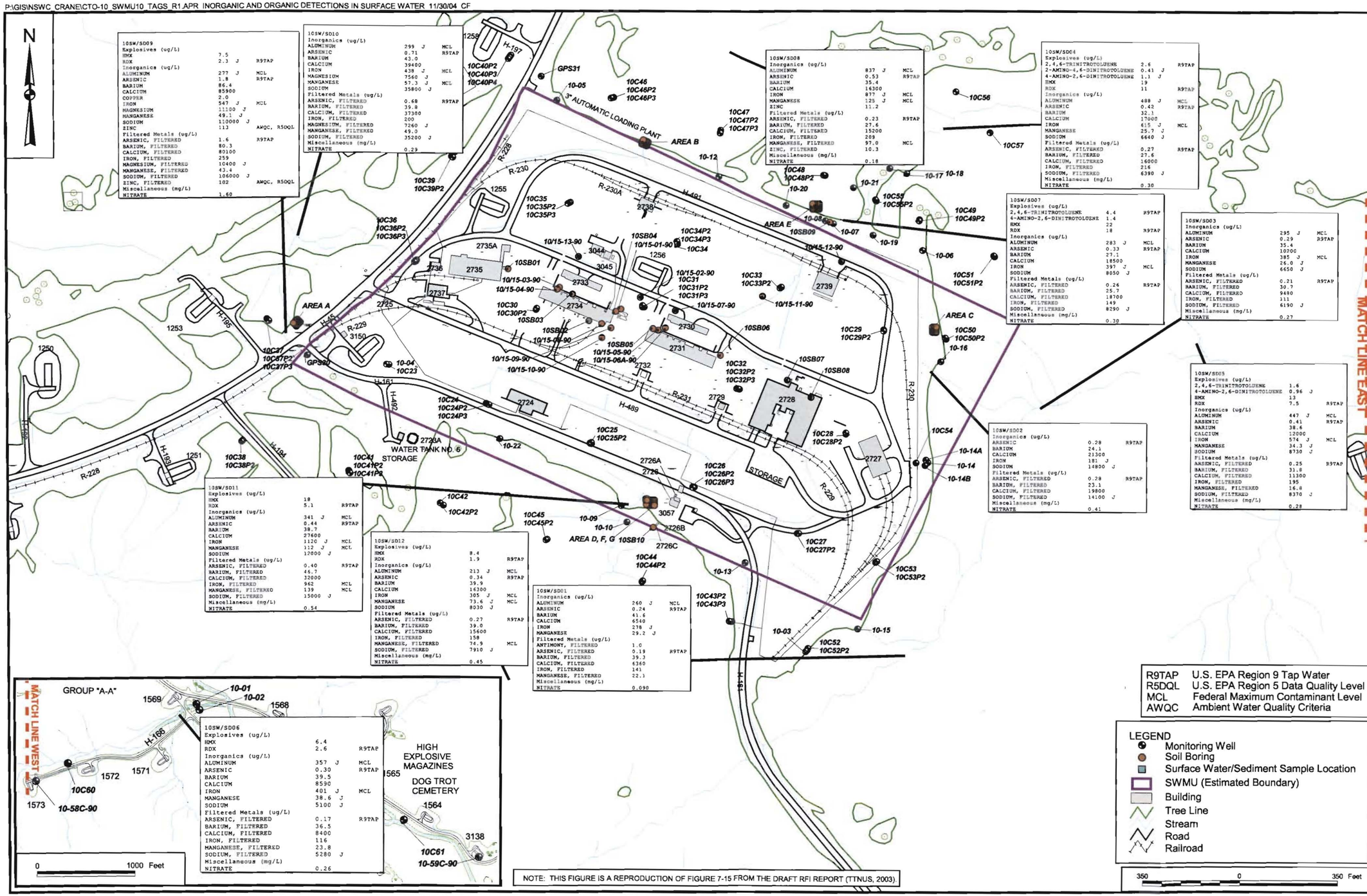

10SW/SD09		
Explosives (ug/L)		
HMX	7.5	
RDX	2.3 J	R9TAP
Inorganics (ug/L)		
ALUMINUM	277 J	MCL
ARSENIC	1.8	R9TAP
BARIUM	86.4	
CALCIUM	85900	
COPPER	2.0	
IRON	547 J	MCL
MAGNESIUM	11100 J	
MANGANESE	49.1 J	
SODIUM	110000 J	
ZINC	113	AWQC, R5DQL
Filtered Metals (ug/L)		
ARSENIC, FILTERED	1.6	R9TAP
BARIUM, FILTERED	80.3	
CALCIUM, FILTERED	80100	
IRON, FILTERED	259	
MAGNESIUM, FILTERED	10400 J	
MANGANESE, FILTERED	43.4	
SODIUM, FILTERED	106000 J	
ZINC, FILTERED	102	AWQC, R5DQL
Miscellaneous (mg/L)		
NITRATE	1.60	

10SW/SD10		
Inorganics (ug/L)		
ALUMINUM	299 J	MCL
ARSENIC	0.71	R9TAP
BARIUM	43.0	
CALCIUM	39400	
IRON	438 J	MCL
MAGNESIUM	7560 J	
MANGANESE	57.3 J	MCL
SODIUM	35800 J	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.68	R9TAP
BARIUM, FILTERED	39.8	
CALCIUM, FILTERED	37300	
IRON, FILTERED	200	
MAGNESIUM, FILTERED	7260 J	
MANGANESE, FILTERED	49.0	
SODIUM, FILTERED	35200 J	
Miscellaneous (mg/L)		
NITRATE	0.29	

10SW/SD08		
Inorganics (ug/L)		
ALUMINUM	837 J	MCL
ARSENIC	0.53	R9TAP
BARIUM	35.4	
CALCIUM	16300	
IRON	877 J	MCL
MANGANESE	125 J	MCL
ZINC	11.2	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.23	R9TAP
BARIUM, FILTERED	27.6	
CALCIUM, FILTERED	15200	
IRON, FILTERED	209	
MANGANESE, FILTERED	97.0	MCL
ZINC, FILTERED	10.3	
Miscellaneous (mg/L)		
NITRATE	0.18	

10SW/SD04		
Explosives (ug/L)		
2,4,6-TRINITROTOLUENE	2.6	R9TAP
2-AMINO-4,6-DINITROTOLUENE	0.41 J	
4-AMINO-2,6-DINITROTOLUENE	1.1 J	
HMX	19	
RDX	11	R9TAP
Inorganics (ug/L)		
ALUMINUM	488 J	MCL
ARSENIC	0.42	R9TAP
BARIUM	32.1	
CALCIUM	17000	
IRON	615 J	MCL
MANGANESE	25.7 J	
SODIUM	6640 J	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.27	R9TAP
BARIUM, FILTERED	27.6	
CALCIUM, FILTERED	16000	
IRON, FILTERED	216	
SODIUM, FILTERED	6390 J	
Miscellaneous (mg/L)		
NITRATE	0.30	

10SW/SD07		
Explosives (ug/L)		
2,4,6-TRINITROTOLUENE	4.4	R9TAP
4-AMINO-2,6-DINITROTOLUENE	1.4	
HMX	22	
RDX	18	R9TAP
Inorganics (ug/L)		
ALUMINUM	283 J	MCL
ARSENIC	0.33	R9TAP
BARIUM	27.1	
CALCIUM	18500	
IRON	397 J	MCL
SODIUM	8050 J	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.26	R9TAP
BARIUM, FILTERED	25.7	
CALCIUM, FILTERED	18700	
IRON, FILTERED	149	
SODIUM, FILTERED	8290 J	
Miscellaneous (mg/L)		
NITRATE	0.30	

10SW/SD03		
Inorganics (ug/L)		
ALUMINUM	295 J	MCL
ARSENIC	0.29	R9TAP
BARIUM	35.4	
CALCIUM	10200	
IRON	385 J	MCL
MANGANESE	26.0 J	
SODIUM	6650 J	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.21	R9TAP
BARIUM, FILTERED	30.7	
CALCIUM, FILTERED	9480	
IRON, FILTERED	111	
SODIUM, FILTERED	6190 J	
Miscellaneous (mg/L)		
NITRATE	0.27	

10SW/SD05		
Explosives (ug/L)		
2,4,6-TRINITROTOLUENE	1.6	
4-AMINO-2,6-DINITROTOLUENE	0.96 J	
HMX	13	
RDX	7.5	R9TAP
Inorganics (ug/L)		
ALUMINUM	447 J	MCL
ARSENIC	0.41	R9TAP
BARIUM	38.6	
CALCIUM	12000	
IRON	574 J	MCL
MANGANESE	34.3 J	
SODIUM	8730 J	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.25	R9TAP
BARIUM, FILTERED	31.8	
CALCIUM, FILTERED	11300	
IRON, FILTERED	195	
MANGANESE, FILTERED	16.8	
SODIUM, FILTERED	8370 J	
Miscellaneous (mg/L)		
NITRATE	0.28	

10SW/SD02		
Inorganics (ug/L)		
ARSENIC	0.28	R9TAP
BARIUM	24.1	
CALCIUM	21300	
IRON	181 J	
SODIUM	14800 J	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.28	R9TAP
BARIUM, FILTERED	23.1	
CALCIUM, FILTERED	19800	
SODIUM, FILTERED	14100 J	
Miscellaneous (mg/L)		
NITRATE	0.41	

10SW/SD11		
Explosives (ug/L)		
HMX	18	
RDX	5.1	R9TAP
Inorganics (ug/L)		
ALUMINUM	341 J	MCL
ARSENIC	0.44	R9TAP
BARIUM	38.7	
CALCIUM	27600	
IRON	1120 J	MCL
MANGANESE	112 J	MCL
SODIUM	12000 J	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.40	R9TAP
BARIUM, FILTERED	46.7	
CALCIUM, FILTERED	32000	
IRON, FILTERED	962	MCL
MANGANESE, FILTERED	139	MCL
SODIUM, FILTERED	15000 J	
Miscellaneous (mg/L)		
NITRATE	0.54	

10SW/SD12		
Explosives (ug/L)		
HMX	8.4	
RDX	1.9	R9TAP
Inorganics (ug/L)		
ALUMINUM	213 J	MCL
ARSENIC	0.34	R9TAP
BARIUM	39.9	
CALCIUM	16300	
IRON	305 J	MCL
MANGANESE	73.6 J	MCL
SODIUM	8030 J	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.27	R9TAP
BARIUM, FILTERED	39.0	
CALCIUM, FILTERED	15600	
IRON, FILTERED	158	
MANGANESE, FILTERED	74.9	MCL
SODIUM, FILTERED	7910 J	
Miscellaneous (mg/L)		
NITRATE	0.45	

10SW/SD01		
Inorganics (ug/L)		
ALUMINUM	260 J	MCL
ARSENIC	0.24	R9TAP
BARIUM	41.6	
CALCIUM	6540	
IRON	278 J	
MANGANESE	29.2 J	
Filtered Metals (ug/L)		
ANTIMONY, FILTERED	1.0	
ARSENIC, FILTERED	0.19	R9TAP
BARIUM, FILTERED	39.3	
CALCIUM, FILTERED	6360	
IRON, FILTERED	141	
MANGANESE, FILTERED	22.1	
Miscellaneous (mg/L)		
NITRATE	0.090	

10SW/SD06		
Explosives (ug/L)		
HMX	6.4	
RDX	2.6	R9TAP
Inorganics (ug/L)		
ALUMINUM	357 J	MCL
ARSENIC	0.30	R9TAP
BARIUM	39.5	
CALCIUM	8590	
IRON	401 J	MCL
MANGANESE	38.6 J	
SODIUM	5100 J	
Filtered Metals (ug/L)		
ARSENIC, FILTERED	0.17	R9TAP
BARIUM, FILTERED	36.5	
CALCIUM, FILTERED	8400	
IRON, FILTERED	116	
MANGANESE, FILTERED	23.8	
SODIUM, FILTERED	5280 J	
Miscellaneous (mg/L)		
NITRATE	0.26	

NOTE: THIS FIGURE IS A REPRODUCTION OF FIGURE 7-15 FROM THE DRAFT RFI REPORT (TTNUS, 2003).

R9TAP	U.S. EPA Region 9 Tap Water
R5DQL	U.S. EPA Region 5 Data Quality Level
MCL	Federal Maximum Contaminant Level
AWQC	Ambient Water Quality Criteria

LEGEND
- Monitoring Well
- Soil Boring
- Surface Water/Sediment Sample Location
- SWMU (Estimated Boundary)
- Building
- Tree Line
- Stream
- Road
- Railroad

CONTRACT NO. N4267

APPROVED BY — DATE

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DRAWING NO. — FIGURE 1 - 6

REV 0

INORGANIC AND ORGANIC DETECTIONS IN SURFACE WATER
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

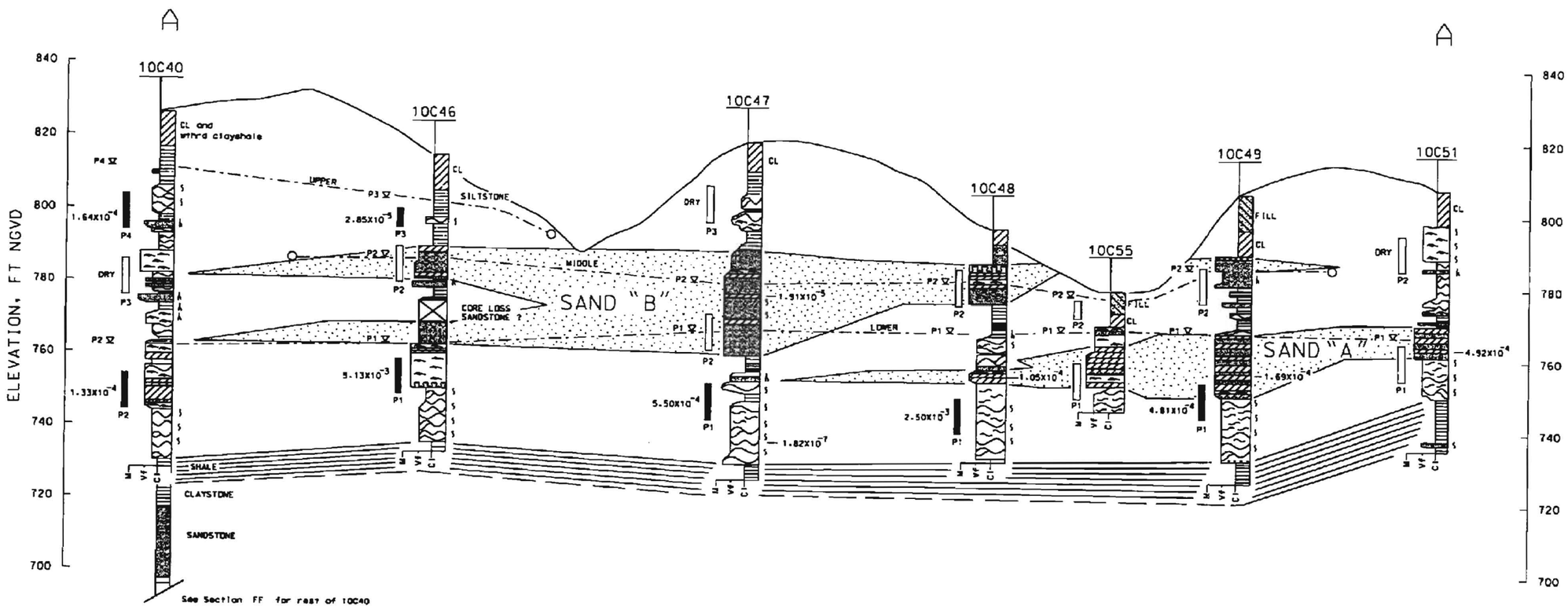
NAVFAC

DRAWN BY J. LAMEY — DATE 9/12/02

CHECKED BY V. PLACHY — DATE 11/29/04

COST/SCHED-AREA

SCALE AS NOTED



THIS FIGURE IS A REPRODUCTION OF PLATE 7 FROM THE FINAL REPORT, RFI, PHASE III GROUNDWATER RELEASE CHARACTERIZATION, SWMU 10/15 ROCKEYE FACILITY, NSWC CRANE, AUGUST 1988.

CONTRACT NO. N4267

APPROVED BY ____ DATE ____

APPROVED BY ____ DATE ____

DRAWING NO. FIGURE 1 - 7

REV 0

GENERALIZED GEOLOGIC SECTION AA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

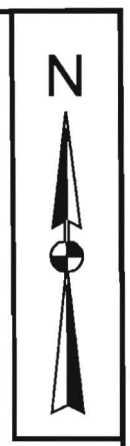
NAVFAC

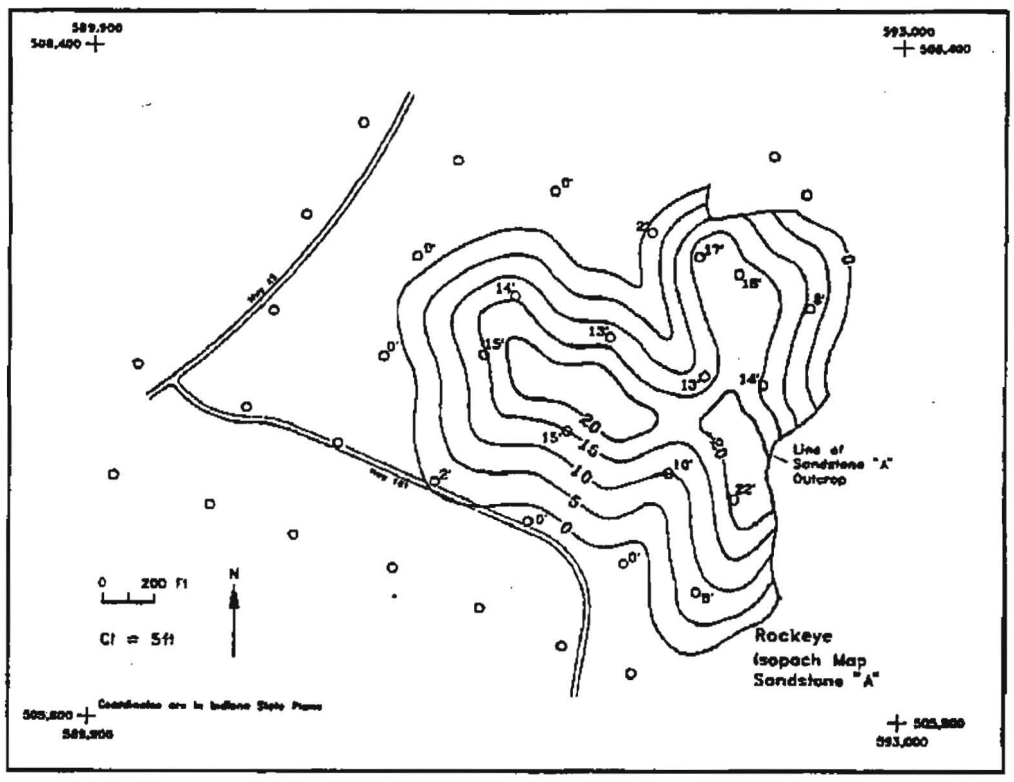
DRAWN BY C. FOSTER DATE 11/24/04

CHECKED BY V. PLACHY DATE 11/24/04

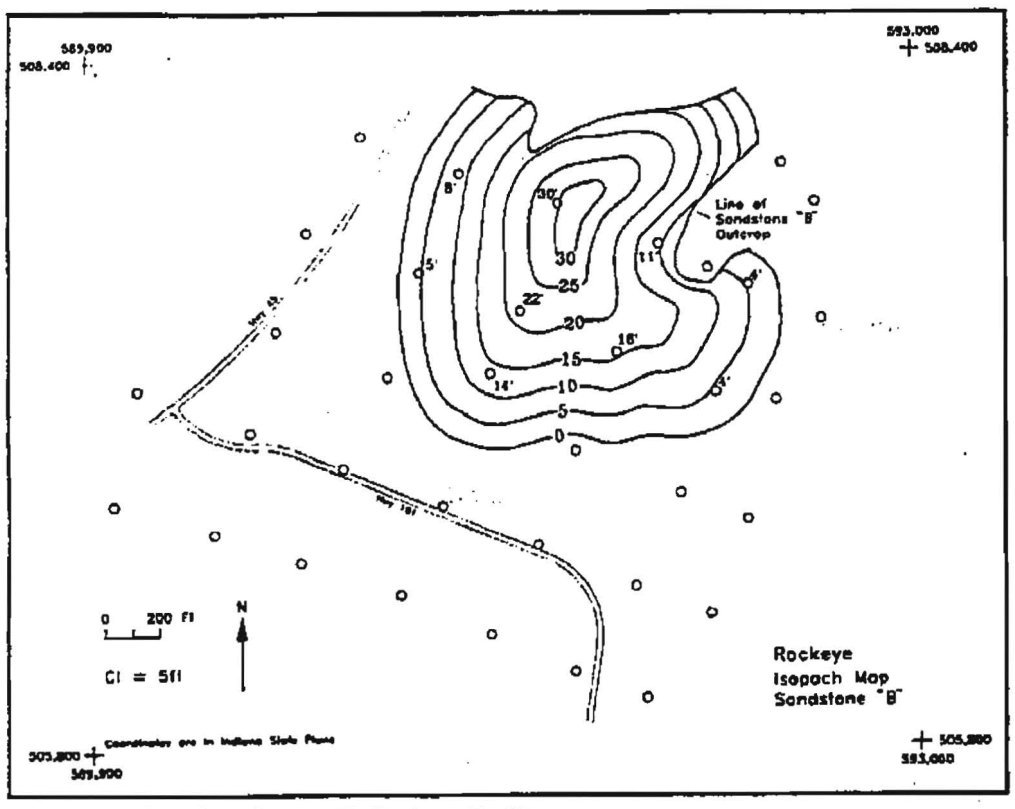
COST/SCHED-AREA

SCALE AS NOTED

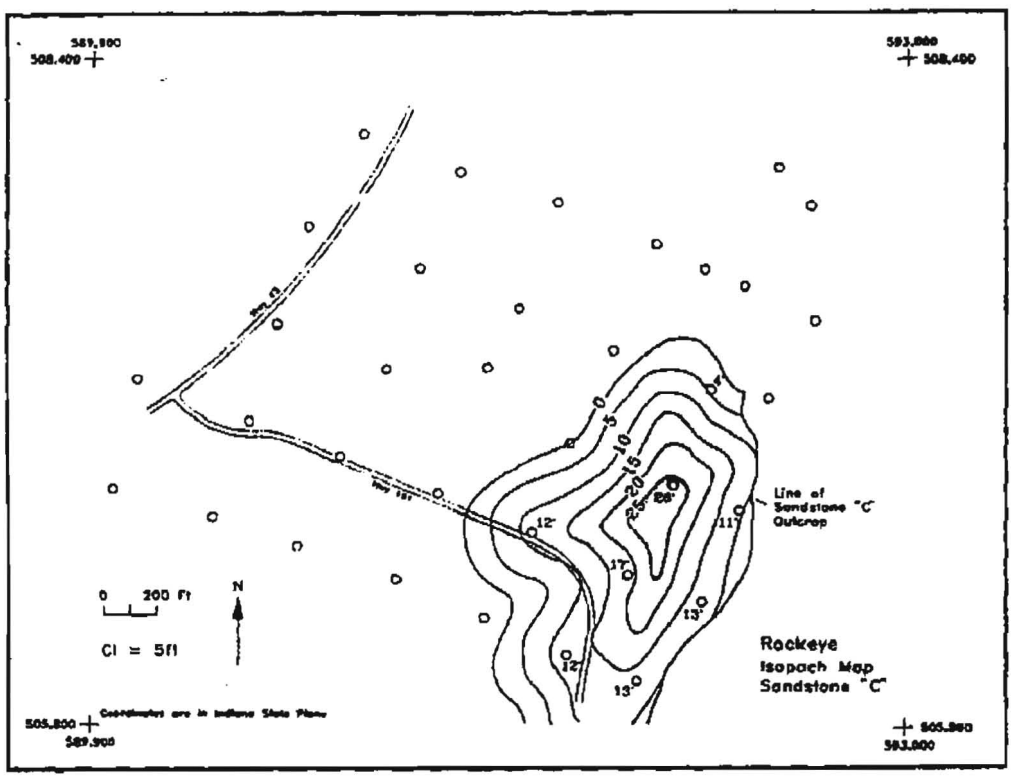




A. Isopach Map of sandstone "A", Rockeye Facility.
Note: this figure was reprinted from USACE, 1998.



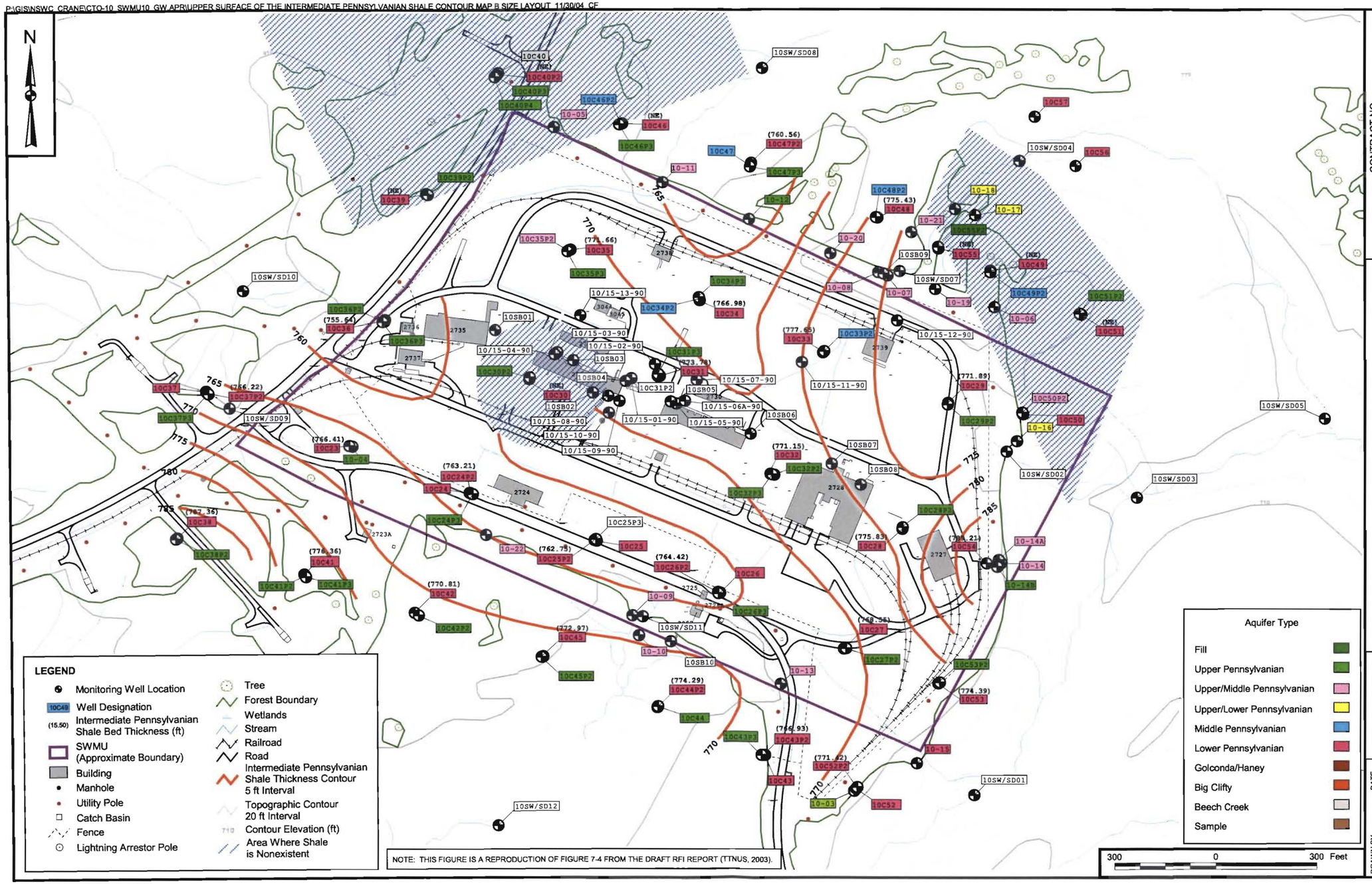
B. Isopach Map of sandstone "B", Rockeye Facility.
Note: this figure was reprinted from USACE, 1998.



C. Isopach Map of sandstone "C", Rockeye Facility.
Note: this figure was reprinted from USACE, 1998.

DRAWN BY C. FOSTER	DATE 11/29/04	NAVFAC	ISOPACH MAPS OF SANDSTONE UNITS A, B, & C CMS REPORT FOR SWMU 10 - ROCKEYE NSWC CRANE CRANE, INDIANA	CONTRACT NO. N4267
CHECKED BY V. PLACHY	DATE 11/29/04			APPROVED BY — DATE —
COST/SCHEDULE-AREA				APPROVED BY — DATE —
SCALE AS NOTED				DRAWING NO. FIGURE 1 - 8 REV 0

P:\GIS\NSWC_CRANE\CTO-10_SWMU10_GW_APR\UPPER SURFACE OF THE INTERMEDIATE PENNSYLVANIAN SHALE CONTOUR MAP B SIZE LAYOUT_11/30/04_CF



NOTE: THIS FIGURE IS A REPRODUCTION OF FIGURE 7-4 FROM THE DRAFT RFI REPORT (TTNUS, 2003).

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APPROVED BY ___ DATE ___

APPROVED BY ___ DATE ___

DRAWING NO. FIGURE 1 - 9

REV 0

UPPER SURFACE OF THE INTERMEDIATE PENNSYLVANIAN SHALE CONTOUR MAP
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

NAVFAC

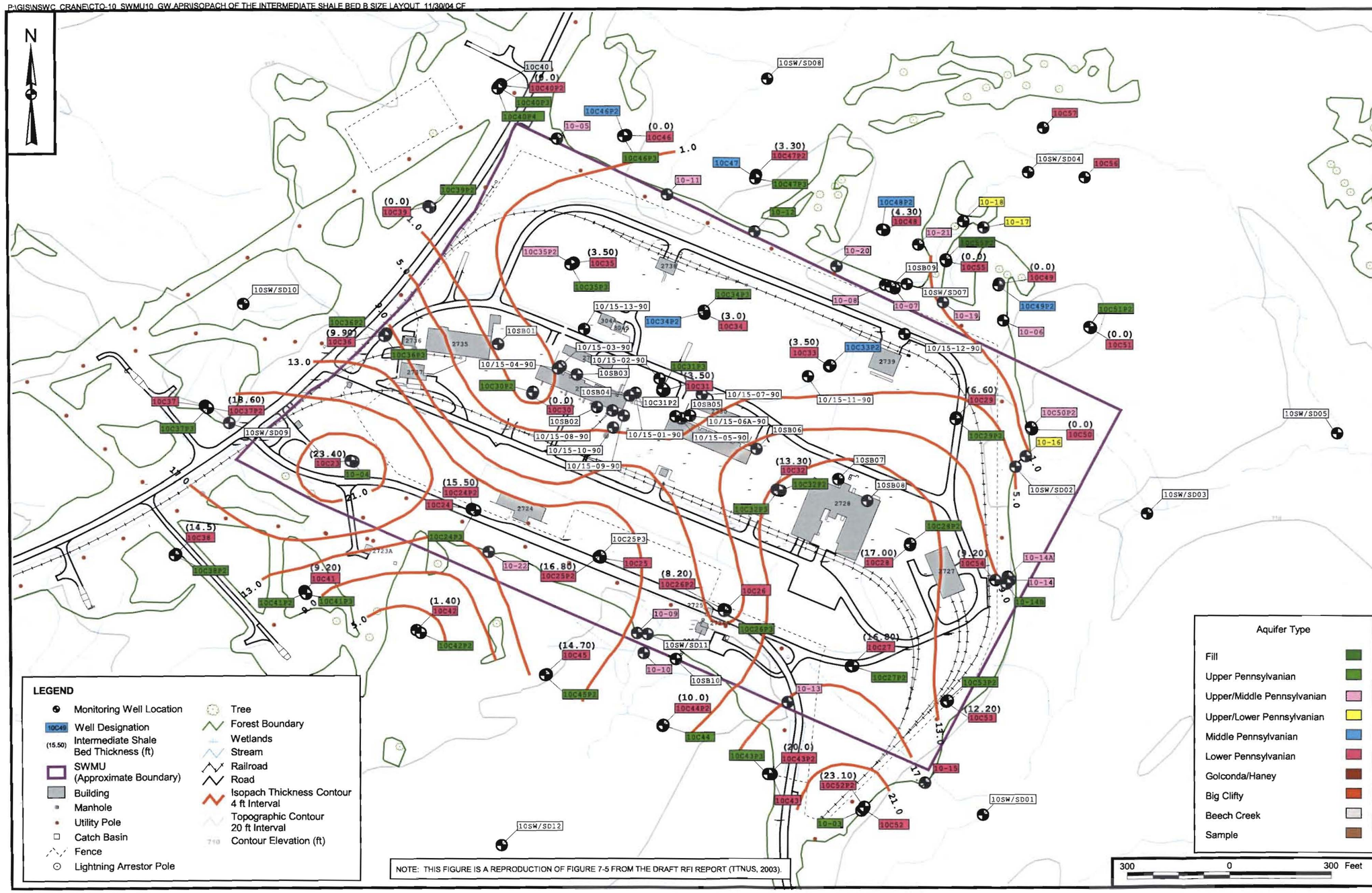
DRAWN BY K. PEILA DATE 5/22/02

CHECKED BY V. PLACHY DATE 11/29/04

COST/SCHED-AREA

SCALE AS NOTED

P:\GIS\NSWC_CRANE\CTO-10_SWMU10_GW.APR\ISOPACH OF THE INTERMEDIATE SHALE BED B SIZE LAYOUT 11/30/04 CF



NOTE: THIS FIGURE IS A REPRODUCTION OF FIGURE 7-5 FROM THE DRAFT RFI REPORT (TTNUS, 2003).

CONTRACT NO. N4267

APPROVED BY ___ DATE ___

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DRAWING NO. FIGURE 1 - 10

REV 0

ISOPACH OF THE INTERMEDIATE SHALE BED
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

NAVFAC

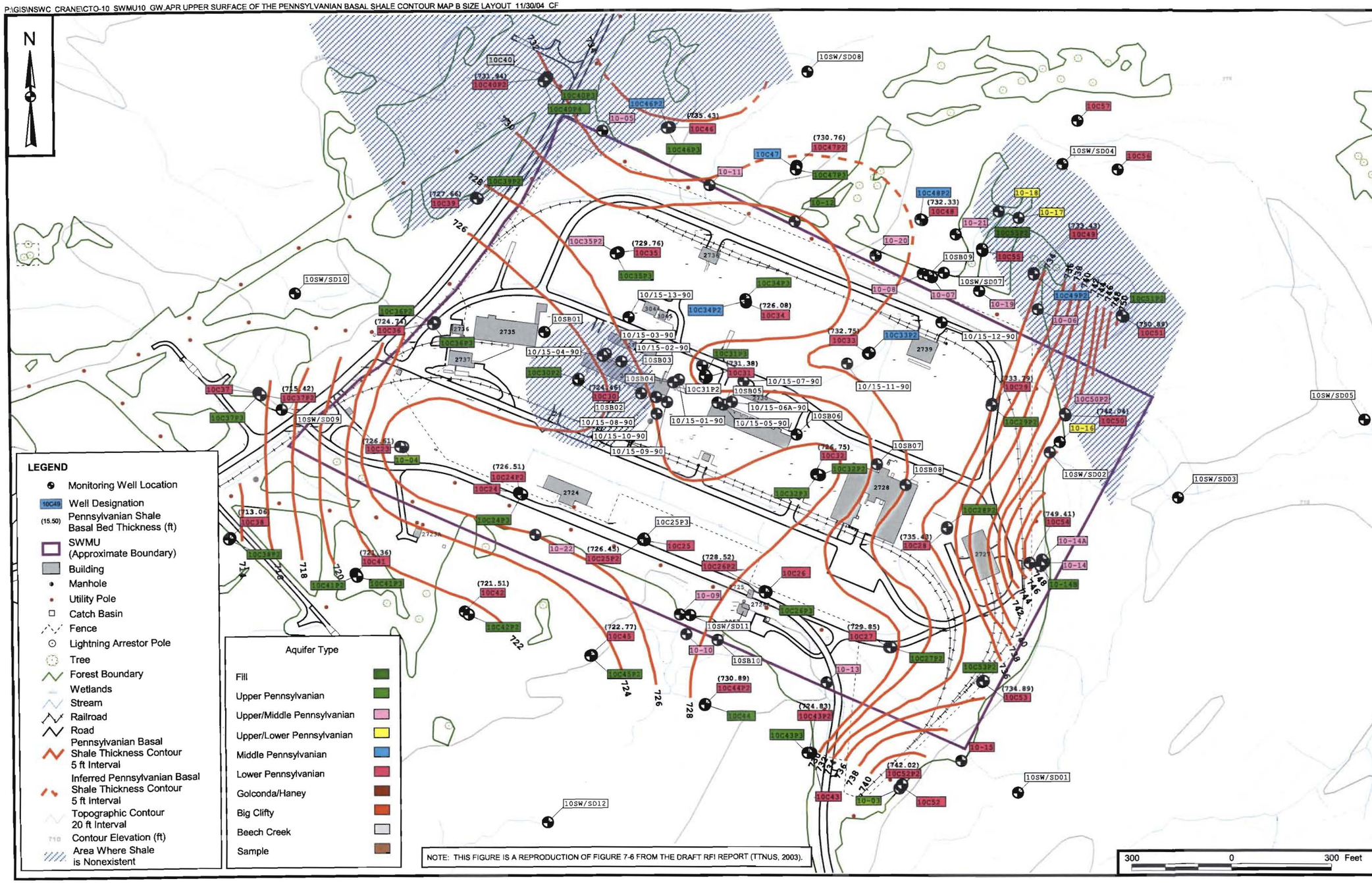
DRAWN BY K. PEILA DATE 5/22/02

CHECKED BY V. PLACHY DATE 11/29/04

COST/SCHED-AREA

SCALE AS NOTED

P:\GIS\NSWC_CRANE\CTO-10_SWMU10_GW.APR UPPER SURFACE OF THE PENNSYLVANIAN BASAL SHALE CONTOUR MAP B SIZE LAYOUT 11/30/04 CF



NOTE: THIS FIGURE IS A REPRODUCTION OF FIGURE 7-6 FROM THE DRAFT RFI REPORT (TTNUS, 2003).

CONTRACT NO. N4267

APPROVED BY ___ DATE ___

APPROVED BY ___ DATE ___

DRAWING NO. FIGURE 1 - 11

REV 0

UPPER SURFACE OF THE PENNSYLVANIAN BASAL SHALE CONTOUR MAP
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

NAVFAC

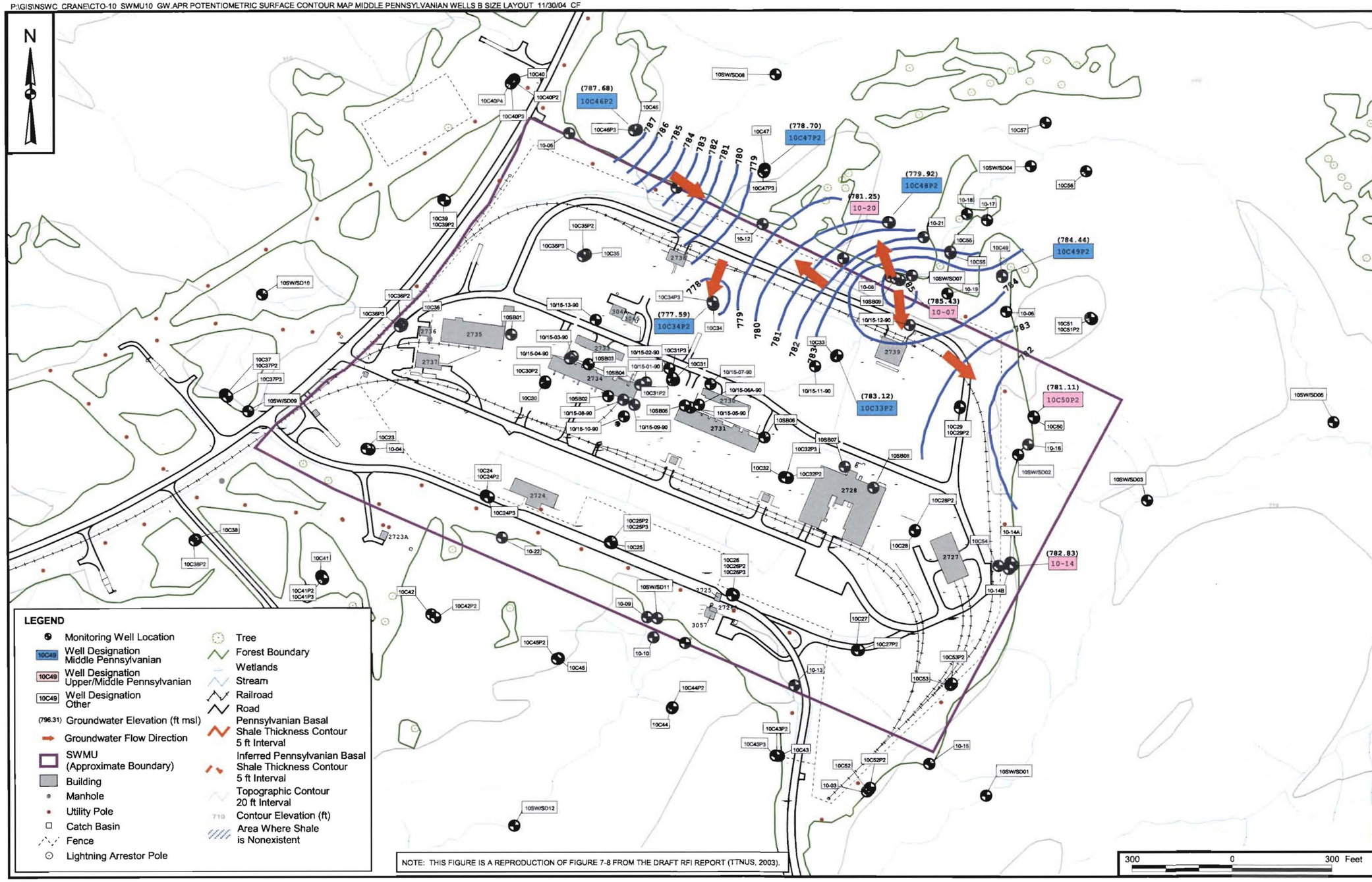
DRAWN BY A. JANOCHA DATE 12/04/01

CHECKED BY V. PLACHY DATE 11/29/04

COST/SCHED-AREA

SCALE AS NOTED

P:\GIS\NSWC_CRANE\CTO-10_SWMU10_GW.APR POTENTIOMETRIC SURFACE CONTOUR MAP MIDDLE PENNSYLVANIAN WELLS B SIZE LAYOUT 11/30/04 CF



NOTE: THIS FIGURE IS A REPRODUCTION OF FIGURE 7-8 FROM THE DRAFT RFI REPORT (TTNUS, 2003).

CONTRACT NO. N4267

APPROVED BY ___ DATE ___

APPROVED BY ___ DATE ___

DRAWING NO. FIGURE 1 - 12

REV 0

POTENTIOMETRIC SURFACE CONTOUR MAP
MIDDLE PENNSYLVANIAN WELLS
NSWC CRANE
CMS REPORT FOR SWMU 10 - ROCKEYE
CRANE, INDIANA

NAVFAC

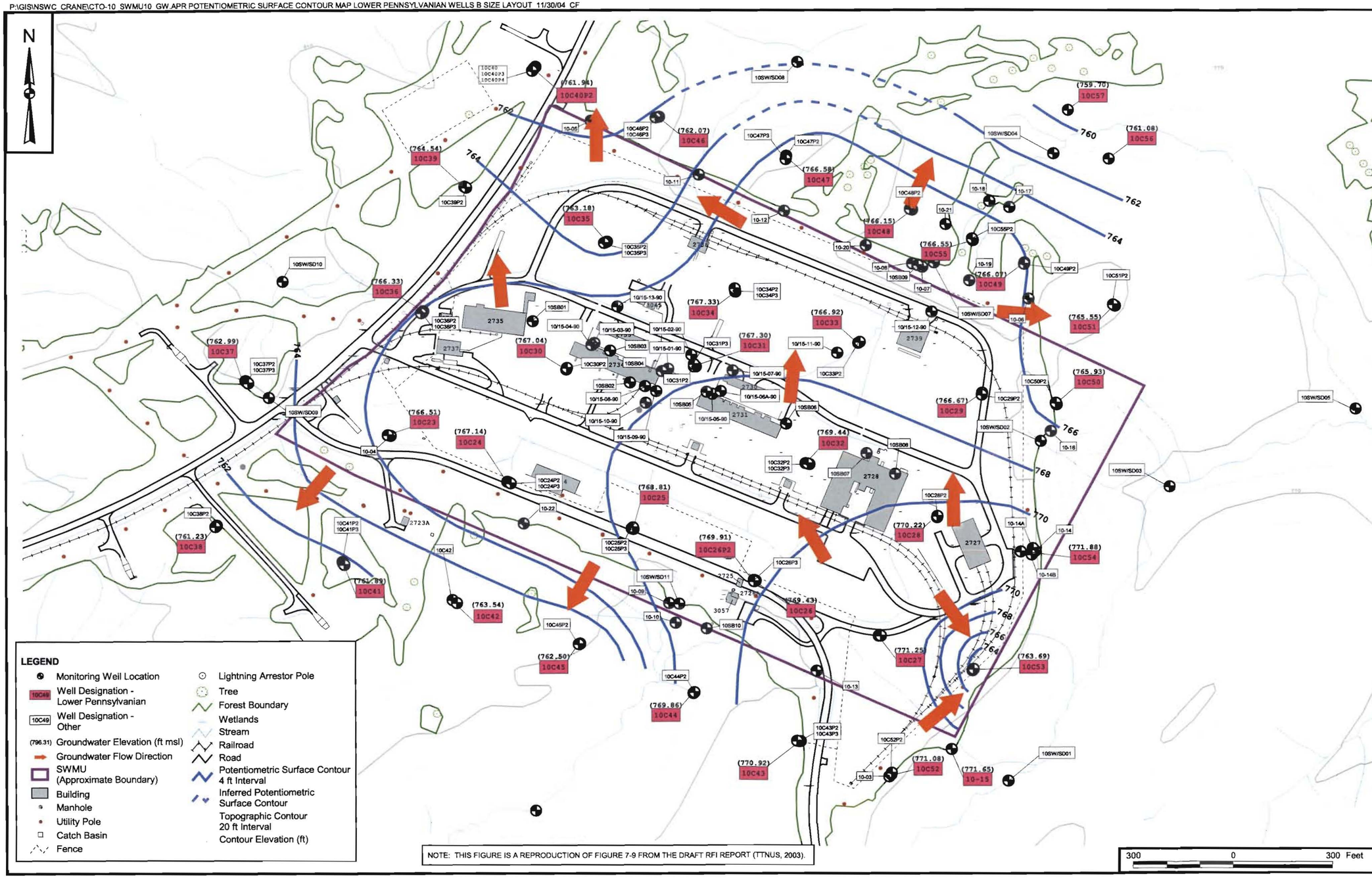
DRAWN BY A. JANOCHA DATE 12/04/01

CHECKED BY V. PLACHY DATE 11/29/04

COST/SCHED-AREA

SCALE AS NOTED

P:\GIS\NSWC CRANE\CTO-10 SWMU10 GW.APR POTENTIOMETRIC SURFACE CONTOUR MAP LOWER PENNSYLVANIAN WELLS B SIZE LAYOUT 11/30/04 CF



NOTE: THIS FIGURE IS A REPRODUCTION OF FIGURE 7-9 FROM THE DRAFT RFI REPORT (TTNUS, 2003).

CONTRACT NO. N4267

APPROVED BY ___ DATE ___

APPROVED BY ___ DATE ___

DRAWING NO. FIGURE 1 - 13

REV 0

POTENTIOMETRIC SURFACE CONTOUR MAP
LOWER PENNSYLVANIAN WELLS
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

NAVFAC

DRAWN BY A. JANOCHA DATE 12/04/01

CHECKED BY V. PLACHY DATE 11/29/04

COST/SCHED-AREA

SCALE AS NOTED

2.0 DESCRIPTION OF CURRENT CONDITIONS AT SWMU 10

This section presents a summary of the current contamination conditions for SWMU 10. The information presented in this section is used as the basis for the development of site-specific media cleanup standards and CAOs which are presented in Section 3.0. The discussion is extracted from a more complete presentation in the Phase II Groundwater Release Characterization Report (Murphy et al., 1998) and the RFI Report (TtNUS, 2005). The RFI Report presents the HHRAs and ERAs developed for SWMU 10. The following situations are presented in summary:

- Nature and extent of contamination
- Human health and ecological risk assessment drivers
- Contamination fate and transport

2.1 NATURE AND EXTENT OF CONTAMINATION

This section provides a general overview of the RFI investigation and results which were used as the basis for determining which media required consideration in the CMS. Tables 2-1 through 2-5 summarize the chemicals detected, COPCs, COCs, and risk drivers by media (surface soil, subsurface soil, groundwater, surface water, and sediment). Table 2-6 presents the summary of the risk drivers for the exposure route for each media. Following is a discussion of the information presented in Tables 2-1 through 2-5. Additional information can be found in the RFI Report (TtNUS, 2005).

2.1.1 Surface Soil Contamination

Ten surface soil samples were collected from a depth of 0 to 2 feet bgs to evaluate the nature and extent of contamination. All 10 surface soil samples were analyzed for Appendix IX explosives, Target Analyte List (TAL) metals (plus tin), and cyanide. One surface soil sample was analyzed for Appendix IX SVOCs. Additionally, one surface soil sample was analyzed for cation exchange capacity (CEC), pH, and total organic carbon (TOC). One sample was collected to evaluate soil conditions in an area where pink water discharges pooled. One sample was collected near Building 2726C because of historical documentation that a chlorination tank for the now incapacitated sewage treatment plant was present in this area. Table 2-1 summarizes the chemicals detected, COPCs, COCs, and human health and ecological risk drivers for surface soil.

Semivolatiles

Thirteen SVOCs [acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)flouranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, pheanthrene, and pyrene] were detected in the surface soil samples.

Contaminants Associated with Human Health Risk

Four SVOCs [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and dibenzo(a,h)anthracene] were retained as COPCs in the human health risk assessment (HHRA). These four SVOCs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and dibenzo(a,h)anthracene) were retained as COCs in the HHRA. SVOCs in surface soil were not found to present a significant risk in the HHRA.

Contaminants Associated with Ecological Risk

The levels of these SVOCs in the surface soil are not expected to adversely impact ecological receptors.

Explosives

Four explosive compounds [2-amino-4,6-dinitrotoluene (2-amino-4,6-DNT), HMX, RDX, and TNT] were detected in the surface soil samples.

Contaminants Associated with Human Health Risk

Two explosive compounds (2-amino-4,6-DNT and RDX) were retained as COPCs in the HHRA. No explosives were retained as COCs. Explosive compounds in surface soil were not found to present a significant risk in the HHRA.

Contaminants Associated with Ecological Risk

All four explosive compounds detected (2-amino-4,6-DNT, HMX, RDX, and TNT) were retained as COPCs and COCs for the ecological risk assessment (ERA) because no surface soil screening levels are available for these chemicals. The levels of these explosive compounds in the surface soil are not expected to adversely impact ecological receptors.

Inorganics

Eighteen inorganics (aluminum, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, vanadium, and zinc) were detected in the surface soil samples.

Contaminants Associated with Human Health Risk

No inorganics were retained as COPCs or COCs for the HHRA because their concentrations were below the background concentrations for the site. Inorganics in surface soil were not found to present a significant risk in the HHRA.

Contaminants Associated with Ecological Risk

No inorganics were retained as COPCs or COCs for the ecological risk assessment because their concentrations were below the background concentrations for the site. Inorganics in surface soil were not found to present a significant risk in the ERA.

2.1.2 Subsurface Soil Contamination

Ten subsurface soil samples were collocated with the surface soil samples discussed above. All 10 subsurface soil samples were analyzed for explosive compounds, TAL metals (plus tin), and cyanide. Five subsurface soil samples were analyzed for CEC, pH, and TOC. Table 2-2 summarizes the chemicals detected, COPCs, COCs, and human health risk drivers for subsurface soil.

Subsurface soils are not considered to be a source of ecological risk; therefore, only human health risk drivers are addressed in this subsection.

Semivolatiles

Thirteen SVOCs [acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)flouranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, pheanthrene, and pyrene] were detected in the subsurface soil samples.

Four SVOCs [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and dibenzo(a,h)anthracene] were retained as COPCs and COCs in the HHRA. SVOCs in subsurface soil were not found to present a significant risk in the HHRA.

Explosive compounds

Three explosive compounds (2-amino-4,6-DNT, HMX, and RDX) were detected in the subsurface soil samples.

Two explosive compounds (4-amino-4,6-DNT and RDX) were retained as COPCs in the HHRA. No explosive compounds were retained as COCs in the RFI (TtNUS, 2005). Explosive compounds in subsurface soil were not found to present risk in the HHRA.

Inorganics

Seventeen inorganics (aluminum, antimony, arsenic, barium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, vanadium, and zinc) were detected in the surface soil samples. No inorganics were retained as COPCs or COCs. Inorganics in subsurface soil were not found to present a risk in the HHRA.

2.1.3 Groundwater Contamination

Eighteen groundwater samples were collected to evaluate the nature and extent of contamination in groundwater. No explosive compounds were detected in any of the groundwater wells located within the SWMU boundary. Explosives were only detected in four wells. Three of the four wells are located within 300 feet of the northern SWMU border and not far from locations where it is believed that "pink water" had been discharged. The fourth well is located approximately 3,000 feet east of the northern site border. Table 2-3 summarizes the chemicals detected, COPCs, COCs, and human health risk drivers for groundwater.

Groundwater in and of itself is not considered to be a source of ecological risk. However, the potential ecological risks associated with groundwater were determined to be the risk associated with the migration of chemicals from groundwater to surface water and sediment. Therefore, only human health risk drivers are addressed in this subsection and the risk associated with groundwater contamination migration is considered as part of the surface water and sediment ecological risk assessment.

Explosive compounds

Seven explosive compounds (1,3,5-trinitrobenzene, 2,6-DNT, 2-amino-4,6-DNT, 4-amino-2,6-DNT, HMX, RDX, and TNT) were detected in the groundwater samples. Six explosive compounds (2,6-DNT, 2-amino-4,6-DNT, 4-amino-2,6-DNT, HMX, RDX, and TNT) were retained as COPCs in the HHRA. Four explosive compounds (2-amino-4,6-DNT, 4-amino-2,6-DNT, RDX, and TNT) were retained as COCs in the HHRA.

For the future adult resident, the HHRA determined that there was a significant risk associated with the ingestion of groundwater containing 2-amino,4,6-DNT, 4-amino-2,6-DNT, and RDX. For the future child resident, the HHRA determined that a significant risk was associated with the ingestion of groundwater containing 2,6-DNT, 2-amino,4,6-DNT, 4-amino-2,6-DNT, and RDX.

Inorganics

Nineteen inorganics (aluminum, arsenic, barium, beryllium, cadmium, calcium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, sodium, thallium, and zinc) were detected in the groundwater samples. Ten inorganics (aluminum, arsenic, beryllium, cadmium, cobalt, iron, manganese, nickel, thallium, and zinc) were retained as COPCs for HHRA. Seven inorganics (arsenic, beryllium, iron, manganese, nickel, thallium, and zinc) were retained as COCs for HHRA. For the future adult resident, the HHRA determined that a significant risk was associated with dermal contact of groundwater containing manganese. For the future child resident, the HHRA determined that a significant risk was associated with the dermal of groundwater containing manganese.

2.1.4 Surface Water Contamination

Twelve unfiltered and 12 filtered surface water samples were collected to assess risks associated with migration of contaminants to surface water and sediment via groundwater flow and surface water runoff. All surface water samples were analyzed for Appendix IX explosives, total and dissolved TAL metals (plus tin), cyanide, hardness, nitrate/nitrite, and total suspended solids.

Prior to 1978, explosive-contaminated wastewater that was collected in sumps on the northern side of Buildings 2734 and 2731 was released to several drainageways that lead to various tributaries and/or creeks. Samples from six water stations were used to evaluate contributions of affected runoff from the northern and eastern drainageways, which lead to a tributary of Sulphur Creek. One station was used to assess impacts of runoff northwest of the site. West of the site, runoff from the Area A drainageway, which leads to a tributary of Furst Creek, was assessed by samples from two stations. Contributions from

the southern side of the facility to Turkey Creek were determined by collecting samples at two stations near the Area D, F, and G, and drainageways (see Figure 2-1 for location). Additionally, samples from 10SW/SD07 were used to evaluate contributions of pink water discharge that pooled near Area E (see Figure 2-1 for locations). Table 2-4 summarizes the chemicals detected, COPCs, COCs, and human health and ecological risk drivers for surface water.

Explosive Compounds

Five explosive compounds (2-amino-4,6-DNT, 4-amino-2,6-DNT, HMX, RDX, and TNT) were detected in the surface water samples.

Contaminants Associated with Human Health Risk

Four explosive compounds (2-amino-4,6-DNT, 4-amino-2,6-DNT, RDX, and TNT) were retained as COPCs in the HHRA. One explosive compound (RDX) was retained as COC in the HHRA. Explosive compounds in surface water were not found to present a significant risk in the HHRA (TtNUS, 2005).

Contaminants Associated with Ecological Risk

All five explosive compounds detected (2-amino-4,6-DNT, 4-amino-2,6-DNT, HMX, RDX, and TNT) were retained as COPCs for the ERA because no Region 5 surface water screening levels are available for these chemicals. No explosive compounds were retained as COCs in the ERA. The levels of these explosives in the surface water are not expected to adversely impact ecological receptors (TtNUS, 2005).

Inorganics

Eleven inorganics (aluminum, arsenic, barium, calcium, copper, iron, lead, magnesium, manganese, sodium, and zinc) were detected in the surface soil samples.

Contaminants Associated with Human Health Risk

Four inorganics (aluminum, arsenic, iron, and manganese) were retained as COPCs for the HHRA. One inorganic (arsenic) was retained as COC for the HHRA. Inorganics in surface water were not found to present a significant risk in the HHRA.

Contaminants Associated with Ecological Risk

Three inorganics (aluminum, iron, and manganese) were retained as COPCs for the ERA because no surface water COPC screening levels are available for these chemicals. Zinc was retained as a COPC because the maximum detected surface water concentrations for unfiltered and filtered samples exceeded the U.S. EPA Region 5 screening level. No inorganics were retained as COCs in the ERA. Inorganics in surface water are not expected to adversely impact ecological receptors.

2.1.5 Sediment Contamination

Twelve sediment samples collocated with the surface water samples were collected during the investigation. All sediment samples were analyzed for Appendix IX explosives, TAL metals (plus tin), cyanide, and TOC. Table 2-5 summarizes the chemicals detected, COPCs, COCs, and human health and ecological risk drivers for sediment.

Explosive Compounds

One explosive compound (HMX) was detected in the sediment samples.

Contaminants Associated with Human Health Risk

No explosive compounds were retained as COPCs or COCs in the HHRA. Explosive compounds were not found to present a significant risk in the HHRA.

Contaminants Associated with Ecological Risk

HMX was retained as a COPC for the ERA because the maximum concentration exceeds the sediment COPC screening level for HMX. No explosive compounds were retained as COCs. The level of HMX in the sediment is not expected to adversely impact ecological receptors.

Inorganics

Eighteen inorganics (aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, vanadium, and zinc) were detected in the surface soil samples.

Contaminants Associated with Human Health Risk

Six inorganics (aluminum, arsenic, chromium, iron, magnesium, and vanadium) were retained as COPCs for the HHRA. Three inorganics (arsenic, iron, and manganese) were retained as COCs. Inorganics were not found to present a significant risk in the HHRA.

Contaminants Associated with Ecological Risk

Seven inorganics (aluminum, antimony, barium, beryllium, iron, manganese, and vanadium) were retained as COPCs for the ERA because the maximum concentrations exceed the sediment COPC screening levels available for these chemicals. No inorganics were retained as COCs. Inorganics are not expected to adversely impact ecological receptors.

2.2 CONTAMINANT FATE AND TRANSPORT

This section presents a brief overview of the contaminant fate and transport at SWMU 10. This discussion focuses on some of the major types of contaminants found at the site.

Based on a review of the existing data for the site, a release of hazardous constituents to the surrounding soil has occurred as a result of the site activities. The data also indicate that residual contaminants in the soil have migrated to groundwater via infiltration and percolation. Additional release mechanisms, which are also expected to contribute to the contaminant transport, include discharge of groundwater to surface water and sediment (unnamed tributaries), and deposition via surface water runoff.

The following classes of chemicals were detected in the media of concern at SWMU 10:

Soil - PAHs, explosives, and metals
Groundwater - Explosives and metals
Surface Water - Explosives and metals
Sediment - Explosives (HMX only) and metals

Fate and transport characteristics of these chemicals are briefly discussed in the following sections.

2.2.1 Polycyclic Aromatic Hydrocarbons

PAHs are generally considered to be fairly immobile chemicals in the environment. They are large molecules with high organic carbon partition coefficients and low solubilities when compared to VOCs.

These compounds, when found in the soil, generally do not migrate vertically to a great extent. Instead, they are more likely to adhere to soil particles and be removed from the site via surface runoff and erosional processes. Their absence in groundwater is evidence of their immobility. Their presence in sediment may stem from surface erosion, but their absence in surface water is consistent with their low water solubilities and their ability to bind to soil and sediment.

2.2.2 Explosives

Nitrogen-containing compounds, such as 2-amino-2,6-DNT, 4-amino-2,6-DNT, HMX, RDX, and TNT have relatively low organic carbon partition coefficient (K_{oc}) values and tend to be fairly mobile in the environment. The K_{oc} for 1,3,5-trinitrobenzene is somewhat higher, indicating that this compound is less mobile than the other explosives. The nitrotoluenes, RDX, and HMX in water are not expected to bioconcentrate significantly and will have only a slight tendency to partition to suspended and sediment organics. 2-Amino-2,6-DNT and 4-amino-2,6-DNT are likely degradation products of TNT.

Explosives were detected in all media sampled at SWMU 10. Their presence in groundwater indicates that migration from soil to groundwater has occurred. The explosives may be present on particulate matter, but since they are somewhat water soluble, compared to PAHs and PCBs, they will be most likely present in the dissolved phase. Therefore, they are likely to be more environmentally mobile than PAHs and PCBs.

2.2.3 Inorganics

Because inorganics are frequently sorbed into the soil matrix and remain bound to particulate matter, they tend to migrate from the source areas via erosion and sediment transport. Heavy metals and transition metals are generally not expected to be mobile in groundwater systems, except when the groundwater is acidic (e.g., a pH less than 6.0) or is under reducing conditions (i.e., have a low oxidation/reduction potential).

There are some instances, however, where these metals are found at such concentrations or in such form as to be able to migrate in groundwater as dissolved species. It is possible that industrial activities could saturate all available exchange sites in soil and result in metals being mobilized. In these cases, it is possible for metals to migrate vertically through the soil column and reach the groundwater.

TABLE 2-1

SUMMARY OF POSITIVE ANALYTICAL RESULTS, COPCs, COCs,
AND RISK DRIVERS FOR SURFACE SOIL
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Chemical Detected	Human Health		Ecological	
	COPCs	COC/Risk Drivers	COPCs	COC/Risk Drivers
Semivolatile Organics				
ACENAPHTHYLENE		No		No
ANTHRACENE		No		No
BENZO(A)ANTHRACENE	Yes	No		No
BENZO(A)PYRENE	Yes	No		No
BENZO(B)FLUORANTHENE	Yes	No		No
BENZO(G,H,I)PERYLENE		No		No
BENZO(K)FLUORANTHENE		No		No
CHRYSENE		No		No
DIBENZO(A,H)ANTHRACENE	Yes	No		No
FLUORANTHENE		No		No
INDENO(1,2,3-CD)PYRENE		No		No
PHENANTHRENE		No		No
PYRENE		No		No
Explosives				
2-AMINO-4,6-DINITROTOLUENE	Yes	No	Yes	No
HMX		No	Yes	No
RDX	Yes	No	Yes	No
2,4,6-TRINITROTOLUENE		No	Yes	No
Inorganics				
ALUMINUM		No		No
ARSENIC		No		No
BARIUM		No		No
BERYLLIUM		No		No
CADMIUM		No		No
CALCIUM		No		No
CHROMIUM		No		No
COBALT		No		No
COPPER		No		No
IRON		No		No
LEAD		No		No
MAGNESIUM		No		No
MANGANESE		No		No
MERCURY		No		No
NICKEL		No		No
POTASSIUM		No		No
VANADIUM		No		No
ZINC		No		No

TABLE 2-2

SUMMARY OF POSITIVE ANALYTICAL RESULTS, COPCs, COCs, AND RISK DRIVERS FOR SUBSURFACE SOIL
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Chemical Detected	Human Health	
	COPCs	COC/Risk Drivers
Semivolatile Organics		
ACENAPHTHYLENE		No
ANTHRACENE		No
BENZO(A)ANTHRACENE	Yes	No
BENZO(A)PYRENE	Yes	No
BENZO(B)FLUORANTHENE	Yes	No
BENZO(G,H,I)PERYLENE		No
BENZO(K)FLUORANTHENE		No
CHRYSENE		No
DIBENZO(A,H)ANTHRACENE	Yes	No
FLUORANTHENE		No
INDENO(1,2,3-CD)PYRENE		No
PHENANTHRENE		No
PYRENE		No
Explosives		
2-AMINO-4,6-DINITROTOLUENE	Yes	No
HMX		No
RDX	Yes	No
Inorganics		
ALUMINUM		No
ANTIMONY		No
ARSENIC		No
BARIUM		No
CALCIUM		No
CHROMIUM		No
COBALT		No
COPPER		No
IRON		No
LEAD		No
MAGNESIUM		No
MANGANESE		No
MERCURY		No
NICKEL		No
POTASSIUM		No
VANADIUM		No
ZINC		No

TABLE 2-3

SUMMARY OF POSITIVE ANALYTICAL RESULTS, COPCs, COCs, AND RISK DRIVERS FOR GROUNDWATER
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Chemical Detected	Human Health	
	COPCs	COC/Risk Drivers
Explosives		
1,3,5-TRINITROBENZENE		No
2,4,6-TRINITROTOLUENE	Yes	Yes
2,6-DINITROTOLUENE	Yes	No
2-AMINO-4,6-DINITROTOLUENE	Yes	Yes
4-AMINO-2,6-DINITROTOLUENE	Yes	Yes
HMX	Yes	No
RDX	Yes	Yes
Inorganics		No
ALUMINUM	Yes	No
ARSENIC	Yes	No
BARIUM		No
BERYLLIUM	Yes	No
CADMIUM	Yes	No
CALCIUM		No
COBALT	Yes	No
COPPER		No
IRON	Yes	Yes
LEAD		No
MAGNESIUM		No
MANGANESE	Yes	Yes
MERCURY		No
NICKEL	Yes	Yes
POTASSIUM		No
SELENIUM		No
SODIUM		No
THALLIUM	Yes	No
ZINC	Yes	No
Filtered Metals		No
BARIUM, FILTERED		No
CALCIUM, FILTERED		No
COBALT, FILTERED		No
IRON, FILTERED	Yes	No
MAGNESIUM, FILTERED		No
MANGANESE, FILTERED	Yes	No
NICKEL, FILTERED	Yes	No
SODIUM, FILTERED		No
ZINC, FILTERED		No

TABLE 2-4

SUMMARY OF POSITIVE ANALYTICAL RESULTS, COPCs, COCs, AND RISK DRIVERS FOR SURFACE WATER
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Chemical Detected	Human Health		Ecological	
	COPCs	COC/Risk Drivers	COPCs	COC/Risk Drivers
Explosives				
2,4,6-TRINITROTOLUENE	Yes	No	Yes	No
2-AMINO-4,6-DINITROTOLUENE	Yes	No	Yes	No
4-AMINO-2,6-DINITROTOLUENE	Yes	No	Yes	No
HMX		No	Yes	No
RDX	Yes	No	Yes	No
Inorganics				
ALUMINUM	Yes	No	Yes	No
ARSENIC	Yes	No		No
BARIUM		No		No
CALCIUM		No		No
COPPER		No		No
IRON	Yes	No	Yes	No
LEAD		No		No
MAGNESIUM		No		No
MANGANESE	Yes	No	Yes	No
SODIUM		No		No
ZINC		No	Yes	No
Filtered Metals				
ANTIMONY, FILTERED		No		No
ARSENIC, FILTERED	Yes	No		No
BARIUM, FILTERED		No		No
CALCIUM, FILTERED		No		No
IRON, FILTERED	Yes	No	Yes	No
MAGNESIUM, FILTERED		No		No
MANGANESE, FILTERED	Yes	No	Yes	No
SODIUM, FILTERED		No		No
ZINC, FILTERED		No	Yes	No

TABLE 2-5

SUMMARY OF POSITIVE ANALYTICAL RESULTS, COPCs, COCs,
AND RISK DRIVERS FOR SEDIMENT
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Chemical Detected	Human Health		Ecological	
	COPCs	COC/Risk Drivers	COPCs	COC/Risk Drivers
Explosives				
HMX		No	Yes	No
Inorganics				
ALUMINUM	Yes	No	Yes	No
ANTIMONY		No	Yes	No
ARSENIC	Yes	No		No
BARIUM		No	Yes	No
BERYLLIUM		No	Yes	No
CADMIUM		No		No
CALCIUM		No		No
CHROMIUM	Yes	No		No
COBALT		No		No
COPPER		No		No
IRON	Yes	No	Yes	No
LEAD		No		No
MAGNESIUM		No		No
MANGANESE	Yes	No	Yes	No
MERCURY		No		No
NICKEL		No		No
VANADIUM	Yes	No	Yes	No
ZINC		No		No

TABLE 2-6

CUMULATIVE RISK SUMMARY - REASONABLE MAXIMUM EXPOSURE FOR
SURFACE SOIL, SUBSURFACE SOIL, SURFACE WATER, GROUNDWATER, AND SEDIMENT
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Exposure Route	Construction Worker	Maintenance Worker	Occupational Worker	Adult Recreational User	Adolescent Trespasser	Future Adult Resident	Future Child Resident
HAZARD INDEX							
Ingestion of Groundwater	NA	NA	NA	NA	NA	3.8E+01	1.3E+02
Dermal Contact with Groundwater	1.6E+00	NA	NA	NA	NA	3.4E+00	1.0E+01
Inhalation of Volatiles from Groundwater While Showering	NA	NA	NA	NA	NA	NA	NA
Incidental Ingestion of Surface Soil	NA	5.1E-04	5.3E-03	1.1E-03	8.9E-04	7.4E-03	6.9E-02
Dermal Contact with Surface Soil	NA	3.3E-04	3.5E-03	4.4E-04	6.8E-04	3.0E-03	1.4E-02
Incidental Ingestion of Surface/Subsurface Soil	1.3E-02	NA	NA	NA	NA	NA	NA
Dermal Contact with Surface/Subsurface Soil	4.8E-03	NA	NA	NA	NA	NA	NA
Incidental Ingestion of Surface Water	NA	NA	NA	1.6E-02	2.7E-03	1.1E-01	1.0E-01
Dermal Contact with Surface Water	NA	NA	NA	1.1E-02	3.8E-03	7.4E-02	7.6E-02
Incidental Ingestion of Sediment	NA	NA	NA	4.6E-02	3.7E-02	3.1E-01	2.9E+00
Dermal Contact with Sediment	NA	NA	NA	3.7E-02	2.5E-03	1.1E-02	5.1E-02
Total Hazard:	**1.6E+00**	**8.4E-04**	**8.7E-03**	**1.1E-01**	**4.8E-02**	**4.2E+01**	**1.5E+02**

TABLE 2-6

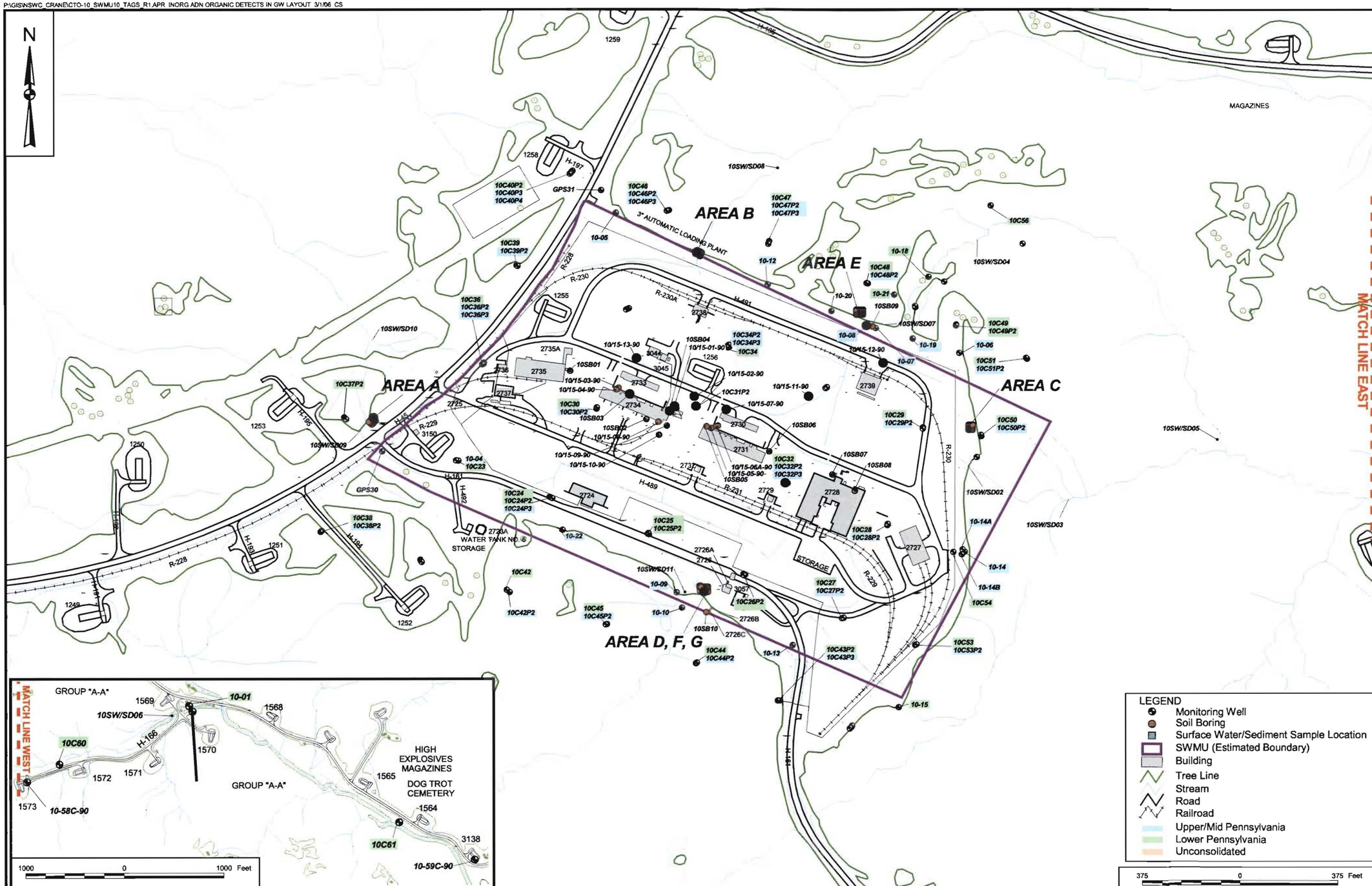
CUMULATIVE RISK SUMMARY - REASONABLE MAXIMUM EXPOSURE FOR
SURFACE SOIL, SUBSURFACE SOIL, SURFACE WATER, GROUNDWATER, AND SEDIMENT
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

INCREMENTAL CANCER RISK

Exposure Route	Construction Worker	Maintenance Worker	Occupational Worker	Adult Recreational User	Adolescent Trespasser	Future Adult Resident	Future Child Resident
Ingestion of Groundwater	NA	NA	NA	NA	NA	1.5E-04	1.3E-04
Dermal Contact with Groundwater	1.4E-08	NA	NA	NA	NA	1.2E-06	6.9E-07
Inhalation of Volatiles from Groundwater While Showering	NA	NA	NA	NA	NA	NA	NA
Incidental Ingestion of Surface Soil	NA	3.4E-07	3.5E-06	8.9E-07	2.6E-07	4.8E-06	1.1E-05
Dermal Contact with Surface Soil	NA	2.9E-07	3.0E-06	4.6E-07	2.6E-07	2.5E-06	2.9E-06
Incidental Ingestion of Surface/Subsurface Soil	4.0E-07	NA	NA	NA	NA	NA	NA
Dermal Contact with Surface/Subsurface Soil	1.9E-07	NA	NA	NA	NA	NA	NA
Incidental Ingestion of Surface Water	NA	NA	NA	5.40899E-07	3.22862E-08	2.91253E-06	6.79591E-07
Dermal Contact with Surface Water	NA	NA	NA	7.47271E-08	9.39302E-09	4.02377E-07	1.03515E-07
Incidental Ingestion of Sediment	NA	NA	NA	2.6E-06	7.7E-07	1.4E-05	3.3E-05
Dermal Contact with Sediment	NA	NA	NA	7.1E-06	1.8E-07	1.7E-06	2.0E-06
Total Risk:	**6.0E-07**	**6.3E-07**	**6.6E-06**	**1.2E-05**	**1.5E-06**	**1.7E-04**	**1.8E-04**

NOTES
NA - Not applicable; exposure route is not applicable for this receptor.
Chemical-specific risks presented in Appendix G-3 of the RFI Report (TtNUS, 2003).

P:\GIS\NSWC_CRANE\CTO-10_SWMU10_TAGS_R1.APR INORG ADN ORGANIC DETECTS IN GW LAYOUT 3/1/06 CS



CONTRACT NO. N4267

APPROVED BY ____ DATE ____

APPROVED BY ____ DATE ____

DRAWING NO. FIGURE 2 - 1

REV 0

AREAS AND SAMPLE LOCATIONS
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

NAVFAC

DRAWN BY J. LAMEY DATE 9/12/02

CHECKED BY V. PLACHY DATE 2/27/06

COST/SCHED-AREA

SCALE AS NOTED

3.0 DEVELOPMENT OF CORRECTIVE MEASURES OBJECTIVES

The purpose of this section is to identify potentially applicable ARARs and TBC criteria, and to develop CMOs for soil and groundwater. The corrective measures objectives are based on contaminant characterization, risk assessment, and compliance with risk-based and ARAR-based action levels.

3.1 ARARS

ARARs include the requirements, criteria, or limitations promulgated under the Federal and state law that address a chemical, location, or action at a site. The definition of ARARs is a follows:

- Any standard, requirement, criterion, or limitation under Federal environmental law.

- Any promulgated standard, requirement, criterion, or limitation under a state environmental or facility-citing law that is more stringent that the associated Federal standard, requirement criterion, or limitation.

One of the primary concerns during the development of CMOs is the degree of human health and environmental protection afforded by a given remedy. Consideration should be given to remedies that attain or exceed ARARs.

Definitions of the two types of ARARs, as well as TBC criteria, are given below:

- Applicable Requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law that directly and fully address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a site.

- Relevant and Appropriate Requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law that, while not "applicable", address problems or situations sufficiently similar (relevant) to those encountered at a site such that their use is well suited (appropriate) to the particular site.

- TBC Criteria are non-promulgated, enforceable guidelines or criteria that may be useful for developing remedial actions or necessary for determining what is protective of human health and/or

the environment. Examples of TBC criteria include U.S. EPA Drinking Water Advisories and Risk-Based Concentrations (RBCs).

ARARs fall into three categories, based on the manner in which they are applied:

- Contaminant Specific – These include health/risk-based numerical values or methodologies that establish concentration or discharge limits for particular contaminants. Examples of contaminant-specific ARARs include Maximum Contaminant Levels (MCLs) and the Clean Water Act (CWA).

- Location Specific – These restrictions are based on the concentration of specific contaminants or the conduct of activities in specific locations. These may restrict or preclude certain remedial actions or may apply only to certain portions of a site.

- Action Specific – These are technology- or activity-based controls or restrictions on activities related to management of contaminants. Action-specific ARARs pertain to implementing a given remedy.

A summary listing of all contaminant-, location-, and action-specific ARARs and TBC criteria for SWMU 10 are listed in Tables 3-1, 3-2, and 3-3, respectively. Sections 3.1.2.1, 3.1.2.2, and 3.1.2.3 provide a brief description of each contaminant-, location-, and action-specific ARAR or TBC criteria shown in Tables 3-1 through 3-3.

3.1.1 Contaminant-Specific ARARs and TBC Criteria

The Safe Drinking Water Act (SDWA) (40 CFR §§141-143) promulgated National Primary Drinking Water Standard MCLs (40 CFR §141). MCLs are enforceable standards for contaminants in public drinking water supply systems. They consider not only health factors but also the economic and technical feasibility of removing a contaminant from a water supply system. Secondary MCLs (SMCLs) (40 CFR §143) are not enforceable, but are intended as guidelines for contaminants that may adversely affect the aesthetic quality of drinking water, such as taste, odor, color, and appearance, and may deter public acceptance of drinking water provided by public water systems.

The SDWA also established MCLGs for several organic and inorganic compounds in drinking water. MCLGs indicate the level of contaminants in drinking water at which no known or anticipated health effects would occur, allowing for an adequate margin of safety. MCLGs are non-enforceable public health goals. The National Contingency Plan (NCP) [40 CFR §300.430(e)(2)(i)] states that MCLGs that are set at levels greater than zero shall be attained by remedial actions for groundwater or surface waters that

are current or potential sources of drinking water where MCLs are relevant and appropriate to the circumstances of the release. SMCLs and MCLGs are TBC criteria.

Clean Water Act (CWA) Ambient Water Quality Criteria (AWQC) are non-enforceable guidelines developed for pollutants in surface water pursuant to CWA Section 304(a); under CWA Section 303, states must develop water quality standards based on AWQC to protect existing and attainable uses of surface waters that receive discharges of pollutants. CERCLA Section 121 states that hazardous substances, pollutants, and contaminants left onsite at the conclusion of a remedial action must attain AWQC where they are relevant and appropriate under the circumstances of the release. More specifically, AWQC are available for the protection of human health from exposure to contaminants in drinking water as well as from ingestion of aquatic biota and for the protection of freshwater and saltwater aquatic life. AWQC may be considered for actions that involve discharge to nearby surface waters. Guidance from the U.S. EPA, dated October 1, 1993 (U.S. EPA, 1993), is available concerning Interpretation and Implementation of Aquatic Life Metals Criteria, particularly concerning the use of dissolved metals rather than total metals. Contaminant concentrations in surface water must be measured through monitoring to evaluate offshore impacts of the discharge to surface waters through seeps/sediment, and to ensure that AWQCs are being met. AWQC is TBC Criteria.

U.S. EPA Health Advisories are non-enforceable guidelines developed by the U.S. EPA Office of Drinking Water for contaminants that may be intermittently encountered in public water supply systems. Health advisories are available for short-term, longer-term, and lifetime exposures for a 10-kg child and a 70-kg adult. Health advisories may be pertinent for remedial action/corrective measures involving groundwater, especially for contaminants that are not regulated by the SDWA. U.S. EPA Health Advisories are TBC criterium.

U.S. EPA Generic Soil Screening Levels (SSLs) are guidance that, if exceeded through three possible exposure pathways, may be of potential concern to human receptors: SSLs consider the following exposure pathways: direct ingestion of soil, inhalation of volatile compounds and fugitive dust, and migration of groundwater. SSLs are risk-based concentrations derived from equations combining exposure information assumptions with U.S. EPA toxicity data. SSLs for protection of groundwater use a simple linear equilibrium soil/water partition equation or leach test to estimate contaminant releases in soil leachate. SSLs are TBC criteria.

Reference Doses (RfDs), as defined in the U.S. EPA Integrated Risk Information System (IRIS), are an estimate (with uncertainty spanning perhaps an order of magnitude) of daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious

effects during a lifetime. RfDs are developed for chronic and/or subchronic human exposure to hazardous chemicals and are based on the assumption that thresholds exist for certain toxic effects. The RfD is usually expressed as an acceptable dose in milligrams (mg) per unit body weight in kilograms (kg) per unit time (day). The RfD is derived by dividing the no-observed-adverse effect level (NOAEL) or the lowest-observed-adverse effect level (LOAEL) by an uncertainty factor (UF) times a modifying factor (MF). RfDs are TBC criteria.

U.S. EPA Carcinogenic Slope Factors, as defined in the IRIS, are an upper bound, approximating a 95 percent confidence limit, on the increased cancer risk from a lifetime exposure to a contaminant. This estimate, usually expressed in units of proportion (of a population) affected per mg/kg/day, is generally reserved for use in the low-dose region of the dose-response relationship, that is, for exposures corresponding to risks less than 1 in 100. Carcinogenic slope factors are TBC criteria.

U.S. Region 9 Primary Remediation Goals (PRGs) are risk-based concentrations, derived from standardized equations combining exposure information assumptions with U.S. EPA toxicity data for contaminants in soil, air, and tap water. They are considered to be protective for humans (including sensitive groups), over a lifetime. However, PRGs are not always applicable to a particular site and do not address non-human health endpoints such as ecological impacts. PRGs are not de facto cleanup standards; however, they could be used to establish final cleanup levels for a site after a proper evaluation takes place. Region 9 PRGs are risk-based concentrations that are intended to assist risk assessors and others in initial screening-level evaluations of environmental measurements. PRGs are TBC criteria.

Handbook on the Management of Ordnances and Explosives at Closed, Transferring, and Transferred Ranges and other Sites facilitates understanding of the wide variety of technical issues that surround the investigation and cleanup of closed, transferring, and transferred (CTT) ranges and other sites at current and former Department of Defense (DoD) facilities. The handbook is TBC criteria.

Indiana Department of Environmental Management (IDEM) Risk Integrated System of Closure (RISC) is a non-rule policy called the RISC that incorporates environmental risk assessment principles to protect human health and the environment and achieve consistent closure of contaminated soil and groundwater. As a non-rule policy document, RISC guidance does not have the effect of law. However, the policy provides a systematic approach for consistently and rationally implementing the laws and rules that govern site investigation and closure. Included in this policy are risk-based closure level constituent concentrations calculated to be protective of human health. The RISC is TBC criteria.

Indiana Water Quality Standards (IWQS) (IAC 327) establish minimum standards for the protection of surface water quality. IDEM has established two sets of water quality criteria; one for bodies of water that are in the Great Lakes Basin and another for all other state bodies of water. Each set of criteria includes values for the protection of human health, aquatic life, and wildlife. There are two categories of human health criteria, drinking and non-drinking. The drinking water criteria apply to the point of intake. Separate human health cancer and non-cancer criteria are derived if the contaminant has the potential to cause cancer. The value of the highest level of protection is used for each contaminant. Water from SWMU 10 does not drain to the Great Lakes Basin. IWQS are ARARs.

3.1.2. Location-Specific ARARs and TBC Criteria

Endangered Species Act of 1973 (16 USC 1531) (50 CFR §17) provides to conserve the ecosystems upon which endangered and threatened species depend and to conserve and recover listed species. Corrective measure actions, if required, would need to be conducted in a manner such that the continued existence of any endangered or threatened species is not jeopardized or its critical habitat is not adversely affected. Consultation with the United States Fish and Wildlife Service is also required. SWMU 10 is located in Martin County. The State of Indiana has identified a list of endangered, threatened, and rare species for Martin County. The species include plants, insects, birds, reptiles, and birds. In addition, migrating species may move through the area. The Endangered Species Act of 1978 is potential ARAR.

U.S. EPA Groundwater Protection Strategy and Classification Guidelines (U.S. EPA, 1986) are policies to protect groundwater for its highest present or potential beneficial use. The strategy designates three classifications of groundwater:

- Class I – Special Groundwater: Water that is highly vulnerable to contamination and is either irreplaceable or ecologically vital sources of drinking water.

- Class II – Current and Potential Sources of Drinking Water and Waters Having Other Beneficial Uses: Waters that are currently used or that are potentially available.

- Class III – Groundwater Not a Potential Source of Drinking Water and of Limited Beneficial Use. Class III groundwater units are further subdivided into two subclasses:

  - Subclass IIIA includes groundwater units that are highly to intermediately interconnected to adjacent groundwater units of a higher class and/or surface waters. They may, as a result, be contributing to the degradation of the adjacent waters. They may be managed at a similar level

as Class II groundwater, depending on the potential for producing adverse effects on the quality of adjacent waters.

- Subclass IIIB is restricted to groundwater characterized by a low degree of interconnection to adjacent surface waters or other groundwater units of a higher class within the Classification Review Area. These groundwaters are naturally isolated from the source of drinking waters in such a way that little potential exists for producing adverse effects on quality. They have low resource values outside of mining or waste disposal.

At SWMU 10, groundwater is likely considered to be Class IIIA. However, a potential future residential land use has been evaluated in the RFI, and although unlikely, the groundwater can be considered as Class II. The U.S. EPA groundwater protection strategy and classification guidelines are TBC criteria.

The Fish and Wildlife Coordination Act (FWCA) (16 U.S.C. §§ 661-667e, March 10, 1934, as amended 1946, 1958, 1978, and 1995) provides that whenever the waters or channel of a body of water are modified by a department or agency of the U.S., the department or agency first will consult with the U.S. Fish and Wildlife Service and with the head of the agency exercising administration over the wildlife resources of the state where construction will occur, with a view to the conservation of wildlife resources. The Act provides that land, water, and interests may be acquired by federal construction agencies for wildlife conservation and development. In addition, real property under jurisdiction or control of a federal agency and no longer required by that agency can be utilized for wildlife conservation by the state agency exercising administration over wildlife resources upon that property.

FWCA provides the basic authority for the Service's involvement in evaluating impacts to fish and wildlife from proposed water resource development projects. It requires that fish and wildlife resources receive equal consideration to other project features. It also requires that Federal agencies that construct, license or permit water resource development projects must first consult with the Fish and Wildlife Service (and the National Marine Fisheries Service in some instances) and State fish and wildlife agency regarding the impacts on fish and wildlife resources and measures to mitigate these impacts. Full consideration is to be given to Fish and Wildlife Service recommendations. The FWCA is a potential ARAR.

The Archaeological and Historic Preservation Act (AHPA) provides for the preservation of historical and archeological data (including relics and specimens) which might otherwise be irreparably lost or destroyed as the result of:

1) Flooding, the building of access roads, the erection of workmen's communities, the relocation of railroads and highways, and other alterations of the terrain caused by the construction of a dam by any agency of the U.S., or by any private person or corporation holding a license issued by any such agency.

2) Any alteration of the terrain caused as a result of any Federal construction project or federally licensed activity or program findings or policy.

The purposes of the AHPA are to recognize the vital contribution of our wildlife resources to the nation, and their increasing public interest and significance, and to provide that wildlife conservation receive equal consideration and be coordinated with other features of water-resource development programs through planning, development, maintenance, and coordination of wildlife conservation and rehabilitation. In furtherance of the stated purposes, the U.S. Secretary of the Interior (Secretary) is authorized to provide assistance to, and cooperate with, federal, state, and public or private agencies and organizations in:

- Developing, protecting, rearing, and stocking all species of wildlife, resources thereof, and their habitat; controlling losses from disease or other causes; minimizing damages from overabundant species.

- Providing public shooting and fishing areas, including easements across public lands; carrying out other necessary measures.

The Secretary is also authorized to make surveys and investigations of the wildlife of the public domain, including lands and waters or interest acquired or controlled by an agency of the U.S., and to accept donations of land and contributions of funds in furtherance of the purposes of AHPA. The AHPA is a potential ARAR.

Federal Protection of Wetlands Executive Order (EO) 11990 authorizes federal protection of wetlands. The order requires federal agencies to consider the potential effects of a proposed project on the survival and quality of wetlands including the conservation and long term productivity of existing faunal species and habitat diversity and stability. EO 11990 applies to the issuance by federal agencies of permits, licenses, or allocations to private parties for activities involving wetlands on federal lands.

The purpose of EO 11990 is to "minimize the destruction, loss or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands." To meet these objectives, EO 11990

requires federal agencies, in planning their actions, to consider alternatives to wetland sites and limit potential damage if an activity affecting a wetland cannot be avoided. EO 11990 applies to:

- Acquisition, management, and disposition of federal lands and facilities construction and improvement projects which are undertaken, financed or assisted by federal agencies.

- Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulation, and licensing activities.

EO 11990 is a potential ARAR.

Bald and Gold Eagle Protection Act (BGEPA) (16 USC 668a-d) prohibits any form of possession or taking of both bald and golden eagles. The statute imposes criminal and civil sanctions as well as an enhanced penalty provision for subsequent offenses. Further, the BGEPA provides for the forfeiture of anything used to acquire eagles in violation of the statute. The statute accepts from its prohibitions on possession the use of eagles or eagle parts for exhibition, scientific, and Indian religious uses. The BGEPA is a potential ARAR.

Indiana Non-game and Endangered Species Conservation Act (IESA) (IC 14-22-34) provides a list of those species and subspecies of wildlife indigenous to Indiana which are determined to be endangered in Indiana. In addition, this rule governs the taking, possession, removal capture, destruction, and management of state listed endangered species. The IESA is a potential ARAR.

Indiana Wildlife Regulation (IWR) (IC 14-22-10) provides protection for wildlife from releases or discharges of contaminants or waste materials into state waters or land that may result in the destruction of wild animals. The state Department of Natural Resources has the authority and responsibility to protect and properly manage the fish and wildlife resources of the state. The release of contaminated waste during the remedy activity could be released on to soil and possibly result in discharge to state waters. The IWR is a potential ARAR.

Indiana Natural Heritage Protection Campaign (IC 14-31-2) promotes the preservation of areas of unusual natural interest for scientific, educational, recreational, cultural, and aesthetic purposes as a link to the Indiana's past and future. The rule also provides for the maintenance and management of those natural areas and the rare native species for which the areas are habitat. Remedy activities at SWMU 10 may result in disturbance of natural areas inhabited by Indiana rare species. The Indiana Heritage Protection Campaign is a potential ARAR.

3.1.3 Action-Specific ARARs and TBC Criteria

Clean Air Act (CAA) (40 CFR §50) contains two programs or requirements that may be ARARs: National Ambient Air Quality Standards (NAAQS) (40 CFR §§ 50 and 53) and National Emission Standards for Hazardous Air Pollutants (NESHAPs) (40 CFR §61). NESHAPs, which are emission standards for source types (i.e., industrial categories) that emit hazardous air pollutants, are not likely to be applicable or relevant because they were developed for specific contaminants and sources. U.S. EPA requires the attainment and maintenance of primary and secondary NAAQS to protect public health and public welfare. These standards are contaminant and averaging period specific national limitations on ambient air quality. States are responsible for assuring compliance with the NAAQS. NAAQS and NESHAPs are potential ARARs.

CWA National Pollutant Discharge Elimination System (NPDES) (40 CFR §122) specifies that NPDES permits are required for any discharge to surface water. CMAs that include discharges to surface water would have to comply with the permit requirements. The CWA is a potential ARAR.

RCRA Solid Waste Management Regulations RCRA (40 CFR §258) provides for design and operating standards for solid waste (nonhazardous) landfills. CMAs that include solid waste landfills or where nonhazardous soil is stockpiled or disposed on site would have to comply with RCRA.

RCRA (40 CFR §261) provides for regulations that govern the procedures for identifying if a material is a hazardous waste. CMAs at SWMU 10 have the potential to generate specific materials that may be classifiable as a characteristic or listed hazardous waste. RCRA standards are applicable to generators of hazardous wastes (40 CFR §262). CMAs at SWMU 10 have the potential to generate waste for removal that may be determined to be hazardous. Generated wastes that are determined to be hazardous and transportation off-site are regulated under RCRA (40 CFR §263).

RCRA regulations are applicable to owners and operators of hazardous waste treatment storage and disposal TSD) facilities as standards and interim standards (40 CFR §§264 and 265). These regulations would be applicable to waste removed from this site including both on-site and off-site management; however, the reuse of treated soils as backfill would not be subject to the disposal facility standard.

RCRA Land Disposal Restrictions (LDRs) (40 CFR §268) identifies hazardous wastes that are restricted from land disposal and waste analysis requirements. CMAs at SWMU 10 may include the treatment or

disposal of contaminated soils/wastes and/or treatment residuals that may be considered hazardous wastes are subject to land disposal restrictions.

RCRA is a potential ARAR.

Department of Transportation (DOT) Rules for Hazardous Materials Transport (40 CFR §107 and §§171 to 179) regulate the transportation of hazardous materials including requirements that regulate packaging, marking, labeling, and transportation methods. CMAs at SWMU 10 have the potential to generate off-site shipments of contaminated waste including soil that could be classified as a hazardous material. The DOT rules for the transportation of hazardous materials are potential ARARs.

Indiana Environmental Remediation Act (IERA) (IC 13-30-10) requires certain environmental remediation plans to specify remediation objectives based on specified factors. The IERA directs IDEM to certify completion of plans and to issue covenants not to sue with respect to completed plans. The IERA is potentially applicable.

Indiana Solid Waste Management Board (ISWMB) (329 IAC) provides for design and operating standards for solid waste (nonhazardous) landfills. Additionally, Indiana adopted regulations identical to the federal regulations for the listing of hazardous waste (40 CFR §261), generators of hazardous wastes (40 CFR §262), and transporters of hazardous wastes (40 CFR §263). Additionally, Indiana adopted regulations identical to the federal standards and interim standards applicable to owners and operators of hazardous waste treatment, storage, and disposal facilities (40 CFR §§264 and 265). These regulations are potentially applicable.

Indiana Air Screening Levels (IASLs) (325 IAC) and Ambient Air Quality Standards (IAAQS) (326 IAC) are two state requirements that may be ARARs or TBC criteria. IASLs are non-rule guidelines that are used to by IDEM to evaluate the ambient impact of hazardous contaminants. When determining a pollutant's maximum allowable concentration, the toxicity of a compound is measured by its permissible exposure limit (PEL). The PEL is the maximum concentration under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effects. The PEL for each chemical is determined by the Occupational Safety and Health Administration (OSHA). IDEM calculates IASLs as generally 0.5 percent of the PEL. If the maximum air concentration is less than the ASL, it indicates that there should not be a significant impact on public health and welfare. Site specific exceptions may be made.

The purpose of the IAAQS is to establish primary and secondary ambient air quality standards for the state and, to the extent necessary, to protect the public health and welfare. IAAQS are in accordance

with the provisions of the CAA. 326 IAC provides air quality standards for carbon monoxide, lead, nitrogen oxides, particulate matter, ozone, and sulfur oxides emitted from a major source of emissions. IASLs are TBC criteria. IAAQS are potential ARARs.

Indiana Water Pollution Control Board (IWPCB) (327 IAC) provides for NPDES permits requirements for any discharge to surface water. The IWPCB regulations are potentially applicable.

3.2 MEDIA-SPECIFIC CORRECTIVE ACTION OBJECTIVES

3.2.1 Groundwater

Human Health Risk

CAOs are developed in this section to address contaminated groundwater at SWMU 10. CAOs generally identify COCs, receptors, pathways, and action clean-up levels. The RFI for SWMU 10 concluded the following in regard to human health risk:

TNT

- For the future child resident, a significant risk was associated with the ingestion of groundwater containing TNT.

2-amino-4,6-DNT

- For the future adult and child resident, a significant risk was associated with the ingestion of groundwater containing 2-amino,4,6-DNT.

4-amino-2,6-DNT

- For the future adult and child resident, a significant risk was associated with the ingestion of groundwater containing 4-amino-2,6-DNT.

RDX

- For the adult and child resident, a significant risk was associated with the ingestion of groundwater containing RDX.

Iron

- For the adult and child resident, a significant risk was associated with the ingestion of groundwater containing RDX.

Manganese

- For the future adult and child resident, a significant risk was associated with the ingestion of groundwater containing manganese.

- For the future and child resident, a significant risk was associated with the dermal contact of groundwater containing manganese.

- For the future adult construction worker, a significant risk was associated with dermal contact of groundwater containing manganese.

Nickel

- For the future adult and child resident, a significant risk was associated with the ingestion of groundwater containing nickel.

The medium-specific CAOs for contaminated groundwater are as follows:

- Prevent human exposure (ingestion and dermal contact) to contaminated groundwater with concentrations greater than the MCL.

- Prevent plume migration of groundwater.

- Comply with chemical-specific, location-specific, and action-specific ARARs and TBC criteria guidance.

3.2.2 Other Media

There is no significant risk associated with surface soil, subsurface soil, surface water, or sediment (TtNUS, 2005).

3.3 CHEMICALS OF CONCERN

3.3.1 Surface Soil

Human Health

As discussed in Section 2.1.1, the chemicals detected in surface soil are not found to present a significant risk in the HHRA.

Ecological

As discussed in Section 2.1.1, the chemicals detected in the surface soil are not expected to adversely impact ecological receptors.

3.3.2 Subsurface Soil

As discussed in Section 2.1.2, the chemicals detected in subsurface soil are not found to present a significant risk in the HHRA.

3.3.3 Groundwater

As discussed in Section 2.1.3, five explosive compounds (2-amino-4,6-DNT, 4-amino-2,6-DNT, RDX, and TNT) and three inorganics (iron, manganese, and nickel) were retained as COCs for groundwater at SWMU 10.

TNT

Under the future land use scenario, elevated non-carcinogenic and/or carcinogenic risks were calculated for future child resident from exposure to TNT in groundwater. TNT concentrations in groundwater exceed the background concentrations and human health risk-based criteria at two locations (wells 10-17 and 10C55) (see Figure 2-1 for locations), with the greatest groundwater concentration in well 10-17 [26 micrograms per liter (µg/L)].

2-Amino-4,6-DNT

Under the future land use scenario, elevated non-carcinogenic and/or carcinogenic risks were calculated for future child resident from exposure to 2-amino-4,6-DNT in groundwater. 2-amino-4,6-DNT concentrations in groundwater exceed the background concentrations and human health risk-based

criteria at two locations (wells 10-17 and 10C55), with the greatest groundwater concentration in well 10-17 (20 µg/L).

4-Amino-2,6-DNT

Under the future land use scenario, elevated non-carcinogenic and/or carcinogenic risks were calculated for future child resident from exposure to 4-amino-2,6-DNT in groundwater. 4-amino-2,6-DNT concentrations in groundwater exceed the background concentrations and human health risk-based criteria at three locations (wells 10-02, 10-17, and 10C55), with the greatest groundwater concentration in well 10-17 (18 µg/L).

RDX

Under the future land use scenario, elevated non-carcinogenic and/or carcinogenic risks were calculated for future child resident from exposure to RDX in groundwater. RDX concentrations in groundwater exceed the background concentrations and human health risk-based criteria at three locations (wells 10-02, 10-17, and 10C55) (see Figure 2-1 for locations) with the greatest groundwater concentration in well 10C55 (240 µg/L).

Iron

Under the future land use scenario, elevated non-carcinogenic and/or carcinogenic risks were calculated for future child resident from exposure to iron in groundwater based upon the recommended daily dietary allowance of iron. Iron concentrations in groundwater exceed the background concentrations and human health risk-based criteria at all locations, with the greatest groundwater concentration in well 10C41 (39,700 µg/L).

Manganese

Under the future land use scenario, elevated non-carcinogenic and/or carcinogenic risks were calculated for future child resident from exposure to manganese in groundwater. Manganese concentrations in groundwater exceed the background concentrations and human health risk-based criteria at most locations, with the greatest groundwater concentration in well 10C41 (105,000 µg/L).

Nickel

Under the future land use scenario, elevated non-carcinogenic and/or carcinogenic risks were calculated for future child resident from exposure to nickel in groundwater. Nickel concentrations in groundwater exceed the background concentrations and human health risk-based criteria at most locations, with the greatest groundwater concentration in well 10C31 (695 µg/L).

3.3.4 Surface Water Contamination

As discussed in Section 2.1.4, the chemicals detected in surface water are not found to present a significant risk in the HHRA or ERA.

3.3.5 Sediment Contamination

As discussed in Section 2.1.5, the chemicals detected in sediment are not found to present a significant risk in the HHRA or ERA.

3.4 MEDIA CLEANUP STANDARDS

3.4.1 Groundwater

Human Health Risk

The human health groundwater MCSs for SWMU 10 were back calculated from the risk assessment included in the RFI for SWMUs 4, 5, 9, and 10 according to the methodology used by U.S. EPA Region 9 in the development of its PRGs. The calculated MCSs for groundwater at SWMU 10 are presented in Table 3-4. Because risk assessment equations are linear in the concentration term, an acceptable remediation concentration for the site can be calculated using a ratio of the site concentration to the resulting risk estimate which was determined in the risk assessment for utilizing a target cancer risk (TCR) or target hazard index (THI). Two carcinogens (2,4,6-trinitrotoluene and RDX) and five noncarcinogens (4-amino-2,6-DNT, 2-amino-4,6-DNT, iron, manganese, and nickel) were identified as COCs for SWMU 10 in groundwater. A TCR of $1x10^{-6}$ is used to determine the remediation concentration for carcinogens and a THI of unity (1) is used for noncarcinogens. Example calculations for each type of chemical are provided below.

Example Calculation for Carcinogenic Effects

The groundwater MCS for carcinogens was calculated by the following equation:

$$MCS = \frac{Cgw \times TCR}{Risk}$$

Where:

MCS	=	Media Cleanup Standard (µg/L)
Cgw	=	Groundwater exposure point concentration used in the SWMU 10 risk assessment (µg/L)
TCR	=	Target Cancer Risk = 1×10^{-6} $(mg/kg/day)^{-1}$
Risk	=	Groundwater risk calculated in the SWMU 10 risk assessment

According to the methodology specified in the U.S. EPA Region 9 PRG calculations, PRGs for carcinogens are based on a 30 year exposure duration (6 years for a child + 24 years for an adult). Therefore, the Risk term used in the calculations represents the sum of child and adult risks from the SWMU 10 risk assessment. For example, the total residential risk for RDX (2.24×10^{-4}) presented in the risk assessment is the sum of the child (1.04×10^{-4}) and adult (1.2×10^{-4}) risks.

Example Calculation: Residential groundwater MCS for RDX

Cgw	=	115 µg/L
THI	=	1×10^{-6} $(mg/kg/day)^{-1}$
Risk	=	2.24×10^{-4} = combined child + adult residential risk (ingestion + dermal contact)

$$MCS = \frac{115 \times 1 \times 10^{-6}}{2.24 \times 10^{-4}}$$

MCS (RDX) = 0.5 µg/L

<u>Example Calculation for Noncarcinogenic Health Effects</u>

As specified in the Region 9 PRG guidance, the MCS for exposure to noncarcinogens in groundwater is based on exposure by an adult resident drinking two liters of water per day. The groundwater MCS for noncarcinogens was calculated by the following equation:

$$MCS = \frac{Cgw \times THI}{Risk}$$

Where:

MCS	=	Media Cleanup Standard (µg/L)
Cgw	=	Groundwater exposure point concentration used in the SWMU 10 risk assessment (µg/L)
THI	=	Target Hazard Index
Risk	=	Groundwater risk calculated in the SWMU 10 risk assessment

Example Calculation: Residential groundwater MCS for manganese

Cgw	=	21,800 µg/L
THI	=	1
Risk	=	28.1 (ingestion + dermal HI)

$$MCS = \frac{21{,}800 \times 1}{28.1}$$

MCS (manganese) = 775 µg/L

TNT

A groundwater MCS of 2 µg/L was established to reduce human health risks from TNT associated with the future residents (i.e., the future child and adult residents) to acceptable levels. TNT concentrations at groundwater wells 10-17 (26 µg/L), 10C55 (56 µg/L), and 10C55P2 (5.8 µg/L) exceeded this cleanup level.

2-Amino-4,6-DNT

A groundwater MCS of 7 µg/L was established to reduce human health risks from 2-amino-4,6-DNT associated with the future residents to acceptable levels. 2-Amino-4,6-DNT concentrations at groundwater wells 10-17 (20 µg/L) and 10C55P2 (7.2 µg/L) exceeded this cleanup level.

4-Amino-2,6-DNT

A groundwater MCS of 7 µg/L was established to reduce human health risks from 4,-amino-2,6-DNT associated with the future residents to acceptable levels. 4-Amino-2,6-DNT concentrations at groundwater wells 10-17 (18 µg/L) and 10C55P2 (15 µg/L) exceeded this cleanup level.

RDX

A groundwater MCS of 0.5 µg/L was established to reduce human health risks from RDX associated with the future residents to acceptable levels. RDX concentrations at groundwater wells 10-02 (4.9 µg/L), 10-17 (33 µg/L), 10C55 (240 µg/L), and 10C55P2 (21 µg/L) exceeded this cleanup level.

Iron

A groundwater MCS of 11,000 µg/L was established to reduce human health risks from iron associated with the future residents to acceptable levels. Iron concentrations at groundwater wells 10-16 (23,700 µg/L), 10-16 (17,100 µg/L), 10C33P2 (20,200 µg/L), 10C35 (93,700 µg/L), 10C37 (16,300 µg/L), 10C37P3 (31,400 µg/L), 10C41 (39,700 µg/L), 10C52 (22,200 µg/L), and 10C57 (17,300 µg/L) exceeded this cleanup level.

Iron occurs naturally in the sandstone, siltstone, shale, and coal units of the Pennsylvanian bedrock. Concentrations of iron in groundwater contained in the bedrock can be naturally elevated, especially if the groundwater is acidic (e.g., pH < 6.0) and/or the groundwater is under moderately to strongly reducing conditions. Concentrations of iron were found above the MCS in numerous monitoring wells within the SWMU and surrounding the SWMU. The wells having iron MCS exceedances were evenly distributed across the site and did not appear to be linked to any specific building, industrial activity, spills, or waste-handling activity. Thus, the Navy believes that the elevated iron concentrations in groundwater are derived from the Pennsylvanian bedrock, and are not related to any industrial or waste activities. Therefore, iron will not be carried forward in this CMS report.

Manganese

A groundwater concentration MCS of 775 µg/L was established to reduce human health risks from manganese associated with the future residents to acceptable levels. High concentrations of manganese are present in many of the monitoring wells at SWMU 10. The highest manganese concentration encountered to date has been 35,300 µg/L in well 10C31P3 in June 1991.

Groundwater analytical data [1991 (U.S. ACE WES, 1998), 1992 (U.S. ACE WES, 1998), and 2001 (TtNUS, 2005)] have been evaluated. The manganese and pH data were sorted into groups of ascending pH values (i.e., 3-4, 4-5, etc.). The lowest pH encountered in any well was 3.24, which was measured in well 10C25P3 on 1/09/92. The average manganese concentration for each pH group is plotted vs. pH in Figure 3-2. As shown in Figure 3-2, there is an inverse correlation between pH and manganese concentrations. As pH goes down, concentrations of manganese in groundwater increase. Note: there is significant variation around this general relationship, but the relationship is still very discernable. As stated in the CMS, the low pH values are strongly suggested as the cause of the elevated manganese concentrations in groundwater. The source of manganese is attributed to Pennsylvanian-age sandstones, siltstones, and shales. The low pH is attributed to the oxidation of iron pyrite found naturally in the bedrock. As the pyrite in the bedrock is oxidized over time, the oxidation reactions release acidity and lowers the pH in the rock and groundwater. The lower pH subsequently increases the solubility of manganese.

The 10 wells with the highest historical manganese concentrations are 10C31P3, 10C41, 10-04, 10C30P2, 10C39P2, 10C38, 10C36P2, 10C29P2, 10C25P3, and 10-22. These wells are scattered around the SWMU 10 facility, but are somewhat more concentrated on the western side of the facility. According to the potentiometric map (Figures 7-7) in the RFI report, the western wells are generally upgradient or sidegradient of most buildings and activities at the SWMU. Hence, there is no known SWMU-related source that is known that could have caused the elevated manganese concentrations. In addition, there is no known material used at SMWU 10 that was acidic or would generate acid conditions if spilled.

Therefore, the hypothesis that lower pH values have caused the higher manganese concentrations is the most plausible explanation fore elevated manganese concentrations in groundwater. Pyrite (naturally occurring mineral) oxidation in Pennsylvanian bedrock could easily account for the low pH values that have been measured in groundwater. Drill logs of monitoring wells are contained in historical documents for the site (Dunbar 1984; US ACE WES, 1998; and TtNUS, 2005). Very fine-grained pyrite is difficult to visually observe in rock materials, so it is not surprising to find that pyrite is not mentioned in most of the boring logs. However, compared to other sites at NSWC Crane, the uppermost bedrock (e.g., uppermost 20-30 feet of strata) appears to be soft, highly weathered, friable, and iron-stained. This would be expected if pyrite was oxidizing and weathering rate of the rock was accelerated due to acidic conditions.

Thus, the Navy believes that the elevated manganese concentrations in groundwater are derived from the Pennsylvanian bedrock and are not related to any industrial or waste activities. Therefore, manganese will not be carried forward in this CMS report.

Manganese occurs naturally in the sandstone, siltstone, shale, and coal units of the Pennsylvanian bedrock. Concentrations of manganese in groundwater contained in the bedrock can be naturally elevated, especially if the groundwater is acidic (e.g., pH < 6.0) and/or the groundwater is under moderately to strongly reducing condition. Concentrations of manganese were found above the MCS in numerous monitoring wells within the SWMU and surrounding the SWMU. The wells having manganese MCS exceedances were evenly distributed across the site and did not appear to be linked to any specific building, industrial activity, spills, or waste-handling activity. Thus, the Navy believes that the elevated manganese concentrations in groundwater are derived from the Pennsylvanian bedrock, and are not related to any industrial or waste activities. Therefore, manganese will not be carried forward in this CMS report.

Nickel

A groundwater MCS of 700 µg/L was established to reduce human health risks from manganese associated with the future residents to acceptable levels. Nickel concentrations in all groundwater wells were less than this cleanup level. Therefore, nickel will not be carried forward in this CMS report.

3.5 VOLUME OF CONTAMINATED MEDIA

In this section, estimate volumes of contaminated groundwater are developed for use in evaluation of corrective measure alternatives that may be used to remediate groundwater at SWMU 10.

A list of the chemicals retained as groundwater COCs for SWMU 10, together with the range of detected concentrations and MCSs for these chemicals are presented in Table 3-4.

3.5.1 Groundwater

Based on the results of investigations, the presence of an explosives contaminant plume has been determined in the SWMU 10 groundwater. This plume is approximately 900 feet long by 170 feet wide, extending in a north to northeast direction from the vicinity of Building 2739 to monitoring wells 10C56 and 10C57. Within that plume two circular areas 100 feet in diameter and centered around monitoring well cluster 10C55/10C55P2 and monitoring well 10-17, where the highest concentrations of explosives have been detected, have been designated as "Hot-Spot" No. 1 and "Hot-Spot" No. 2, respectively. The location and size of the explosives contaminant plume and "hot-spots" are illustrated on Figure 3-1.

Areal extent of the explosives contaminant plume is approximately 150,000 square feet (ft^2) and depth of contamination is assumed to extend from 5 to 30 feet bgs. Based on a typical average porosity of 0.10, the volume of contaminated groundwater in the SWMU 10 explosives plume is estimated at 375,000 cubic feet (ft^3), or 2,807,000 gallons.

The surface area and volume of contaminated groundwater of each "hot-spot" are 8,750 ft^2 and 164,000 gallons, respectively.

The "hot-spot" concept was not developed to accurately delineate particular areas of contamination outside of which groundwater quality meets the cleanup criteria. Instead, this concept was meant to identify and approximately size the two general areas within the contamination plume that contain the highest levels of groundwater contamination and would therefore benefit the most from remedial action. Therefore, the centers of Hot-Spots Nos. 1 and 2 were selected as the two monitoring wells where the highest concentrations of explosives have been detected (240 µg/L at 10C55 for Hot-Spot No. 1 and 33 µg/L at 10-17 for Hot-Spot No. 2) and the approximate boundaries of these hot spots were delineated by assuming that they extend to the eastern edge of the plume on one side and halfway towards the nearest monitoring well where much lower explosives concentrations were detected (10-21 with 26 µg/L for Hot-Spot No. 1 and 10-18 with 37 µg/L for Hot-Spot No. 2) on the other side. For both hot-spots, this corresponds to a distance of approximately 100 feet and; therefore, it was decided to identify each hot-spot as a circular area with a 100-foot diameter.

Computations of the volume of contaminated groundwater and quantities of COCs in the SWMU 10 explosives plume are presented in Appendix A.

TABLE 3-1

SUMMARY OF CONTAMINANT-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Requirement	Citation	Status	Synopsis	Comment
FEDERAL				
Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs) Secondary MCLs (SMCLs) MCL Goals (MCLGs)	42 USC 300f et seq. 40 CFR §§141 to 143	MCLs are relevant and appropriate; SMCLs and MCLGs are TBC Criteria	MCLs, SMCLs, and MCLGs established under this act are health-based limits for certain chemical substances in drinking water.	Can be used for determining PRGs for groundwater.
Clean Water Act (CWA) Ambient Water Quality Criteria (AWQC)	33 USC 1251 et seq. Section 304(a)(1)	TBC Criteria	Water-quality criteria are non-enforceable guidance and are used in conjunction with the designated use for a stream segment to establish water quality standards under CWA 303.	During remedial activities, groundwater or treatment by-products may be collected. Can be used to determine discharge limits or PRGs for surface water.
U.S. EPA Health Advisories	EPA 822-B-96-002	TBC Criteria	U.S. EPA Office of Drinking Water guidelines for chemicals that may be encountered in public water supply systems.	Can be used for determining PRGs for groundwater.
U.S. EPA Generic Soil Screening Levels (SSLs)	EPA 540-R-96-018 Appendix A	TBC Criteria	Federal guidance that provides screening levels for protection of human health and groundwater from soil contaminants.	Can be used for determining PRGs for soil.
Reference Doses (RfDs) from Integrated Risk Information System (IRIS)	NA	TBC Criteria	EPA Office of Research and Development guidelines used in the public health assessment.	Can be used for determining risk-based PRGs.

TABLE 3-1

SUMMARY OF CONTAMINANT-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Requirement	Citation	Status	Synopsis	Comment
U.S. Carcinogenic Slope Factors from IRIS	NA	TBC Criteria	EPA Environmental Criteria and Assessment Office; EPA Carcinogen Assessment Group guidelines used in the public health assessment.	Can be used for determining risk-based PRGs.
U.S. EPA Region 9 PRGs	NA	TBC Criteria	EPA Region 9 has developed primary remediation goals (PRGs) for contaminants in soil, air, and drinking water. These are risk-based concentrations are intended to assist risk assessors and others in initial screening-level evaluations of environmental measurements.	Can be used for determining PRGs.
Handbook on the Management of Ordnances and Explosives at Closed, Transferring, and Transferred Ranges and other Sites	Interim Final February 2002 (http://www.epa.gov/swerffrr/pdf/IFUXOCTTHandbook.pdf)	TBC Criteria	The handbook facilitates understanding of the wide variety of technical issues that surround the investigation and cleanup of closed, transferring, and transferred (CTT) ranges and other sites at current and former Department of Defense (DoD) facilities.	Explosive residues are present at the site. This handbook discusses common chemical residues of explosives that may or may not retain reactive and/or ignitable properties that could have a potential impact on human health and the environment through a variety of pathways (surface and subsurface, soil, air and water).

TABLE 3-1

SUMMARY OF CONTAMINANT-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Requirement	Citation	Status	Synopsis	Comment
STATE				
Indiana Department of Environmental Management (IDEM) Risk Integrated System of Closure (RISC) http://www.in.gov/idem/land/risc/techguide/riscguidance.pdf	NA	TBC Criteria	A non-rule policy that incorporates environmental risk assessment principles to protect human health and the environment and achieve consistent closure of contaminated soil and groundwater.	TBC Criteria in risk assessment.
IDEM Water Quality Standards Applicable to All State Waters Except Waters of the State within the Great Lakes System	327 IAC Article 2	TBC Criteria	Establishes final acute value (FAV) in the undiluted discharge or the acute aquatic criterion (AAC), continuous criterion concentrations (CCCs), chronic aquatic criterion (CAC) to protect aquatic life from chronic toxic effects, terrestrial life cycle safe concentration (TLSC) to protect terrestrial organisms from toxic effects, human life cycle safe concentration (HLSC) to protect human health from toxic effects for state waters.	During remedial activities, groundwater or treatment by-products may be collected. Can be used to determine discharge limits for surface water.

TABLE 3-2

SUMMARY OF LOCATION-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE INDIANA

Requirement	Citation	Status	Synopsis	Comment
FEDERAL				
Endangered Species Act of 1973	16 USC 1531 50 CFR §§17 and 402	Potential ARAR	Requires federal agencies to ensure that any action authorized, funded, or carried out by the agency is not likely to jeopardize the future existence or critical habitat of any endangered or threatened species.	The Indiana Bat and several bird species are either endangered, threatened or species of special interest may reside in the vicinity of SWMU 10. In addition, migrating species may occasionally move through the area.
U.S. EPA Groundwater Protection Strategy and Classification Guidelines	NA	TBC Criteria	Provides guidance in determining the potential beneficial uses of contaminated groundwater.	Groundwater at SWMU 10 is classified as a shallow bedrock acquifer.
The Fish and Wildlife Coordination Act of 1934, as amended 1946, 1958, 1978, and 1995	16 USC 611 16 U.S.C. 661-667e; the Act of March 10, 1934; Ch. 55; 48 Stat. 401	Potential ARAR	Requires federal agencies to consult with appropriate state agencies before discharging pollutants or dredge and fill material into a body of water of wetlands.	Aquatic habitats have been identified at Crane.
The Archaeological and Historic Preservation Act	16 USC 469 36 CFR §65	Potential ARAR	Establishes requirements relating to potential loss or destruction of significant scientific, historical, or archeological data as a result of a proposed remedy.	Artifacts may be discovered during site work.
Federal Protection of Wetlands Executive Order	Executive Order (EO) 11990 40 CFR 6 Appendix A	Potential ARAR	Requires the action of federal agencies to minimize the destruction, loss, or degradation of wetlands and preserve and enhance the natural and beneficial values of wetlands	Applicable where there are wetlands at or near SWMU.

TABLE 3-2

SUMMARY OF LOCATION-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE INDIANA

Requirement	Citation	Status	Synopsis	Comment
Bald and Gold Eagle Protection Act	(16 U.S.C. §§ 668a-668d, 54 Stat. 250) as amended -- Approved June 8, 1940, and amended by P.L 86-70 (73 Stat. 143) June 25, 1959; P.L. 87-884 (76 Stat. 1346) October 24, 1962; P.L. 92-535 (86 Stat. 1064) October 23, 1972; and P.L. 95-616 (92 Stat. 3114) November 8, 1978.	Potential ARAR	Prohibitions. The Act imposes criminal and civil penalties on anyone (including associations, partnerships and corporations) in the U.S. or within its jurisdiction who, unless excepted, takes, possesses, sells, purchases, barters, offers to sell or purchase or barter, transports, exports or imports at any time or in any manner a bald or golden eagle, alive or dead; or any part, nest or egg of these eagles; or violates any permit or regulations issued under the Act. The definition of "take" includes pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest or disturb. The definition of "transport" includes convey or carry by any means; also deliver or receive for conveyance.	Applicable where that there are Bald Eagle nesting or habitat which might be disturbed during CMA at or near a SWMU.

TABLE 3-2

SUMMARY OF LOCATION-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE INDIANA

Requirement	Citation	Status	Synopsis	Comment
STATE				
Indiana Non-game and Endangered Species Conservation	IC 14-22-34	Potential ARAR	Establishes a list of those species and subspecies of wildlife indigenous to Indiana which are determined to be endangered in Indiana. In addition, this rule governs the taking, possession, removal, capture, destruction, and management of state listed endangered species.	The State of Indiana has identified a list of endangered, threatened, and rare species for Martin County including the Indiana Bat and Bald Eagle. The species include plants, insects, birds, reptiles, birds, and, migrating species that may move through or live in the SWMUs. These threatened or species of special interest that may reside in the vicinity of the SWMUs. In addition, migrating species may occasionally move through the area.
Indiana Wildlife Regulation	IC 14-22-10	Potential ARAR	Establishes protection for wildlife from releases or discharges of contaminants or waste materials into state waters or land that may result in the destruction of wild animals. The state Department of Natural Resources has the authority and responsibility to protect and properly manage the fish and wildlife resources of the state.	Any release of contaminated waste during the remedy activity that could be released on to soil and possibly result in discharge to state waters and result in harm to wild animals would have to comply with these requirements.

TABLE 3-2

SUMMARY OF LOCATION-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE INDIANA

Requirement	Citation	Status	Synopsis	Comment
Indiana Natural Heritage Protection Campaign	IC 14-31-2	Potential ARAR	Promotes the preservation of areas of unusual natural interest for scientific, educational, recreational, cultural, and aesthetic purposes as a link to the Indiana's past and future. The rules also provides for the maintenance and management of those natural areas and the rare native species for which the areas are habitat.	Remedy activities at SWMUs may result in disturbance of natural areas inhabited by Indiana rare species.

TABLE 3-3

SUMMARY OF ACTION-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Requirement	Citation	Status	Synopsis	Comment
FEDERAL				
Clean Air Act (CAA) National Ambient Air Quality Standards (NAAQS)	40 CFR §50 and §53	Potential ARAR	Establishes air quality standards for carbon monoxide, lead, nitrogen oxides, particulate matter, ozone, and sulfur oxides emitted from a major source of emissions.	These pollutants may be generated during groundwater treatment or soil excavation, handling, or treatment activities.
CAA National Emission Standards for Hazardous Air Pollutants (NESHAPs)	40 CFR §61	Potential ARAR	Establishes emission standards for particular air contaminants from specific sources.	Hazardous air pollutants may be discharged during groundwater or soil treatment activities.
Clean Water Act (CWA) National Pollutant Discharge Elimination System (NPDES)	40 CFR §122	Potential ARAR	NPDES permits are required for any discharge to surface water.	Any alternative that includes discharges to surface water would have to comply with the permit requirements.
RCRA Solid Waste Management Regulations	40 CFR §258	Potential ARAR	Establishes design and operating standards for solid waste (nonhazardous) landfills.	Applicable if nonhazardous soil is stockpiled or disposed on site.
RCRA Identification and Listing of Hazardous Waste	40 CFR §261	Potential ARAR	Regulations that govern the procedures for identifying if a material is a hazardous waste.	Specific materials at the site may be classifiable as a characteristic or listed hazardous waste.
RCRA Standards Applicable to Generators of Hazardous Waste	40 CFR §262	Potential ARAR	Establishes standards for generators of hazardous waste.	Applicable for removed wastes determined to be hazardous.

TABLE 3-3

SUMMARY OF ACTION-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Requirement	Citation	Status	Synopsis	Comment
RCRA Standards Applicable to Transporters of Hazardous Waste	40 CFR §263	Potential ARAR	Establishes standards for off-site transportation of hazardous waste.	Applicable for removed wastes determined to be hazardous that are transported off site.
RCRA Standards and Interim Standards for Owners and Operators of Hazardous Waste TSD Facilities	40 CFR §§264 and 265	Potential ARAR	Regulations that govern the treatment, storage, and disposal of hazardous waste.	These regulations would be applicable to waste removed from this site including both on-site and off-site management; however, the reuse of treated soils as backfill would not be subject to the disposal facility standard.
RCRA Land Disposal Restrictions (LDRs)	40 CFR §268	Potential ARAR	Identifies hazardous wastes that are restricted from land disposal and waste analysis requirements.	Treatment or disposal of contaminated soils/ wastes and/or treatment residuals may be considered hazardous waste subject to land disposal restrictions.
Department of Transportation (DOT) Rules for Hazardous Materials Transport	49 CFR §107 and §§171 to 179	Potential ARAR	Regulations for the transportation of hazardous materials. Requirements cover packaging, marking, labeling, and transportation methods.	Off-site shipments of any contaminated soil that is classified as a hazardous material from this site would have to comply with these regulations.

TABLE 3-3

SUMMARY OF ACTION-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Requirement	Citation	Status	Synopsis	Comment
STATE				
Indiana Environmental Remediation Act	IC 13-30-10	Potential ARAR	This rule requires certain environmental remediation plans to specify remediation objectives based on specified factors. It directs the IDEM to certify completion of plans and to issue covenants not to sue with respect to completed plans.	Applicable to certain remediation plans.
IDEM Solid Waste Management Board	329 IAC 3 329 IAC 10 329 IAC 11 329 IAC 12 329 IAC 13	Potential ARAR	Establishes design and operating standards for solid waste (nonhazardous) landfills. Indiana adoption of federal identification and listing of hazardous waste (40 CFR §261), applicable to generators of hazardous wastes (40 CFR §262), applicable to transporters of hazardous wastes (40 CFR §263), and for management of specific hazardous wastes and types of hazardous waste facilities (40 CFR §266 Subpart M). Indiana adoption of federal standards and interim standards applicable to owners and operators of wastes treatment, storage, and disposal facilities (40 CFR §§264 and 265),	Applicable if nonhazardous soil is stockpiled or disposed on-site. Specific materials at the site may be classifiable as a characteristic or listed hazardous waste. These regulations could be applicable to waste removed from this site including both on-site and off-site management. These regulations detail storage and transportation requirements for solid waste military munitions as well as emergency responses.

TABLE 3-3

SUMMARY OF ACTION-SPECIFIC ARARs AND TBC CRITERIA
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Requirement	Citation	Status	Synopsis	Comment
Indiana Air Screening Levels (IASLs) and Ambient Air Quality Standards (IAAQS)	325 IAC 1-3-4 326 IAC 1-2-52	IASLs are TBC Criteria. IAAQS are potential ARAR.	325 IAC establishes IASLs which are non-rule guidelines used to by IDEM to evaluate the ambient impact of hazardous contaminants. Establishes primary and secondary ambient air quality standards for the state to the extent necessary to protect public health and welfare and are in accordance with the provisions of the CAA.	When determining a pollutant's maximum allowable concentration, the toxicity of a compound is measured by its permissible exposure limit (PEL). These pollutants may be generated during groundwater treatment or soil excavation, handling, or treatment activities.
Indiana Water Pollution Control Board (IWPCB)	327 IAC 5-4 327 IAC 15-15	Potential ARAR	NPDES permits are required for any discharge to surface water.	Any alternative that includes discharges to surface water would have to comply with the permit requirements.

TABLE 3-4

RANGE OF CHEMICAL CONCENTRATIONS DETECTED IN THE EXPLOSIVES PLUME[1] AND HUMAN HEALTH MEDIA CLEANUP STANDARDS

CMS REPORT FOR SMWU 10 - ROCKEYE

NSWC CRANE

CRANE, INDIANA

Chemicals	Detection						MCSs Ground Water (µg/L)[2]
	Minimum (µg/L)	Qualifier	Sample Number	Maximum (µg/L)	Qualifier	Sample Number	
Explosives (COCs)							
2 amino-4,6-DNT	2.8		10GWC5501	20.0		10GW1701	7.0
4-amino-2,6-DNT	3.7		10GWC5501	18.0		10GW1701	7.0
TNT	5.8	J	10GWC55P201	33.0		10-08 (92b) (05/14/92)	2.0
RDX	21.0		10GWC55P201	240.0		10GWC5501	0.5
Explosives (Other)							
HMX	20.0	U[3]	10-21 (92b) (05/14/92)	240.0		10GW1701	
Inorganics							
Iron[4]	100.0	U[3]	10GWC55P201	10,100.0		10-21 (92b) (05/14/92)	11,000.0
Manganese[4]	15.0	U[3]	10GWC55P201	471.0		10-07 (92b) (05/14/92)	775.0
Nickel[5]	5.0	U[3]	10-07 (92b) (05/14/92) 10-08 (92b) (05/14/92) 10-18 (92b) (05/14/92)	177.0		10-21 (92b) (05/14/92)	700.0

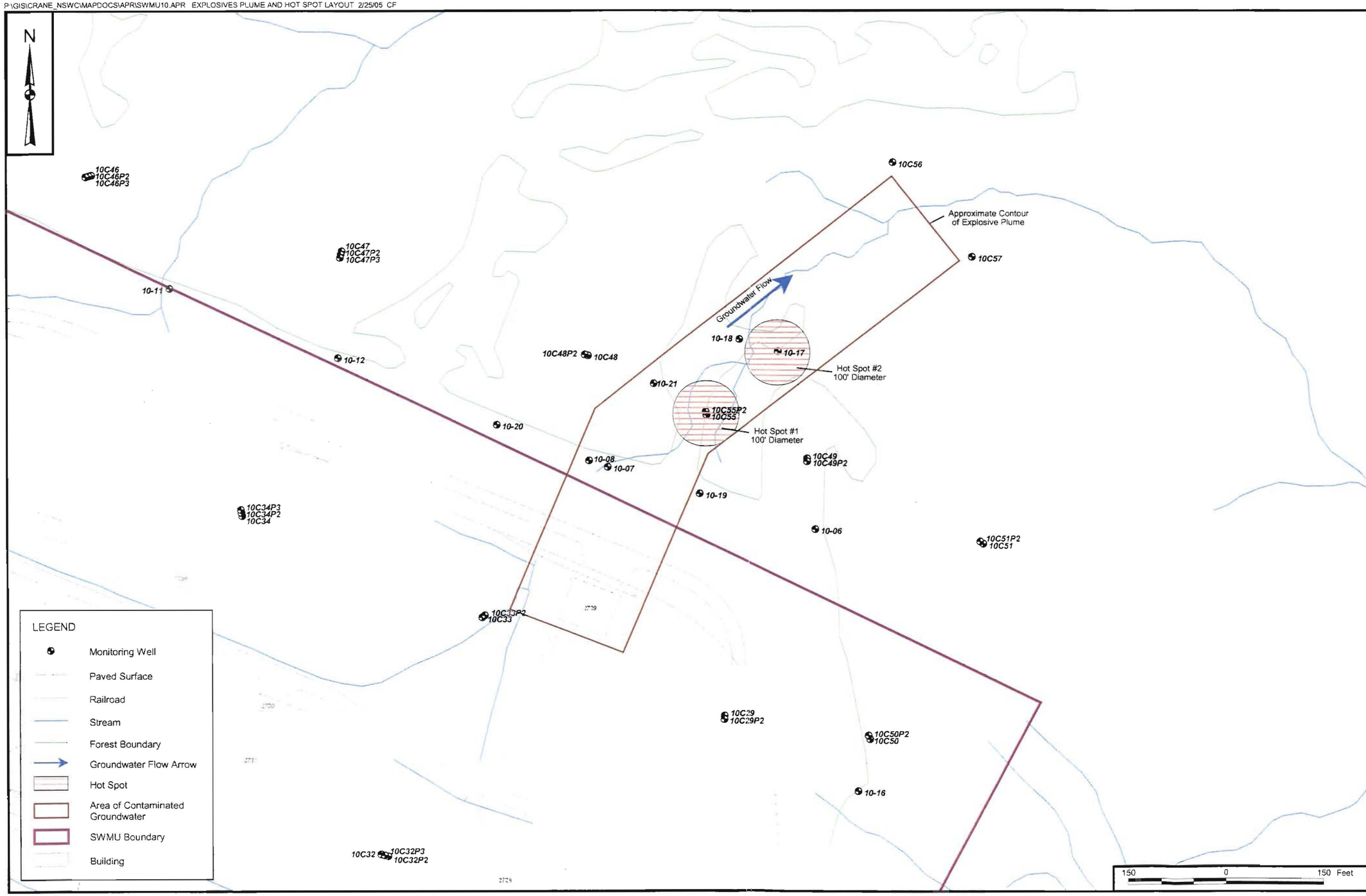
1 — Based upon the latest sample data.
2 — MSCs are calculated from the risk assessment for SWMU 10 as described in Section 3.4.
3 — Analytical results marked with a "U" qualifier were set equal to 50 percent of the detection limit for the minimum and maximum detection value.
4 — Concentrations of iron and manganese in groundwater frequently exceed their respective MCSs. However, bedrock is the source of the dissolved iron and manganese because these metals are not related to the SWMU activities. Therefore, iron and manganese will not be further evaluated in this CMS.
5 — All 2001 groundwater sampling results for nickel were below the MCSs (TtNUS, 2003). Therefore, nickel will not be further in the CMS.

COC — Chemical of concern.
DNT — dinitrotoluene.
MCSs — Media cleanup standards.
TNT — 2,4,6-trinitrotoluene
RDX — hexahydro 1,3,5 trinitro 1,3,5 triazine.
µg/L — micrograms per liter.

U - Indicates that the chemical was not detected at the numerical detection limit (sample-specific quantitation limit) noted. Nondetected results from the laboratory are reported in this manner. This qualifier is also added to a positive result (reported by the laboratory) if the detected concentration is determined in data validation to be attributable to contamination introduced during field sampling or laboratory analysis.

J - Indicates that the chemical was detected. However, the associated numerical result is not a precise representation of the amount that is actually present in the sample. The laboratory-reported concentration is considered to be an estimate of the true concentration.

P:\GIS\CRANE_NSWC\MAPDOCS\APR\SWMU10.APR EXPLOSIVES PLUME AND HOT SPOT LAYOUT 2/25/05 CF



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REV 0

SWMU 10 EXPLOSIVES PLUME AND "HOT SPOTS"
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

NAVFAC

DRAWN BY C. FOSTER DATE 02/25/05

CHECKED BY V. PLACHY DATE 02/25/05

COST/SCHED-AREA

SCALE AS NOTED

4.0 IDENTIFICATION AND SCREENING OF CORRECTIVE MEASURES TECHNOLOGIES

In this section, a variety of corrective measures technologies and process options are identified under each general response action and screened. The screening is first conducted at a preliminary level to focus on relevant technologies and process options. Then the screening is conducted at a more detailed level based on certain evaluation criteria. Finally, process options are selected to represent the technologies that have passed the detailed evaluation and screening.

The preliminary screening is conducted to eliminate those technologies that are clearly not applicable to SWMU 10. The preliminary technology screening is based on overall applicability to the medium of concern (contaminated groundwater), COCs (explosives), and specific conditions present at SWMU 10. The purpose of this screening effort is to investigate a reasonable range of available technologies and process options and to eliminate those obviously not applicable to the site.

The technologies retained from the preliminary screening are broadly evaluated in this section. The evaluations are based on criteria of effectiveness, implementability, and relative cost, which are defined as follows:

- Effectiveness - This criterion focuses on the potential effectiveness of process options in protecting human health and the environment and in meeting the CAOs and MCSs. This criterion considers potential impacts to human health and the environment during construction and implementation, and how proven and reliable the process is with respect to COCs and site conditions.

- Implementability - Implementability is a measure of both the technical and administrative feasibility of implementing a technology. It provides a means of evaluating the ability of a technology to be adapted to site-specific conditions. Technical feasibility includes consideration of construction and operational issues, demonstrated performance, and adaptability to site conditions. Administrative feasibility considerations include the ability to obtain any necessary permits or easements, and adherence to applicable laws and concerns of other regulatory agencies. General availability of necessary equipment and resources is also evaluated.

- Cost - Cost evaluations allow a relative comparison between similar technologies and play a limited role in technology screening. The cost analysis is based on engineering judgment and each technology is evaluated as to whether costs are low, medium, or high relative to the other options in

the same technology type. If there is only one process option, costs are compared to other candidate technologies.

4.1 PRELIMINARY SCREENING OF CORRECTIVE MEASURES TECHNOLOGIES

Table 4-1 provides a preliminary screening of groundwater corrective measures technologies.

4.2 DETAILED SCREENING OF CORRECTIVE MEASURES TECHNOLOGIES

The technologies retained from the preliminary screening are broadly evaluated in this section.

4.2.1 No Action

No Action consists of maintaining status quo at the site. No Action is considered in the CMS process to provide a baseline for comparison with other corrective measures technologies and their effectiveness in mitigating risks posed by site COCs. Because no remedial actions are taken with this technology, there are no costs associated with No Action. There is also no reduction in risk through exposure control or treatment. No Action would not be effective in evaluating contaminant mobility and potential migration off-site because no monitoring would be performed.

Effectiveness

No Action would not be effective in meeting the CAOs. Because nothing would restrict access to contaminated groundwater and future site development, unacceptable risk could eventually develop because of exposure to contaminated groundwater. Because no monitoring would be performed, there would be no warning of the potential future off-site migration of groundwater COCs.

Implementability

There would be no implementability concerns because no action would be implemented.

Cost

There would be no costs associated with No Action.

Conclusion

Although it would not be effective, No Action is retained as a baseline for comparison with other corrective measures technologies and alternatives.

4.2.2 Limited Action

Three technologies were retained for this general action: institutional controls, monitoring, and natural attenuation.

4.2.2.1 Institutional Controls

Institutional controls would consist of formulating and implementing LUCs to prevent the use of the groundwater at SWMU 10 as a source of drinking water. A formal notice would be sent to the regulatory agency requesting that no permits be issued for the installation of drinking water wells at SWMU 10. As part of institutional controls, regular site inspections would be conducted to verify and enforce the continued application of these controls.

Effectiveness

Groundwater use restrictions would be effective in combination with source control activities. These controls would minimize potential human health risks associated with exposure to contaminated groundwater. At SWMU 10, significant source control activities have already been implemented, including removal of contaminated soil. As such, institutional controls would achieve the CAOs for SWMU 10.

Implementability

Institutional controls would be readily implementable for SWMU 10. LUCs would be prepared and described in the Corrective Measures Design (CMD). The Navy could relatively easily prepare and implement the controls.

Cost

Costs of institutional controls would be low.

Conclusion

Institutional controls are retained for the development of corrective measures alternatives.

4.2.2.2 Monitoring

Monitoring would consist of using sampling and analysis of groundwater throughout the area of groundwater contamination to evaluate potential migration of contaminants. Monitoring could also be used to evaluate possible natural attenuation of contaminants and/or the progress of active groundwater remediation.

Effectiveness

Monitoring would not of itself reduce the toxicity, mobility, or volume of contaminants in the groundwater, but it would allow the evaluation of potential off-site migration of COCs and the potential reduction in COCs concentrations through natural attenuation. Regular groundwater monitoring would be an effective warning mechanism in case of groundwater contaminant migration. Monitoring would also be helpful in measuring and evaluating the effectiveness of natural attenuation or active remediation technologies.

Implementability

A groundwater monitoring program could be readily implemented. Based on availability of existing monitoring wells, no new monitoring wells would need to be installed.

Cost

Capital and operating and maintenance (O&M) costs of monitoring would be low.

Conclusion

Monitoring is retained for the development of corrective measures alternatives.

4.2.2.3 Natural Attenuation

Natural attenuation would consist of monitoring groundwater quality to determine the extent to which naturally occurring processes, such as dispersion, biodegradation, and dilution, would reduce concentrations of COCs over time. For this purpose, groundwater samples would be regularly collected and analyzed for COCs.

Effectiveness

Naturally occurring processes are likely to reduce concentrations of COCs (explosives) in groundwater. Preliminary modeling as presented in Appendix A indicates that explosives concentrations in the SWMU 10 groundwater contaminant plume would likely decline below MCSs within an estimated 159 years. More precise modeling based upon additional data would be required to further refine this timeframe.

As shown on the temporal plots provided in Appendix B, available historical data provide mixed results. Concentrations of RDX detected in monitoring wells 10-07, 10-08, 10-17, and 10-18 show significant decline over time, but concentrations of RDX detected in monitoring wells 10-21 and 10-C55 do not. However, these results probably do not yet fully reflect the impact of a source removal action performed from January 2000 to October 2001. As part of this action, approximately 900 cubic yards (1,300 tons) of contaminated soil and rock were excavated and treated at the NSWC Crane Bioremediation Facility (TolTest, 2002).

Groundwater monitoring would provide an effective means of evaluating the concentrations of explosives in groundwater and of assessing the rate of decrease of these concentrations.

Implementability

Natural attenuation would be easy to implement. Monitoring groundwater quality, restricting groundwater use, and periodic review of site conditions could readily be performed and the necessary resources are available to provide these services. Additional modeling would be required to more precisely define the remediation timeframe.

Cost

Capital and O&M costs for natural attenuation would be low.

Conclusion

Although its effectiveness is not fully supported by historical data, natural attenuation is retained for the development of corrective measures alternatives because the full effect of the recent removal action is yet to be reflected in that data and there are no current threats to human health and the environment.

4.2.3 Containment

The only technology retained for this general action is vertical barriers and the only process option retained was slurry walls.

4.2.3.1 Slurry Walls

Conventional vertical barrier walls are most often formed by the slurry trenching method. This is a two-step process. First, a backhoe excavates soil under a cover of lightweight bentonite clay slurry. The slurry supports the walls of the excavation. The excavated soil is mixed with bentonite and sometimes cement or imported clay soil to form a suitable backfill material. This backfill is pushed or pumped into the trench to displace the lightweight bentonite slurry and form the final wall. Walls are typically installed to depths of 50 feet or less and are generally 2 to 4 feet thick. To be effective, a slurry wall also generally needs to be "keyed" 2 to 3 feet into a low-permeability layer, such as clay or bedrock.

Effectiveness

Slurry walls would prevent further migration of the groundwater contaminant plume but would not restore groundwater quality. Because migration of groundwater COCs is not as important a concern for SWMU 10 as restoration of the aquifer quality, this technology would not be very effective in addressing site-specific concerns. The long-term effectiveness of slurry walls may be reduced through deterioration as wall components degrade over time.

Implementability

Slurry walls would be difficult to install at SWMU 10 because bedrock occurs very near the ground surface and this installation would require special excavation equipment. The resources, equipment, and materials necessary to install slurry walls are readily available. Groundwater sampling and analysis downgradient of the wall would be required to monitor wall effectiveness and integrity.

Cost

Capital costs are moderate and O&M costs are low.

Conclusion

Slurry walls are eliminated from further consideration because of effectiveness and implementability concerns.

4.2.4 Removal

The only technology retained for this general action is groundwater extraction. Two process options were retained: extraction wells and collection trenches.

4.2.4.1 Extraction Wells

Wells are drilled into the aquifer and screened below the water table to access the groundwater. Pumping is used to extract the water as it collects in the wells and bring it to the surface. The process of extraction creates a hydraulic gradient, which induces further flow of groundwater into the well. Extraction wells that are placed in the path of migration of a contaminant plume can also be used to intercept and contain the plume. Extraction wells that are placed within the contaminated plume can be used to clean the aquifer by removing the contaminated groundwater and flushing the saturated zone. The flushing action occurs when the fresh water from upgradient (clean) areas replaces the extracted contaminated groundwater and causes more contaminants to desorb from the saturated zone soils. Thus, theoretically, the saturated zone soils progressively lose contaminants until the concentrations in the groundwater are at acceptable levels. The selection of the appropriate well system depends upon the depth of contamination and the hydrologic and geologic characteristics of the aquifer.

Extraction pumps are typically submersible, electrically operated centrifugal pumps or pneumatically operated ejector pumps. For shallow groundwater extraction (depths up to 10 feet), surface pumps may be used. Centrifugal pumps are generally not practical for extraction rates of less than 1 gallon per minute (gpm), and, in such cases, pneumatic ejector pumps are preferred.

Effectiveness

Theoretically, extraction wells should be effective for the capture of the SWMU 10 explosives plume. This technology is also reliable, with minimal effects on human health and the environment. However, widespread experience has shown that the theoretical effectiveness of this technology can be limited by such practical factors as slow desorption of COCs and heterogeneity of saturated media including in particular fractured bedrock. This often leads to a remediation pattern where a significant initial decline in COC concentrations is then followed by a leveling or even a rebound of these concentrations.

Implementability

Extraction wells are relatively easily installed, even in bedrock, as would be required at SWMU 10. Pneumatic ejector type pumps such as would most likely be used at SWMU 10 are widely available. Implementation of this technology would require long-term O&M. Well screens require regular inspection and well flushing to remove fine-grained material that may clog the wells. Pumps also require regular preventive maintenance. Pneumatic pumps require a compressed air source and regular inspection of the pump mechanism as well as the air supply lines. Local and state permits may be required for installation of extraction wells. Extracted groundwater would require treatment prior to disposal/discharge.

Cost

Capital and O&M costs of extraction wells would be low.

Conclusion

Extraction wells are eliminated from further consideration because of long-term effectiveness concerns.

4.2.4.2 Collection Trenches

Collection trenches are used to convey and collect aqueous discharges by gravity flow. They essentially function like a line of extraction wells by creating a continuous zone of influence. Groundwater within this zone flows toward the collection points. However, trenches cannot create as steep a hydraulic gradient as extraction wells and, consequently, are less effective at depressing the water table. Since collection trenches function like a line of extraction wells, they can perform many of the same functions. They offer the advantage of being able to collect contaminated water in situations where the groundwater recharge rate is insufficient to sustain extraction well pumping.

A collection trench is formed by excavating a ditch a few feet wide to a depth below where contaminated groundwater is encountered. Typically a backhoe or clamshell is used for the excavation, but different equipment and methods may be required depending on the geology of the site to be excavated. A collection pipe (French drain) and pump (if required) are placed at the bottom of trench for water removal and the trench is then backfilled with permeable material, such as gravel or crushed rock.

Effectiveness

Theoretically, extraction trenches should be effective for the capture of the SWMU 10 explosives plume. This technology is also reliable with minimal effects on human health and the environment. However, collection trenches do not generate hydraulic gradients as steep as those created by extraction wells. Therefore, remediation of the aquifer generally requires more time because the flushing action will not be as powerful. In addition, experience has also shown that the theoretical effectiveness of extraction trenches is subject to the same limitation as those discussed for extraction wells.

Implementability

Collection trenches are used for relatively shallow aquifers and have a practical depth limitation of 25 to 30 feet bgs. Since the groundwater contamination at SWMU 10 does not extend below approximately 30 feet bgs, a collection trench could be suitable. However, because the explosives plume extends almost exclusively into bedrock, a collection trench would be relatively difficult to excavate and would require special equipment (e.g., jackhammer) to do so.

Cost

Because a groundwater extraction trench at SWMU 10 would have to be excavated almost exclusively into bedrock, capital cost for this technology would be moderate to high. O&M costs would be low.

Conclusion

Collection trenches are eliminated from further consideration because of long-term effectiveness and implementability concerns.

4.2.5 In-Situ Treatment

Two technologies were retained for this general action: enhanced in-situ bioremediation and phytoremediation.

4.2.5.1 Enhanced In-situ Bioremediation

This technology typically consists of enhancing naturally-occurring biological activity by the subsurface injection of reagents. To remove the explosives present in the SWMU 10 groundwater, a food-grade emulsified oil compound could be used. Injection can either be implemented:

- by adding discrete amounts of reagent in a number of injection points laid out in a grid pattern to cover the area of groundwater contamination or

- by establishing a groundwater recirculation pattern through the area to be remediated and adding the necessary reagent to the recirculating groundwater.

Effectiveness

In-situ bioremediation with emulsified oil has been successfully used for the removal of explosives such as RDX from groundwater. However, at SWMU 10 most groundwater contamination occurs into bedrock which could significantly impact the effectiveness of this technology because the low porosity of the surrounding medium would restrict the ease and completeness with which the emulsified oil reagent could be distributed throughout the contaminated groundwater. Also, a treatability study would be required to verify the effectiveness of in-situ bioremediation and/or to confirm design parameters.

Implementability

In-situ bioremediation with emulsified oil injection could be implemented. Qualified contractors would be available for the implementation of this technology. Because of the previously mentioned concerns about the impact of the relatively low porosity of the surrounding bedrock medium, injection into a groundwater recirculation pattern would most likely be preferable to injection in a grid pattern. This approach would also limit the number of new wells to be installed which would provide a significant economic advantage given the relatively high cost of installing wells into bedrock. However, even under these circumstances, remediation of a large plume would remain economically impractical.

Cost

Capital and O&M costs would be moderate if in-situ bioremediation is only applied to a limited area. However, these costs would become very high if this technology were to be applied to the entire SWMU 10 explosives plume.

Conclusion

Although site conditions at SWMU 10 would significantly impact the effectiveness, implementability, and cost of in-situ bioremediation with emulsified oil injection, application of this technology would still be very appropriate if restricted to relatively small areas of groundwater contamination. This would particularly be the case for the two areas designated as "hot-spots" in Section 3.5.1.

4.2.5.2 Phytoremediation

Phytoremediation uses plants to remediate various media impacted with different types of contaminants. These technologies can be implemented either in-situ or ex-situ. Typical organic contaminants that can be addressed using this technology include petroleum hydrocarbons, chlorinated compounds, pesticides, and explosive compounds. Typical inorganic contaminants include salts (salinity), heavy metals, metalloids, and radioactive materials. The affected media that phytoremediation can be used to address include soil, groundwater, sediment, and surface water. The specific phytoremediation mechanism(s) used to address specific contaminants is dependent not only on the type of constituents to be treated but also the media that are affected.

Plants typically grow by sending their roots into the soil and producing leaf and woody material in a terrestrial environment. To accomplish these basic growth habits, plants utilize carbon dioxide to photosynthesize carbon biomass, produce energy and release oxygen to the environment, take up and transpire water from the subsurface, absorb dissolved inorganics through the root system, and exude photosynthetic products into the root zone. Each of these biological processes contributes to the remediation of contaminants.

Specifically, the ability of plant roots to sequester certain inorganic elements in the root zone is known in the phytoremediation process as phytostabilization.

Similarly, the exudation of photosynthetic products into the rhizosphere (the area immediately adjacent to the root system) can lead to the phytostabilization of organic compounds as well. Alternatively, the exuded plant products can also lead to the enhanced biodegradation of organics by the soil organisms. In phytoremediation, this process is known as rhizodegradation.

The ability of plants to take up and transpire large volumes of groundwater also has been used in phytoremediation to provide hydraulic control at contaminated sites. This hydraulic control can be used to prevent the horizontal migration or vertical leaching of contaminants. During the transpirational uptake of groundwater, dissolved organic and inorganic contaminants can enter into the plant where they are subject to additional phytoremediation mechanisms. Specifically, once inside the plant, organic chemicals can be subject to various plant-produced enzymes that can break down the contaminants. This mechanism is known as phytodegradation. Similarly, the uptake and accumulation of inorganic elements into the plant tissues is known as phytoaccumulation. Finally, the uptake and subsequent transpiration of volatile contaminants through the leaves is known as phytovolatilization.

Effectiveness

Phytoremediation could be effective for the removal of explosives from groundwater. Bench-scale tests were performed at the U.S. EPA Research Laboratory at Athens, Georgia on contaminated material from the Ammunition Burning Ground (ABG) site at NSWC Crane, which has many similarities to SWMU 10. These tests showed that Tall Fescue grass (*Festuca arundinacea*) and Eastern Cottonwoods trees (*Populus deltoides*) were well suited for the removal of explosives such as RDX and TNT from soil and groundwater (U.S. ACE, 2003). However, at SWMU 10, the effectiveness of phytoremediation would be severely limited by the fact that most groundwater contamination occurs in bedrock, making interaction with the root systems very difficult.

Implementability

Phytoremediation should be implementable at SWMU 10. The explosives plume is located somewhat apart from the main zone of site activities and the plume area could be covered with grasses, plants, or trees without significantly impacting the site use. Some trees are already present in that area, as well as in the area immediately north of the leading edge of the plume. However, the site topography and the presence of bedrock very near the ground surface would severely limit the areas and species that could be successfully planted.

Cost

Capital costs of phytoremediation are typically low to moderate. O&M costs are low.

Conclusion

Phytoremediation is eliminated from further consideration because of effectiveness and implementabilty concerns.

4.2.6 Ex-Situ Treatment

Technologies retained for this general action from preliminary screening include equalization, chemical oxidation/greensand filtration, filtration, and aerobic/anaerobic biodegradation. However, because groundwater extraction technologies have been eliminated through detailed screening, these ex-situ treatment technologies are no longer applicable to the SWMU 10 groundwater and are eliminated from further consideration.

4.2.7 Discharge/Disposal

Surface water discharge was retained for this general action from preliminary screening. However, because groundwater extraction technologies have been eliminated through detailed screening, this disposal technology is no longer applicable to the SWMU 10 groundwater and is eliminated from further consideration.

4.3 SELECTION OF CORRECTIVE MEASURES TECHNOLOGIES AND PROCESS OPTIONS

The following corrective measures technologies and process options are retained to develop CMAs:

- No Action
- Institutional Controls - LUCs
- Monitoring - Groundwater Sampling and Analysis
- Natural Attenuation - Naturally Occurring Physical and Chemical Process
- In-Situ Treatment (Biological) - Enhanced In-situ Bioremediation

Using these technologies, the following three CMAs were developed.

- Alternative 1: No Action
- Alternative 2: Natural Attenuation, Institutional Controls, and Monitoring
- Alternative 3: "Hot-Spots" Enhanced In-situ Bioremediation, Natural Attenuation, Institutional Controls, and Monitoring

The following sections outline the components of each of these CMAs to address the contaminated groundwater at SWMU 10.

4.3.1 Alternative 1: No Action

Alternative 1 maintains the site as is. Existing monitoring programs and institutional controls would be discontinued, and the site would be available for unrestricted use. This alternative does not address the groundwater contamination and is retained to provide a baseline for comparison to other alternatives.

4.3.2 Alternative 2: Natural Attenuation, Institutional Controls, and Monitoring

Alternative 2 would consist of three major components: (1) natural attenuation, (2) institutional controls, and (3) monitoring.

Component 1: Natural Attenuation

Natural attenuation would rely on naturally occurring processes within the aquifer to reduce the concentrations of explosives. Biodegradation, dispersion, and dilution through aquifer movement, and adsorption on soil particles are expected to be the processes primarily responsible for this natural attenuation. Aquifer conditions and quality would be continually monitored to track the progress of remediation.

Component 2: Institutional Controls

Institutional controls would include land use limitation to industrial purposes and aquifer use prohibition as a drinking water supply. These controls would eliminate or reduce pathways of exposure to contaminants at the site. Details of the appropriate controls would be developed as part of a CMD. These controls would be implemented during the corrective measure implementation phase to insure that, prior to any future development at SWMU 10, adequate measures would be taken to minimize adverse human health and environmental effects. In particular, LUCs would prevent future site development for residential purposes.

Use of groundwater would be controlled through LUCs, such as requiring well installation and construction permits to be reviewed by appropriate facility departments, such as public works and environmental control. Regular site inspections would be performed to verify continued implementation of the LUCs.

Component 3: Monitoring

Monitoring would consist of regularly collecting and analyzing groundwater samples from locations within of the explosives plume to assess trends in explosives concentrations. Monitoring would also consist of regularly collecting and analyzing ground and surface water samples from locations downgradient of the leading edge of the explosives plume to verify that no off-site migration of explosives is occurring.

Monitoring would take place over an estimated period of 30 years and consist of collecting groundwater samples from 7 existing monitoring wells located within the explosives plume and from 5 existing

monitoring wells and 3 surface water sampling locations located downgradient of the leading edge of the plume. Sampling frequency would be quarterly for the first two years, semi-annually for the next 3 years, and annually thereafter. Samples from each round of monitoring would be analyzed for explosives. Samples from one round of monitoring during the first two years and from every other round of monitoring thereafter would also be analyzed for explosive degradation products.

Reviews would be performed every 5 years to evaluate site status, assess the continued adequacy of remedial activities, and determine whether further action is necessary.

4.3.3 Alternative 3: "Hot-Spots" Enhanced In-Situ Bioremediation, Natural Attenuation, Institutional Controls, and Monitoring

Alternative 3 would consist of four major components: (1) enhanced in-situ bioremediation of explosives "hot-spots" with emulsified oil injection, (2) natural attenuation, (3) institutional controls, and (4) monitoring.

Component 1: "Hot-Spots" In-situ Bioremediation

The elevated concentrations of explosives COCs in the two "hot-spots" of groundwater contamination as defined in Section 3.5.1 would be removed by injecting food-grade emulsified oil to enhance the growth of indigenous microorganisms and augment the natural biodegradation of these explosives COCs. Emulsified oil would be injected and recirculated in the contaminated groundwater using existing and new wells.

Based upon the information obtained from a qualified remediation contractor specializing with this technology (EOS Remediation, see Appendix C), it is assumed that enhanced in-situ bioremediation of each the two "hot-spots" would proceed in accordance with the following sequence of operations:

1 Install four new 30-foot deep wells on the periphery of the "hot-spot" so that these wells form a five well pattern with a new well at each corner and an existing monitoring well at the center (10C55 for "Hot-Spot" No. 1, 10-17 for "Hot-Spot" No. 2).

2 Install a pump in each of the corner wells and pump groundwater from these wells into the center well to establish a groundwater recirculation pattern. Operation of the pumps in the corner well would be regulated by a level controller installed in the center well that would shutdown these

pumps if the water level in the center well gets too high. It is anticipated that the recirculation rate would be approximately 2.0 gallons per minute (gpm).

3 Once the recirculation pattern is well established and balanced, gradually add 550 gallons of emulsified oil concentrate diluted with 2,200 gallons of water into the center well and keep the recirculation pattern going until emulsified oil is observed in the groundwater extracted from the corner wells. According to the hydrogeological characteristics of the SWMU 10 explosives plume area, this should require between one and two weeks.

4 Once the initial emulsion recirculation is complete, install one of the corner well extraction pumps into the center well and reverse the recirculation pattern by pumping from the center well into that corner well. Gradually add 55 gallons of emulsified oil concentrate diluted with 220 gallons of water and chase this mixture with 1,000 gallons of recirculated groundwater. Repeat this operation for each corner well.

The total amount of emulsified oil concentrate used for this procedure would be 770 gallons (14 55-gallon drums) per "hot-spot." The design of the enhanced in-situ biotreatment system would need to be verified through treatability testing based on the fractured bedrock lithology and groundwater at SWMU 10. Additional information on in-situ bioremediation is included in EOS Remediation's proposal that is provided in Appendix C.

Component 2: Natural Attenuation

This component would be identical to Component 1 of Alternative 2.

Component 3: Institutional Controls

This component would be identical to Component 2 of Alternative 2.

Component 4: Monitoring

This component would be similar to Component 3 of Alternative 2, except that some groundwater samples would be analyzed for additional parameters to assess the bioremediation process.

Groundwater samples collected from monitoring well cluster 10C55/10C55P2 in "Hot-Spot" No. 1 and from monitoring well 10-17 in "Hot-Spot" No. 2 would not only be analyzed for explosives and explosives degradation products, but also for Total Organic Carbon (TOC), metabolic acids (lactic, pyruvic, acetic,

propionic, and butyric), nitrates, sulfates, and dissolved gases (carbon dioxides, methane, ethane, and ethene).

Every 5 years, a review would be performed to evaluate site status, assess the continued adequacy of remedial activities, and determine whether further action is necessary.

TABLE 4-1

PRELIMINARY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

General Action	Technology	Process Options	Description	General Screening/Decision	Retain?
No Action	No Action	No Action	No activities conducted at site to address contamination.	No action is retained to provide a baseline for comparison with other alternatives.	Y(1)
Limited Action	Institutional Controls	Land Use Controls (LUCs)	Administrative action used to restrict groundwater use and future site activities.	LUCs would be viable, in combination with other technologies, since groundwater chemicals of concern (COCs) are not very mobile. LUCs would consist of preventing the residential development and use of groundwater for drinking purpose.	Y(1)
	Monitoring	Groundwater Sampling and Analysis	Sampling and analysis to evaluate the migration of COCs within the aquifer.	Groundwater monitoring could be used to assess the effectiveness of naturally-occurring processes (biodegradation, dilution, dispersion) and/or active remedial measures. Monitoring would also effectively evaluate potential migration of COCs.	Y(1)
	Natural Attenuation	Naturally Occurring Physical and Chemical Processes	Allows naturally-occurring physical and chemical processes to lower concentrations of COCs.	Naturally-occurring processes would reduce explosives concentrations below cleanup level. Modeling would be required to verify the effectiveness of these processes.	Y(1)
Containment	Capping	Capping	Impermeable or semi-permeable cover (e.g., clay, synthetic membrane, or asphalt) to reduce the vertical migration of COCs from soil to groundwater.	Capping does not address groundwater contamination. Overlying soil is not a source for groundwater contamination.	N
	Vertical Barriers	Slurry Wall	Clay wall used to restrict horizontal migration of COCs.	A properly designed and installed wall could prevent potential off-site migration of contaminant plumes. However, a slurry wall would be difficult and expensive to install into bedrock.	Y(1)
		Sheet Piling	Sheet made of wood, pre-cast concrete or steel used as a retaining wall to restrict horizontal migration of COCs.	A properly designed and installed wall could prevent potential off-site migration of contaminant plumes. However, sheet piling would be extremely difficult and expensive to install into bedrock.	N
	Horizontal Barriers	Jet Grouting Curtain	Use of pressure-injected cement to restrict vertical migration of soil COCs to groundwater.	Horizontal barriers would not address groundwater contamination. Soil is not a contaminant source.	N
Removal	Groundwater Extraction	Extraction Wells	Discrete pumping wells strategically placed to remove contaminated groundwater.	Contaminated groundwater could be effectively extracted via pumping wells and treated prior to discharge.	Y(1)
		Collection Trenches	A permeable trench used to intercept and collect contaminated groundwater.	A trench could be installed along the leading edge of the contaminant plumes to collect to remove contaminated groundwater and minimize potential plume migration.	Y(1)
	Enhanced Removal	Enhanced Removal	Blasting or hydro-fracturing of bedrock to promote access to groundwater in bedrock fractures.	Enhanced removal is not necessary based on site geology. The aquifer is sufficiently permeable to extract groundwater via conventional means.	N
In-Situ Treatment	Chemical/Physical	Air Sparging/Soil Vapor Extraction (AS/SVE)	Use of an air injection / vapor extraction system to volatilize and extract groundwater COCs.	This technology would not be effective for groundwater treatment because explosives are not volatile. In addition, installation of an air injection / vapor extraction system in bedrock would be very difficult and expensive and the radius of influence (ROI) of individual wells would be very limited.	N
		In-Situ Oxidation	Subsurface injection of strong oxidizing agents such as permanganate or Fenton's Reagent to destroy contaminants.	This technology might be effective but is unproven for the treatment of explosives in groundwater. Also, injection of oxidation agents into bedrock would be difficult and expensive and the ROI of individual injection points would be very limited.	N

TABLE 4-1

PRELIMINARY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

General Action	Technology	Process Options	Description	General Screening/Decision	Retain?
In-Situ Treatment (continued)	Chemical/Physical (continued)	Permeable Reactive Barriers (PRBs)	Use of downgradient trenches backfilled with reactive media to remove COCs.	This technology might be effective but is unproven for the removal of explosives. Also, installation of a PRB in bedrock would be difficult and expensive.	N
	Biological	Enhanced In-Situ Bioremediation	Enhancement of naturally-occurring biodegradation through injection of nutrients, hydrogen-release compounds such as lactates and emulsified oils.	Emulsified oil injection has been proven effective for the removal of explosives. However, injection of oxidation agents into bedrock would be difficult and expensive and the ROI of individual injection points would be limited.	Y(1)
		Phytoremediation	Removal of COCs through adsorption and metabolization by root system of selected plants.	This technology has proven effective for the in-situ treatment of explosives. However, the site-specific implementability of this technology would not be optimum because of the topography of the site and shallowness of bedrock.	Y(2)
Ex-situ Treatment	Physical	Solvent Extraction	Separation of contaminants from a solution by contact with an immiscible liquid with a higher affinity for the contaminants of concern.	This technology is typically utilized for high concentration wastewater streams and is rarely utilized for groundwater remediation.	N
		Equalization	Dampening of flow and/or contaminant concentrations variation in a large vessel to promote constant discharge rate and water quality.	This technology would be beneficial ahead of an ex-situ groundwater treatment system to dampen excessive variations in groundwater extraction flow and/or concentrations of COCs.	Y(2)
		Filtration	Separation of suspended materials from water via entrapment in a bed or membrane separation.	This technology would be effective as a pre-treatment for removal of suspended solids that might otherwise interfere with some treatment processes.	Y(2)
		Reverse Osmosis/ Ultrafiltration	Use of high pressure and membranes to remove dissolved organic or inorganic chemicals from water.	This technology would not likely be effective for the removal of explosives and is typically only considered when other feasible options are not available.	N
		Volatilization	Use of an air stream to volatilize contaminants from groundwater.	This technology would not be effective for the removal of explosives.	N
		Gravity Settling/ Clarification	Flow of water through a quiescent tank to allow gravity settling of solids.	This technology is only used if high concentrations of suspended solids must be removed from groundwater, which is not the case at SWMU 10.	N
		Adsorption	Adsorption of contaminants onto granular activated carbon (GAC), resins, or activated alumina.	This technology would be effective for removal of explosives. Pre-treatment would be required for iron, manganese, and suspended solids control.	Y(1)
		Evaporation	Change from the liquid to the gaseous state at a temperature below the boiling point.	Evaporation is typically utilized for high concentration wastewater streams and is rarely utilized for groundwater remediation.	N
		Electrodialysis	Recovery of anions or cations using special membranes under the influence of an electrical current.	This technology would not be effective for the removal of explosives. Could be effective for pretreatment of iron and manganese but too expensive for this purpose.	N
	Chemical	Ion Exchange	Ions, held by electrostatic forces to charged functional groups on the ion exchange resin surface, are exchanged for ions of similar charge in a water stream.	This technology would not be effective for the removal of explosives. Could be effective for pretreatment of iron and manganese but too expensive for this purpose.	N

TABLE 4-1

PRELIMINARY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

General Action	Technology	Process Options	Description	General Screening/Decision	Retain?
Ex-situ Treatment (continued)	Chemical (continued)	Chemical Oxidation / Greensand Filtration	Use of strong oxidizers such as potassium permanganate to chemically oxidize COCs, followed by percolation on Greensand to remove oxidized materials.	This technology would not remove explosives. However, this technology would likely be required for the removal of "nuisance" contaminants (e.g., iron and manganese) that might otherwise interfere with the main treatment process.	Y(2)
		pH Adjustment/Neutralization	Use of acids or bases to counteract excessive pHs or to adjust pH to optimum for a given technology.	Based upon site-specific groundwater analytical data it is unlikely that this technology will be required either to optimize treatment or	N
		Flocculation/ Coagulation	Use of chemicals to neutralize surface charges and promote attraction of colloidal particles to facilitate settling.	This technology is only used if high concentrations of suspended solids must be removed from groundwater, which is not the case at SWMU 10.	N
		Precipitation	Use of reagents to convert soluble chemicals into insoluble materials.	This technology would not remove explosives. This technology would be effective for pretreatment of iron and manganese but is not warranted by the concentrations present at SWMU 10.	N
	Biological	Aerobic/Anaerobic Biodegradation	Use of suspended or fixed-medium aerobic or anaerobic biological reactors to degrade COCs.	This technology would likely be effective for the treatment of explosives.	Y(1)
Discharge/Disposal	Beneficial Reuse	Beneficial Re-use as Process Water/Potable Water	On-site re-use of groundwater once the contaminants have been removed.	Beneficial re-use of treated effluent as process water/potable water is not warranted since there is no need for process water/potable water services at this time.	N
	Surface Discharge	Direct Discharge	Discharge of extracted and treated water to local surface water.	Treated groundwater could be discharged to a surface water body near SWMU 10. Discharge would have to comply with NPDES criteria.	Y(1)
		Indirect Discharge to an On-Base Treatment Facility.	Discharge of extracted groundwater to a local sanitary or industrial sewer.	Indirect discharge would most likely not be acceptable to the on-base wastewater treatment facility and may not be practical.	N
		Off-site Treatment Facility	Treatment and disposal of hazardous or non-hazardous materials at permitted off-site facilities.	Off-site treatment would not be feasible because the volume of contaminated groundwater would be too large (4,000 gal/day) to cost-effectively transport and treat off-site.	N
	Subsurface Discharge	Reinjection	Use of reinjection, spray irrigation, or infiltration to discharge collected/treated groundwater to underground.	Reinjection of untreated effluent is not a viable option. Reinjection of treated effluent would only be advantageous if the source was well defined and injection of treated water could be used for flushing contaminants out of the source area. Spray irrigation requires relatively large and flat areas that are not available in the vicinity of SWMU 10. Also, spray irrigation cannot be operated during the winter.	N

COCs - chemicals of concern.
AS/SVE - Air Sparging/Soil Vapor Extraction.
ROI - radius of influence.
PRB - Permeable Reactive Barrier.
GAC - granular activated carbon.

1 - Potentially applicable as a primary technology.
2 - Potentially applicable as a secondary technology (i.e., handling of treatment residuals resulting from a primary technology).

5.0 EVALUATION OF THE CORRECTIVE MEASURES ALTERNATIVES

This section evaluates the CMAs presented in Section 4. The alternatives are evaluated using criteria set forth in the Office of Solid Waste and Emergency Response (OSWER) Guidance Document 9902.3-2A, RCRA Corrective Action Plan (U.S. EPA, 1995):

- Protection of human health and the environment
- Attainment of MCSs
- Control of release sources
- Compliance with applicable standards for waste management
- Other factors including:
  - Long-term reliability and effectiveness
  - Reduction in toxicity, mobility, or volume of wastes
  - Short-term effectiveness
  - Implementability
  - Cost
  - State acceptance
  - Community acceptance

The last two of these other factors (i.e., State and community acceptance) will not be evaluated until a proposed remedy has been identified and submitted for comments to IDEM and the public.

5.1 ALTERNATIVE 1: NO ACTION

5.1.1 Protection of Human Health and the Environment

Alternative 1 is considered primarily as a baseline for comparison to the other corrective measures alternatives. This alternative would not be protective of human health because of lack of monitoring and institutional controls. Although there are no current users of groundwater at SWMU 10 and thus no unacceptable risks to human receptors, Alternative 1 would not prevent future use of the aquifer as a drinking water source, which could result in unacceptable human health risks.

Although there is no current evidence that migration of groundwater contaminants to surrounding surface water has resulted in unacceptable human health or ecological risks, continued migration of the

explosives plume could still potentially lead to such unacceptable risks and, in the absence of long-term monitoring, there would be no warning of their occurrence.

5.1.2 Attainment of MCSs

Alternative 1 would eventually attain the explosives MCSs through natural attenuation but, in the absence of long-term monitoring, this occurrence would not be verified.

5.1.3 Source Control

Contaminated soil that could have acted as sources of explosives contamination in groundwater have been excavated and disposed off-site as part of a removal action performed from 2000 to 2001 (Toltest, 2002). The RFI investigation did not identify any other sources of explosive contamination in soil. Alternative 1 would not involve any additional source control because no action would be performed as part of this alternative.

5.1.4 Compliance with Waste Management Standards

There are no actions to be implemented for Alternative 1 and, therefore, no waste would be generated.

5.1.5 Other Factors

5.1.5.1 Long-Term Reliability and Effectiveness

Alternative 1 would not be reliable and effective in the long-term because no action would occur. Although explosives concentrations in groundwater would decrease as a result of natural attenuation, the effectiveness of this process would not be verified through monitoring. The potential threat to human health and the environment would remain because there would be no controls to prevent future groundwater use or monitoring to warn of potential contaminant migration.

Alternative 1 would not meet the CAOs and compliance with ARARs would be incidental and not verified.

5.1.5.2 Reduction in Toxicity, Mobility, and Volume

Alternative 1 would not reduce contaminant mobility. However, Alternative 1 would reduce the toxicity and volume of explosives through natural attenuation, but this would not be verified through monitoring.

5.1.5.3 Short-Term Effectiveness

Alternative 1 would involve no action and, therefore, would not pose any risks to on-site workers during remedy implementation and no environmental impacts would be expected.

5.1.5.4 Implementability

Because no action would occur, Alternative 1 would be readily implementable. The technical feasibility criteria, including constructability, operability, and reliability, are not applicable.

5.1.5.5 Cost

There are no costs associated with the No Action alternative.

5.2 ALTERNATIVE 2: NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING

5.2.1 Protection of Human Health and the Environment

Alternative 2 would be protective of human health and the environment. Natural attenuation would protect human health by reducing explosives concentrations in the groundwater. Institutional controls would protect human health by preventing exposure to contaminated groundwater as long as concentrations of explosives remain unacceptable. Monitoring would protect human health and the environment by verifying the progress of groundwater remediation and warning of potential contaminant migration.

5.2.2 Attainment of MCSs

Alternative 2 would eventually attain the explosives MCSs through natural attenuation. Current site information does not allow the accurate prediction of the timeframe required for natural attenuation to attain MCSs. However, preliminary estimations indicate that this timeframe is probably somewhat in excess of 100 years.

5.2.3 Source Control

Contaminated soil that could have acted as sources of explosives contamination in groundwater have been excavated and disposed off-site as part of a removal action performed from 2000 to 2001 (Toltest,

2002). The RFI investigation did not identify any other source of explosive contamination in soil. Alternative 2 would not involve any additional source control measures.

5.2.4 Compliance with Waste Management Standards

Alternative 2 would not involve any removal or ex-situ treatment of contaminated groundwater. However, periodic sampling activities would generate some residues (e.g., purge water) that would have to be disposed of properly. The volume of residues generated would be very small and waste management regulations would be easily met.

5.2.5 Other Factors

5.2.5.1 Long-Term Reliability and Effectiveness

Alternative 2 would be reliable and effective in the long-term. Natural attenuation would eventually reduce groundwater explosives concentrations. Institutional controls would reliably and effectively prevent potential future exposure to contaminated groundwater. Monitoring would reliably and effectively verify the progress of remediation and warn of potential contaminant migration. Five-year site reviews would verify the long-term reliability and effectiveness of Alternative 2 and trigger consideration of another more active alternative in case this alternative does not perform to expectations.

Alternative 2 would meet the CAOs and comply with ARARs.

5.2.5.2 Reduction in Toxicity, Mobility, and Volume

Alternative 2 would not reduce contaminant mobility. However, Alternative 2 would reduce toxicity and volume of explosives through natural attenuation. Overall, it is anticipated that approximately 5.5 pounds of explosives would be permanently and irreversibly removed from groundwater by this alternative.

5.2.5.3 Short-Term Effectiveness

Alternative 2 would involve administration of institutional controls and long-term monitoring. The short-term human health risks associated with these limited remedial activities would be minimal. Sampling personnel would undergo site-specific health and safety training and wear appropriate personal protection equipment (PPE). Implementation of this alternative would not result in any short-term threat to the surrounding community or ecological receptors.

5.2.5.4 Implementability

Alternative 2 would be readily implementable. LUCs would be readily implementable. Monitoring would also be readily implementable and would be similar to that ongoing at several other environmental sites within NSWC Crane.

Alternative 2 could be implemented within approximately 6 months and it is estimated that this alternative would attain the explosives MCSs within somewhat more than 100 years.

5.2.5.5 Cost

The following costs are estimated for Alternative 2:

Capital Cost:	$ 26,000
30-Year NPW of O&M Costs:	$267,000
30-Year NPW:	$294,000

The above cost figures have been rounded to the nearest $1,000 to reflect the preliminary nature of these estimates. Detailed cost estimates are provided in Appendix D.

5.3 ALTERNATIVE 3: "HOT-SPOTS" ENHANCED IN-SITU BIOREMEDIATION, NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING

5.3.1 Protection of Human Health and the Environment

Alternative 3 would be protective of human health and the environment. Natural attenuation enhanced by in-situ bioremediation of "hot-spots" would protect human health by reducing explosives concentrations in the groundwater. Institutional controls would protect human health by preventing exposure to contaminated groundwater as long as concentrations of explosives remain unacceptable. Monitoring would protect human health and the environment by verifying the progress of groundwater remediation and warning of potential contaminant migration.

5.3.2 Attainment of MCSs

Alternative 3 would eventually attain the explosives MCSs through natural attenuation accelerated by enhanced in-situ bioremediation. As discussed earlier current site information does not allow for an accurate prediction of the timeframe required for natural attenuation alone to attain the MCSs. Therefore,

the impact of the enhanced in-situ bioremediation of "hot-spots" on the timeframe cannot be predicted accurately. However, preliminary estimations indicate that this impact should be significant and that Alternative 3 should attain MCS within somewhat less than 100 years. Monitoring would verify compliance with the MCSs.

5.3.3 Source Control

Contaminated soil that could have acted as sources of explosives contamination in groundwater have been excavated and disposed off-site as part of a removal action performed from 2000 to 2001 (Toltest, 2002). However, the RFI investigation did not identify any other sources of explosives contamination in soils. Alternative 3 would use in-situ bioremediation to actively treat areas of contaminated groundwater where the highest concentrations of explosives have been detected and that could be construed as potential sources of plume expansion.

5.3.4 Compliance with Waste Management Standards

Alternative 3 would not involve any removal or ex-situ treatment of contaminated groundwater. However, periodic sampling activities would generate some residues (e.g., purge water) that would have to be disposed of properly. The volume of residues generated would be very small and waste management regulations would be easily met.

5.3.5 Other Factors

5.3.5.1 Long-Term Reliability and Effectiveness

Alternative 3 would be reliable and effective in the long-term. Although enhanced in-situ bioremediation of the entire explosives plume is not practical because of unfavorable site conditions and the size of the impacted area, this technology is still appropriate for the removal of explosives from groundwater and it should effectively remove "hot-spots" of contamination, thereby preventing expansion of the explosives plume and enhancing the effectiveness of the natural attenuation process. However, as discussed in Section 4.3.3, treatability testing would be required to determine the effectiveness of enhanced remediation in the fractured bedrock lithology and groundwater at SWMU 10. Due to the difficulty in delivering bio-amendments in fractured rock settings and the uncertainty in the long-term effectiveness of bioremediation for the explosives compounds, it is uncertain how much of an enhancement to natural attenuation would be realized with Alternative 3. Institutional controls would reliably and effectively prevent potential future exposure to contaminated groundwater. Monitoring would reliably and effectively verify the progress of remediation and warn of potential contaminant migration. Five-year site reviews

would verify the long-term reliability and effectiveness of Alternative 3 and would allow for re-evaluation in case this alternative does not perform to expectations.

Alternative 3 would meet the CAOs and comply with ARARs.

5.3.5.2 Reduction in Toxicity, Mobility, and Volume

Alternative 3 would not reduce contaminant mobility. However, Alternative 3 would reduce toxicity and volume of explosives through natural attenuation reinforced by enhanced in-situ bioremediation. Overall, it is anticipated that approximately 5.5 pounds of explosives would be permanently and irreversibly removed from groundwater by this alternative.

5.3.5.3 Short-Term Effectiveness

Alternative 3 would involve installation of new wells, injection of emulsified oil in the groundwater, long-term monitoring, and administration of institutional controls. The short-term human health risks associated with these remedial activities would be minimal. Bioremediation and sampling personnel would undergo site-specific health and safety training and wear appropriate PPE. Implementation of this alternative would not result in any short-term threat to the surrounding community or ecological receptors.

5.3.5.4 Implementability

The availability of equipment (e.g., pumps, well casing, biological amendments) and personnel trained in the operation of groundwater recirculation systems makes Alternative 3 implementable. However, the technical feasibility of in-situ bioremediation of explosives contamination in fractured bedrock is uncertain. The geological complexities inherent in fractured rock settings and the difficulty in the hydraulic control of injected biostimulants makes operating a recirculation system for bioremediation a difficult task. LUCs would be readily implementable. Monitoring would also be readily implementable and would be similar to that ongoing at several other environmental sites within NSWC Crane.

Alternative 3 could be implemented within approximately one year and it is estimated that this alternative would attain the explosives MCSs within 100 years.

5.3.5.5 Cost

The following costs are estimated for Alternative 3:

Capital Cost:	$187,000
30-Year NPW of O&M Costs:	$285,000
30-Year NPW:	$472,000

Detailed cost estimates are provided in Appendix D.

6.0 COMPARATIVE ANALYSIS AND RECOMMENDATION

The following sections provide a comparative analysis of the corrective measures alternatives, using the same criteria used to evaluate these alternatives in Section 5.0. The comparative analysis of alternatives is summarized on Table 6-1.

6.1 PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

Although groundwater explosives concentrations would eventually decrease below MCSs, Alternative 1 would not be protective of human health and the environment because it would not prevent use of groundwater nor detect potential future contaminant migration because of lack of monitoring and institutional controls, both of which could result in unacceptable human health and ecological risks. Alternative 2 would be protective of human health and the environment because it would prevent use of groundwater until the MCSs have been met and warn of potential future contaminant migration. Alternative 3 would also be protective of human health and the environment because it would enhance natural attenuation with in-situ bioremediation, prevent the use of groundwater until the MCSs have been met, and warn of potential future contaminant migration.

6.2 ATTAINMENT OF MCSs

Alternatives 1 and 2 would attain the explosives MCSs through natural attenuation within approximately 100 years, but this would only be verified through monitoring by Alternative 2. The enhanced in-situ bioremediation component of Alternative 3 may reduce the timeframe for attainment of MCSs, but it would most likely be somewhat less than 100 years to attain explosives MCSs.

6.3 SOURCE CONTROL

Contaminated soil that could have acted as a source of explosives contamination in groundwater have been excavated and disposed off-site as part of a removal action performed from 2000 to 2001 (Toltest, 2002). However, the RFI investigation did not identify any other sources of explosive contamination in soils. Alternatives 1 and 2 would not involve any additional source control. Alternative 3 would use in-situ bioremediation to actively treat areas of contaminated groundwater where the highest concentrations of explosives have been detected, and that could be considered as potential sources of plume expansion.

6.4 COMPLIANCE WITH WASTE MANAGEMENT STANDARDS

Alternative 1 would not generate any waste material. Alternatives 2 and 3 would generate a minimal amount of waste material associated with groundwater monitoring activities (purge water). Alternatives 2 and 3 would comply with all applicable regulations for the handling and of the generated wastes and permitted off-site facilities would be readily available for the disposal of these wastes.

6.5 OTHER FACTORS

6.5.1 Long-Term Reliability and Effectiveness

Alternative 1 would not be reliable and effective in the long-term because no action would occur and potential future risks would not be prevented. Alternative 2 would be reliable and effective because there is evidence that natural attenuation reduces explosives concentrations and will eventually attain MCSs. This would be confirmed through monitoring. Alternative 2 would also be reliable and effective in the long-term because institutional controls and monitoring are well-proven and reliable methods for the prevention of exposure to contaminated groundwater and detection of potential contaminant migration, respectively. Alternative 3 would also provide long-term reliability and effectiveness because enhanced in-situ bioremediation of "hot-spots" would remove explosives from these areas and accelerate natural attenuation. However, it is uncertain how effective the use of in-situ bioremediation in a fractured bedrock and groundwater environment at SWMU 10 because of the inherent geological complexities and the inability to hydraulically control the injection of biostimulants.

6.5.2 Reduction in Toxicity, Mobility, and Volume

None of the alternatives would reduce contaminant mobility. Alternatives 1, 2, and 3 would reduce the toxicity and volume of explosives through natural attenuation, but this would only be verified through monitoring with Alternatives 2 and 3. Alternative 3 would reduce the toxicity and volume of explosives through natural attenuation and, with the potential for acceleration of natural attenuation, through enhanced in-situ bioremediation. Reduction would be verified through monitoring. Overall, all three alternatives would irreversibly and permanently remove an estimated 5.5 pounds of explosives from groundwater.

6.5.3 Short-Term Effectiveness

Alternative 1 would not result in any short-term risks to human health or the environment because no action would take place. Alternatives 2 and 3 would result in minimal short-term risks to remediation

workers (Alternative 3 only) and groundwater monitoring personnel. These risks would be addressed through health and safety training and the wearing of appropriate PPE.

6.5.4 Implementability

Alternative 1 would be the easiest to implement, because no action would occur.

Alternative 2 would be easy to implement. Institutional controls would be easy to implement because SWMU 10 is located within a government-operated facility, where such controls can be strictly enforced. Monitoring would be similar to that currently ongoing at several NSWC Crane environmental sites. Alternative 2 would require approximately 6 months to implement and it is estimated that this alternative would attain the explosives MCSs within somewhat more than 100 years.

Alternative 3 would be more difficult to implement than Alternative 2 because, in addition to the same monitoring and institutional controls as Alternative 2, it would require treatability testing and the installation and operation of a groundwater recirculation and emulsified oil injection system in each of the two "hot-spots." In-situ bioremediation through groundwater recirculation would be difficult in a fractured rock setting due to geological complexities and the difficulty in controlling the injection of emulsified oil. There is much less industry experience in the in-situ treatment of contaminants in fractured bedrock and groundwater than in unconsolidated porous media. Therefore, the long-term success of in-situ bioremediation is unknown. Contractors and equipment are readily available to install and operate the recirculation system. Alternative 3 would require approximately one year for design and installation and it is estimated that this alternative would attain the explosives MCSs within slightly less than 100 years.

6.5.5 Cost

There are no costs associated with Alternative 1. The capital cost of Alternative 2 is $26,000 compared with $187,000 for Alternative 3. The 30-year NPW of O&M and monitoring costs for Alternatives 2 and 3 are $267,000 and $285,000, respectively. The total 30-Year NPW of Alternatives 2 and 3 are $294,000 and $472,000, respectively. Detailed cost estimates are provided in Appendix D.

6.5.6 RECOMMENDED CORRECTIVE MEASURE

Because of its long-term reliability and effectiveness, ability to attain MCSs for explosives, and ease of implementability, Alternative 2 is recommended for use at SWMU 10. Although Alternative 3 may result in a slight reduction of the remediation time, there is considerable uncertainty and lack of industry

experience in the implementability and long-term effectiveness of in-situ treatment in fractured bedrock settings. After 5 years of monitoring, a formal site review would be performed to verify the continued effectiveness of Alternative 2. If, at that time, it is determined that natural attenuation is not sufficient to restore SWMU 10 groundwater quality or if the explosives plume is shown to be migrating and/or expanding, a more active remedy will be considered.

TABLE 6-1

SUMMARY OF COMPARATIVE ANALYSIS OF CORRECTIVE MEASURES ALTERNATIVES
SWMU 10 CORRECTIVE MEASURES STUDY
NSWC CRANE - CRANE, INDIANA

Evaluation Criteria	Alternative 1: No Action	Alternative 2: Natural Attenuation, Institutional Controls, & Monitoring	Alternative 3: "Hot-Spots" Enhanced In-Situ Bioremediation, Natural Attenuation, Institutional Controls, & Monitoring
Protection of Human Health and Environment	Would not protect of human health and the environment because it would not prevent groundwater use or detect potential contaminant migration.	Would protect human health and the environment because it would prevent use of groundwater until the MCSs have been met, and warn of potential contaminant migration	Would protect human health and the environment because it would accelerate natural attenuation of explosives, prevent use of groundwater until the MCSs have been met, and warn of potential contaminant migration
Attainment of MCSs	Would attain explosives MCSs within somewhat more than 100 years, but this would not be verified through monitoring.	Would attain explosives MCS within somewhat more than 100 years and this would be verified through monitoring	Would attain explosives MCS within somewhat less than 100 years and this would be verified through monitoring
Control of Release Sources	Main explosives source has probably been removed. Would not provide additional source control.	Main explosives source has probably been removed. Would not provide additional source control.	Main explosives source has probably been removed. Would provide some additional source control through in-situ bioremediation.
Compliance with Waste Management Standards	Not applicable.	Would comply.	Would comply.
Long-Term Reliability and Effectiveness	Would not be reliable or effective because because no action would occur and potential future risks would not be prevented.	Would be reliable and effective because there is some evidence that natural attenuation would reduce explosives concentrations. Also, institutional controls and monitoring are proven and reliable methods to prevent exposure to contamination and detect its migration.	Would be reliable and effective because there is some evidence that natural attenuation would reduce explosives concentrations and enhanced in-situ bioremediation would accelerate that process. Also, institutional controls and monitoring are proven and reliable methods to prevent exposure to contamination and detect its migration.

TABLE 6-1

SUMMARY OF COMPARATIVE ANALYSIS OF CORRECTIVE MEASURES ALTERNATIVES
SWMU 10 CORRECTIVE MEASURES STUDY
NSWC CRANE - CRANE, INDIANA

Evaluation Criteria	Alternative 1: No Action	Alternative 2: Natural Attenuation, Institutional Controls, & Monitoring	Alternative 3: "Hot-Spots" Enhanced In-Situ Bioremediation, Natural Attenuation, Institutional Controls, & Monitoring
Reduction of Toxicity, Mobility, or Volume	Would reduce toxicity and volume through natural attenuation but this would not be verified through monitoring. A total of 5.5 pounds of explosives would be removed. Would not remove mobility.	Would reduce toxicity, mobility, and volume through natural attenuation as verified through monitoring. A total of 5.5 pounds of explosives would be removed.	Would reduce toxicity, mobility, and volume through natural attenuation and enhanced in-situ bioremediation as verified through monitoring. A total of 5.5 pounds of explosives would be removed.
Short-Term Effectiveness	Would not result in short-term risks to site workers or adversely impact the surrounding community.	Would result in slight risk to site workers during sampling activities. This risk would be reduced through compliance with site-specific health and safety procedures.	Would result in slight risk to site workers during sampling activities. This risk would be reduced through compliance with site-specific health and safety procedures.
Implementability	Would be extremely simple to implement because no action would be required.	Technical implementation would be simple. Resources, materials, and equipment are readily available to perform monitoring. Administrative implementation of institutional controls would be simple because NSWC Crane is a federal facility where such controls can easily be enforced. No permit would be required.	Technical implementation would be simple. Resources, materials, and equipment are readily available to perform monitoring. Administrative implementation of institutional controls would be simple because NSWC Crane is a federal facility where such controls can easily be enforced. No permit would be required.
Costs: Capital NPW of O&M NPW	 $0 $0 $0	 $26,000 $267,000 (30-Year) $294,000 (30-Year)	 $187,000 $285,000 (30-Year) $472,000 (30-Year)

NOTES:

MCS	Media cleanup standards	NSWC	Naval Surface Warfare Center
NPW	Net present worth	O&M	Operation and maintenance

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APPENDIX A

CONTAMINATED GROUNDWATER COMPUTATIONS

APPENDIX A

HYDROGEOLOGIC INFORMATION AND CALCULATIONS REGARDING CONTAMINATED GROUNDWATER PLUME AND NATURAL ATTENUATION

Shallow groundwater [less than 90 feet below ground surface (bgs)] on the northeast side of the Ordnance Renovation Complex (ORC) formerly known as the Rockeye Facility (SWMU 10) is contaminated with hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), 2,4,6-trinitrotoluene (TNT), and other explosive compounds and degradation products. The main area of contamination is shown on Figures A-1, A-2, and A-3. In 2001, the highest concentration of RDX [240 micrograms per liter (µg/L)] was detected in monitoring well 10C55. The contamination also extends along the channel of the unnamed tributary of Sulphur Creek, which flows north and then eastward from SWMU 10. Monitoring wells 10C60, 10-01, and 10-02 are located along this channel and contain moderate levels of RDX (8.1 to 46 µg/L). Surface water in this gully also displayed low to moderate concentrations of RDX.

All RFI and historical groundwater data were used to map the area of the contaminant plume, as shown in Figure A-1. These data are included in Appendix A. The wells contained in the plume area include 10-07, 10-08, 10-17, 10-18, 10-21, 10C55, and 10C55P2 (seven wells total). These wells contain various concentrations of RDX, TNT, 4-amino-2,6-dinitrotoluene (4-amino-2,6-DNT), and 2-amino-4,6-dinitrotoluene (2-amino-4,6-DNT) (see Calculation Worksheet A-1). The plume area is bordered by 12 monitoring wells that showed no detections of explosive compounds (10-19, 10-20, 10C29, 10C29P2, 10C33, 10C33P2, 10C48, 10C48P2, 10C49, 10C49P2, 10C56, and 10C57, see Figure A-1). These wells surrounding the plume were used to help define the shape and extent of the groundwater plume.

The groundwater in this plume appears to travel northeast parallel to the small ravine and eventually discharges into the ravine. The fact that explosives were not detected in wells 10C56 and 10C57 downgradient of the plume is evidence that the plume is most likely discharging to the ravine. Wells 10C60, 10-01, and 10-02 are located approximately 3,500 to 5,000 feet downstream of the plume (see Figure 1-4). These three wells also have historically had significant groundwater concentrations of RDX. Concentration-time graphs of RDX in wells 10-02 and 10C60 (see Appendix B) shown that the RDX concentrations have decreased over time and are now at or less than 10 µg/L. The RDX concentrations in well 10-01, however, are greater than 20 µg/L and do not appear to be decreasing over time (1983 through 1992). It is believed that RDX has been discharged directly to the ravine as surface water and/or has discharged to the ravine in the form of groundwater seepage between 1940 and the present. The RDX has traveled down the gully as surface water. Once the surface water in the gully migrated to the lower reaches, some of the surface water reenters the shallow groundwater system. This may be the reason that RDX was detected in the three wells located close to a mile downslope of the main plume area. As stated above, explosive compounds have not been detected in monitoring wells 10C56 and 10C57 on the northeastern side the plume. Hence, the plume is not considered to be continuous between the main plume area shown in Figure A-1 and wells 10-01, 10-02, and 10C60 located along the gully to the east of SWMU 10..

The contaminated plume area shown on Figures A-1, A-2, and A-3 is found primarily in sandstones and siltstones that lie between 740 and 810 feet above mean sea level (msl). The ground surface in this area ranges from about 760 to 820 feet msl. The area of primary groundwater contamination (150,000 ft^2) is calculated in Figure A-3. Information regarding the average estimated porosity, hydraulic conductivity, and hydraulic gradients used in the calculations are presented in Calculation Worksheets A-1 and A-2. The best estimate of linear groundwater velocity in the contaminated area is about 0.2 ft/day, or 73 ft/year. Based on the

hydraulic properties presented in Calculation Worksheet A-2, the ambient flow rate through the contaminated portion of the aquifer [0.39 gallons per minute (gpm)].

Under ambient flow conditions, the contaminated plume area will clean up in about 85 years due to natural attenuation.

Because of the large amount of variation in the lateral extent of thicknesses of the lithologic units; the large variability in the fracture densities and apertures, porosity, hydraulic conductivity, and other hydraulic properties; the uncertainty regarding fraction of organic carbon (f_{oc}) in the rock; and uncertainties in other parameters which affect the groundwater flow and contaminant transport at the site, the data and calculations presented in this Appendix should be viewed as rough approximations of the conditions that currently exist at the site, and how the groundwater system (including contaminants) might react in the future. To be conservative, it is believed that the groundwater plume containing explosive compounds will reach 0.5 µg/L in 100 to 150 years due to natural attenuation and flushing.

Graphs of RDX concentrations measured over time are included in Appendix B for the 10 monitoring wells where RDX has been detected. Note that the graphs are log concentrations versus time. As shown on these graphs, RDX is decreasing in seven of the ten wells: 10-02, 10-07, 10-08, 10-17, 10-18, 10C55P2, and 10C60. In the other three wells (10-01, 10-21, and 10C55), the RDX concentrations appear to be relatively stable over time. Overall, it is believed that the total mass of RDX in the plume is decreasing over time and the size of the plume is shrinking.

TABLE A-1

HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10-01			
100 U	N	10-01 (83a) (03/02/83)	3/2/1983
100 U	N	10-01 (83b) (08/02/83)	8/2/1983
77	N	10-01 (84a) (02/03/84)	2/3/1984
31	N	10-01 (84b) (06/14/84)	6/14/1984
24	N	10-01 (85) (01/16/85)	1/16/1985
60	N	10-01 (86) (02/07/86)	2/7/1986
23.4	N	10-01 (89) (04/26/89)	4/26/1989
20 U	N	10-01 (91a) (03/16/91)	3/16/1991
56	N	10-01 (92a) (01/09/92)	1/9/1992
46	N	10-01 (92b) (05/14/92)	5/14/1992
10-02			
100 U	N	10-02 (83a) (03/02/83)	3/2/1983
255	N	10-02 (83b) (08/02/83)	8/2/1983
110	N	10-02 (84a) (02/03/84)	2/3/1984
92	N	10-02 (84b) (06/14/84)	6/14/1984
70	N	10-02 (85) (01/16/85)	1/16/1985
17	N	10-02 (86) (02/09/86)	2/9/1986
13.3	N	10-02 (89) (04/26/89)	4/26/1989
20 U	N	10-02 (91a) (03/16/91)	3/16/1991
34	N	10-02 (92a) (01/09/92)	1/9/1992
44	N	10-02 (92b) (05/14/92)	5/14/1992
4.9	Y	10GW0201	1/6/2001
8.1	Y	10GW0201-D	1/6/2001
10-03			
20 U	N	10-03 (83b) (07/12/83)	7/12/1983
10 U	N	10-03 (85) (01/16/85)	1/16/1985
10 U	N	10-03 (86) (02/09/86)	2/9/1986
20 U	N	10-03 (91a) (03/16/91)	3/16/1991
20 U	N	10-03 (92a) (01/09/92)	1/9/1992
20 U	N	10-03 (92b) (05/14/92)	5/14/1992
0.7 U	Y	10GW0301	1/18/2001
10-04			
20 U	N	10-04 (83b) (07/12/83)	7/12/1983
10 U	N	10-04 (85) (01/16/85)	1/16/1985
10 U	N	10-04 (86) (02/09/86)	2/9/1986
5 U	N	10-04 (89) (04/26/89)	4/26/1989
20 U	N	10-04 (91a) (03/16/91)	3/16/1991
20 U	N	10-04 (91b) (06/01/91)	6/1/1991
20 U	N	10-04 (92a) (01/09/92)	1/9/1992
20 U	N	10-04 (92b) (05/14/92)	5/14/1992

TABLE A-1

HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10-05			
20 U	N	10-05 (83b) (07/12/83)	7/12/1983
10 U	N	10-05 (85) (01/16/85)	1/16/1985
10 U	N	10-05 (86) (02/09/86)	2/9/1986
20 U	N	10-05 (91a) (03/16/91)	3/16/1991
20 U	N	10-05 (92a) (01/09/92)	1/9/1992
20 U	N	10-05 (92b) (05/14/92)	5/14/1992
20 U	N	10-06 (83b) (07/12/83)	7/12/1983
10-06			
10 U	N	10-06 (85) (01/30/85)	1/30/1985
10 U	N	10-06 (86) (02/09/86)	2/9/1986
20 U	N	10-06 (91a) (03/16/91)	3/16/1991
20 U	N	10-06 (91b) (06/01/91)	6/1/1991
20 U	N	10-06 (92a) (01/09/92)	1/9/1992
20 U	N	10-06 (92b) (05/14/92)	5/14/1992
10-07			
180	N	10-07 (83b) (07/27/83)	7/27/1983
260	N	10-07 (83c) (09/06/83)	9/6/1983
72	N	10-07 (85) (01/30/85)	1/30/1985
370	N	10-07 (86) (02/09/86)	2/9/1986
83	N	10-07 (89) (04/26/89)	4/26/1989
22	N	10-07 (91a) (03/16/91)	3/16/1991
32	N	10-07 (91b) (06/01/91)	6/1/1991
35	N	10-07 (92a) (01/09/92)	1/9/1992
82	N	10-07 (92b) (05/14/92)	5/14/1992
10 U	N	10-07	
10-08			
150	N	10-08 (83b) (07/27/83)	7/27/1983
62	N	10-08 (83c) (09/06/83)	9/6/1983
113	N	10-08 (85) (01/30/85)	1/30/1985
240	N	10-08 (86) (02/09/86)	2/9/1986
33.8	N	10-08 (89) (04/26/89)	4/26/1989
22	N	10-08 (91a) (03/16/91)	3/16/1991
134	N	10-08 (91b) (06/01/91)	6/1/1991
41	N	10-08 (92a) (01/09/92)	1/9/1992
135	N	10-08 (92b) (05/14/92)	5/14/1992
140	N	10-08	

TABLE A-1

HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10-09			
120	N	10-09 (83b) (07/27/83)	7/27/1983
10 U	N	10-09 (83c) (09/06/83)	9/6/1983
10 U	N	10-09 (86) (02/09/86)	2/9/1986
5 U	N	10-09 (89) (04/26/89)	4/26/1989
20 U	N	10-09 (91a) (03/16/91)	3/16/1991
20 U	N	10-09 (91b) (06/01/91)	6/1/1991
20 U	N	10-09 (92a) (01/09/92)	1/9/1992
20 U	N	10-09 (92b) (05/14/92)	5/14/1992
10 U	N	10-09	
10-10			
20 U	N	10-10 (83b) (07/27/83)	7/27/1983
10 U	N	10-10 (83c) (09/06/83)	9/6/1983
10 U	N	10-10 (85) (01/16/85)	1/16/1985
10 U	N	10-10 (86) (02/09/86)	2/9/1986
20 U	N	10-10 (91a) (03/16/91)	3/16/1991
20 U	N	10-10 (91b) (06/01/91)	6/1/1991
20 U	N	10-10 (92a) (01/09/92)	1/9/1992
20 U	N	10-10 (92b) (05/14/92)	5/14/1992
10 U	N	10-10	
10-11			
10 U	N	10-11 (83c) (09/06/83)	9/6/1983
10 U	N	10-11 (85) (01/30/85)	1/30/1985
10 U	N	10-11 (86) (02/09/86)	2/9/1986
20 U	N	10-11 (91a) (03/16/91)	3/16/1991
20 U	N	10-11 (92a) (01/09/92)	1/9/1992
20 U	N	10-11 (92b) (05/14/92)	5/14/1992
10-12			
10 U	N	10-12 (83c) (09/06/83)	9/6/1983
10 U	N	10-12 (85) (01/30/85)	1/30/1985
10 U	N	10-12 (86) (02/09/86)	2/9/1986
10-13			
10 U	N	10-13 (83c) (09/06/83)	9/6/1983
10 U	N	10-13 (85) (01/16/85)	1/16/1985
10 U	N	10-13 (86) (02/09/86)	2/9/1986
20 U	N	10-13 (91a) (03/16/91)	3/16/1991
20 U	N	10-13 (92a) (01/09/92)	1/9/1992
20 U	N	10-13 (92b) (05/14/92)	5/14/1992
10-14			
10 U	N	10-14 (83c) (09/06/83)	9/6/1983

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HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10-14B			
10 U	N	10-14B (86) (02/09/86)	2/9/1986
20 U	N	10-14B (91a) (03/16/91)	3/16/1991
20 U	N	10-14B (91b) (06/01/91)	6/1/1991
20 U	N	10-14B (92a) (01/09/92)	1/9/1992
20 U	N	10-14B (92b) (05/14/92)	5/14/1992
10 U	N	10-14B	
10-15			
10 U	N	10-15 (83c) (09/06/83)	9/6/1983
10 U	N	10-15 (85) (01/30/85)	1/30/1985
10 U	N	10-15 (86) (02/09/86)	2/9/1986
20 U	N	10-15 (91a) (03/16/91)	3/16/1991
20 U	N	10-15 (92a) (01/09/92)	1/9/1992
20 U	N	10-15 (92b) (05/14/92)	5/14/1992
10-16			
10 U	N	10-16 (83c) (09/21/83)	9/21/1983
10 U	N	10-16 (85) (01/30/85)	1/30/1985
10 U	N	10-16 (86) (02/09/86)	2/9/1986
20 U	N	10-16 (91a) (03/16/91)	3/16/1991
20 U	N	10-16 (91b) (06/01/91)	6/1/1991
20 U	N	10-16 (92a) (01/09/92)	1/9/1992
20 U	N	10-16 (92b) (05/14/92)	5/14/1992
1.7 U	Y	10GW1601	1/21/2001
10-17			
14	N	10-17 (85) (01/30/85)	1/30/1985
8200	N	10-17 (86) (02/09/86)	2/9/1986
1370	N	10-17 (89) (04/26/89)	4/26/1989
806	N	10-17 (91a) (03/16/91)	3/16/1991
632	N	10-17 (91b) (06/01/91)	6/1/1991
422	N	10-17 (92a) (01/09/92)	1/9/1992
618	N	10-17 (92b) (05/14/92)	5/14/1992
33	Y	10GW1701	1/23/2001
7200 U	N	10-17-0983c	
10-18			
6190	N	10-18 (85) (01/30/85)	1/30/1985
69	N	10-18 (86) (02/09/86)	2/9/1986
83	N	10-18 (89) (04/26/89)	4/26/1989
43	N	10-18 (91a) (03/16/91)	3/16/1991
20 U	N	10-18 (91b) (06/01/91)	6/1/1991
20 U	N	10-18 (92a) (01/09/92)	1/9/1992
37	N	10-18 (92b) (05/14/92)	5/14/1992
26	N	10-18-0983c	

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HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10-19			
25	N	10-19 (83c) (09/21/83)	9/21/1983
26	N	10-19 (85) (01/30/85)	1/30/1985
10 U	N	10-19 (86) (02/09/86)	2/9/1986
5 U	N	10-19 (89) (04/26/89)	4/26/1989
20 U	N	10-19 (91a) (03/16/91)	3/16/1991
20 U	N	10-19 (91b) (06/01/91)	6/1/1991
20 U	N	10-19 (92a) (01/09/92)	1/9/1992
20 U	N	10-19 (92b) (05/14/92)	5/14/1992
10 U	N	10-19	
10-20			
10	N	10-20 (83c) (09/21/83)	9/21/1983
10 U	N	10-20 (85) (01/30/85)	1/30/1985
10 U	N	10-20 (86) (02/09/86)	2/9/1986
5 U	N	10-20 (89) (04/26/89)	4/26/1989
20 U	N	10-20 (91a) (03/16/91)	3/16/1991
20 U	N	10-20 (91b) (06/01/91)	6/1/1991
20 U	N	10-20 (92a) (01/09/92)	1/9/1992
20 U	N	10-20 (92b) (05/14/92)	5/14/1992
10-21			
10 U	N	10-21 (83c) (09/21/83)	9/21/1983
10 U	N	10-21 (85) (01/30/85)	1/30/1985
10 U	N	10-21 (86) (02/09/86)	2/9/1986
23	N	10-21 (91a) (03/16/91)	3/16/1991
20 U	N	10-21 (91b) (06/01/91)	6/1/1991
12 J	N	10-21 (92a) (01/09/92)	1/9/1992
26	N	10-21 (92b) (05/14/92)	5/14/1992
10-22			
10 U	N	10-22 (83c) (09/21/83)	9/21/1983
10 U	N	10-22 (85) (01/16/85)	1/16/1985
10 U	N	10-22 (86) (02/09/86)	2/9/1986
20 U	N	10-22 (91a) (03/16/91)	3/16/1991
20 U	N	10-22 (92b) (05/14/92)	5/14/1992
10C23			
5 U	N	10C23-042689	4/26/1989
20 U	N	10C23 (91a) (03/16/91)	3/16/1991
20 U	N	10C23 (91b) (06/01/91)	6/1/1991
20 U	N	10C23 (92a) (01/09/92)	1/9/1992
20 U	N	10C23 (92b) (05/14/92)	5/14/1992
20 U	N	10C24 (91a) (03/16/91)	3/16/1991
20 U	N	10C24 (91b) (06/01/91)	6/1/1991
20 U	N	10C24 (92a) (01/09/92)	1/9/1992
20 U	N	10C24 (92b) (05/14/92)	5/14/1992

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HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10C24P2			
20 U	N	10C24P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C24P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C24P2 (92b) (05/14/92)	5/14/1992
5 U	N	10C24P3-042689	4/26/1989
20 U	N	10C24P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C24P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C24P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C24P3 (92b) (05/14/92)	5/14/1992
10C25			
5 U	N	10C25-042689	4/26/1989
20 U	N	10C25 (91a) (03/16/91)	3/16/1991
20 U	N	10C25 (91b) (06/01/91)	6/1/1991
20 U	N	10C25 (92a) (01/09/92)	1/9/1992
20 U	N	10C25 (92b) (05/14/92)	5/14/1992
10C25P2			
5 U	N	10C25P2-042689	4/26/1989
20 U	N	10C25P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C25P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C25P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C25P2 (92b) (05/14/92)	5/14/1992
20 U	N	10C25P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C25P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C25P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C25P3 (92b) (05/14/92)	5/14/1992
10C26			
20 U	N	10C26 (91a) (03/16/91)	3/16/1991
20 U	N	10C26 (92a) (01/09/92)	1/9/1992
20 U	N	10C26 (92b) (05/14/92)	5/14/1992
10C26P2			
20 U	N	10C26P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C26P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C26P2 (92b) (05/14/92)	5/14/1992
5 U	N	10C26P3 (89) (04/26/89)	4/26/1989
20 U	N	10C26P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C26P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C26P3 (92b) (05/14/92)	5/14/1992
10C27			
20 U	N	10C27 (91a) (03/16/91)	3/16/1991
20 U	N	10C27 (91b) (06/01/91)	6/1/1991
20 U	N	10C27 (92a) (01/09/92)	1/9/1992
20 U	N	10C27 (92b) (05/14/92)	5/14/1992

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HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10C27P2			
5 U	N	10C27P2 (89) (04/26/89)	4/26/1989
20 U	N	10C27P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C27P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C27P2 (92a) (01/09/92)	1/9/1992
10C28			
5 U	N	10C28-042689	4/26/1989
20 U	N	10C28 (91a) (03/16/91)	3/16/1991
20 U	N	10C28 (91b) (06/01/91)	6/1/1991
20 U	N	10C28 (92a) (01/09/92)	1/9/1992
20 U	N	10C28 (92b) (05/14/92)	5/14/1992
10C28P2			
5 U	N	10C28P2 (89) (04/26/89)	4/26/1989
20 U	N	10C28P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C28P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C28P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C28P2 (92b) (05/14/92)	5/14/1992
10C29			
5 U	N	10C29-042689	4/26/1989
20 U	N	10C29 (91a) (03/16/91)	3/16/1991
20 U	N	10C29 (91b) (06/01/91)	6/1/1991
20 U	N	10C29 (92a) (01/09/92)	1/9/1992
20 U	N	10C29 (92b) (05/14/92)	5/14/1992
10C29P2			
5 U	N	10C29P2 (89) (04/26/89)	4/26/1989
20 U	N	10C29P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C29P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C29P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C29P2 (92b) (05/14/92)	5/14/1992
10C30			
5 U	N	10C30 (89) (04/26/89)	4/26/1989
20 U	N	10C30 (91a) (03/16/91)	3/16/1991
20 U	N	10C30 (92a) (01/09/92)	1/9/1992
20 U	N	10C30 (92b) (05/14/92)	5/14/1992
10C30P2			
5 U	N	10C30P2 (89) (04/26/89)	4/26/1989
20 U	N	10C30P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C30P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C30P2 (92b) (05/14/92)	5/14/1992

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HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10C31			
5 U	N	10C31 (89) (04/26/89)	4/26/1989
20 U	N	10C31 (91a) (03/16/91)	3/16/1991
20 U	N	10C31 (91b) (06/01/91)	6/1/1991
20 U	N	10C31 (92a) (01/09/92)	1/9/1992
20 U	N	10C31 (92b) (05/14/92)	5/14/1992
0.7 U	Y	10GWC3101	1/8/2001
10C31P3			
5 U	N	10C31P3 (89) (04/26/89)	4/26/1989
20 U	N	10C31P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C31P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C31P3 (92a) (01/09/92)	1/9/1992
1.2 U	Y	10GWC31P301	1/22/2001
10C32			
5 U	N	10C32 (89) (04/26/89)	4/26/1989
20 U	N	10C32 (91a) (03/16/91)	3/16/1991
20 U	N	10C32 (91b) (06/01/91)	6/1/1991
20 U	N	10C32 (92a) (01/09/92)	1/9/1992
20 U	N	10C32 (92b) (05/14/92)	5/14/1992
10C32P2			
20 U	N	10C32P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C32P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C32P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C32P2 (92b) (05/14/92)	5/14/1992
5 U	N	10C32P3 (89) (04/26/89)	4/26/1989
20 U	N	10C32P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C32P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C32P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C32P3 (92b) (05/14/92)	5/14/1992
10C33			
5 U	N	10C33 (89) (04/26/89)	4/26/1989
20 U	N	10C33 (91a) (03/16/91)	3/16/1991
20 U	N	10C33 (91b) (06/01/91)	6/1/1991
20 U	N	10C33 (92a) (01/09/92)	1/9/1992
20 U	N	10C33 (92b) (05/14/92)	5/14/1992
0.43 U	Y	10GWC3301	1/20/2001
10C33P2			
5 U	N	10C33P2 (89) (04/26/89)	4/26/1989
20 U	N	10C33P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C33P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C33P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C33P2 (92b) (05/14/92)	5/14/1992
0.58 U	Y	10GWC33P201	1/20/2001

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HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10C34			
5 U	N	10C34 (89) (04/26/89)	4/26/1989
20 U	N	10C34 (91a) (03/16/91)	3/16/1991
20 U	N	10C34 (91b) (06/01/91)	6/1/1991
20 U	N	10C34 (92a) (01/09/92)	1/9/1992
20 U	N	10C34 (92b) (05/14/92)	5/14/1992
10C34P2			
5 U	N	10C34P2 (89) (04/26/89)	4/26/1989
20 U	N	10C34P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C34P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C34P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C34P2 (92b) (05/14/92)	5/14/1992
10C34P3			
5 U	N	10C34P3 (89) (04/26/89)	4/26/1989
20 U	N	10C34P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C34P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C34P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C34P3 (92b) (05/14/92)	5/14/1992
10C35			
5 U	N	10C35 (89) (04/26/89)	4/26/1989
20 U	N	10C35 (91a) (03/16/91)	3/16/1991
20 U	N	10C35 (91b) (06/01/91)	6/1/1991
6 J	N	10C35 (92a) (01/09/92)	1/9/1992
20 U	N	10C35 (92b) (05/14/92)	5/14/1992
0.49 U	Y	10GWC3501	1/21/2001
10C35P2			
20 U	N	10C35P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C35P2 (91b) (06/01/91)	6/1/1991
20.8 U	N	10C35P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C35P2 (92b) (05/14/92)	5/14/1992
0.52 U	Y	10GWC35P201	1/21/2001
5 U	N	10C35P3 (89) (04/26/89)	4/26/1989
20 U	N	10C35P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C35P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C35P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C35P3 (92b) (05/14/92)	5/14/1992
10C36			
20 U	N	10C36 (91a) (03/16/91)	3/16/1991
20 U	N	10C36 (91b) (06/01/91)	6/1/1991
20 U	N	10C36 (92a) (01/09/92)	1/9/1992
20 U	N	10C36 (92b) (05/14/92)	5/14/1992

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HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10C36P2			
5 U	N	10C36P2 (89) (04/26/89)	4/26/1989
20 U	N	10C36P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C36P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C36P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C36P2 (92b) (05/14/92)	5/14/1992
10C36P3			
5 U	N	10C36P3 (89) (04/26/89)	4/26/1989
20 U	N	10C36P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C36P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C36P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C36P3 (92b) (05/14/92)	5/14/1992
10C37			
5 U	N	10C37 (89) (04/26/89)	4/26/1989
18 J	N	10C37 (91a) (03/16/91)	3/16/1991
20 U	N	10C37 (91b) (06/01/91)	6/1/1991
20 U	N	10C37 (92a) (01/09/92)	1/9/1992
20 U	N	10C37 (92b) (05/14/92)	5/14/1992
0.68 U	Y	10GWC3701	1/19/2001
10C37P2			
20 U	N	10C37P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C37P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C37P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C37P2 (92b) (05/14/92)	5/14/1992
10C37P3			
5 U	N	10C37P3 (89) (04/26/89)	4/26/1989
20 U	N	10C37P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C37P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C37P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C37P3 (92b) (05/14/92)	5/14/1992
0.29 U	Y	10GWC37P301	1/6/2001
10C38			
5 U	N	10C38 (89) (04/26/89)	4/26/1989
20 U	N	10C38 (91a) (03/16/91)	3/16/1991
20 U	N	10C38 (91b) (06/01/91)	6/1/1991
20 U	N	10C38 (92a) (01/09/92)	1/9/1992
20 U	N	10C38 (92b) (05/14/92)	5/14/1992
10C39			
5 U	N	10C39 (89) (04/26/89)	4/26/1989
20 U	N	10C39 (91a) (03/16/91)	3/16/1991
20 U	N	10C39 (91b) (06/01/91)	6/1/1991
20 U	N	10C39 (92a) (01/09/92)	1/9/1992
20 U	N	10C39 (92b) (05/14/92)	5/14/1992

TABLE A-1

HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10C39P2			
5 U	N	10C39P2 (89) (04/26/89)	4/26/1989
20 U	N	10C39P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C39P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C39P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C39P2 (92b) (05/14/92)	5/14/1992
10C40			
5 U	N	10C40 (89) (04/26/89)	4/26/1989
20 U	N	10C40 (91a) (03/16/91)	3/16/1991
10C40P2			
5 U	N	10C40P2 (89) (04/26/89)	4/26/1989
20 U	N	10C40P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C40P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C40P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C40P2 (92b) (05/14/92)	5/14/1992
5 U	N	10C40P4 (89) (04/26/89)	4/26/1989
20 U	N	10C40P4 (91a) (03/16/91)	3/16/1991
20 U	N	10C40P4 (91b) (06/01/91)	6/1/1991
20 U	N	10C40P4 (92a) (01/09/92)	1/9/1992
20 U	N	10C40P4 (92b) (05/14/92)	5/14/1992
10C41			
5 U	N	10C41 (89) (04/26/89)	4/26/1989
20 U	N	10C41 (91a) (03/16/91)	3/16/1991
20 U	N	10C41 (91b) (06/01/91)	6/1/1991
20 U	N	10C41 (92a) (01/09/92)	1/9/1992
20 U	N	10C41 (92b) (05/14/92)	5/14/1992
0.61 U	Y	10GWC4101	1/9/2001
10C41P3			
5 U	N	10C41P3 (89) (04/26/89)	4/26/1989
20 U	N	10C41P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C41P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C41P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C41P3 (92b) (05/14/92)	5/14/1992
0.49 U	Y	10GWC41P301	1/9/2001
10C42			
5 U	N	10C42 (89) (04/26/89)	4/26/1989
20 U	N	10C42 (91a) (03/16/91)	3/16/1991
20 U	N	10C42 (91b) (06/01/91)	6/1/1991
20 U	N	10C42 (92a) (01/09/92)	1/9/1992
20 U	N	10C42 (92b) (05/14/92)	5/14/1992

TABLE A-1

HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10C42P2			
5 U	N	10C42P2 (89) (04/26/89)	4/26/1989
20 U	N	10C42P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C42P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C42P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C42P2 (92b) (05/14/92)	5/14/1992
10C43			
5 U	N	10C43-042689	4/26/1989
20 U	N	10C43 (91a) (03/16/91)	3/16/1991
20 U	N	10C43 (91b) (06/01/91)	6/1/1991
20 U	N	10C43 (92a) (01/09/92)	1/9/1992
20 U	N	10C43 (92b) (05/14/92)	5/14/1992
10C43P2			
20 U	N	10C43P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C43P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C43P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C43P2 (92b) (05/14/92)	5/14/1992
5 U	N	10C43P3 (89) (04/26/89)	4/26/1989
20 U	N	10C43P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C43P3 (91b) (06/01/91)	6/1/1991
20 U	N	10C43P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C43P3 (92b) (05/14/92)	5/14/1992
10C44			
20 U	N	10C44 (91a) (03/16/91)	3/16/1991
20 U	N	10C44 (91b) (06/01/91)	6/1/1991
20 U	N	10C44 (92a) (01/09/92)	1/9/1992
20 U	N	10C44 (92b) (05/14/92)	5/14/1992
20 U	N	10C44P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C44P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C44P2 (92b) (05/14/92)	5/14/1992
10C45			
20 U	N	10C45 (91a) (03/16/91)	3/16/1991
20 U	N	10C45 (92a) (01/09/92)	1/9/1992
20 U	N	10C45 (92b) (05/14/92)	5/14/1992
10C45P2			
20 U	N	10C45P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C45P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C45P2 (92b) (05/14/92)	5/14/1992
10C46			
20 U	N	10C46 (91a) (03/16/91)	3/16/1991
20 U	N	10C46 (92a) (01/09/92)	1/9/1992
20 U	N	10C46 (92b) (05/14/92)	5/14/1992
20 U	N	10C46P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C46P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C46P2 (92b) (05/14/92)	5/14/1992

TABLE A-1

HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10C46P3			
20 U	N	10C46P3 (91a) (03/16/91)	3/16/1991
20 U	N	10C46P3 (92a) (01/09/92)	1/9/1992
20 U	N	10C46P3 (92b) (05/14/92)	5/14/1992
10C47			
20 U	N	10C47 (91a) (03/16/91)	3/16/1991
20 U	N	10C47 (92a) (01/09/92)	1/9/1992
20 U	N	10C47 (92b) (05/14/92)	5/14/1992
10C47P2			
20 U	N	10C47P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C47P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C47P2 (92b) (05/14/92)	5/14/1992
10C48			
20 U	N	10C48 (91a) (03/16/91)	3/16/1991
20 U	N	10C48 (91b) (06/01/91)	6/1/1991
20 U	N	10C48 (92a) (01/09/92)	1/9/1992
20 U	N	10C48 (92b) (05/14/92)	5/14/1992
10C48P2			
20 U	N	10C48P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C48P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C48P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C48P2 (92b) (05/14/92)	5/14/1992
10C49			
20 U	N	10C49 (91a) (03/16/91)	3/16/1991
20 U	N	10C49 (91b) (06/01/91)	6/1/1991
20 U	N	10C49 (92a) (01/09/92)	1/9/1992
20 U	N	10C49 (92b) (05/14/92)	5/14/1992
10C49P2			
20 U	N	10C49P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C49P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C49P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C49P2 (92b) (05/14/92)	5/14/1992
10C50			
20 U	N	10C50 (91a) (03/16/91)	3/16/1991
20 U	N	10C50 (91b) (06/01/91)	6/1/1991
20 U	N	10C50 (92a) (01/09/92)	1/9/1992
20 U	N	10C50 (92b) (05/14/92)	5/14/1992
10C51			
20 U	N	10C51 (91a) (03/16/91)	3/16/1991
20 U	N	10C51 (91b) (06/01/91)	6/1/1991
20 U	N	10C51 (92a) (01/09/92)	1/9/1992
20 U	N	10C51 (92b) (05/14/92)	5/14/1992

TABLE A-1

HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample Number	Sample Date
10C52			
20 U	N	10C52 (91a) (03/16/91)	3/16/1991
20 U	N	10C52 (92a) (01/09/92)	1/9/1992
20 U	N	10C52 (92b) (05/14/92)	5/14/1992
0.9 U	Y	10GWC5201	1/18/2001
10C53			
20 U	N	10C53 (91a) (03/16/91)	3/16/1991
20 U	N	10C53 (91b) (06/01/91)	6/1/1991
20 U	N	10C53 (92a) (01/09/92)	1/9/1992
20 U	N	10C53 (92b) (05/14/92)	5/14/1992
10C53P2			
20 U	N	10C53P2 (91a) (03/16/91)	3/16/1991
20 U	N	10C53P2 (91b) (06/01/91)	6/1/1991
20 U	N	10C53P2 (92a) (01/09/92)	1/9/1992
20 U	N	10C53P2 (92b) (05/14/92)	5/14/1992
10C54			
20 U	N	10C54 (91a) (03/16/91)	3/16/1991
20 U	N	10C54 (91b) (06/01/91)	6/1/1991
20 U	N	10C54 (92a) (01/09/92)	1/9/1992
20 U	N	10C54 (92b) (05/14/92)	5/14/1992
10C55			
548	N	10C55 (91a) (03/16/91)	3/16/1991
244	N	10C55 (91b) (06/01/91)	6/1/1991
278	N	10C55 (92a) (01/09/92)	1/9/1992
160	N	10C55 (92b) (05/14/92)	5/14/1992
240	Y	10GWC5501	1/21/2001
240	Y	10GWC5501-D	1/21/2001
10C55P2			
88	N	10C55P2 (91a) (03/16/91)	3/16/1991
115	N	10C55P2 (91b) (06/01/91)	6/1/1991
116	N	10C55P2 (92a) (01/09/92)	1/9/1992
94	N	10C55P2 (92b) (05/14/92)	5/14/1992
21	Y	10GWC55P201	1/22/2001
10C56			
20 U	N	10C56 (91a) (03/16/91)	3/16/1991
20 U	N	10C56 (91b) (06/01/91)	6/1/1991
20 U	N	10C56 (92a) (01/09/92)	1/9/1992
20 U	N	10C56 (92b) (05/14/92)	5/14/1992
10C57			
20 U	N	10C57 (91a) (03/16/91)	3/16/1991
20 U	N	10C57 (92a) (01/09/92)	1/9/1992
20 U	N	10C57 (92b) (05/14/92)	5/14/1992
0.64 U	Y	10GWC5701	1/24/2001

TABLE A-1

HISTORICAL AND RF INVESTIGATION RDX SAMPLE DATA
SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

Results (µg/L)	Validated (Yes/No)	Sample	
		Number	Date
10C60			
51	N	10C60 (91a) (03/16/91)	3/16/1991
12 J	N	10C60 (92a) (01/09/92)	1/9/1992
20 U	N	10C60 (92b) (05/14/92)	5/14/1992
10C61			
20 U	N	10C61 (91a) (03/16/91)	3/16/1991
20 U	N	10C61 (92a) (01/09/92)	1/9/1992
20 U	N	10C61 (92b) (05/14/92)	5/14/1992

1.0 ASSUMPTIONS

The following assumptions are made based upon results of field investigations:

- As illustrated on attached Figures A-1 and A-2, there is a groundwater contaminant plume at SWMU 10 with elevated concentrations of explosives.
- The explosives plume is approximately 900 feet long by 170 feet wide, extending in a north to northeast direction from the vicinity of Building 2739 to monitoring wells 10C56 and 10C57.
- Within that plume, two circular areas approximately 100 feet in diameter are centered around monitoring well cluster 10C55/10C55P2 and monitoring well 10-17, where the highest concentrations of explosives have been detected. These circular areas have been designated as "Hot-Spot" No. 1 and "Hot-Spot" No. 2, respectively (Figure A-2).
- The thickness of contaminated groundwater is estimated at approximately 25 ft.

2.0 EXPLOSIVES PLUME SURFACE AREA, THICKNESS, AND VOLUME

2.1. Explosives Plume Surface Area

As illustrated on attached Figure A-3 the surface area of the explosives plume is estimated at approximately 150,000 ft^2.

2.2 Explosives Plume Thickness

As stated in the assumptions the thickness of contaminated groundwater is estimated at approximately 25 ft. Groundwater surface elevation is approximately 5 ft below ground surface (bgs).

2.3 Explosives Plume Volume

Groundwater in the explosives plume area occurs in bedrock with a porosity ranging from 0.03 to 0.15, with an average of 0.10. Therefore, the estimated volume of contaminated groundwater in the explosives plume can be computed as follows:

$150{,}000\ ft^2 \times 25\ ft \times 0.10 \approx 375{,}000\ ft^3$ or 2,805,000 gallons

3.0 COCS QUANTITIES COMPUTATIONS

The quantities of COCs within the explosives plume groundwater can be computed based upon the volume of contaminated groundwater and the average concentrations of these COCs in that area. Average concentrations are assumed to be the mathematical average of the historical concentrations detected in samples collected from monitoring wells located within the explosives plume.

Average concentrations (in µg/L) of COCs in the explosives plume groundwater are computed in the table below. Analytical results shown on this table are those for samples collected at the indicated date that corresponds to the latest sampling.

COC	10-07 (5/14/92)	10-08 (5/14/92)	10-17 (1/23/01)	10-18 (5/14/92)	10-21 (5/14/92)	10C55 (1/21/01)	10C55P2 (1/22/01)	Average
Explosives (µg/L)								
RDX	82	140	33	37	26	240	21	83
TNT	9 J	60	26	20 U	20 U	56 J	5.8 J	25
2A-DNT	NA	NA	20	NA	NA	2.8	7.2	10
4A-DNT	NA	NA	18	NA	NA	3.7	18	13
HMX	119	98	240	70	20 U	59	91	98
Inorganics (µg/L)								
Iron	448	308	286	77	10,100	612	100 U	1,697
Manganese	471	296	299	442	468	336	15 U	331

NOTES

NA Not analyzed

J Estimated value

U Not detected at the indicated analytical detection limit. Half of the detected value was used for estimating the average concentration.

Quantities (in pounds) of COCs in the explosives plume groundwater can be calculated according to the following formula:

$$\text{Quantity} = (2{,}805{,}200 \text{ gallons}) \times (8.34 \text{ lb/gal}) \times (\text{average } \mu\text{g/L concentration}) \times (10^{-9})$$

Accordingly, estimated quantities of COCs in the explosives plume groundwater are as follows:

COC	Quantity (pounds)
Explosives	
RDX	1.94
TNT	0.58
2A-DNT	0.23
4A-DNT	0.30
HMX	2.29
Total Explosives	5.36
Inorganics	
Iron	39.70
Manganese	7.74
Total Inorganics	47.44

GROUNDWATER FLOW VELOCITY, PLUME FLUSHING RATE, AND ESTIMATED TIME FOR NATURAL ATTENUATION

Project:	NSWC Crane, SWMU 10 CMS	**Project No.:**	N4267
Subject:	SWMU 10 CMS - Calculations for Groundwater Flow and Natural Attenuation		
By:	JPS	**Date:**	8/24/2005
Checked:		**Date:**	

Project/Design Objective:

Characterize groundwater flow system in plume area and calculate flushing rates and time to naturally attenuate plume. The desired cleanup level for RDX in groundwater is 0.5 ug/L.

Basis of Calculations: (Input cells yellow, blue automatically calculated)

Groundwater Plume Information

Plume Width (W):	150	ft.
Plume Thickness (P_T):	25	ft.
Plume Area (P_A):	150,000	ft^2
Volume of Groundwater in Plume (= P_T * P_A * n):	375,000	ft^3
Avg Hydraulic Conductivity, Plume Area (Hydr-c_{avg}):	1	ft/day

Aquifer Characteristics

Thickness (B):	25	ft.
Avg. Hydraulic Conductivity (K):	1	ft/day
Transmissivity (T = B * K):	25	ft^2/day
Porosity (n):	0.1	
Storativity (S):	0.1	
Fractional Organic Carbon Content (foc) *:	0.0005	
Flow Gradient (i):	0.02	

Contaminant Characteristics

Contaminant A Representative gw conc.:	RDX	100	µg/L
Koc, Contaminant A:		150	
Kd, Contaminant A (= T * Koc):		0.075	
Half-life, Contaminant A:		20	years
Target Cleanup Level, Contaminant A:		0.5	ug/L

Estimated Flow Rate of Contaminated Groundwater (through plane normal to flow direction)

Qt = T * i * W

Qt = 75.00 ft^3/day, or 0.39 gpm

All groundwater/soil contaminant concentrations are in consistent units, i.e., mg/L & mg/kg, or µg/L & µg/kg.

*** for contaminants that partition between soil and water through mechanisms other than adsoption onto organic carbon, i.e., metals, the compound's K_d is input directly into the K_{OC} entry cell, with f_{OC} then set to 1. For fractured bedrock, reduce the f_{OC} by 1-2 orders of magnitude to adjust for typical low fracture porosity and resulting high model-perceived mass of aquifer material in contact with water.**

This spreadsheet calculates flushing rates and cleanup times for a groundwater flow system that consists of up to 3 groundwater "flow units". Flow units are discrete portions of the aquifer that have unique properties, i.e., higher or lower average hydraulic conductivity, porosity, or specific gravity relative to other portions of the aquifer, higher/lower contaminant concentrations, and/or different organic carbon contents. The spreadsheet factors in different flushing rates for discrete portions of the aquifer based on the differences in the physical/chemical characteristics of the flow units. *First-order contaminant decay/degradation processes can also be factored into the cleanup rate prediction through the optional use of contaminant half-life data.*

Groundwater Flow Unit Physical/Chemical Data

Flow Unit 1 (U1)		Flow Unit 2 (U2)		Flow Unit 3 (U3)	
Cw_{01}	100.000	Cw_{02}	100.000	Cw_{03}	100.000
n	0.100	n	0.100	n	0.100
S_G	2.650	S_G	2.650	S_G	2.650
f_{OC}*	0.0005	f_{OC}*	0.0005	f_{OC}*	0.0005
K_d	0.075	K_d	0.075	K_d	0.075
M_W	10.000	M_W	10.000	M_W	10.000
C_S	7.500	C_S	7.500	C_S	7.500
M_S	17.888	M_S	17.888	M_S	17.888
M_T	27.888	M_T	27.888	M_T	27.888
M_S/M_T	0.6414	M_S/M_T	0.6414	M_S/M_T	0.6414

Cw_{0N} = Initial contaminant concentration in groundwater flow unit N

Groundwater Flow Unit Hydrogeologic Characteristics

Avg. K, ft/d highest to lowest	Relative average K, K_U	Fraction of aquifer volume, FV_U	Fraction of total flow, FQ_U	Flow unit number, U
1	1.000	0.333	0.333	1
1	1.000	0.334	0.334	2
1	1.000	0.333	0.333	3

Pore Volumes and Pore Volume Removal Rates

Groundwater discharge rate, gpm	Groundwater discharge rate, ft^3/day, Q_T	Total volume occupied by plume, ft^3, PV_T
0.39	75.00	4,375,000

Discharge rate, Unit 1 ft^3/day, Q_1	Discharge rate, Unit 2 ft^3/day, Q_2	Discharge rate, Unit 3 ft^3/day, Q_3	Plume pore Vol., Unit 1 ft^3, PV_1	Plume pore Vol., Unit 2 ft^3, PV_2	Plume pore Vol., Unit 3 ft^3, PV_3	Time for 1 PV flush, Unit 1, days, t_1	Time for 1 PV flush, Unit 2, days, t_2	Time for 1 PV flush, Unit 3, days, t_3
24.98	25.03	24.98	145687.5	146125	145687.5	5831.28	5837.12	5831.28

Contaminant Half-Life Data

Does contaminant have a decay half-life (yes/no):	yes	If yes, half-life (days):	7300
1st order decay coefficient (k):	0.000095		

Average Pumped/Discharged and Residual Plume Concentrations Over Time

Target Cleanup Concentration :			0.5	ug/L
Time period	Time span, days, t	Avg pumped GW conc.	Avg residual GW conc.	Time span, years
0	0	0	**100**	0
0.1	583.13	90.507	**90.507**	1.60
0.15	874.69	86.104	**86.104**	2.39
0.2	1166.26	81.915	**81.915**	3.19
0.3	1749.39	74.139	**74.139**	4.79
0.4	2332.51	67.101	**67.101**	6.39
0.5	2915.64	60.731	**60.731**	7.98
0.7	4081.90	49.747	**49.747**	11.18
0.9	5248.16	40.751	**40.751**	14.37
1.2	6997.54	30.212	**30.212**	19.16
1.5	8746.93	22.399	**22.399**	23.95
1.8	10496.31	16.606	**16.606**	28.74
2.1	12245.70	12.312	**12.312**	33.53
2.5	14578.21	8.261	**8.261**	39.91
3	17493.85	5.017	**5.017**	47.90
3.5	20409.50	3.047	**3.047**	55.88
4	23325.14	1.850	**1.850**	63.86
5	29156.42	0.682	**0.682**	79.83
6	34987.71	0.252	**0.252**	95.79
8	46650.28	0.034	**0.034**	127.72
10	58312.85	0.005	**0.005**	159.65
5.2	30322.68	0.559	**0.559**	83.02
5.3	30905.81	0.506	**0.506**	84.62
5.31	30964.12	0.501	**0.501**	84.78
5.32	31022.44	0.496	**0.496**	84.93
5.33	31080.75	0.491	**0.491**	85.09

Adjust the initial time period to auto-adjust the following 19 time periods and obtain the desired range in concentrations.

The last 5 time periods can be modified to more precisely determine the time required to meet a specific residual concentration.

Natural GW flow rate = W * P_T * Hydr-c_{avg} * i * (7.48 gal/ft^3)/[(24 hrs/day) * (60 min/hr)]

Natural GW flow rate through the plume area =	0.39	gpm,
Calculated time estimate for RDX to naturally attenuate =	85	years

Based on the conditions calculated above, the projected time for RDX in the plume area to naturally attenuate is approximately 85 years. However, because of uncertainties in site geology, hydrogeology, contaminant source, and contaminant behaviour in the plume area, a suitable safety factor should be included in the estimate. Based on the degree of confidence in the site data, and best scientific judgement, the time for natural attenuation to reduce RDX to a cleanup goal of 0.5 ug/L is more conservatively estimated to be 100 - 150 years.

Time conservatively estimated for RDX to naturally attenuate = 100 - 150 years

Average RDX concentration in groundwater @ time T = $[Cw_{01} \times (M_S/M_T)_1^{t/t_1} \times FQ_1 + Cw_{02} \times (M_S/M_T)_2^{t/t_2} \times FQ_2 + Cw_{03} \times (M_S/M_T)_3^{t/t_3} \times FQ_3] \times 2.718^{-kt}$

where FQ_1, FQ_2, FQ_3 = Fraction of total flow per day from each groundwater flow unit.

Number of pore volumes (PVs) required to reach a target groundwater concentration Cw_x: PVs = log (Cw_x/Cw_0) / log (M_S/M_T), for each groundwater flow unit

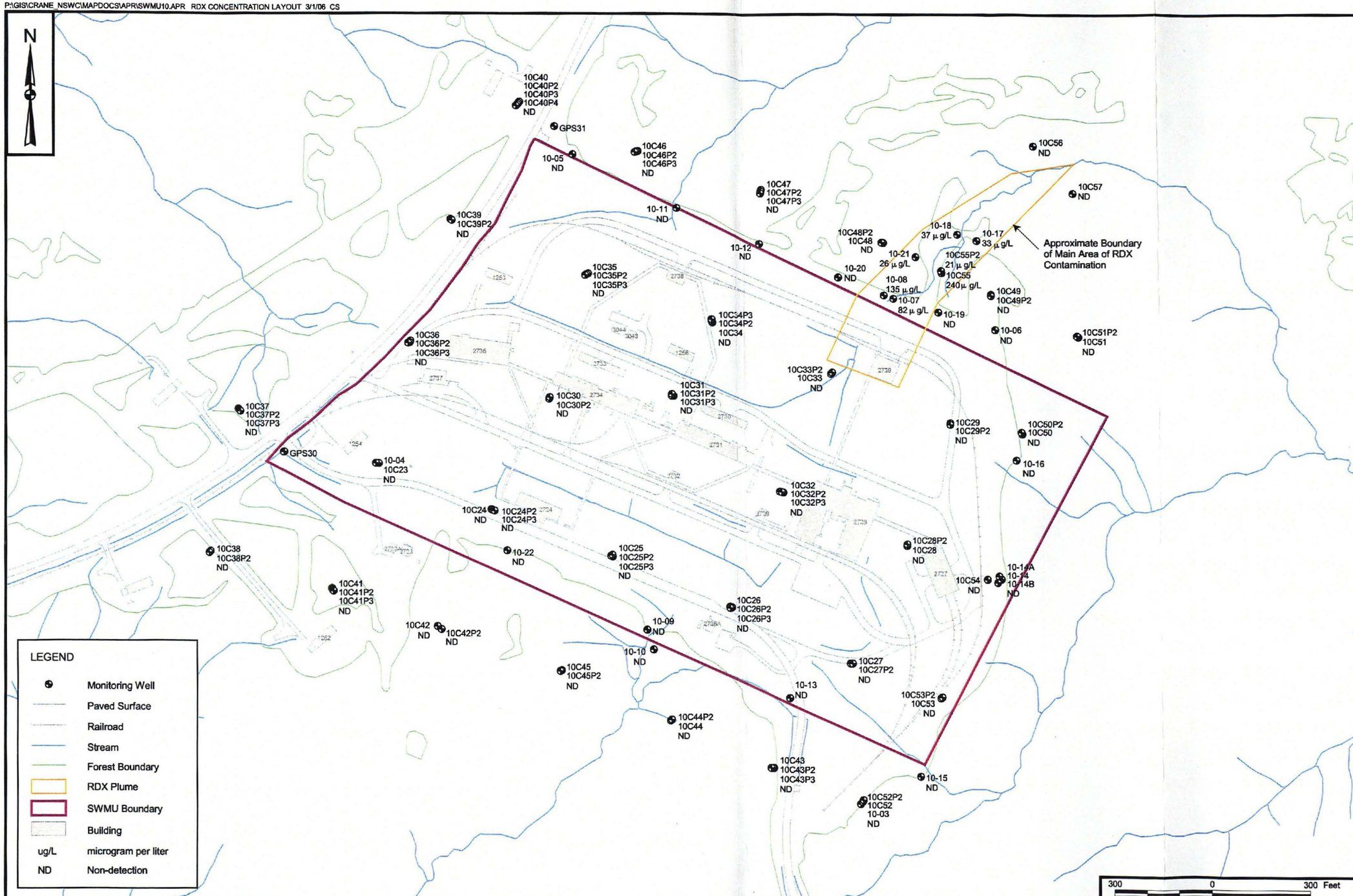
Contaminant Partitioning Formulas :

M_W	=	$C_W \times n$
C_S	=	$K_{OC} \times f_{OC} \times C_W$, or, $K_d \times C_W$
K_d	=	$K_{OC} \times f_{OC}$, or, C_S/C_W
M_S	=	$S_G \times (1-n) \times C_S$
M_T	=	$M_W + M_S$
Cw_x	=	$[Cw_i](M_S/M_T)^x$

where:

Cw_i	=	initial contaminant concentration in groundwater
n	=	aquifer porosity
S_G	=	specific gravity of aquifer solids (default value = 2.65)
M_W	=	mass of contaminants per unit volume of aquifer water
C_S	=	contaminant concentration on aquifer solids
Cw_x	=	Pore water concentration after x number of pore volume exchanges
M_S	=	mass of contaminants per unit volume of aquifer solids
M_T	=	total mass of contaminants per unit volume of aquifer
K_{OC}	=	organic carbon partition coefficient
f_{OC}	=	fractional organic carbon content of solids
K_d	=	soil/water distribution coefficient

P:\GIS\CRANE_NSWC\MAPDOCS\APR\SWMU10.APR RDX CONCENTRATION LAYOUT 3/1/06 CS



CONTRACT NO. N4267

APPROVED BY ___ DATE ___

APPROVED BY ___ DATE ___

DRAWING NO. FIGURE A - 1

REV 0

RDX CONCENTRATION
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

NAVFAC

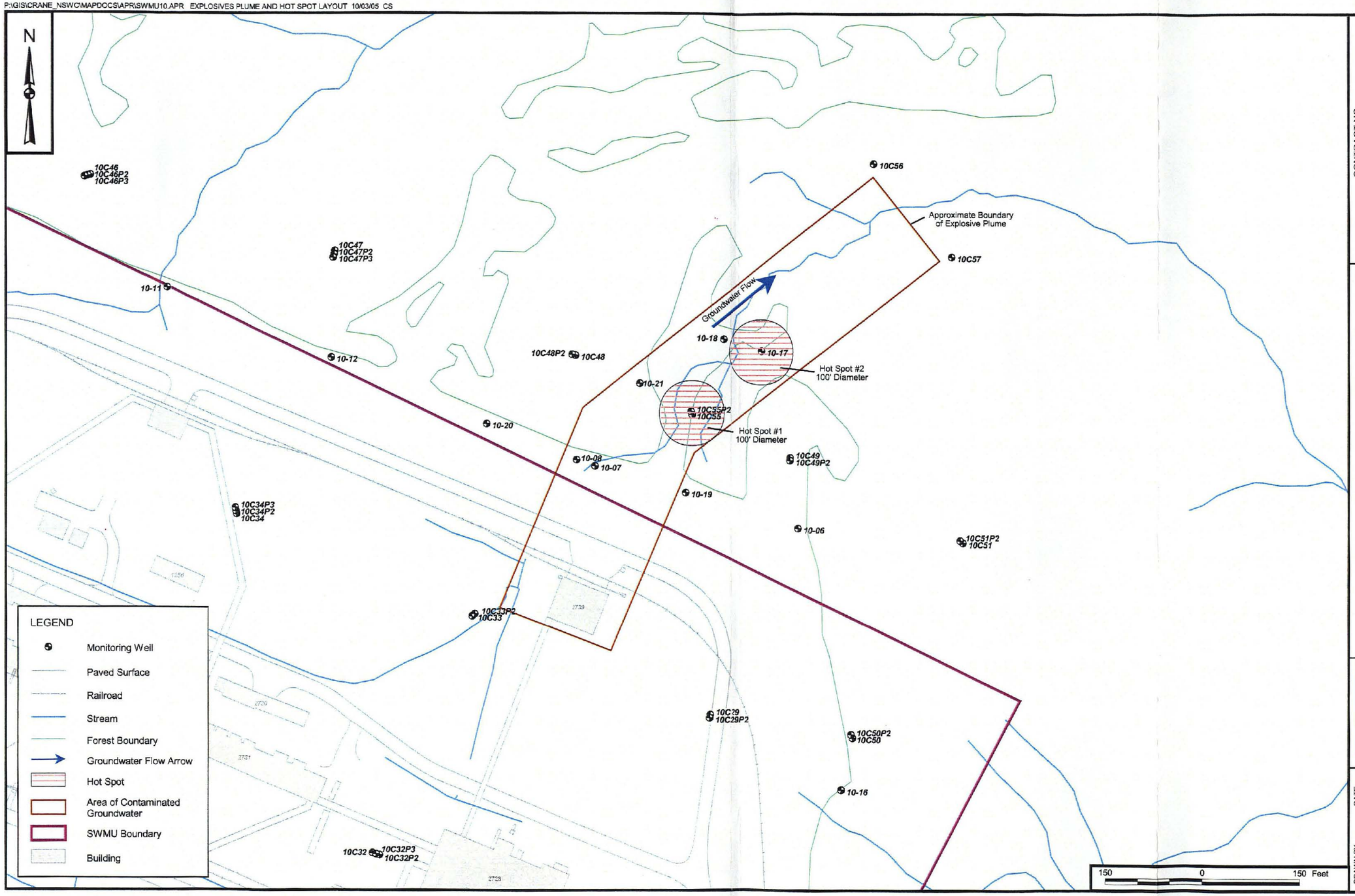
DRAWN BY C. FOSTER DATE 11/11/04

CHECKED BY V. PLACHY DATE 11/29/04

COST/SCHED-AREA

SCALE AS NOTED

P:\GIS\CRANE_NSWC\MAPDOCS\APR\SWMU10.APR EXPLOSIVES PLUME AND HOT SPOT LAYOUT 10/03/05 CS



CONTRACT NO. N4267

APPROVED BY ____ DATE ____

APPROVED BY ____ DATE ____

DRAWING NO. FIGURE A - 2

REV 0

SWMU 10 EXPLOSIVES PLUME AND "HOT SPOTS"
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

NAVFAC

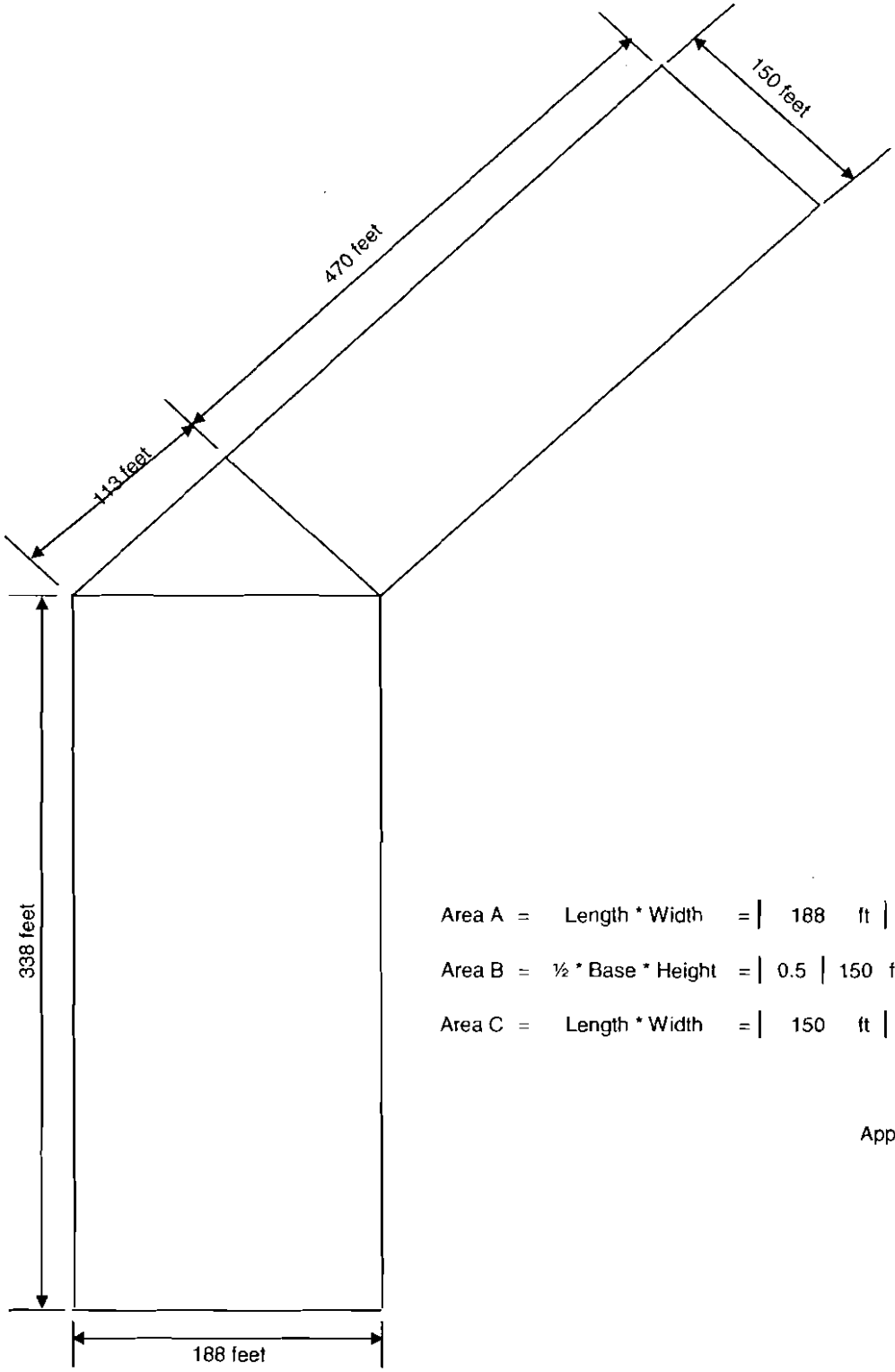
DRAWN BY C. FOSTER DATE 02/25/05

CHECKED BY V. PLACHY DATE 02/25/05

COST/SCHED-AREA

SCALE AS NOTED

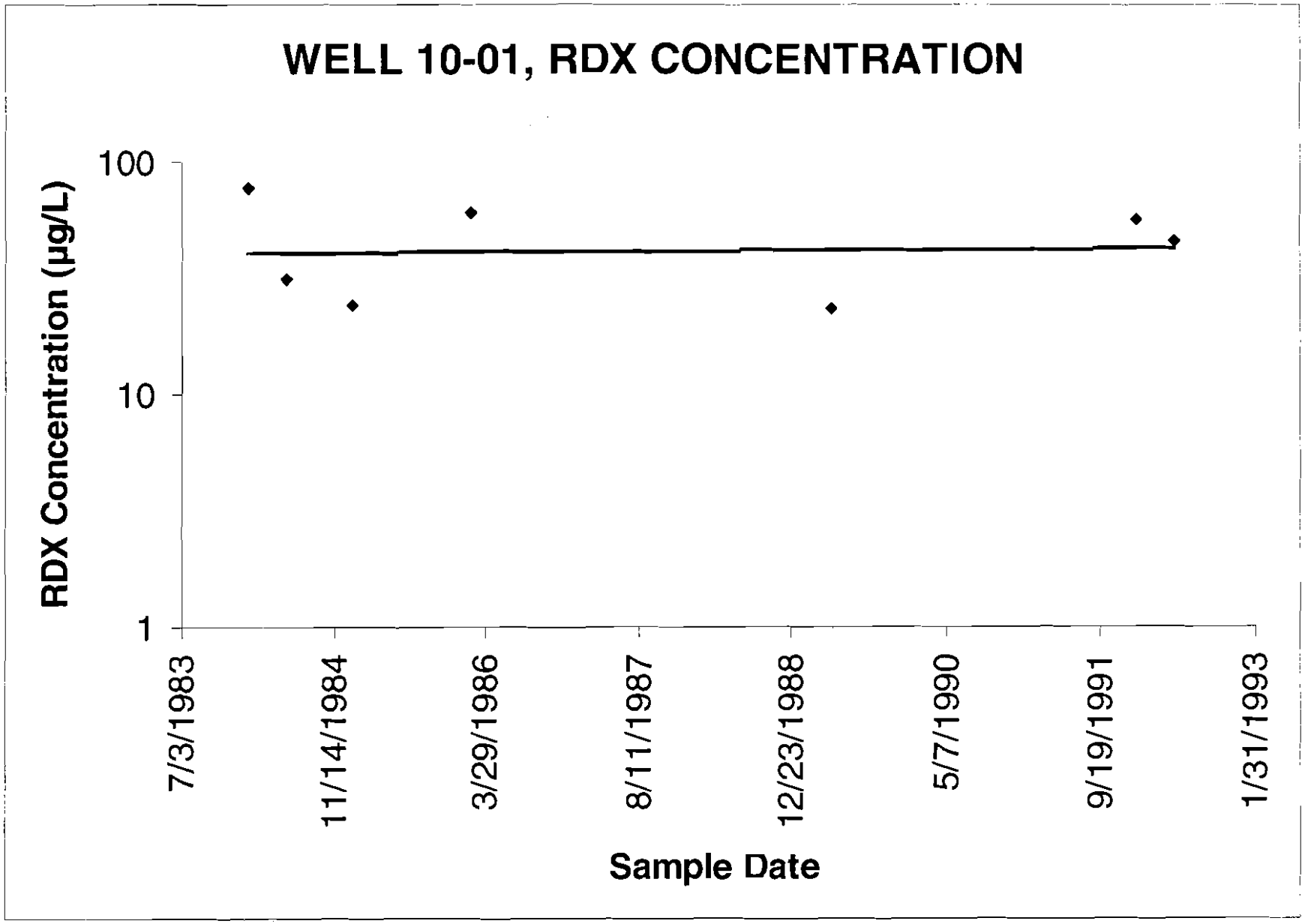
FIGURE A-3
AREA CALCULATIONS FOR RDX-CONTAMINATED GROUNDWATER
CMS REPORT FOR SWMU 10 - ROCKEYE
NSWC CRANE
CRANE, INDIANA

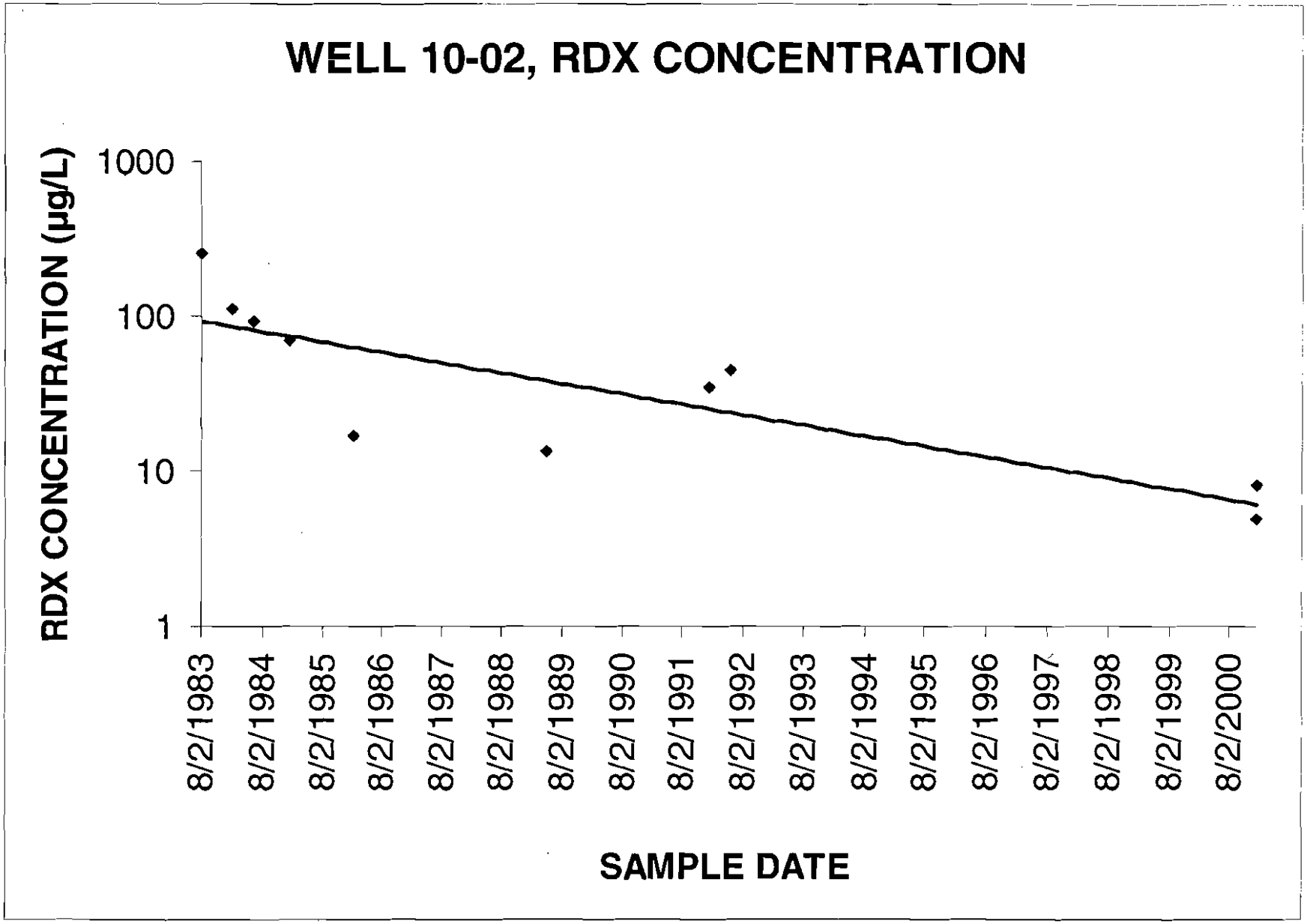


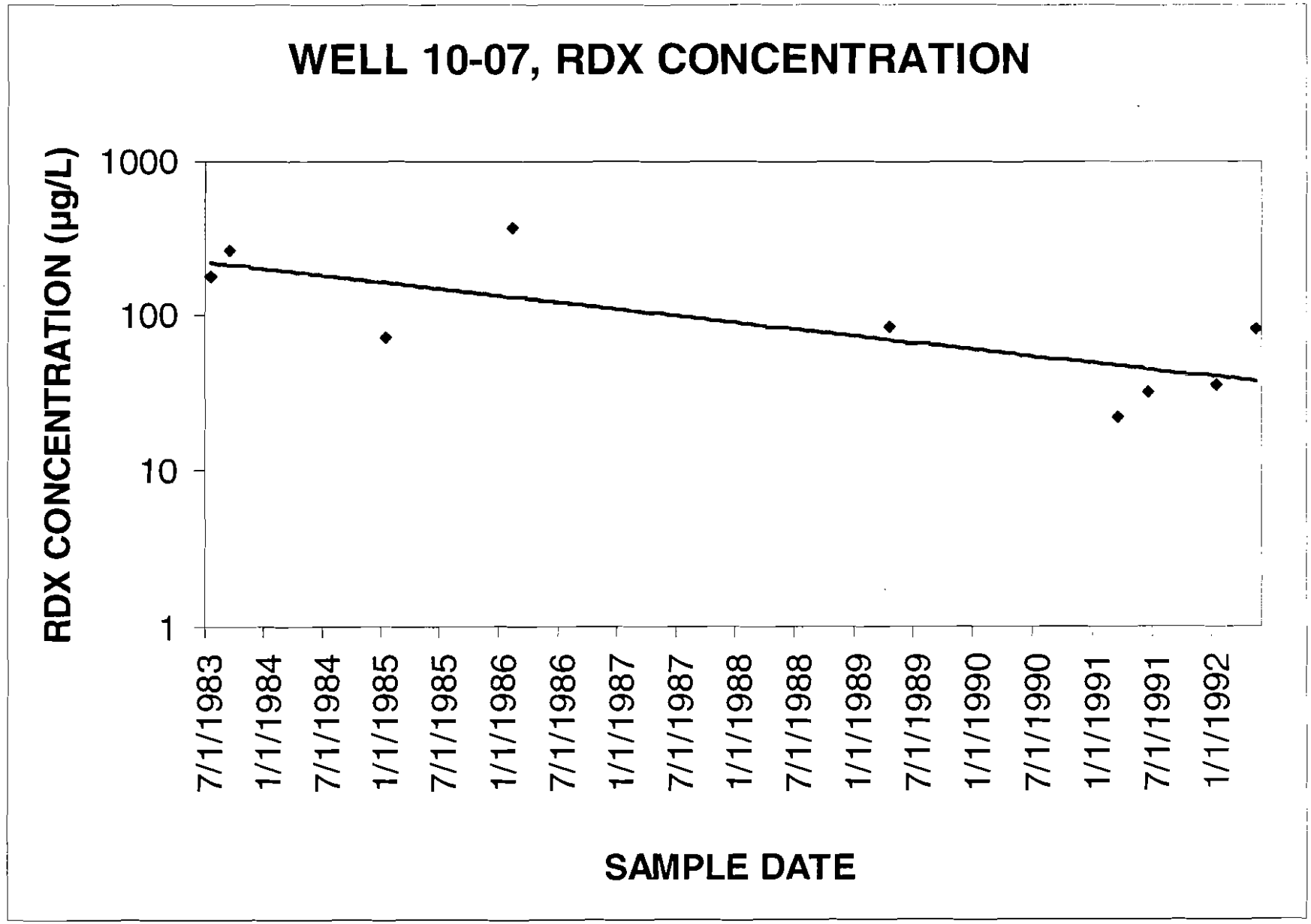
Area A =	Length * Width	=	188	ft	338	ft	=	63,544	ft^2
Area B =	½ * Base * Height	=	0.5	150 ft	113	ft	=	8,475	ft^2
Area C =	Length * Width	=	150	ft	470	ft	=	70,500	ft^2
						Total Area	=	142,519	ft^2
						Approxmimately	≃	150,000	ft^2

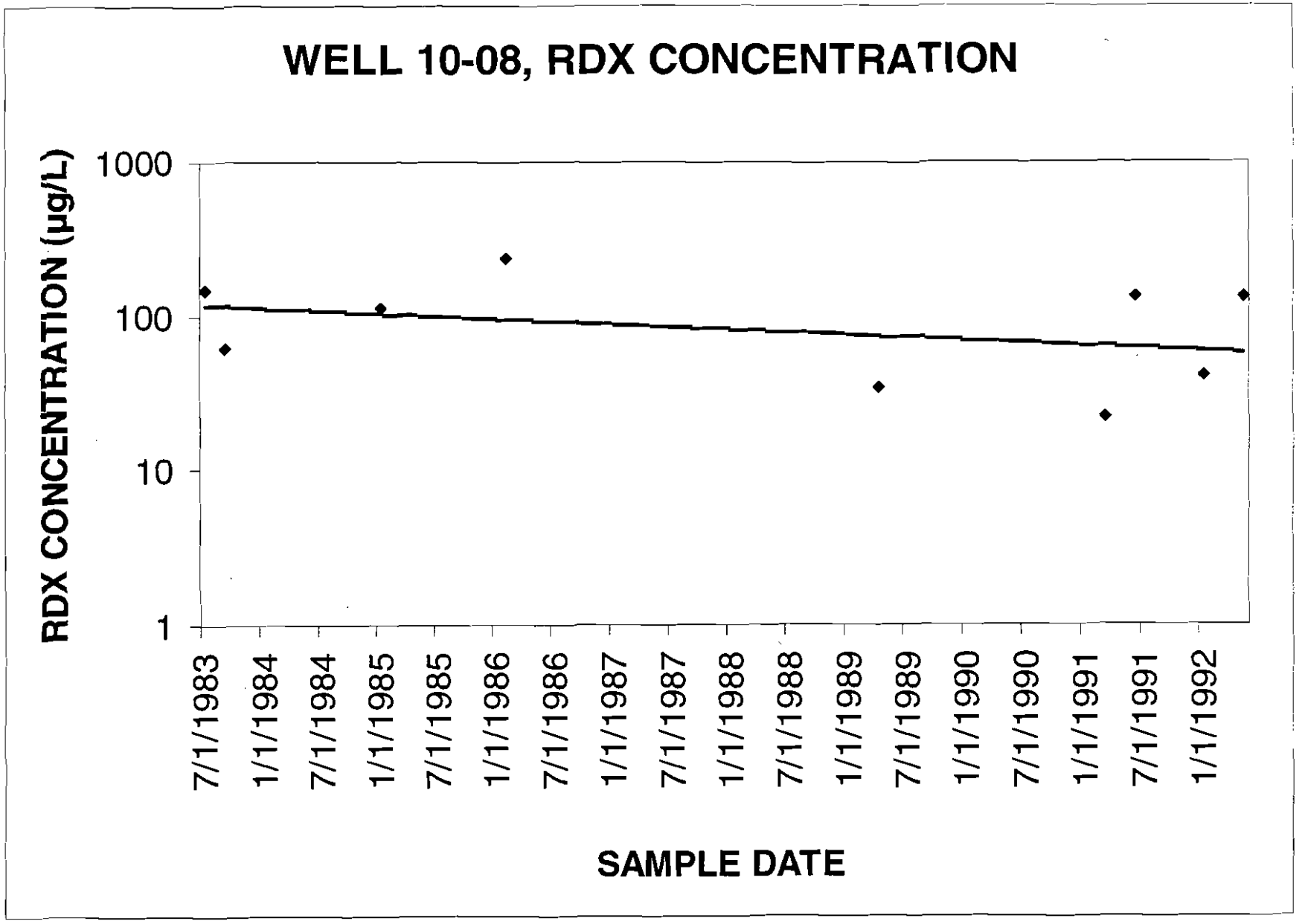
APPENDIX B

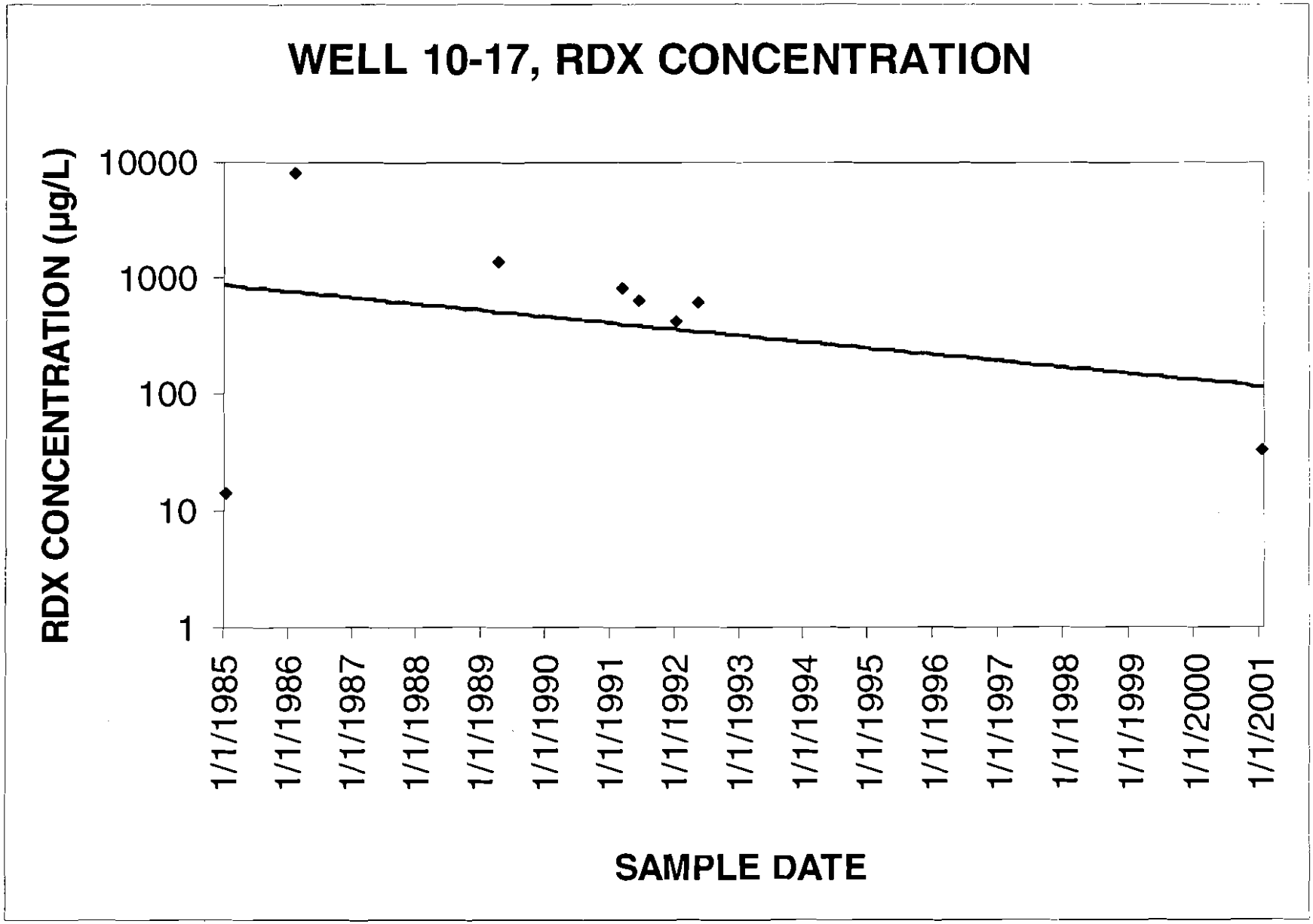
RDX CONCENTRATIONS TRENDS

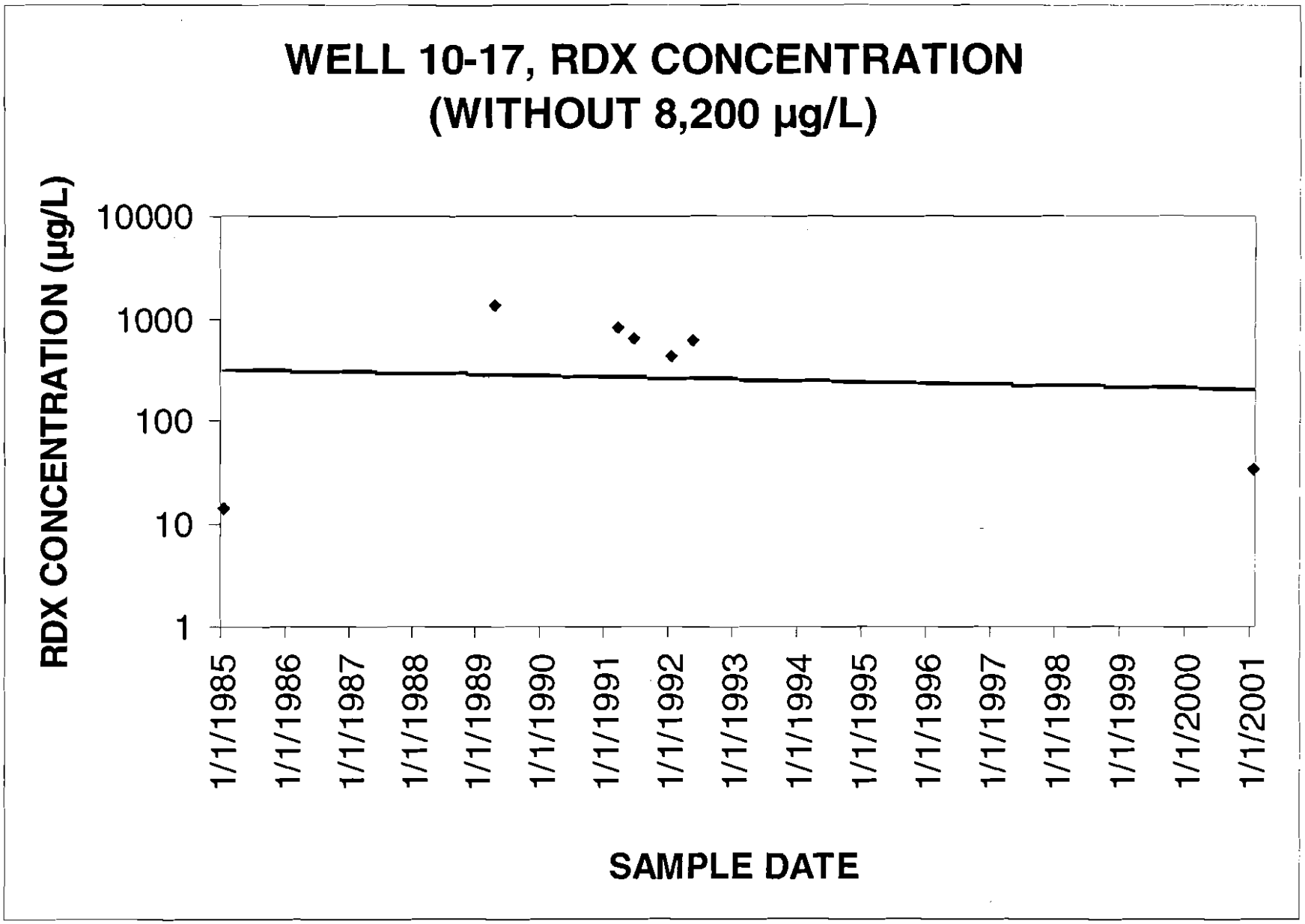

WELL 10-01, RDX CONCENTRATION
RDX Concentration (µg/L)
100
10
1
7/3/1983
11/14/1984
3/29/1986
8/11/1987
12/23/1988
5/7/1990
9/19/1991
1/31/1993
Sample Date

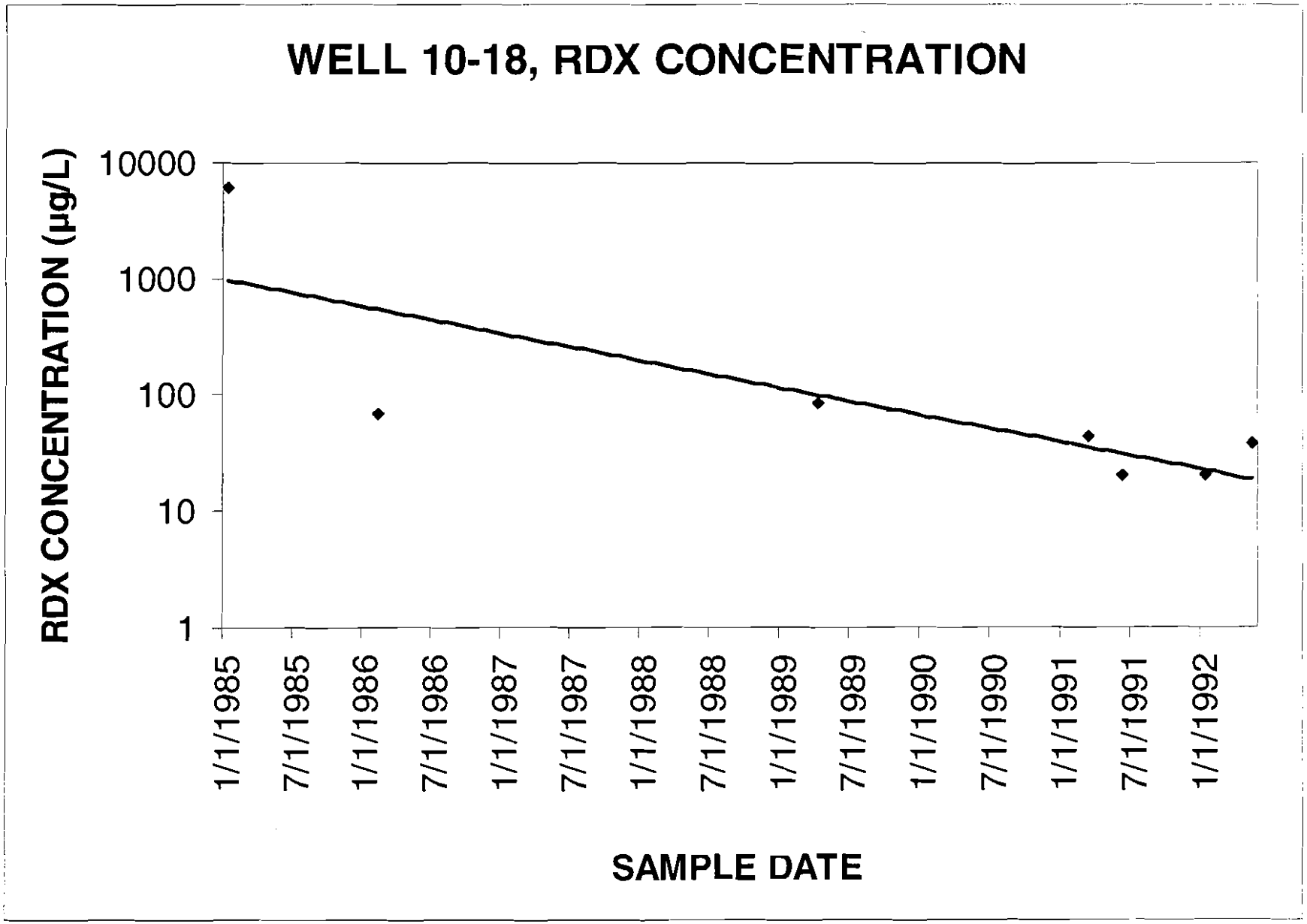

WELL 10-02, RDX CONCENTRATION
RDX CONCENTRATION (µg/L)
1000
100
10
1
8/2/1983
8/2/1984
8/2/1985
8/2/1986
8/2/1987
8/2/1988
8/2/1989
8/2/1990
8/2/1991
8/2/1992
8/2/1993
8/2/1994
8/2/1995
8/2/1996
8/2/1997
8/2/1998
8/2/1999
8/2/2000
SAMPLE DATE

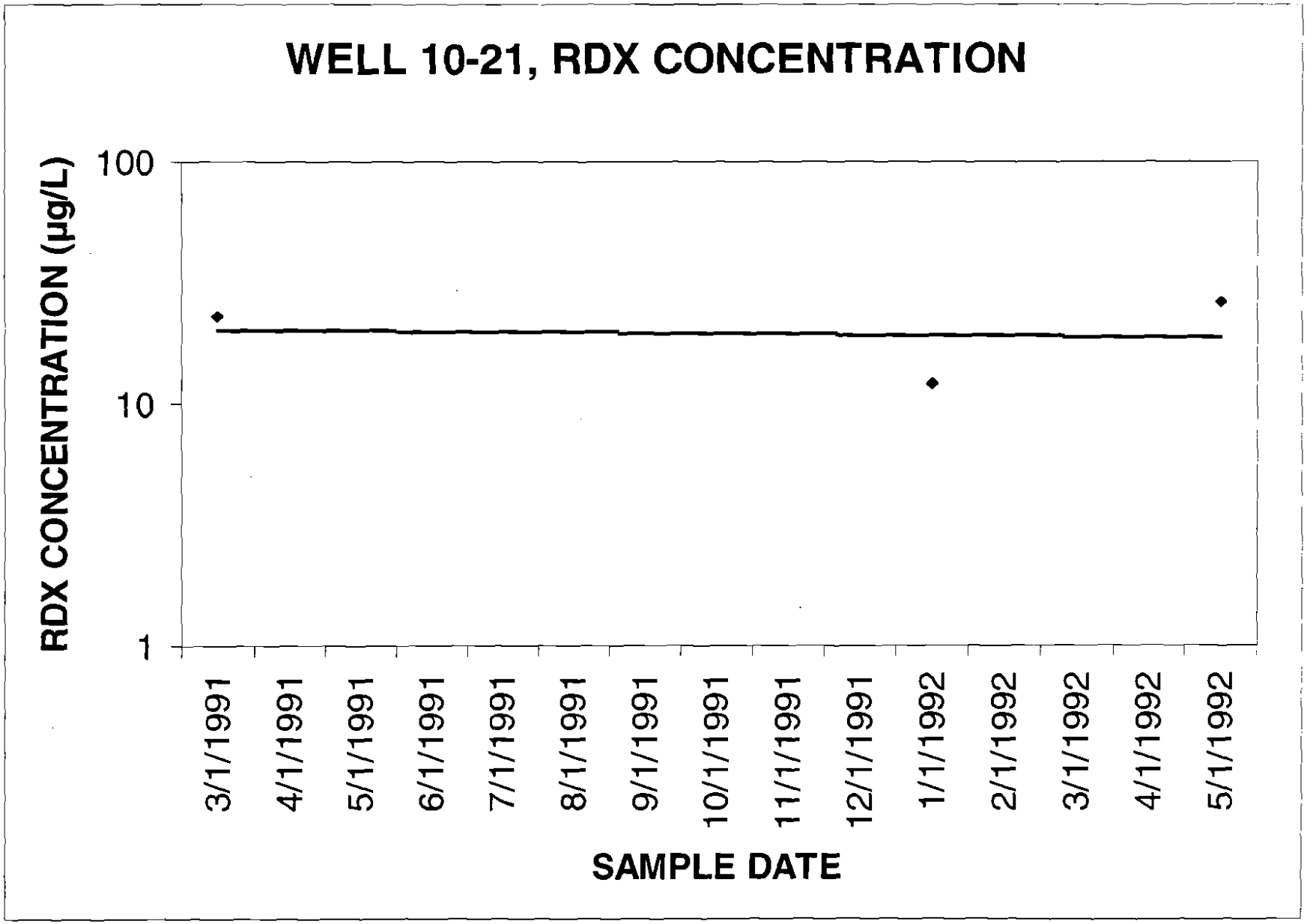

WELL 10-07, RDX CONCENTRATION
RDX CONCENTRATION (µg/L)
1000
100
10
1
7/1/1983
1/1/1984
7/1/1984
1/1/1985
7/1/1985
1/1/1986
7/1/1986
1/1/1987
7/1/1987
1/1/1988
7/1/1988
1/1/1989
7/1/1989
1/1/1990
7/1/1990
1/1/1991
7/1/1991
1/1/1992
SAMPLE DATE

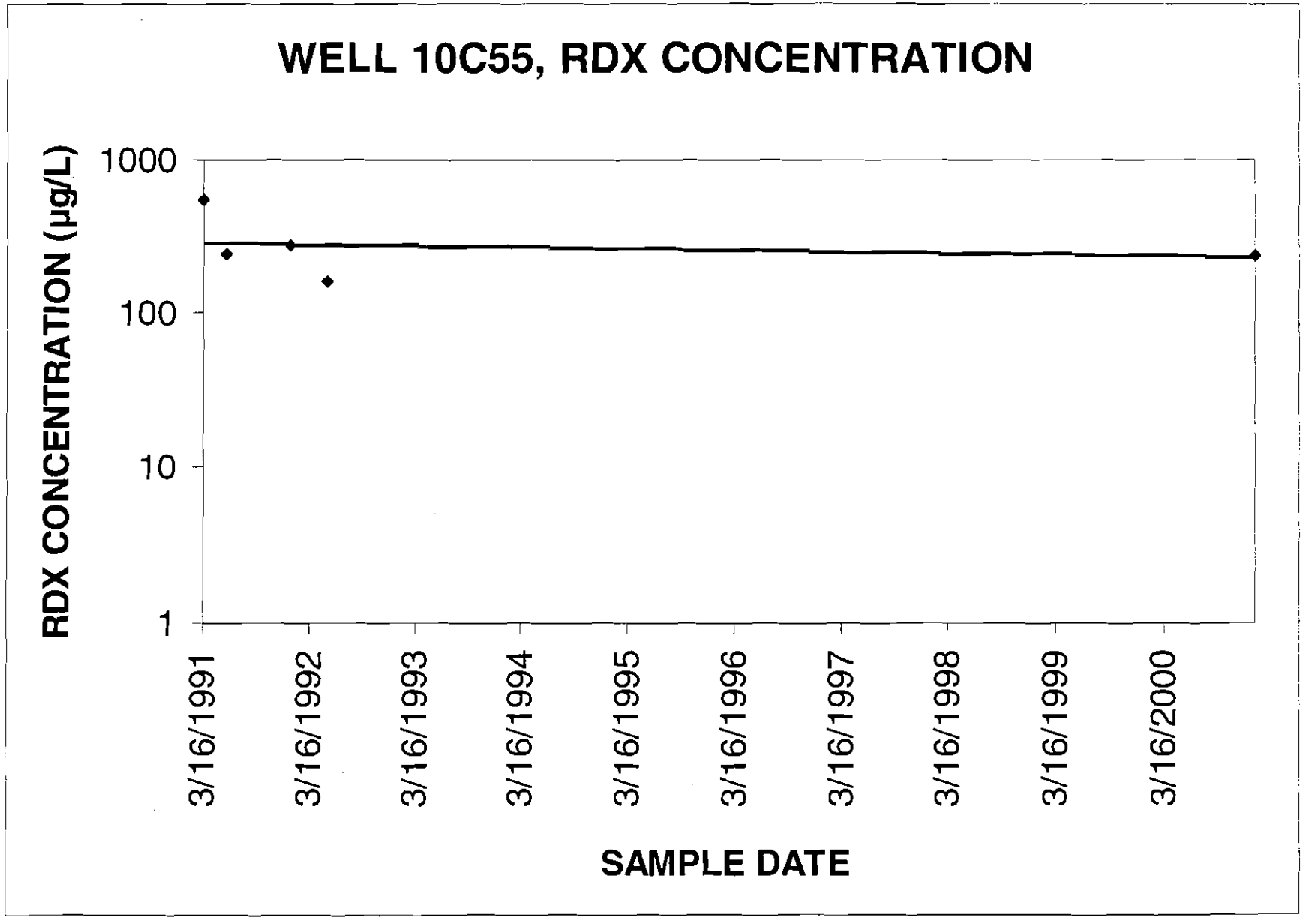

WELL 10-08, RDX CONCENTRATION
RDX CONCENTRATION (µg/L)
1000
100
10
1
7/1/1983
1/1/1984
7/1/1984
1/1/1985
7/1/1985
1/1/1986
7/1/1986
1/1/1987
7/1/1987
1/1/1988
7/1/1988
1/1/1989
7/1/1989
1/1/1990
7/1/1990
1/1/1991
7/1/1991
1/1/1992
SAMPLE DATE

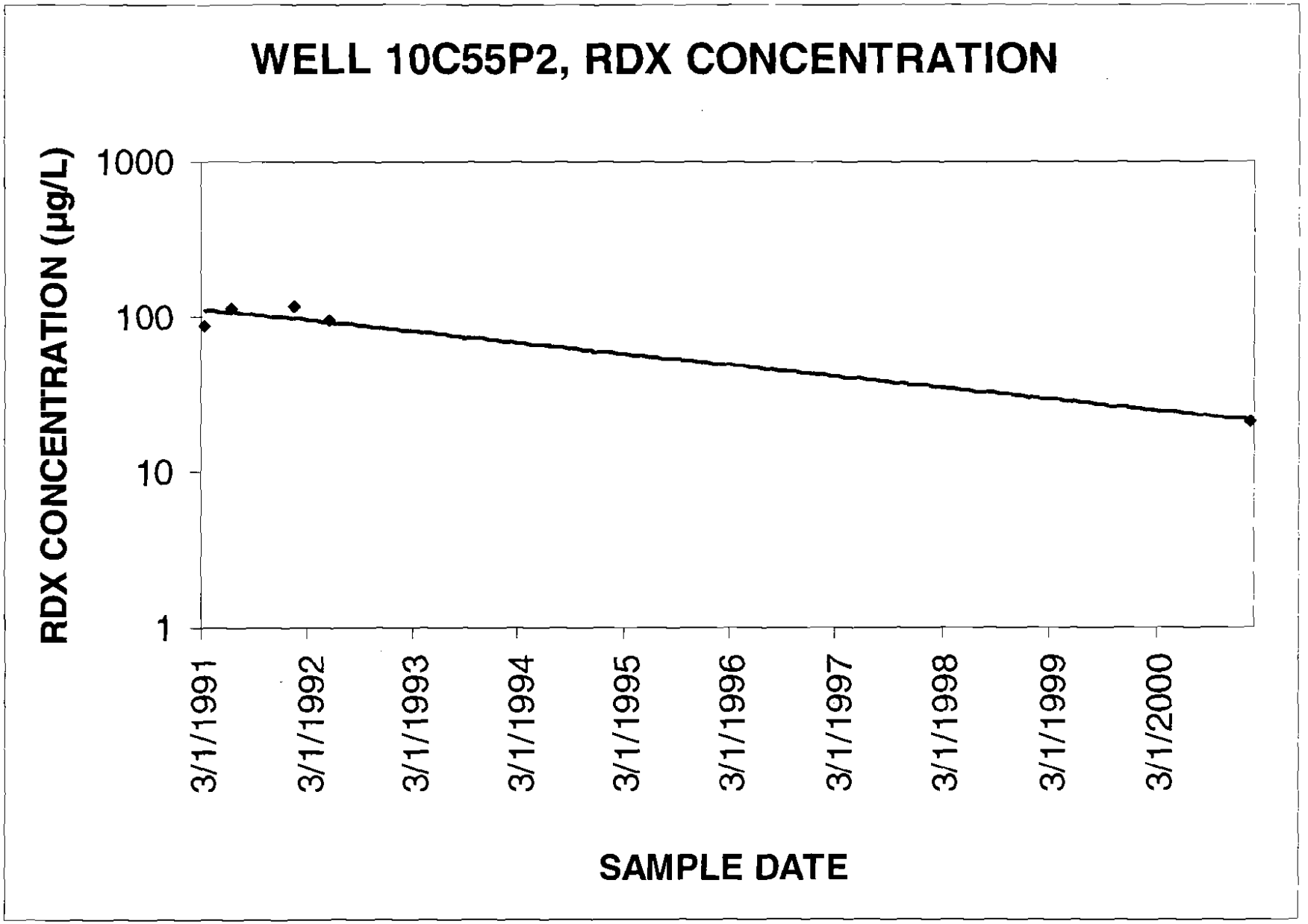

WELL 10-17, RDX CONCENTRATION
RDX CONCENTRATION (µg/L)
10000
1000
100
10
1
1/1/1985
1/1/1986
1/1/1987
1/1/1988
1/1/1989
1/1/1990
1/1/1991
1/1/1992
1/1/1993
1/1/1994
1/1/1995
1/1/1996
1/1/1997
1/1/1998
1/1/1999
1/1/2000
1/1/2001
SAMPLE DATE

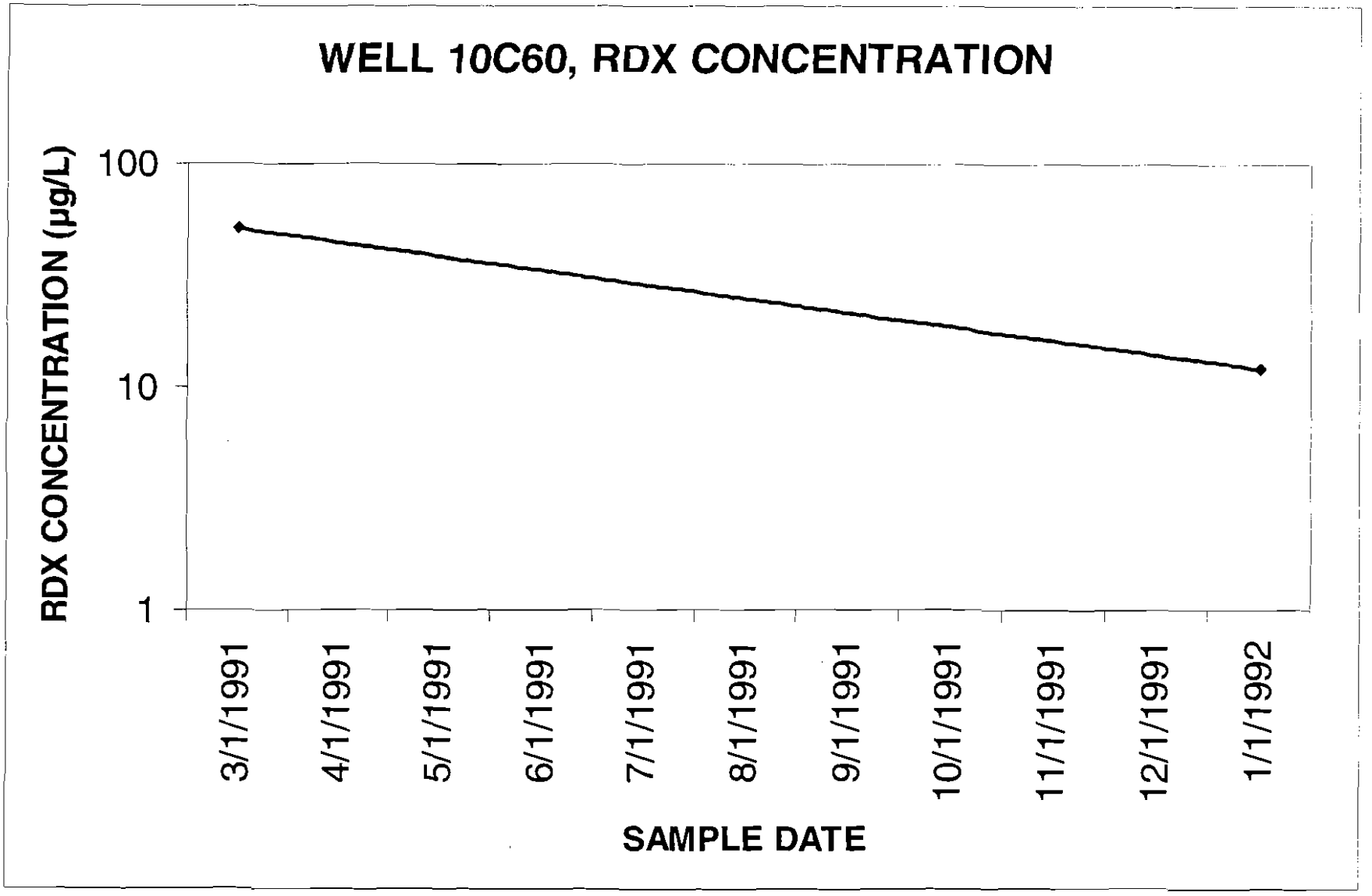

WELL 10-17, RDX CONCENTRATION
(WITHOUT 8,200 µg/L)
RDX CONCENTRATION (µg/L)
10000
1000
100
10
1
1/1/1985
1/1/1986
1/1/1987
1/1/1988
1/1/1989
1/1/1990
1/1/1991
1/1/1992
1/1/1993
1/1/1994
1/1/1995
1/1/1996
1/1/1997
1/1/1998
1/1/1999
1/1/2000
1/1/2001
SAMPLE DATE


WELL 10-18, RDX CONCENTRATION
RDX CONCENTRATION (µg/L)
10000
1000
100
10
1
1/1/1985
7/1/1985
1/1/1986
7/1/1986
1/1/1987
7/1/1987
1/1/1988
7/1/1988
1/1/1989
7/1/1989
1/1/1990
7/1/1990
1/1/1991
7/1/1991
1/1/1992
SAMPLE DATE


WELL 10-21, RDX CONCENTRATION
RDX CONCENTRATION (µg/L)
100
10
1
3/1/1991
4/1/1991
5/1/1991
6/1/1991
7/1/1991
8/1/1991
9/1/1991
10/1/1991
11/1/1991
12/1/1991
1/1/1992
2/1/1992
3/1/1992
4/1/1992
5/1/1992
SAMPLE DATE


WELL 10C55, RDX CONCENTRATION
RDX CONCENTRATION (µg/L)
1000
100
10
1
3/16/1991
3/16/1992
3/16/1993
3/16/1994
3/16/1995
3/16/1996
3/16/1997
3/16/1998
3/16/1999
3/16/2000
SAMPLE DATE


WELL 10C55P2, RDX CONCENTRATION
RDX CONCENTRATION (µg/L)
1000
100
10
1
3/1/1991
3/1/1992
3/1/1993
3/1/1994
3/1/1995
3/1/1996
3/1/1997
3/1/1998
3/1/1999
3/1/2000
SAMPLE DATE


WELL 10C60, RDX CONCENTRATION
RDX CONCENTRATION (µg/L)
100
10
1
3/1/1991
4/1/1991
5/1/1991
6/1/1991
7/1/1991
8/1/1991
9/1/1991
10/1/1991
11/1/1991
12/1/1991
1/1/1992
SAMPLE DATE

APPENDIX C

"HOT-SPOTS" IN-SITU BIOREMEDIATION PROPOSAL

Emulsified Oil Amendment
In-Situ Bio-Enhancement System
SWMU 10 Groundwater
NSWC Crane, Indiana
CTO No, 0256

EOS Proposal No. EOS05132P

Prepared For:

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Prepared By:

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Raleigh, NC 27609

February 1, 2005

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February 1, 2005

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Pittsburgh, PA 15220

Sent Via email: GlorieuxJ@ttnus.com

Reference: **Emulsified Oil Amendment,** In-Situ Bio-Enhancement System, SWMU 10 Groundwater, NSWC Crane, Indiana, CTO No, 0256
EOS Proposal No. EOS05132P

Dear Mr. Glorieux:

We appreciate your considering **EOS®** as an alternative for enhanced *in situ* bioremediation for your project site. Considering the information that you have provided, we have tailored our proposal to specifically address your questions as well as provide supporting data as to why **EOS®** is a superior product to the other substrates that you are considering.

Brief Description of EOS®

The **EOS®** process (US patent 6,398,960; international patents pending) covers the injection of emulsified, food-grade oil into the contaminated aquifer to stimulate anaerobic biodegradation of a wide variety of chlorinated solvents (e.g., PCE, TCE, TCA, cis-DCE and 1,2-DCA), energetic materials (perchlorate, RDX, TNT, etc.), nitrates and some heavy metals, into non-toxic end products. The **EOS®** amendment is easy to handle, has a low viscosity similar to milk, does not clog aquifers, can be distributed over a larger volume of the aquifer and lasts well in excess of three years. In a two-step reductive dechlorination reaction carried out by microorganisms residing in or added to the aquifer, the oil is slowly degraded with the consumption of oxygen and the production of hydrogen. The hydrogen is then available to support reductive dechlorination. Degradation of other compounds may occur by microbes using **EOS®** for both carbon and energy.

EOS® Versus Other Emulsified Oils

EOS® has more organic carbon per pound than other commercially available emulsified oil amendments.

EOS Remediation manufactures our substrate at an emulsion blending facility to produce a micro-emulsion with uniform droplets significantly smaller than soil pore spaces (see photo on page 2). **EOS® 598 B42**, engineered for effective distribution in the subsurface, contains a complex mixture of organic substrates to enhance bacterial growth and reductive dechlorination and is approximately **74%** by weight organic carbon. **EOS® 598 B42**, an emulsified product developed after years of research and testing by

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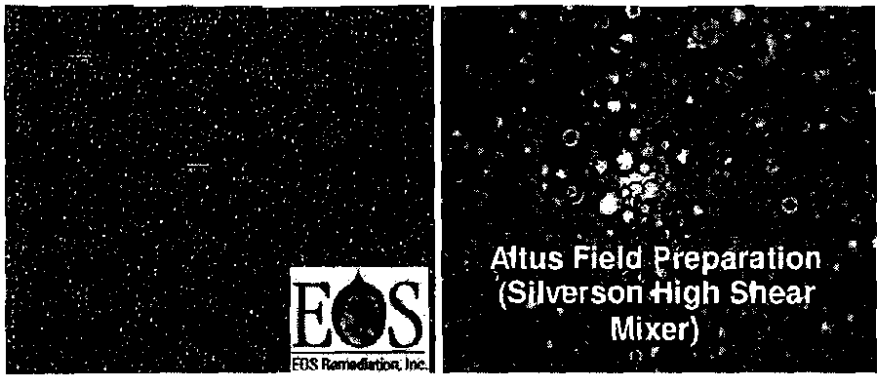
leading scientists and engineers, includes easily biodegradable substrates for rapid bacteria growth (e.g., **lactate**), slowly degradable substrates to support long-term respiration (e.g., edible oil, 59.8% by weight), and amino acids, trace minerals and B vitamins (for enhancing growth of dechlorinating microorganisms, 2% by weight). Other products are only 45% by weight vegetable oil. Our **EOS® 598 B42** contains **33% more oil per pound**.

EOS® 598 B42 provides the added value of an optimal diet for the halorespiring bacteria.

Several studies have shown that growth of dechlorinating microorganisms may be enhanced by providing these bacteria with amino acids and /or vitamins (Deweerd et al, *Appl. Environ. Micro*, 1929-1934, 1991; Holliger et al, *Arch. Microbiol*, 313-321, 1998; Maymo-Gatell et al, *Science*, 1568-1571, 1997). Consequently, microbiologists often include vitamin B12 and yeast extract to generate conditions for optimum growth (Morse et al, Draft Technical Protocol: A Treatability Test for Evaluating the Potential Applicability of the Reductive Anaerobic Biological In Situ Treatment Technology (RABITT) to Remediate Chloroethenes, ESTCP, http://www.estcp.org/documents/techdocs/Rabitt_Protocol.pdf, 1998). With **EOS® 598 B42**, you get the added value of an optimal diet for the halorespiring bacteria. Other products do not include amino acids, trace minerals, B vitamins and the additional B12 supplement that that are found in **EOS® 598 B42**.

EOS® Droplet Size

EOS® is prepared to have small, uniformly sized oil droplets that can be effectively distributed in a wide variety of aquifer materials. Over 90% of the droplets are less than 2 microns in diameter with a mean droplet size of approximately 1 micron (see photo below). While it is possible to prepare emulsions with smaller droplets, there is no significant benefit. The pore diameters of silty and clayey sands typically vary between 20 and 100 microns. 1 to 2 micron droplets pass easily through these pores with negligible clogging (see Coulibaly and Borden, 2004). In addition, injection of oil droplets into very small pores would be wasteful since most bacteria are larger than 1 micron and could not access oil in the smallest pores.



The image on the left shows the emulsified oil substrate manufactured by EOS Remediation with uniform droplets significantly smaller than soil pore spaces. The image on the right shows an emulsion that was field processed using a Silverson high shear mixer.

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EOS® Versus Soybean Oil Based Products High in Unsaturated Fats

Vendors that sell soybean oil based substrates that are higher in unsaturated fats (e.g., CAP18) make the argument that unsaturated fats such as linoleic acid are inhibitory to methanogens and so the oil should last longer. There are several problems with this argument.

- The firms that grow Dehalococcoides (DHC) microorganisms tell us that you cannot enrich for DHC using selective inhibitors since virtually anything that inhibits methanogens will very rapidly kill off any Dehalococcoides microorganisms that you inject or are present.
- Happily, the inhibition effect claimed for the substrates that are high in unsaturated fats doesn't actually occur. "Regular" soybean oil is already 85% mono and polyunsaturated fats. Even if these substrates were 100% unsaturated fat, you would only increase the unsaturated fat content by 15%. It would be less expensive to just inject more soybean oil.

National Recognition / Case Studies

EOS® has been proven effective in over 40 scientific publications.

When it comes to successful bioremediation of recalcitrant compounds, having the right talent on your team and using the right approach and materials is critical. Backed by leading scientists and engineers with over 30 years of success, documented in over 40 scientific publications (see attached list of representative publications), and supported by a premier R&D program, you can be assured that by using **EOS®** you are selecting the best product for this application in the industry today. This experience is not available with other vendors.

At EOS Remediation, *in-situ* anaerobic bioremediation is our specialty. A Fortune 50 Company research center and international consulting firms have independently verified our enhanced oil emulsion, **EOS®**, as a technically superior remedial product.

The technology has been featured twice in Pollution Engineering, including once as the cover story. The cover story and feature article from Pollution Engineering magazine can be accessed through the following hyperlinks:

http://www.pollutioneng.com/pe/cda/articleinformation/coverstory/bnpcoverstoryitem/0,,111043,00+en-uss_01dbc.html

and

www.pollutionengineering.com/CDA/ArticleInformation/features/BNP__Features__Item/0,6649,123560,00.html

EOS® has also been featured in the September 2002 issue of EPA Tech Trends, http://www.clu-in.org/download/newsltrs/tnandt0902.pdf.

General Design Considerations

*Inexpensive field support for **EOS®** is available nationwide, upon request.*

The **EOS®** concentrate is easily diluted in the field with water and can be injected under low pressure to readily disperse the emulsion away from the injection points. This allows broader coverage and wider impact area using fewer injections. **EOS®** can be injected by direct-push apparatus in shallower aquifers or via drilled injection wells constructed to access deeper or specific zones of

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contamination. Upon request, we can send someone to the site to assist at minimal additional cost. We will serve your interests however you like.

*Injection approach for **EOS®** can be easily modified to fit site conditions.*

Field Mixing and Injection Approaches: One of the design considerations of using emulsified oil is the ability to move the material away from the injection point to reduce the number of injection points required. There are two mixing methods currently being used in the field. Each method results in the same effect. The first is more of a batch process where a dilute emulsion mixture is prepared in a container. The emulsion is injected and then followed with clear (potable) water or groundwater. The second is a more continuous process where the emulsion concentrate is introduced into the water stream during the injection. The calculated treatment volume for either approach depends on the total volume of fluid (emulsion and water) injected.

- **Batch Mixing With Clear Water Chase:** Mix the required volume of emulsion concentrate with at least 4 parts water in a suitable container and inject using a low pressure pump outfitted with a manifold, flow totalizer, and pressure gage as modified for the number of wells being injected simultaneously. After the required volume of emulsion has been injected, chase the emulsion with clear water using the same injection equipment, continuing until the required total volume of fluid has been injected.

- **Continuous Mixing "On the fly":** Use a metering device (e.g., Dosatron) or a controlled feed pump to introduce the concentrated emulsion into the stream of water being injected. The manifold system would be the same as described above. Continue injecting until the required volumes have been injected. Dilution rates are limited with this equipment, but suitable within the design limits of the equipment, usually 5 to 10 percent of the total flow.

Groundwater Recirculation: Recirculation (groundwater recovery and re-injection) can be used to eliminate or reduce the need for an accessible supply of potable water used for mixing. Consultants and practitioners should note that the reuse of groundwater is subject to regulation by many States and specific requirements for it's treatment and/or handling may be needed. Nevertheless, the most common approach is to pump groundwater out of one or more wells and inject the groundwater along with emulsion into one or more injection wells. The injection is continued until the design volume has been emplaced or until there is no longer evidence of emulsion in the recovery well (indication the emulsion has sorbed and is no longer mobile).

Some designs stipulate that the process be reversed with additional emulsion being injected into the previous recovery well and vice versa. The decision to perform the injection in two steps is based on the transport of the emulsion through the subsurface. If the emulsion travels to and is recovered in the recovery well during the initial injection, then there may be little benefit in performing the second step injection. On the other hand, if emulsion is not observed in the recovery well, the reverse recirculation phase should be considered.

In general, recirculation continues until the design volume has been injected or until the emulsion is no longer mobile. This time frame can range from a few days to several weeks, dependent on the aquifer characteristics and well separation distances. In most applications, with appropriate simple controls, the recirculation step can be unattended. Visual milkiness or cloudiness are indicators of emulsion breakthrough. Comparison of several sets of laboratory TOC analyses on groundwater recovered from the recovery well(s) is the best indicator of emulsion sorption/mobility.

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Distance of Oil Transport

*The surface charge characteristic of **EOS®** is designed for good transport and retention.*

An important consideration in evaluating an amendment is the transport, dispersion and retention of edible oil emulsions in a wide variety of soil types, which can be described by colloid transport theory. When the oil droplets are significantly smaller than pore spaces (as is the case with **EOS®**), oil retention is controlled by the chemical properties of the droplet and soil surfaces. The surfactants in our emulsified oil amendment have significant benefits for **TtNUS**. The surfactants we use have been tested and chosen so sorption to the aquifer sediment is relatively low. Therefore, you can spread a relatively small amount of **EOS®** over a larger volume of aquifer. Other emulsion blenders make their emulsions, in part, with lecithin. Lecithin contains functional groups with both positive charges (ammonia groups) and negative charges (phosphate groups). As a consequence, lecithin-based emulsions adsorb very strongly to clays and you need more substrate than **EOS®** to treat the same volume of aquifer.

EOS® is designed to move easily through most formations at low pressure (typically 5 to 10 psi as measured at the wellhead). Low injection pressures are desirable because they minimize the potential of hydraulic fracturing and allow use of more-commonly available lower pressure centrifugal pumps in lieu of a high-pressure piston or positive displacement pumps.

When situations warrant, the low viscosity of **EOS®** allows it to be gravity drained into injection wells from portable tanks or totes at remote sites where electric power is not available. Applicators have reported on some sites visual indications of **EOS®** as noted by cloudiness or milkiness in wells located 20 to 50 feet from the injection point(s).

Aquifer Response Time Following Application

From a practical standpoint, measurement of dissolved oxygen and oxidation-reduction potential (ORP) are the best indicators of overall aquifer condition. It has been our experience that the ORP measurements are the better indicator and a reading of –50 mV or less is a good indicator of anaerobic aquifer conditions. This coupled with laboratory analyses of groundwater for ferrous iron, nitrate, sulfate, and methane could be used to confirm reducing conditions are present.

By design, **EOS®** promotes a rapid change from oxidative to reducing conditions because of the incorporated lactate that initiates a quick metabolic response. Our experience suggests you will begin to see a reduction in ORP within a week of injection.

EOS® Designed to Maximize Product Longevity in the Subsurface

EOS® has been widely used throughout the United States. Much research and development has been published in journals showing the effective distribution of **EOS®**. **EOS®** is completely miscible with water and easily disperses with groundwater after injection. The surface charge characteristic of **EOS®** oil droplets is designed to maximize product longevity in the subsurface. Our oil droplets have negative surface charges and are retained when they collide with positively charged sediment surfaces and stick. There has been no evidence of the upward migration of the oil droplets.

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Little Impact on Groundwater Flow

*Easily dispersed **EOS®** oil droplets yield low appreciable permeability loss.*

Coulibaly and Borden (2004) conducted column experiments to evaluate emulsion transport and associated permeability loss in sands with varying clay contents. They concluded that **EOS®** has very little effect on hydraulic conductivity. However, they concluded when a non-emulsified oil is injected, hydraulic conductivity loss is much greater and does not return to preinjection levels during the post-emulsion water flush (Coulibaly and Borden, 2004; Ullmann, 2004). **EOS®** has been shown not to significantly impact groundwater migration or flow.

Suggested Quantity of Electron Donor

EOS Remediation has completed a brief evaluation of the data package you provided us via email on Thursday, January 20, 2005. We suggest that you consider injecting **28** 55-gallon drums (420 lbs per drum) of **EOS® 598 B42**, 14 drums per location. For each of the two locations at SWMU 10, we recommend the following design:

1. Install wells in a five spot pattern with one well in center of a square and one well at each corner of the square. If possible, use an existing monitor well as the center well.

2. Install pumps in four corner wells and pump water into the center well. Set up a flow controller with a high level control that would shut down the pumps if the water level in the center well gets too high.

3. Dilute 10 drums (550 gallons) of **EOS®** concentrate with 2,200 gallons of water (1 part **EOS®** to 4 parts water) and inject the emulsion into the center well. We estimate based on the data you furnished that the corner wells will produce approximately 0.5 to 1.0 gpm. Therefore, the injection should require a level-of-effort of approximately one to two weeks. We suggest that you continue recirculating groundwater water until the emulsion is observed in the corner wells.

4. Move one of pumps from corner well and install it in the center well. Pump groundwater from center well into the four corner injection wells. For each corner well, dilute one drum of **EOS®** concentrate with 4 parts water and inject the resulting emulsion and chase with approximately 1,000 gallons of water per well.

5. Once **EOS®** is injected, remove all pumps and aboveground equipment and monitor.

This design will require 14 55-gallon drums of **EOS®** concentrate for each treatment area. Based on the data you furnished, we recommend our **EOS® 598 B42** emulsion.

Price Proposal

Our soybean oil emulsion line includes three products. A comparison of these three emulsions is provided in Table 1.

"Use or disclosure of data contained on this sheet is subject to the restriction on the title page of this proposal or quotation."

Table 1
Comparison of EOS Soybean Oil Based Emulsion Product Lines

Ingredients / Composition	EOS Remediation, Inc. EOS® 450 (% by Weight)	EOS® 598 (% by Weight)	EOS® 598 B42 (% by Weight)
Soybean Oil (food grade)	45	59.8	59.8
Long Chain Fatty Acids	8	0	0
Sodium Lactate / Lactic Acid	4	4	4
Food Additives/Emulsifiers/Preservatives	6	10.1	10.1
Extracts	0	0	2
Water	Balance	Balance	Balance
Percent Organic, by weight	63	72	74
B12 Supplement	No	No	Yes

The unit rates for our soybean oil based emulsions are provided in Table 2.

Table 2
Unit Rate Quote

Volume	EOS® 450		EOS® 598		EOS® 598 B42	
	Unit Rate per Drum	Unit Rate per lb	Unit Rate per Drum	Unit Rate per lb	Unit Rate per Drum	Unit Rate per lb
Quantities of less than 12 drums	$750.00	$1.79	$950.00	$2.26	$1,260.00	$3.00
12 to 48 drums	$600.00	$1.43	$760.00	$1.81	$1,050.00	$2.50

The above unit rates are based on shipping the product in 55-gallon drums (420 pounds per drum). All shipments are FOB Delafield, Wisconsin. Shipments will be by common carrier. Lift gates must be specified and may incur additional expense. Product is also available in bulk tanker or 270 gallon totes. If tote shipment is requested, a $125 up charge per tote shall apply.

Our quote to provide 28 drums of **EOS® 598 B42** is as follows:

QUANTITY	DESCRIPTION	UNIT RATE	AMOUNT
28	**EOS® Concentrate 598 B42** (Approximately 74% by weight organic substrate)	$1,050.00/drum	$29,400.00
	EOS® B12 Supplement (500 ml per 55-gallon drum)	Included	
		Subtotal	**$29,400.00**
		Sales Tax	NA
		Shipping & Handling	$2,240.00
		Total	**$31,640.00**

Optional Services

We can arrange for on-site assistance, if requested. This on-site technical assistance would include individuals that have been instrumental in the development of the emulsified oil

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technology and have relevant work experience implementing this technology on multiple chlorinated solvent sites. The rate for this service is $1,000/day for each specialist requested, plus travel expenses.

Terms and Conditions of Sale

The attached Terms and Conditions are incorporated as a part of this quotation. The quotation does not include sales tax, since EOS Remediation does not have an office location within the State of Indiana. TtNUS will be responsible for any applicable use tax. Upon acceptance of our proposal, we will need approximately two weeks to process your order. We estimate that the transit time to Indiana is approximately two days.

Closing

We look forward to assisting you with your groundwater remediation needs.

Sincerely,
EOS Remediation, Inc.

Gary Birk
Director of Marketing & Sales

cc: Mark Kluger

†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960 and several international patents pending.
††EOS® is a registered trademark of Solutions Industrial & Environmental Services, Inc.

EOS Remediation, Inc.
LIMITED WARRANTY

Seller warrants that the product sold is made with EOS® with specifications as specified on face of invoice. Seller makes no other warranty of any kind respecting the product, and expressly disclaims all other warranties of whatever kind respecting the product, including all warranties of merchantability and fitness for particular purpose. Buyer's sole remedy for breach of this limited warranty shall be refund of the purchase price, provided that any unused portion of the product is promptly returned to seller. Under no circumstances will seller be liable for any consequential or other damages. Notice of defect or other breach shall be given to Seller by Buyer in accordance with the terms of the Uniform Commercial Code as adopted in North Carolina.

OTHER TERMS AND CONDITIONS

RESALE AND OTHER USE. Buyer agrees to transmit a copy of this Limited Warranty and Other Terms and Conditions set forth herein to any and all persons to whom Buyer sells, or otherwise furnishes the products and/or services provided Buyer by Seller and Buyer agrees to indemnify Seller for any liability, loss, costs and attorney's fees which Seller may incur by reason, in whole or in part, of failure by Buyer to transmit the Terms and Conditions as provided herein. Seller disclaims to the full extent permitted by law all warranties, expressed or implied, including any implied warranty of merchantability, fitness for any particular purpose or against infringement, to any person other than buyer. Where warranties to a person other than buyer may not be disclaimed under law, seller extends to such a person the same warranty seller makes to buyer or lessee as set forth herein, subject to all disclaimers, exclusions and limitations of warranties, all limitations of liability and all other provisions set forth in this Limited Warranty and Other Terms and Conditions.

BUYER'S RESPONSIBILITY AND INDEMNITY. By purchasing the products from Seller, Buyer represents and warrants that it, it's agents, subcontractors and other parties which may utilize the products recognize the risks inherent in the use of the products and that all appropriate personnel are trained and knowledgeable in the proper use and application of the products sold. Instructions, technical advice, or other information provided by Seller are provided as guidelines for the convenience of Buyer only and should not be construed to substitute for appropriate engineering and geologic design by qualified professionals. Requirements for use and the effectiveness of the products will vary according to the specific circumstances and Seller shall not be responsible for the effectiveness of the product, including, but not limited to, the prevention of the spread of environmentally hazardous material. Buyer agrees to defend and indemnify seller of and from any and all claims or liabilities asserted against seller in connection with the manufacture, sale, delivery, resale, or repair or use of any goods covered by or furnished hereunder arising in whole or in part out of or by reason of the failure of buyer, its agents, servants, employees or customers to follow instructions, warnings or recommendations furnished by seller in connection with such goods, by reason of the failure of buyer, its agents, servants, employees or customers to comply with all federal, state and local laws applicable to such goods, or the use thereof, including the Occupational Safety and Health Act of 1970, or by reason of the negligence of buyer, its agents, servants, employees or customers.

CONFIDENTIALITY. In the event that certain trade secrets, product formulations, or other proprietary information of Seller may be disclosed to Buyer which is not in the public domain, Buyer agrees to keep this information from becoming available to others, and will not use this knowledge or information to develop products, or help others develop products, that compete with Seller.

CHANGES. Seller reserves the right to change product specifications and formulations without notice and without liability for such changes.

UNAVOIDABLE CIRCUMSTANCES. Seller shall not be liable for delays in delivery or failure to manufacture or deliver due to causes beyond its reasonable control, including but not limited to acts of God, fires, strikes, flood, epidemic, war, riot, delays in transportation, or inability to obtain necessary labor, materials, components or services through normal supply channels at normal prices. In any such event Seller may, at any time and from time to time, postpone the delivery dates under this contract or make partial delivery or cancel all or any portion of this and any other contract without further liability to buyer. Seller shall give reasonable notice to Buyer, but notice shall not be a prerequisite to Seller's rights or relief as set out herein. Partial cancellation shall not affect Seller's right to payment for any product delivered.

PAYMENT TERMS AND COLLECTION CHARGES. Sales are made to Open Accounts, only if requirements are met; otherwise, cash in advance. Terms for approved Open Accounts are net 15 days from the date of invoice unless otherwise agreed. Any amounts not paid are subject to a late charge of one and one-half percent per month or the highest amount allowed by law, whichever is less, whether before or after judgment. Buyer shall pay all costs of collection including reasonable attorney fees.

TAXES AND OTHER LEVIES. Unless proof of exemption is provided by Buyer, sales tax will be added for all sales subject to North Carolina sales tax. Buyer shall be responsible for all use taxes, customs, import duties and all other taxes, and shall indemnify and hold Seller harmless from any claims arising therefrom.

LOCATION, GOVERNING LAW, JURISDICTION AND CONSTRUCTION. The contract of sale shall be deemed to have been concluded in North Carolina. Except where in conflict with International and United States law, this agreement shall be governed by the laws of the State of North Carolina. All prior understandings of the parties, whether oral or written, are incorporated herein, and no changes may be made except in writing signed by the party against whom enforcement is sought. In the event of conflict between this document and any terms, conditions or other qualifications provided in the Buyer's purchase order or other documents, this document shall control. If any portion of the Limited Warranty or these Terms and Condition are determined to be unenforceable, then the remainder shall be enforced without the unenforceable portion. To the extent permissible by law, the parties agree that any unenforceable provision shall be interpreted and rewritten to achieve the parties' intent. Unless otherwise agreed all matters shall be heard in the Superior Court of Wake County, North Carolina.

RETURNS: All Sales Are Final. No exchanges unless notated otherwise. Returns including those for warranty consideration must be shipped prepaid. Freight collect returns will not be accepted. Minimum restocking charge is 20%. Goods must be in original container and in saleable condition to be considered for restocking.

EOS Remediation, Inc.

3722 Benson Drive, Suite 101
Raleigh, NC 27609
(919) 873-2204 • Fax (919) 873-1074

CREDIT APPLICATION / BILLING INSTRUCTIONS AND CONTINUING PERSONAL GUARANTY

EOS Remediation, Inc. (Seller)

Exact Business Name (Purchaser) _____

Street Address _____ Mailing Address _____

City, State and Zip Code _____ County _____

Business Phone (___) _____ FAX Number (___) _____

☐ Proprietorship ☐ Partnership ☐ Corporation ☐ Joint Venture ☐ Non-Profit Org. ☐ Ltd. Liability Company

Date This Business Commenced _____

Type of Business _____

Business Property is: ☐ Leased, From Whom _____ ☐ Owned, By Whom _____

PRINCIPALS, OWNERS, PARTNERS, AND / OR OFFICERS

Name _____ Title _____ Social Security # _____ - _____ - _____

Home Address _____ Home Phone (____) _____ - _____

Name _____ Title _____ Social Security # _____ - _____ - _____

Home Address _____ Home Phone (____) _____ - _____

Name _____ Title _____ Social Security # _____ - _____ - _____

Home Address _____ Home Phone (____) _____ - _____

List other current business names _____

If any of the principals were in business before, please provide business name, location, date and list the reason for discontinuing:

_____

TRADE REFERENCES

List 4 Suppliers where you have an Active Account:

Name	City, State	Account Number	Telephone
			(____)
			(____)
			(____)
			(____)

BANK REFERENCES

Name of Bank	City, State	Account Number	Telephone
			(____)
			(____)

The undersigned certifies the above information to be true and correct, that it is submitted for the purpose of obtaining credit and agrees to the Terms and Conditions of Sale of Seller on page 2 and any changes to those terms which may occur in the future, all of which are herein incorporated by reference. The undersigned further authorizes Seller to request and receive credit reports from credit bureaus and other credit service organizations regarding the undersigned's personal credit for the purpose of investigating the Purchaser's business and its eligibility for commercial credit. The undersigned consents to an investigation into the creditworthiness of the Purchaser.

PLEASE ATTACH A COPY OF PURCHASER'S MOST RECENT FINANCIAL STATEMENT

_____
Authorized Signature of Purchaser

By (Print or Type) _____ Date: _____

Title: _____

APPENDIX D

REMEDIATION COST ESTIMATES

APPENDIX D.1

ALTERNATIVE 2: NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING

REMEDIATION COST ESTIMATE

NAVAL SU[illegible]E WARFARE CENTER CRANE
CRANE, IND[illegible]NA
SWMU 10
ALTERNATIVE 2: NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING
Annual Cost

Item	Item Cost Years 1 & 2	Item Cost Years 3 - 5	Item Cost Years 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28,and 30	Item Cost Years 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27,and 29	Item Cost Every 5 Years Through 30 Years	Notes
Sampling & Field Tests, Labor and ODCs	$25,200	$12,600	$6,300	$6,300		Sample quarterly Years 1 & 2, semi-annually Years 3 - 5, and annually Years 6 - 30. Seventeen samples per event (twelve monitoring well samples, three surface water samples, and two quality assurance samples).
Analyze Water for Explosives	$9,928	$4,964	$2,482	$2,482		Analyze samples from each round for explosives.
Data Validation	$2,400	$1,200	$600	$600		
Analyze Water for Explosive Degradation Products	$3,230	$3,230	$3,230			Analyze samples from one round of monitoring for Years 1-2 and from every second round thereafter for explosive degradation products.
Annual Monitoring Report	$2,600	$2,600	$2,600	$2,600		Document sampling events and results
CMD Inspection	$300	$300	$300	$300		Annual inspection to verify continued implementation of Corrective Measure Design
Site Review					$7,000	5-year review
TOTALS	$43,658	$24,894	$15,512	$12,282	$7,000	

(1) Sampling would occur quarterly for the Years 1 & 2.
(2) Sampling would occur semi-annually for the Years 3 - 5.
(3) Sampling would occur annually for the Years 6 - 30.

NAVAL SURFACE WARFARE CENTER CRANE
CRANE, INDIANA
SWMU 10
ALTERNATIVE 2: NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING
Capital Costs

Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
1 PROJECT PLANNING & INSTITUTIONAL CONTROLS											
1.1 Prepare Monitoring Plan	100	hr			$35.00		$0	$0	$3,500	$0	$3,500
1.2 Prepare Site-Specific Corrective Measure Design	200	hr			$35.00		$0	$0	$7,000	$0	$7,000
Subtotal							$0	$0	$10,500	$0	$10,500
Local Area Adjustments							100.0%	100.0%	96.9%	96.9%	
							$0	$0	$10,175	$0	$10,175
Overhead on Labor Cost @ 30%									$3,052		$3,052
G & A on Labor Cost @ 10%									$1,017		$1,017
G & A on Material Cost @ 10%								$0			$0
G & A on Subcontract Cost @ 10%							$0				$0
Total Direct Cost							$0	$0	$14,244	$0	$14,244
Indirects on Total Direct Cost @ 30%											$4,273
Profit on Total Direct Cost @ 10%											$1,424
Subtotal											$19,942
Health & Safety Monitoring @ 2%											$399
Contingency on Subtotal Cost @ 20%											$3,988
Engineering on Subtotal Cost @ 10%											$1,994
TOTAL CAPITAL COST											**$26,323**

NAVAL SURFACE WARFARE CENTER CRANE
CRANE, INDIANA
SWMU 10
ALTERNATIVE 2: NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING
Present Worth Analysis

Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate at 7%	Present Worth
0	$26,323		$26,323	1.000	$26,323
1		$43,658	$43,658	0.935	$40,820
2		$43,658	$43,658	0.873	$38,113
3		$24,894	$24,894	0.816	$20,314
4		$24,894	$24,894	0.763	$18,994
5		$31,894	$31,894	0.713	$22,740
6		$15,512	$15,512	0.666	$10,331
7		$12,282	$12,282	0.623	$7,652
8		$15,512	$15,512	0.582	$9,028
9		$12,282	$12,282	0.544	$6,681
10		$22,512	$22,512	0.508	$11,436
11		$12,282	$12,282	0.475	$5,834
12		$15,512	$15,512	0.444	$6,887
13		$12,282	$12,282	0.415	$5,097
14		$15,512	$15,512	0.388	$6,019
15		$19,282	$19,282	0.362	$6,980
16		$15,512	$15,512	0.339	$5,259
17		$12,282	$12,282	0.317	$3,893
18		$15,512	$15,512	0.296	$4,592
19		$12,282	$12,282	0.277	$3,402
20		$22,512	$22,512	0.258	$5,808
21		$12,282	$12,282	0.242	$2,972
22		$15,512	$15,512	0.226	$3,506
23		$12,282	$12,282	0.211	$2,592
24		$15,512	$15,512	0.197	$3,056
25		$19,282	$19,282	0.184	$3,548
26		$15,512	$15,512	0.172	$2,668
27		$12,282	$12,282	0.161	$1,977
28		$15,512	$15,512	0.150	$2,327
29		$12,282	$12,282	0.141	$1,732
30		$22,512	$22,512	0.131	$2,949
				TOTAL PRESENT WORTH	**$293,530**

APPENDIX D.2

ALTERNATIVE 3: "HOT-SPOTS' IN-SITU BIOREMEDIATION, NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING

REMEDIATION COST ESTIMATE

NAVAL SU[illegible]E WARFARE CENTER CRANE
CRANE, IND[illegible]NA
SWMU 10
ALTERNATIVE 3: "HOT SPOTS" IN-SITU BIOREMEDIATION, NATURAL ATTENUATION, INSTIUTIONAL CONTROLS, AND MONITORING
Annual Cost

Item	Item Cost Years 1 & 2	Item Cost Years 3 - 5	Item Cost Years 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28,and 30	Item Cost Years 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27,and 29	Item Cost Every 5 Years Through 30 Years	Notes
Sampling & Field Tests, Labor and ODCs	$25,200	$12,600	$6,300	$6,300		Sample quarterly Years 1 & 2, semi-annually Years 3 - 5, and annually Years 6 - 30. Seventeen samples per event (twelve monitoring well samples, three surface water samples, and two quality assurance samples).
Analyze Water for Explosives	$9,928	$4,964	$2,482	$2,482		Analyze samples from each round for explosives.
Data Validation	$2,400	$1,200	$600	$600		
Analyze Water for Explosive Degradation Products	$3,230	$3,230	$3,230			Analyze samples from one round of monitoring for Years 1-2 and from every second round thereafter for explosive degradation products.
Analyze Water for Biodegradation Products	$4,620	$2,310	$1,155			Analyze three of the twelve well samples for total organic carbon, metabolic acids, nitrates, sulfates, and dissolved gases.
Annual Monitoring Report	$2,600	$2,600	$2,600	$2,600		Document sampling events and results
CMD inspection	$300	$300	$300	$300		Annual inspection to verify continued implementation of Corrective Measure Design
Site Review					$7,000	5-year review
TOTALS	$48,278	$27,204	$16,667	$12,282	$7,000	

(1) Sampling would occur quarterly for the Years 1 & 2.
(2) Sampling would occur semi-annually for the Years 3 - 5.
(3) Sampling would occur annually for the Years 6 - 30.

NAVAL SURFACE WARFARE CENTER CRANE
CRANE, INDIANA
SWMU 10
ALTERNATIVE 3: "HOT SPOTS" IN-SITU BIOREMEDIATION, NATURAL ATTENUATION, INSTIUTIONAL CONTROLS, AND MONITORING
Capital Costs

Item	Quantity	Unit	Unit Cost Subcontract	Unit Cost Material	Unit Cost Labor	Unit Cost Equipment	Extended Cost Subcontract	Extended Cost Material	Extended Cost Labor	Extended Cost Equipment	Subtotal
1 PROJECT PLANNING & INSTITUTIONAL CONTROLS											
1.1 Prepare Monitoring Plan	100	hr			$35.00		$0	$0	$3,500	$0	$3,500
1.2 Prepare Site-Specific Corrective Measure Design	200	hr			$35.00		$0	$0	$7,000	$0	$7,000
2 PERFORM TREATABILITY STUDY											
2.1 Perform Bench-Scale Treatability Study	1	ls	$15,000.00				$15,000	$0	$0	$0	$15,000
3 HOT-SPOTS 1 & 2 IN-SITU BIOREMEDIATION											
3.1 Drilling Mobilization/Demobilization	1	ls	$1,000.00				$1,000	$0	$0	$0	$1,000
3.2 Drilling, ATV Rig	240	ft	$40.00				$9,600	$0	$0	$0	$9,600
3.3 PVC Well Installation, 4-inch Diameter	240	ft	$20.00				$4,800	$0	$0	$0	$4,800
3.4 Protective Casing and Barrier Posts	8	ea	$500.00				$4,000	$0	$0	$0	$4,000
3.5 Clearing and Grubbing	8	hr	$100.00				$800	$0	$0	$0	$800
3.6 IDW Containerization	2	drums	$100.00				$200	$0	$0	$0	$200
3.7 Submersible Centrifugal Pump, 2-inch	4	ea				$200.00	$0	$0	$0	$800	$800
3.8 Operate Submersible Centrifugal Pump, 2-inch, Operate	128	days				$13.00	$0	$0	$0	$1,664	$1,664
3.9 Rent Mobile Power Generator, 3KW	3	mo				$135.00	$0	$0	$0	$405	$405
3.10 Operate Mobile Power Generator, 3KW	8	wk				$161.00	$0	$0	$0	$1,288	$1,288
3.11 Hose, 1-inch Diameter	300	ft		$2.00			$0	$600	$0	$0	$600
3.12 EOS 598 B42 Emulsified Oil, 550 Gallons	11	drums		$1,260.00			$0	$13,860	$0	$0	$13,860
3.13 Construction Oversight, Well Installation	20	days			$200.00		$0	$0	$4,000	$0	$4,000
3.14 Field Operators	720	hr			$30.00		$0	$0	$21,600	$0	$21,600
4 MISCELLANEOUS											
4.1 Post-Construction Documents	15	hr			$35.00		$0	$0	$525	$0	$525
Subtotal							$35,400	$14,460	$36,625	$4,157	$90,642
Local Area Adjustments							100.0%	100.0%	96.9%	96.9%	
							$35,400	$14,460	$35,490	$4,028	$89,378
Overhead on Labor Cost @ 30%									$10,647		$10,647
G & A on Labor Cost @ 10%									$3,549		$3,549
G & A on Material Cost @ 10%								$1,446			$1,446
G & A on Subcontract Cost @ 10%							$3,540				$3,540
Total Direct Cost							$38,940	$15,906	$49,685	$4,028	$108,560
Indirects on Total Direct Cost @ 30%			(On Total Direst Cost Minus Subcontractor Costs)								$21,948
Profit on Total Direct Cost @ 10%											$10,856
Subtotal											$141,363
Health & Safety Monitoring @ 2%											$2,827
Contingency on Subtotal Cost @ 20%											$28,273
Engineering on Subtotal Cost @ 10%											$14,136
TOTAL CAPITAL COST											**$186,600**

NAVAL SURFACE WARFARE CENTER CRANE
CRANE, INDIANA
SWMU 10
ALTERNATIVE 3: "HOT SPOTS" IN-SITU BIOREMEDIATION, NATURAL ATTENUATION, INSTIUTIONAL CONTROLS, A
Present Worth Analysis

Year	Capital Cost	Annual Cost	Total Year Cost	Annual Discount Rate at 7%	Present Worth
0	$186,600		$186,600	1.000	$186,600
1		$48,278	$48,278	0.935	$45,140
2		$48,278	$48,278	0.873	$42,147
3		$27,204	$27,204	0.816	$22,198
4		$27,204	$27,204	0.763	$20,757
5		$34,204	$34,204	0.713	$24,387
6		$16,667	$16,667	0.666	$11,100
7		$12,282	$12,282	0.623	$7,652
8		$16,667	$16,667	0.582	$9,700
9		$12,282	$12,282	0.544	$6,681
10		$23,667	$23,667	0.508	$12,023
11		$12,282	$12,282	0.475	$5,834
12		$16,667	$16,667	0.444	$7,400
13		$12,282	$12,282	0.415	$5,097
14		$16,667	$16,667	0.388	$6,467
15		$19,282	$19,282	0.362	$6,980
16		$16,667	$16,667	0.339	$5,650
17		$12,282	$12,282	0.317	$3,893
18		$16,667	$16,667	0.296	$4,933
19		$12,282	$12,282	0.277	$3,402
20		$23,667	$23,667	0.258	$6,106
21		$12,282	$12,282	0.242	$2,972
22		$16,667	$16,667	0.226	$3,767
23		$12,282	$12,282	0.211	$2,592
24		$16,667	$16,667	0.197	$3,283
25		$19,282	$19,282	0.184	$3,548
26		$16,667	$16,667	0.172	$2,867
27		$12,282	$12,282	0.161	$1,977
28		$16,667	$16,667	0.150	$2,500
29		$12,282	$12,282	0.141	$1,732
30		$23,667	$23,667	0.131	$3,100
				TOTAL PRESENT WORTH	**$472,487**