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# FINAL PERMANGANATE TRACER STUDY WORK PLAN FOR SITE 88 OPERABLE UNIT 15 (OU 15) MCB CAMP LEJEUNE NC

8/1/2015

CH2M HILL

Final

# Permanganate Tracer Study
# Work Plan
# Site 88, Operable Unit 15

## Marine Corps Installations East – Marine Corps Base Camp Lejeune
## North Carolina

**Contract Task Order WE6A**

**August 2015**

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# Acronyms and Abbreviations

| | |
|---|---|
| µg/L | micrograms per liter |
| 2012 Draft FS | *Draft Feasibility Study, Site 88, Operable Unit No. 15, Marine Corps Base, Camp Lejeune, Jacksonville, North Carolina* |
| AST | aboveground storage tank |
| bgs | below ground surface |
| CLEAN | Comprehensive Long-term Environmental Action—Navy |
| COC | contaminant of concern |
| COPC | contaminant of potential concern |
| CSM | conceptual site model |
| CTO | Contract Task Order |
| cVOC | chlorinated volatile organic compound |
| DCE | dichloroethene |
| DNAPL | dense non-aqueous phase liquid |
| DOT | Department of Transportation |
| DWR | Division of Water Resources |
| DWQ | Department of Water Quality |
| EVO | emulsified vegetable oil |
| FRE | fiberglass reinforced epoxy |
| FS | Feasibility Study |
| g/kg | grams per kilogram |
| gpm | gallons per minute |
| HDD | horizontal directional drilled |
| HDPE | high density polyethylene |
| HSP | Health and Safety Plan |
| ID | identification |
| IDW | investigation-derived waste |
| ISCO | in situ chemical oxidation |
| LCH | lower Castle Hayne |
| MCIEAST–MCB CAMLEJ | Marine Corps Installations East – Marine Corps Base Camp Lejeune |
| MCH | middle Castle Hayne |
| mg/L | milligrams per liter |
| msl | mean sea level |
| NAVFAC | Naval Facilities Engineering Command |
| NCAC | North Carolina Administrative Code |
| NCDENR | North Carolina Department of Environment and Natural Resources |
| NCGWQS | North Carolina Groundwater Quality Standard |
| NPT | national pipe thread |
| NTCRA | non-time-critical removal action |
| OU | Operable Unit |
| PCE | tetrachloroethene |
| PNOD | permanganate natural oxidant demand |

| | |
|---|---|
| PPE | personal protective equipment |
| psi | pounds per square inch |
| PVC | polyvinyl chloride |
| RCRA | Resource Conservation and Recovery Act |
| RI | remedial investigation |
| ROI | radius of influence |
| SDS | safety data sheets |
| TCE | trichloroethene |
| UCH | upper Castle Hayne |
| UIC | underground injection control |
| ULOCO | North Carolina One Call Center |
| USEPA | United States Environmental Protection Agency |
| UST | underground storage tank |
| VC | vinyl chloride |
| VI | vapor intrusion |
| VOC | volatile organic compound |
| WMP | Waste Management Plan |
| WP | Work Plan |
| wt | weight |
| ZVI | zero valent iron |

SECTION 1

# 1 Introduction

This document presents the Permanganate Tracer Study Work Plan (WP) for Operable Unit (OU) 15, Site 88 (hereinafter referred to as the Site), located at Marine Corps Installations East – Marine Corps Base Camp Lejeune (MCIEAST–MCB CAMLEJ), North Carolina (**Figures 1-1** through **1-3**). This WP was prepared under the Naval Facilities Engineering Command (NAVFAC) — Comprehensive Long-Term Environmental Action—Navy (CLEAN) 8012 Contract N62470-11-D-8012, Contract Task Order (CTO) WE6A.

The *Draft Feasibility Study, Site 88, Operable Unit No. 15, Marine Corps Base, Camp Lejeune, Jacksonville, North Carolina* (2012 Draft FS) identified in situ chemical oxidation (ISCO) through injection of permanganate via horizontal directionally drilled (HDD) wells as one of the more promising alternatives available for groundwater treatment based on site conditions (CH2M HILL, 2012). This tracer study is being conducted to evaluate the technical feasibility of permanganate distribution through a HDD injection well and to evaluate if extraction and recirculation will enhance the distribution of permanganate effectively in the middle Castle Hayne (MCH) aquifer to refine design parameters and alternative comparisons in support of the Draft Final FS. The purpose of this WP is to present the technical approach for implementing the permanganate tracer study.

This WP is organized as follows:

- **Section 1, Introduction —** Presents a general overview of the project and contents of the WP.
- **Section 2, Site Background —** Summarizes the general site background and description of Site 88 and the tracer study area.
- **Section 3, Tracer Study Basis of Design —** Provides an overview of the tracer study objectives and design basis, including the key features influencing the approach, the rationale for selection, the conceptual location and layout, and design elements.
- **Section 4, Implementation —** Details how the tracer study will be implemented, including the site-specific requirements and constraints for construction.
- **Section 5, Reporting —** Describes the reporting that will occur for the tracer study.
- **Section 6, References —** Provides the references used in this document.

Tables are provided either within their respective section or at the end of the section and all figures are provided at the end of each section.

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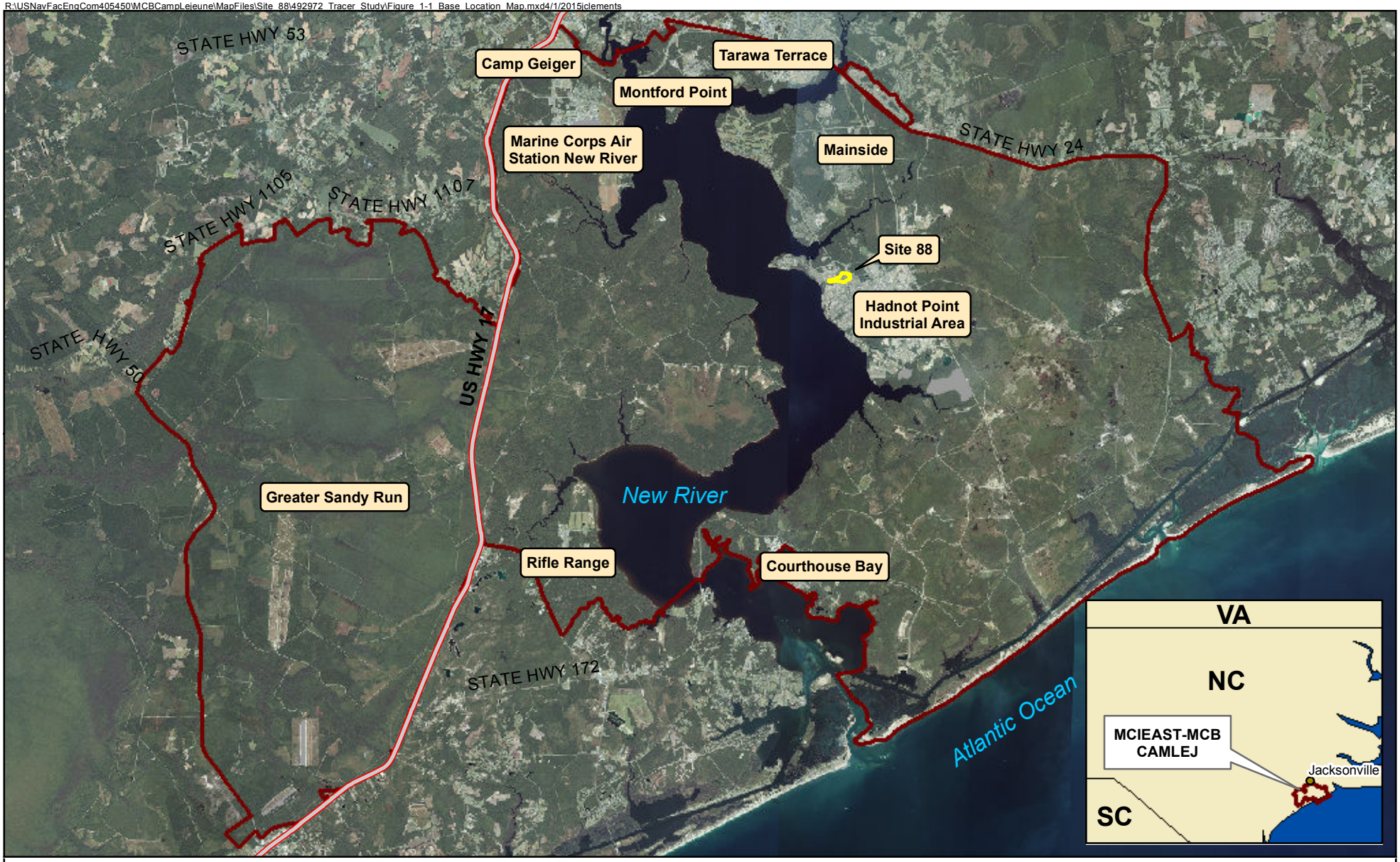


**Legend**

- Highways
- Installation Boundary
- Site 88 Boundary

N

0 7,500 15,000 Feet

1 inch = 15,000 feet

Figure 1-1
Base Location Map
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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**Legend**

- Surface Water Centerline
- Former Building 25
- SWMU 615
- Site 88 Boundary
- Installation Boundary

N

0 200 400 800 Feet

1 inch = 400 feet

Figure 1-2
Site Location Map
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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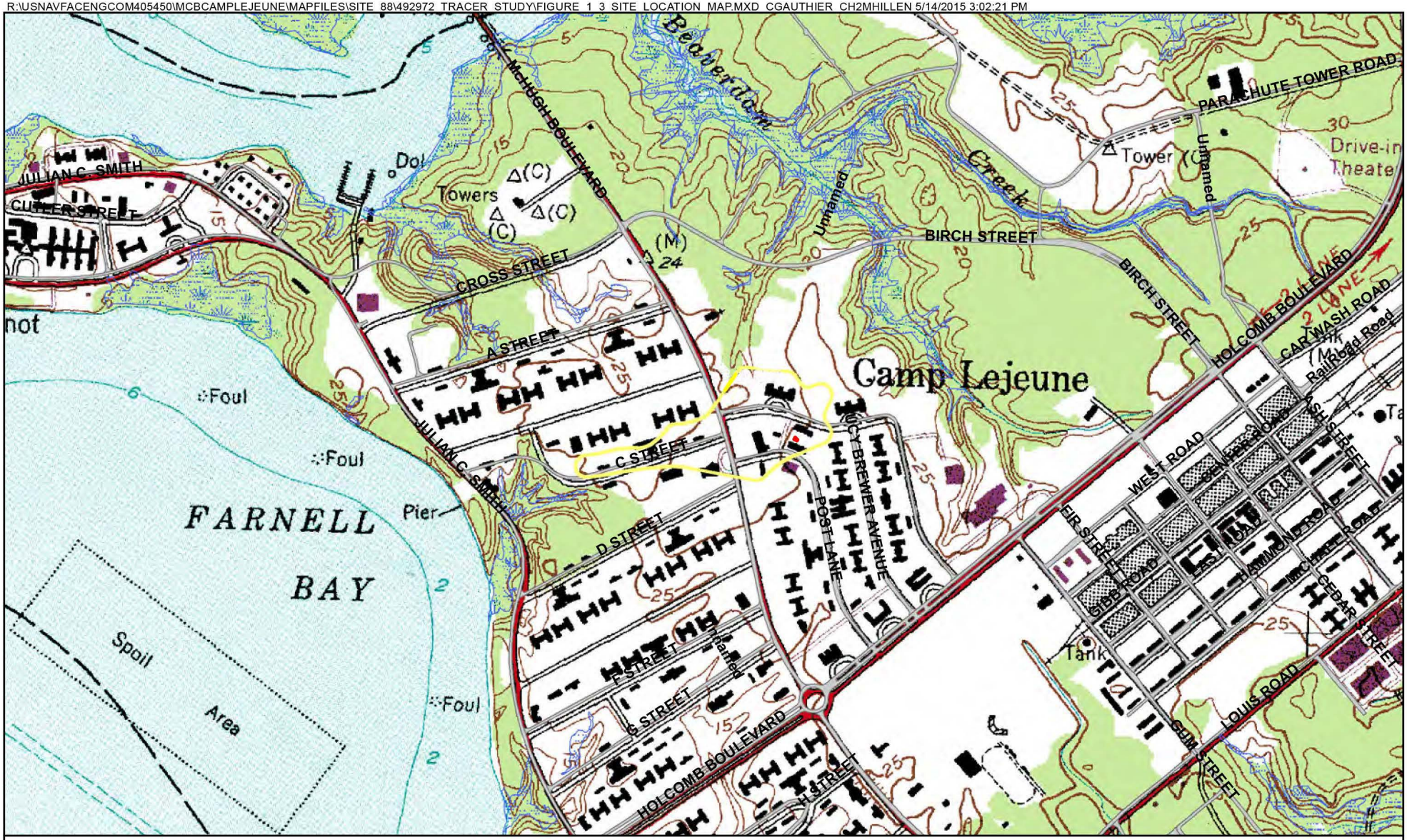


**Legend**

- Site 88 Boundary
- Approximate Former UST-25 Location
- Wetlands

Topo Source: USGS 7.5 min
Quad of Jacksonville South, N.C
Photo inspected in 1988
Elevation in feet above mean sea level
5 - foot contour interval

N

0 300 600 900 1,200 Feet

1 inch = 1,250 feet

Figure 1-3
Site Topographic Map
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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SECTION 2

# Site Background

This section presents the general site background and description of Site 88 and the tracer study area, as well as the tracer study objectives.

## 2.1 Site Description and Background

Site 88, is located within the Mainside of MCIEAST–MCB CAMLEJ, near the intersection of Virginia Dare and McHugh Boulevard to the west (**Figure 1-2**). **Table 2-1** includes a description and brief history of Site 88. A three-dimensional conceptual site model (CSM) of Site 88 is depicted on **Figure 2-1**.

TABLE 2-1

Site 88 Site Description and Background

*Site 88 Tracer Study*

*MCIEAST–MCB CAMLEJ, North Carolina*

| | |
|---|---|
| **Source Areas** | Former dry cleaning facility with associated former above ground storage tanks (ASTs)/underground storage tanks (USTs) and dense non-aqueous phase liquid (DNAPL) |
| **Current Contaminants of Potential Concern (COPCs) and Contaminants of Concern (COCs)** | Soil COPCs: Benzene, aromatics C9 - C22, tetrachloroethene (PCE), trichloroethene (TCE)<br>Groundwater COCs: Benzene, aliphatics C5 - C8, aliphatics C9 - C18, aromatics C9 - C22, naphthalene, and the chlorinated volatile organic compounds (cVOCs) PCE, TCE, cis-1,2-dichloroethene (DCE), and vinyl chloride (VC) |
| **Nature and Extent** | Subsurface soil impacts beneath and near former Building 25 and along an underground sewer line (apparently due to the leakage of solvent-contaminated wastewater) were identified during previous investigations. A non-time-critical removal action (NTCRA) (in-situ chemical reduction via soil mixing with zero-valent iron [ZVI] and clay) was conducted to address DNAPL and subsurface soil impacts within the source area and at the former UST-25 location. To close out UST-25 within the UST program, additional soil sampling was conducted in 2011 that identified benzene, aromatics C9-C22, PCE, and TCE above screening levels within the former soil mixing area.<br>Groundwater PCE impacts in the surficial aquifer extend from the source area (near former Building 25) approximately 400 feet to the west. The vertical extent of impacts within the surficial aquifer ranges from approximately 5 to approximately 25 feet below ground surface (bgs). PCE daughter products, including TCE, cis-1,2-DCE, and VC, are also present at concentrations exceeding North Carolina Groundwater Quality Standards (NCGWQS) in the surficial aquifer. The highest concentrations of TCE, cis-1,2-DCE, and VC are located immediately downgradient of the ZVI soil mixing area.<br>Groundwater PCE impacts are also present in the upper Castle Hayne (UCH) aquifer, extending northwest from the source area (near former Building 25) to approximately 1,600 feet west to the leading edge of the plume. The vertical extent of impacts within the UCH aquifer ranges from 25 to approximately 60 feet bgs.<br>Groundwater PCE impacts in the MCH and lower Castle Hayne (LCH) aquifers extend approximately 700 feet west, downgradient of the surficial and UCH plumes. The vertical extent of impacted groundwater ranges from 60 to approximately 125 feet bgs. PCE daughter products, including TCE, cis-1,2-DCE, and VC, are also present at concentrations exceeding NCGWQS in the MCH and LCH aquifers. The highest concentrations of TCE, cis-1,2-DCE, and VC are located approximately 500 feet downgradient of the ZVI soil mixing area. |
| **Migration Pathway** | Potential contaminant migration pathways are leaching of COCs from vadose zone soils to groundwater; soil vapor intrusion (VI), vertical migration of COCs in groundwater; and horizontal migration in groundwater through advection. |

TABLE 2-1
**Site 88 Site Description and Background**
*Site 88 Tracer Study*
*MCIEAST-MCB CAMLEJ, North Carolina*

| | |
|---|---|
| **Receptors** | Potential Risks to Future Residents – Exposure to volatile organic compounds (VOCs) in groundwater used as a potable water supply<br>Potential Risks to Future Construction Workers – Dermal and inhalation exposure to VOCs in shallow groundwater<br>VI has been investigated and vapor intrusion mitigation systems are in place where potential unacceptable risks were identified. VI pathways would need to be considered in support of any new construction or reclassification of existing buildings in the vicinity of the VOC groundwater plume. |

Comprehensive information concerning Site 88 history, historical contaminant concentrations, plume distribution, and subsurface geology/hydrogeology is presented in the *Remedial Investigation* [RI]*, Site 88, Operable Unit No. 15, Marine Corps Base, Camp Lejeune, North Carolina* (CH2M HILL, 2008) and the 2012 Draft FS (CH2M HILL, 2012). Site characteristics specific to the tracer study area are discussed below.

## 2.2 Tracer Study Location

For the 2012 Draft FS, Site 88 was divided into three treatment zones (Zones 1, 2, and 3) (**Figure 2-2**). Zone 1 was defined as the location of the initial source area (former Building 25), containing high concentrations of COCs at shallow depths (5 to 40 feet bgs). Zones 2 and 3 are located downgradient of Zone 1. Zone 2 was defined as the large footprint of COCs at depths ranging from approximately 40 to 180 feet bgs and Zone 3 is further downgradient (leading edge of the groundwater plume) with impacts limited to approximately 40 to 60 feet bgs. The tracer study will be conducted within Zone 2 near the intersection of McHugh Boulevard and Virginia Dare Drive where the highest COC concentrations within the Site 88 MCH aquifer (from approximately 75 to 115 feet bgs) have been detected based on the results of previous investigations (**Figure 2-2**).

## 2.3 Geology

The Site 88 geologic cross-section location map is shown on **Figure 2-3** and the corresponding cross sections generated from the boring logs of monitoring well installations nearest to the tracer study area, cross sections A-A' and D-D', are presented on **Figures 2-4** and **2-5**. Cross sections located outside of the tracer study are not included in this WP but are presented in the RI (CH2M HILL, 2008).

The geology in the vicinity of Site 88 consists of four distinct formations (undifferentiated sediments, the Belgrade Formation, the River Bend Formation, and the Castle Hayne Formation), which correspond to the surficial aquifer, Castle Hayne semi-confining unit, UCH aquifer, MCH aquifer, and LCH aquifer, respectively. At Site 88, the uppermost undifferentiated formation of Quaternary age sediments consists of mostly fine sand and silt. Thin discontinuous layers of clayey silt and silty clay, which represent the Belgrade Formation, were observed in Zones 1 and 2 at a thickness of 5 to 7 feet, as illustrated on **Figure 2-4**. The undifferentiated sediments or Belgrade Formation (if present) overlies the Oligocene age River Bend Formation, which is encountered at elevations of -27 to -34 feet below mean sea level (msl) in Zones 1 and 2, corresponding to approximately 55 to 60 feet bgs (**Figure 2-5**). This contact is indicated by a significant increase in formation density. Within the River Bend Formation sediments, sand is dominant, with minor amounts of silt and shell fragments. The River Bend Formation overlies the Eocene age Castle Hayne Formation, which consists of fine- to-medium-grained sand with minor amounts of silt and clay. This layer is generally encountered at approximately 80 feet bgs in Zones 1 and 2.

## 2.4 Hydrogeology

A detailed discussion of the hydrogeologic characteristics at Site 88 was presented in the RI (CH2M HILL, 2008) and the DNAPL Site Characterization Report (Duke Engineering and Services, 1999). Additional information was gathered by CH2M HILL during investigations performed through October 2014. Hydrogeologic characteristics of

the surficial (water table) and Castle Hayne aquifers underlying Site 88 were evaluated by reviewing available information from the existing network of monitoring wells. The surficial aquifer is composed of undifferentiated sediments and is underlain by the Castle Hayne confining unit or Belgrade Formation, as described in **Section 2.3**. The Castle Hayne confining unit is not present continuously at the Site and in areas where it is absent, the surficial aquifer and the Castle Hayne aquifer are in direct hydraulic communication. The Castle Hayne confining unit is present under former Building 25 at approximately 20 feet bgs with a variable thickness of approximately 14 to 16 feet (Zone 1). This unit appears to decrease in thickness significantly to the northeast and again to the southwest, and is discontinuous to the west of former Building 25 (Zones 2 and 3). The Castle Hayne confining unit is underlain by the Castle Hayne aquifer (River Bend and Castle Hayne Formations).

**Figure 2-6** presents the potentiometric surface of the MCH aquifer, the target of this tracer study, as measured in February 2010 and October 2014 (**Table 2-2**). Groundwater flow is generally to the west, northwest, and northeast. Based on a hydraulic conductivity of 7.9 feet per day, an estimated effective porosity of 0.2, and a hydraulic gradient of 0.0014 feet per foot (using a geometric mean of 2014 site-wide gauging data from monitoring well pairs IR88-MW04DW/IR88-MW19DW, IR88-MW18DW/IR88-MW32DW, IR88-MW02DW/IR88-MW34DW, and IR88-MW03DW/IR88-MW07DW), the lateral MCH groundwater aquifer flow velocity is estimated to be approximately 0.05 feet per day (20 feet per year).

## 2.5 Groundwater Quality

Laboratory analytical data from the groundwater investigations conducted between 2011 and 2014 indicate that cVOCs are the predominant COCs located within the tracer study area, with PCE concentrations being the highest, at concentrations ranging from 216 D (IR88-MW18DW) to 99,800 D (IR88-MW39MP-B) micrograms per liter (µg/L). Concentrations of cVOC COCs within the tracer study area are summarized in **Table 2-3** and illustrated on **Figures 2-7** through **2-10**. Groundwater analytical results for all monitoring wells screened in the MCH aquifer are included in **Appendix A**.

TABLE 2-3

Tracer Study Area cVOC COC Concentrations

*Site 88 Tracer Study*

*MCIEAST–MCB CAMLEJ, North Carolina*

| Monitoring Well | Sample Date | PCE (µg/L) | TCE (µg/L) | cis-1,2-DCE (µg/L) | VC (µg/L) |
|---|---|---|---|---|---|
| IR88-MW18DW | 10/22/14 | 216 D | 23.3 D | 0.768 J | 1 U |
| IR88-MW39MP-A | 10/21/14 | 14,700 | 1,080 | 932 | 246 |
| IR88-MW39MP-B | 10/21/14 | 99,800 | 2,430 | 658 | 321 J |
| IR88-MW43DW3 | 10/21/14 | 6,330 | 833 | 136 | 25 U |
| IR88-MW44DW3 | 10/21/14 | 57,200 | 1,020 | 3,970 | 100 U |
| IR88-MW45DW3 | 10/21/14 | 68,700 | 2,420 | 498 J | 250 U |
| IR88-MW46DW3 | 10/21/14 | 19,500 | 1,330 | 333 D | 50 U |
| IR88-MW47DW3 | 10/21/14 | 25,700 | 2,050 | 330 | 125 U |
| **North Carolina Groundwater Quality Standard** | | 7 | 3 | 70 | 0.03 |

Notes:

D - Compound identified in an analysis at a secondary dilution factor.

J - Analyte present. Value may or may not be accurate or precise.

U - The material was analyzed for, but not detected.

TABLE 2-2

Well Construction Details and Groundwater Elevations

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

| Well ID | TOC Elevation (ft msl) | Well Depth (ft bgs) | Diameter (inches) | Screened Interval (ft bgs) Top | Bottom | Depth to Water (February 2010) (ft BTOC) | Water Elevation (February 2010) (ft msl) | Depth to Water (October 2014) (ft BTOC) | Water Elevation (October 2014) (ft msl) |
|---|---|---|---|---|---|---|---|---|---|
| **Upper Middle Castle Hayne Aquifer** | | | | | | | | | |
| IR88-GWEX08DW | 26.50 | 85 | 4 | 65 | 85 | 14.32 | 12.18 | 15.77 | 10.73 |
| IR88-MW03DW | 25.32 | 85 | 2 | 80 | 85 | 13.24 | 12.08 | 14.65 | 10.67 |
| IR88-MW04DW | 24.61 | 85 | 2 | 80 | 85 | 11.82 | 12.79 | 14.22 | 10.39 |
| IR88-MW05DW | 24.33 | 85 | 2 | 80 | 85 | 12.10 | 12.23 | 13.47 | 10.86 |
| IR88-MW07DW | 22.97 | 85 | 2 | 80 | 85 | 11.27 | 11.70 | 12.80 | 10.17 |
| IR88-MW11DW | 23.72 | 85 | 2 | 80 | 85 | 11.85 | 11.87 | 13.26 | 10.46 |
| IR88-MW12DW | 25.75 | 85 | 2 | 80 | 85 | 14.01 | 11.74 | 15.41 | 10.34 |
| IR88-MW14DW | 21.40 | 85 | 2 | 80 | 85 | 10.37 | 11.03 | 11.45 | 9.95 |
| IR88-MW15DW | 21.05 | 85 | 2 | 80 | 85 | NM | NM | 11.32 | 9.73 |
| IR88-MW16DW2 | 23.24 | 85 | 2 | 80 | 85 | 11.02 | 12.22 | 12.30 | 10.94 |
| IR88-MW17DW | 26.50 | 85 | 2 | 80 | 85 | 14.65 | 11.85 | 15.71 | 10.79 |
| IR88-MW18DW | 22.59 | 85 | 2 | 80 | 85 | 10.34 | 12.25 | 11.66 | 10.93 |
| IR88-MW19DW | 24.06 | 85 | 2 | 80 | 85 | 14.41 | 9.65 | 15.44 | 8.62 |
| IR88-MW23DW | 22.45 | 85 | 2 | 80 | 85 | 10.88 | 11.57 | 12.13 | 10.32 |
| IR88-MW23MP-A | NA | 82 | 6 | 77 | 82 | NA | NA | NA | NA |
| IR88-MW24DW | 24.64 | 85 | 2 | 80 | 85 | 12.94 | 11.70 | 14.12 | 10.52 |
| IR88-MW32DW | 24.79 | 85 | 2 | 80 | 85 | 14.30 | 10.49 | 15.43 | 9.36 |
| IR88-MW33DW | 22.13 | 83 | 2 | 78 | 83 | NM | NM | 11.66 | 10.47 |
| IR88-MW34DW | 25.02 | 85 | 2 | 80 | 85 | 14.02 | 11.00 | 15.61 | 9.41 |
| IR88-MW35DW | 21.95 | 85 | 2 | 80 | 85 | 10.61 | 11.34 | NM | NM |
| IR88-MW36DW | 22.72 | 85 | 2 | 80 | 85 | 10.35 | 12.37 | 11.67 | 11.05 |
| IR88-MW37DW | 25.25 | 85 | 2 | 80 | 85 | 12.72 | 12.53 | 14.15 | 11.10 |
| IR88-MW38DW | 22.06 | 85 | 2 | 80 | 85 | 10.11 | 11.95 | 11.31 | 10.75 |
| IR88-MW39MP-A | NA | 81 | NA | 76 | 81 | NA | NA | NA | NA |
| IR88-MW40MP-A | NA | 79.5 | NA | 74.5 | 79.5 | NA | NA | NA | NA |
| **Lower Middle Castle Hayne Aquifer** | | | | | | | | | |
| IR88-MW02DW | 25.30 | 97 | 2 | 92 | 97 | 12.77 | 12.53 | 14.22 | 11.08 |
| IR88-MW40MP-B | NA | 99.5 | NA | 89.5 | 99.5 | NA | NA | NA | NA |
| IR88-MW43DW3 | 21.84 | 100 | 2 | 95 | 100 | 12.87* | 8.97 | 11.45 | 10.39 |
| IR88-MW44DW3 | 22.24 | 100 | 2 | 95 | 100 | 13.5* | 8.74 | 12.08 | 10.16 |
| IR88-MW45DW3 | 21.65 | 100 | 2 | 95 | 100 | 13.03* | 8.62 | 11.62 | 10.03 |
| IR88-MW46DW3 | 21.81 | 100 | 2 | 95 | 100 | 13.23* | 8.58 | 11.61 | 10.20 |
| IR88-MW47DW3 | 21.85 | 100 | 2 | 95 | 100 | 13.15* | 8.70 | 11.78 | 10.07 |
| IR88-MW39MP-B | NA | 101 | NA | 96 | 101 | NA | NA | NA | NA |
| IR88-MW23MP-B | NA | 102 | NA | 97 | 102 | NA | NA | NA | NA |

**Notes:**

ft bgs - feet below ground surface

ft BTOC - feet below top of casing

ft msl - feet mean sea level

NA - not available

NM - not measured

*Gauged on 10/10/11, not included in 2010 potentiometric contours

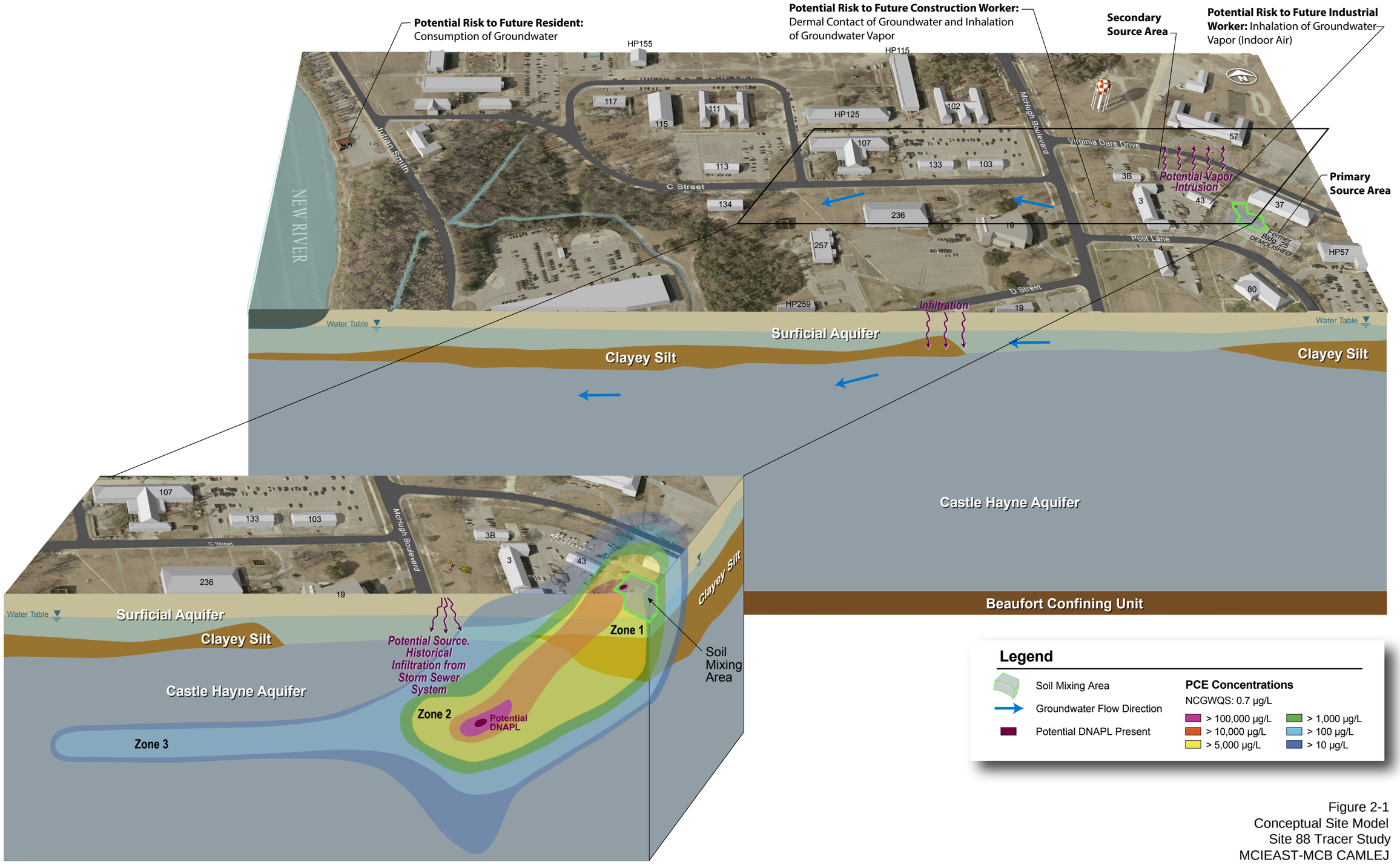


Figure 2-1
Conceptual Site Model
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina



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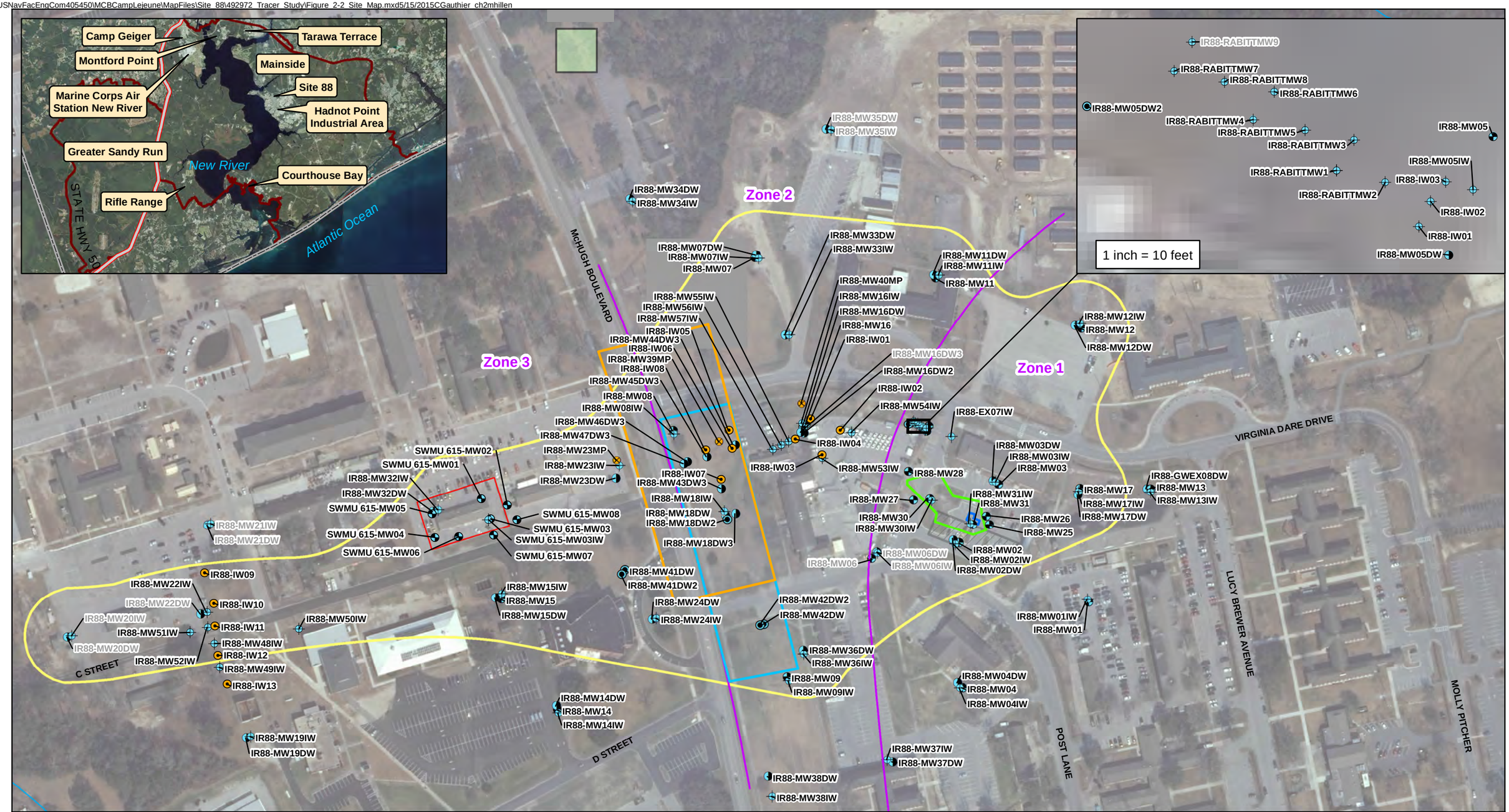


**Legend**

- Injection Well

**Monitoring Well Locations**

- Surficial Aquifer
- Upper Castle Hayne Aquifer
- Middle Castle Hayne Aquifer
- Lower Castle Hayne Aquifer
- Multi-Port

- Surface Water Centerline
- Zone Boundary
- Former Building 25
- Soil Mixing Area
- UST Excavation Area
- SWMU 615
- Site 88 Boundary

- Geophysical Survey Area
- Tracer Study Area
- Tracer Study Equipment Compound/Staging Area

Notes:
Grayed out monitoring wells were not found during October 2014 site-wide groundwater sampling event.

N

0 100 200 400 Feet

1 inch = 200 feet

CH2MHILL

Figure 2-2
Site Map
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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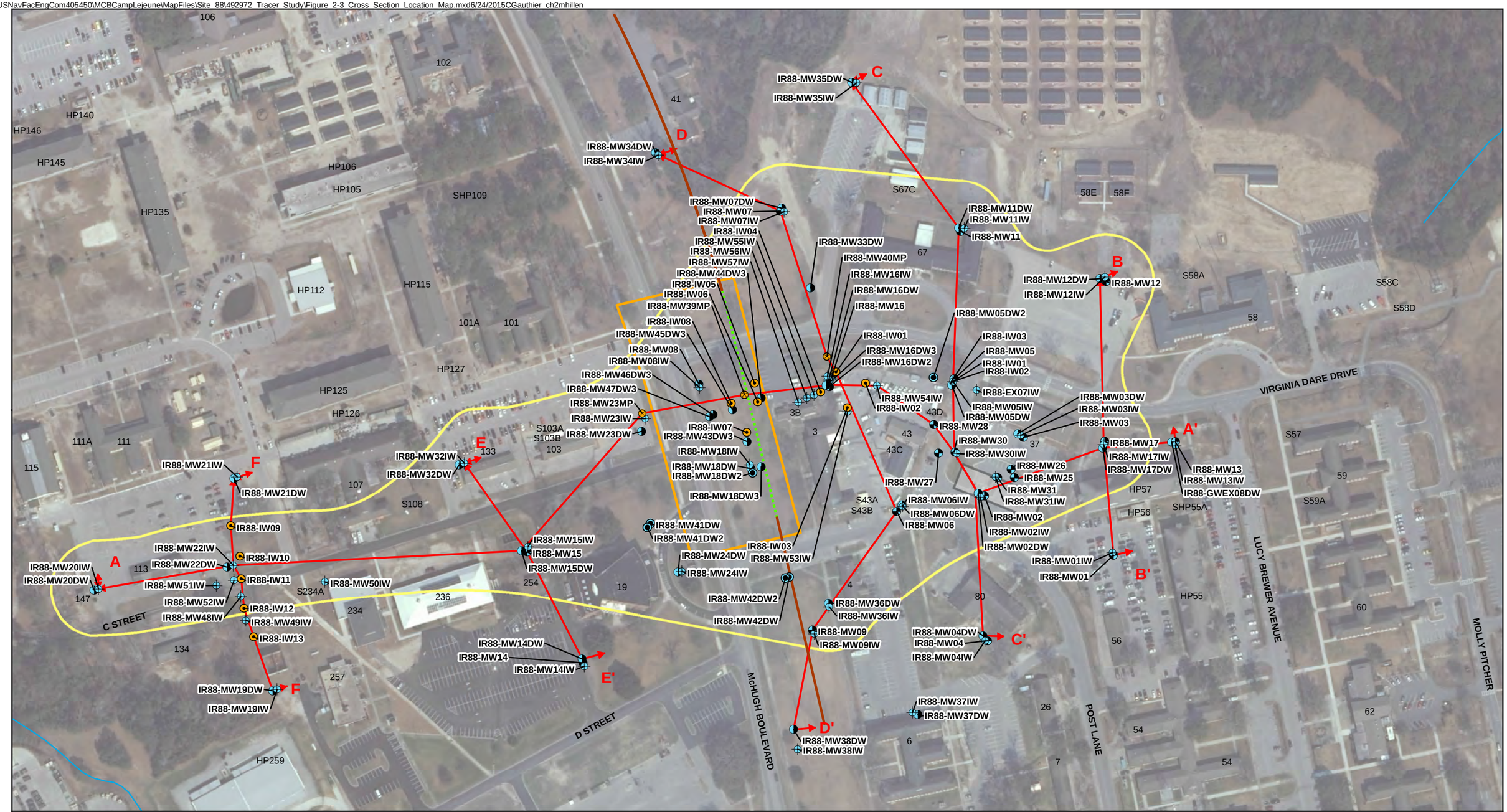


**Legend**

- Injection Well

**Monitoring Well Locations**

- Surficial Aquifer
- Upper Castle Hayne Aquifer
- Middle Castle Hayne Aquifer
- Lower Castle Hayne Aquifer
- Multi-Port

- Surface Water Centerline
- Proposed Horizontal Well Screen (500 feet)
- Proposed Horizontal Well Casing (625+450 feet)
- Geologic Cross-Section
- Tracer Study Area
- Former Building 25
- Site 88 Boundary

N

0 100 200 400 Feet

1 inch = 200 feet

Figure 2-3
Geologic Cross-Section Location Map
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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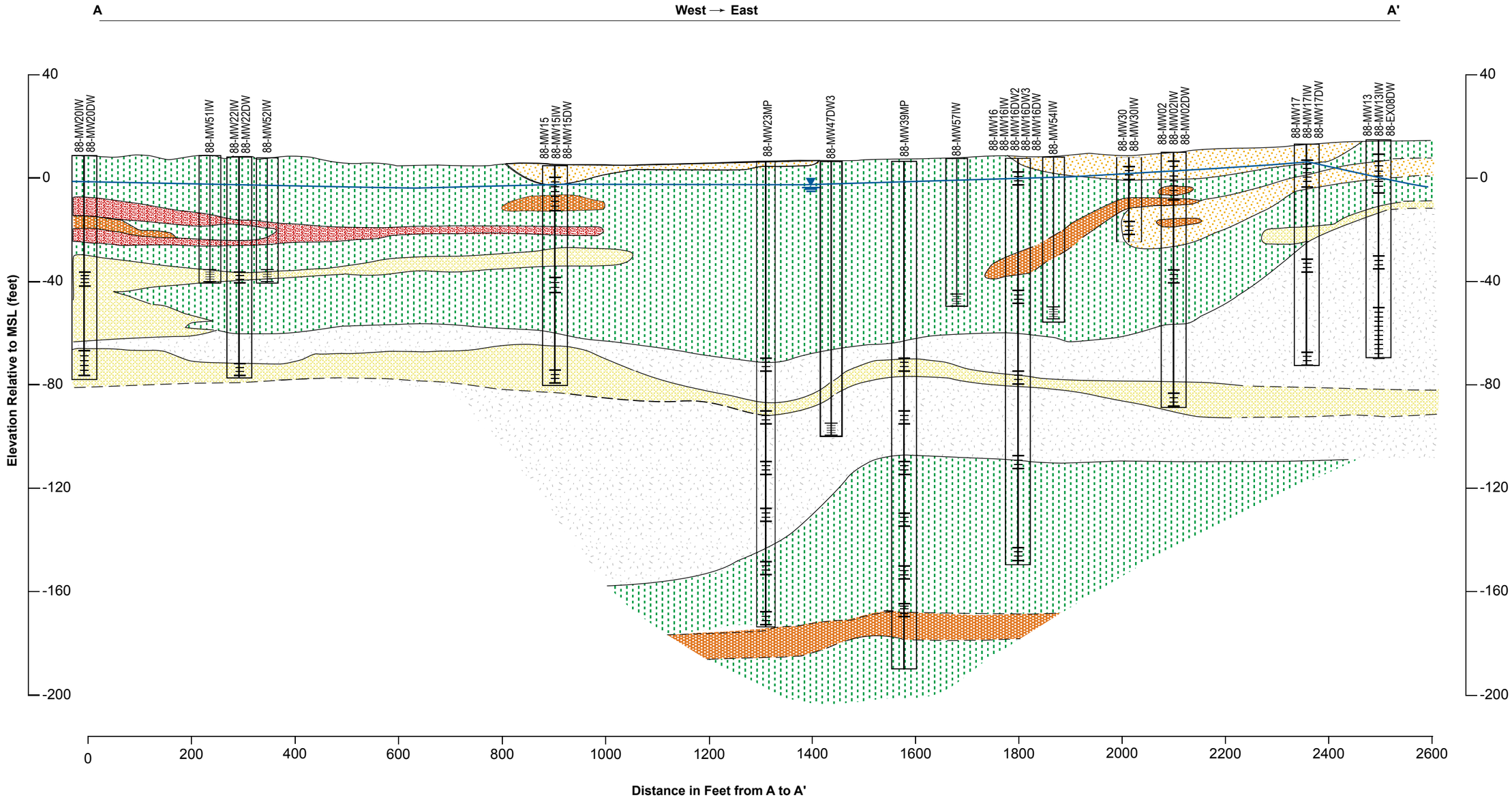


**Legend**

- Clay
- Silt
- Fossiliferous Sand
- Silt/Clay
- Cemented Sand
- Screened Interval
- Sand
- Water Table Elevation

Horizontal : 1" = 200'
Vertical: 1" = 40'
V.E. = 10x

Note:
1. The depth and thickness of the subsurface strata indicated on this section (profile) were generalized from and interpolated between test locations. Information on actual subsurface conditions applies only to the specific locations and dates indicated. Subsurface conditions and water levels at other locations may differ from conditions occurring at the indicated location.

Figure 2-4
Geologic Cross Section A-A'
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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ES102011122008MKE Site_88_Figure2-4_TracerStudy_A-A'_v11.ai 04.06.15 sls

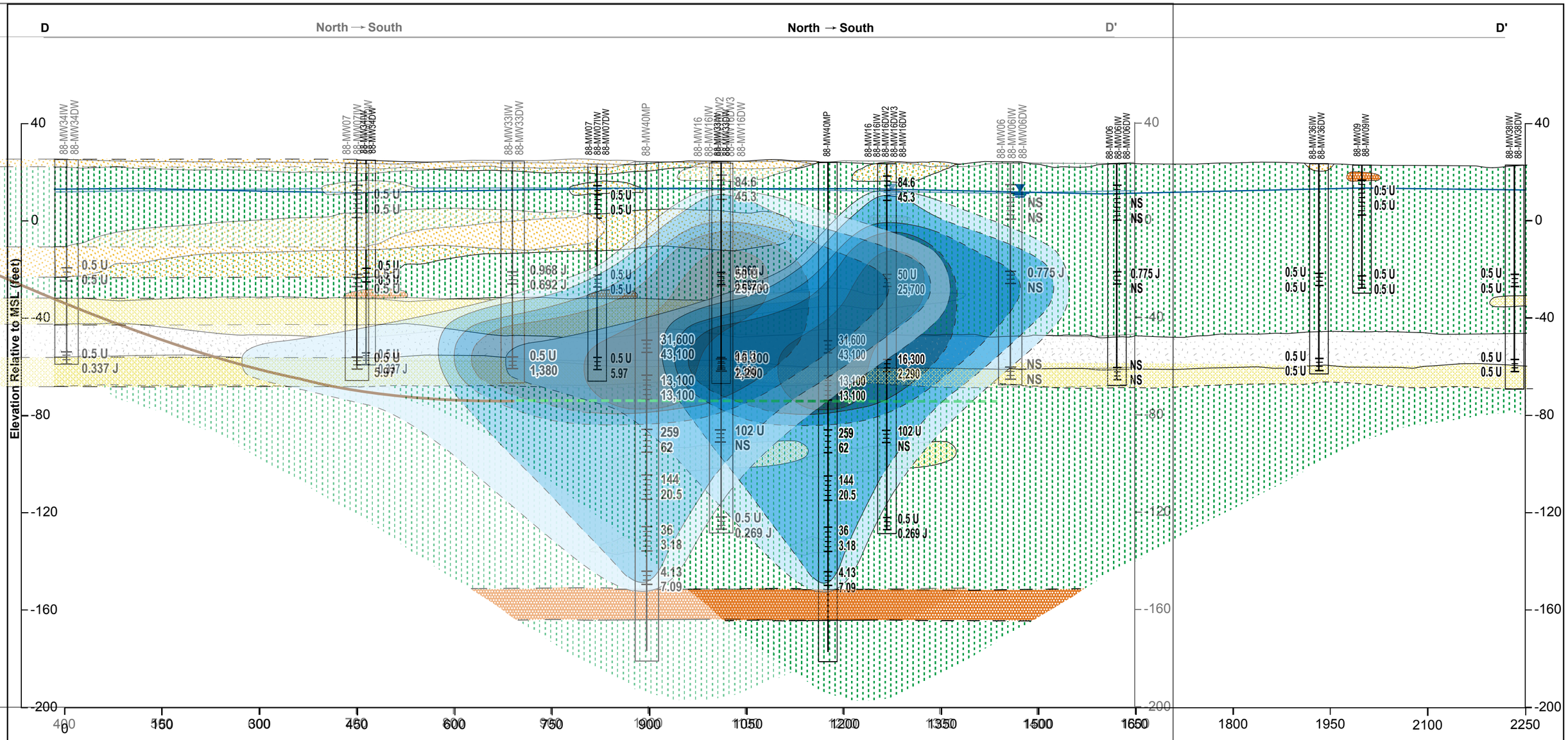


Figure 3-4
Geologic Cross Section A-A'
Tetrachloroethene Concentrations
and Conceptual Layout
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ

PCE Concentrations shown are in µg/L
Top concentration from October 2011
Bottom concentration from October 2014

*PCE detection in well IR88-MW16DW3 in October 2011 was flagged as a "non-detection" due to PCE in an equipment blank. However, the concentration is similar to previous sampling events and is considered a detection for the purposes of analysis.

Figure 2-5
Geologic Cross Section D-D'
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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**Legend**

- Clay
- Fossiliferous Sand
- Cemented Sand
- Sand
- Silt
- Screened Interval
- Water Table Elevation
- NS Not Sampled

Notes:
1. The depth and thickness of the subsurface strata indicated on this section (profile) were generalized from and interpolated between test locations and dashed where inferred. Information on actual subsurface conditions applies only to the specific locations and dates indicated. Subsurface conditions and water levels at other locations may differ from conditions occurring at the indicated location.

Horizontal : 1" = 100'
Vertical: 1" = 40'
V.E. = 10x

PCE Extent
(dashed where inferred)
- 0.7 µg/L - 7 µg/L
- 7 µg/L - 70 µg/L
- 70 µg/L - 700 µg/L
- 700 µg/L - 7,000 µg/L
- 7,000 µg/L - 70,000 µg/L

Notes:
1. The depth and thickness of the subsurface strata indicated on this section (profile) were generalized from and interpolated between test locations. Information on actual subsurface conditions applies only to the specific locations and dates indicated. Subsurface conditions and water levels at other locations may differ from conditions occurring at the indicated location.

Horizontal : 1" = 100'
Vertical: 1" = 40'
V.E. = 10x

PCE Extent
(dashed where inferred)
- 0.7 µg/L - 7 µg/L
- 7 µg/L - 70 µg/L
- 70 µg/L - 700 µg/L
- 700 µg/L - 7,000 µg/L
- 7,000 µg/L - 70,000 µg/L

ES102011122008MKE Site_88_Figure_2-5_TracerStudy_D-D'_v5.ai 07.14.15 sls

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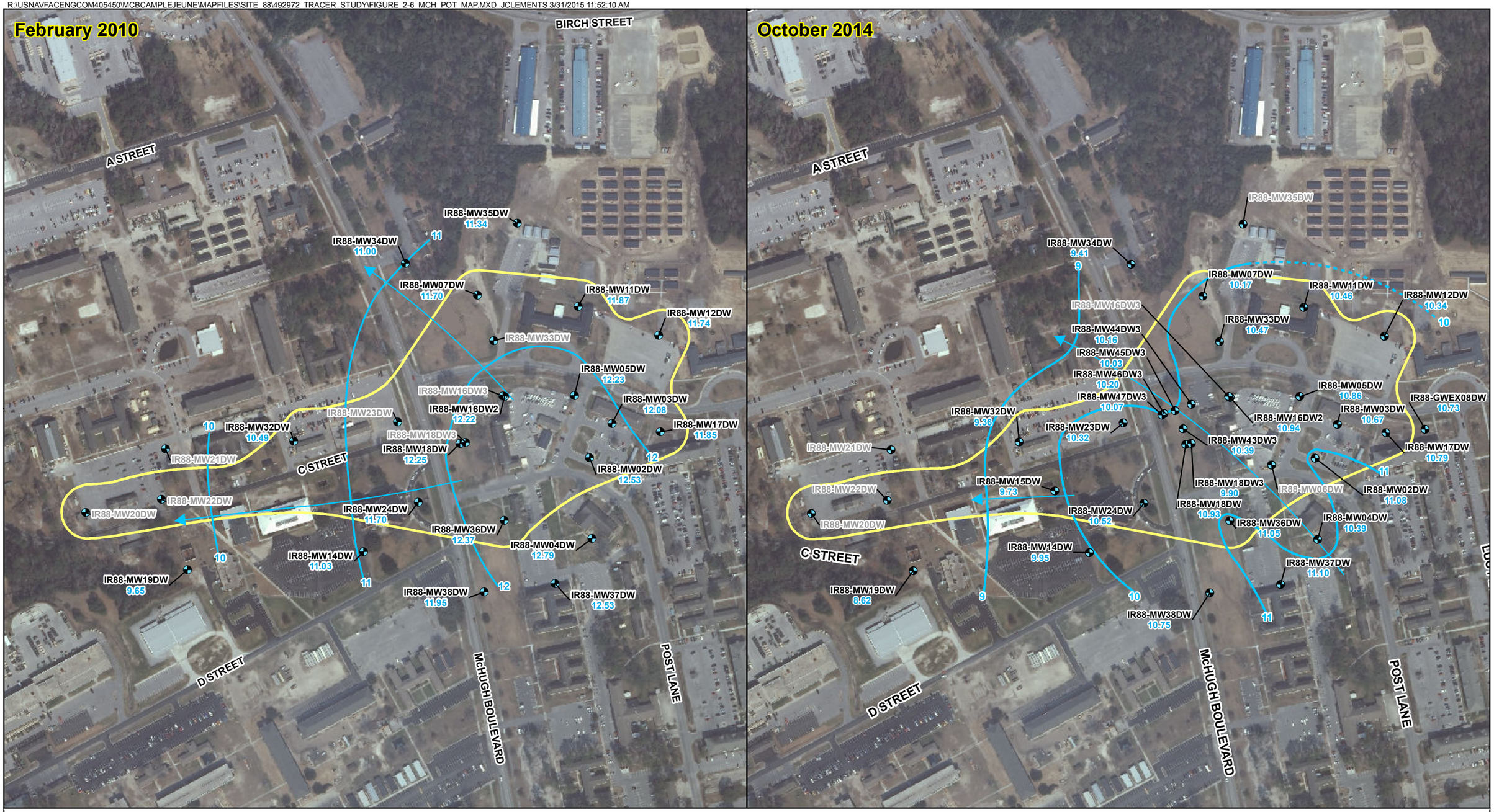


**Legend**

- Monitoring Well
- Potentiometric Contour (dashed where inferred)
- Approximate Groundwater Flow Direction
- Site 88 Boundary
- 14.51 Groundwater Elevation (ft msl)

**Notes:**

- Groundwater elevations are expressed as feet above mean sea level.
- Potentiometric surface contours have been interpolated between monitoring well locations.
- Actual conditions may differ from those shown here.
- Gray monitoring well label Indicates well was not included in contour interpolation.

N

0 175 350 Feet

1 inch = 350 feet

Figure 2-6
Middle Castle Hayne Aquifer Potentiometric Surface
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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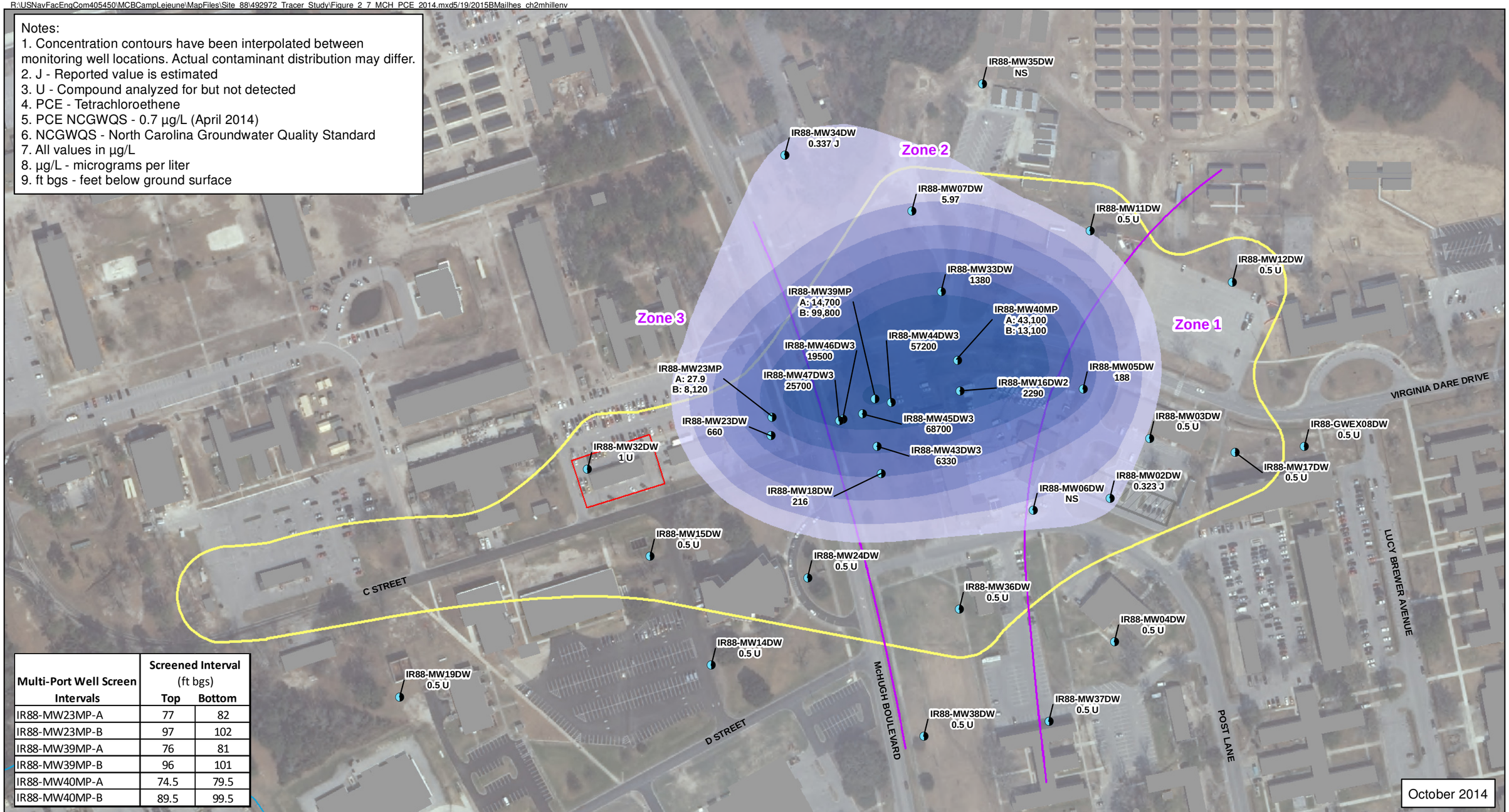


| Multi-Port Well Screen Intervals | Screened Interval (ft bgs) Top | Bottom |
|---|---|---|
| IR88-MW23MP-A | 77 | 82 |
| IR88-MW23MP-B | 97 | 102 |
| IR88-MW39MP-A | 76 | 81 |
| IR88-MW39MP-B | 96 | 101 |
| IR88-MW40MP-A | 74.5 | 79.5 |
| IR88-MW40MP-B | 89.5 | 99.5 |

**Legend**

- Middle Castle Hayne Aquifer Monitoring Well
- Surface Water Centerline
- Zone Boundary
- Former Building 25
- SWMU 615 Boundary
- Site 88 Boundary

**PCE Extent (dashed where inferred)**

- 0 µg/L - 0.7 µg/L
- 0.7 µg/L - 7 µg/L
- 7 µg/L - 70 µg/L
- 70 µg/L - 700 µg/L
- 700 µg/L - 7000 µg/L
- 7000 µg/L - 70000 µg/L
- >70000 µg/L

N

0 100 200 400 Feet

1 inch = 200 feet

Figure 2-7
Approximate Extent of PCE Exceedances in the MCH Aquifer (75-115 ft bgs)
Site 88 Tracer Study
MCIEAST- MCB CAMLEJ
North Carolina

CH2MHILL

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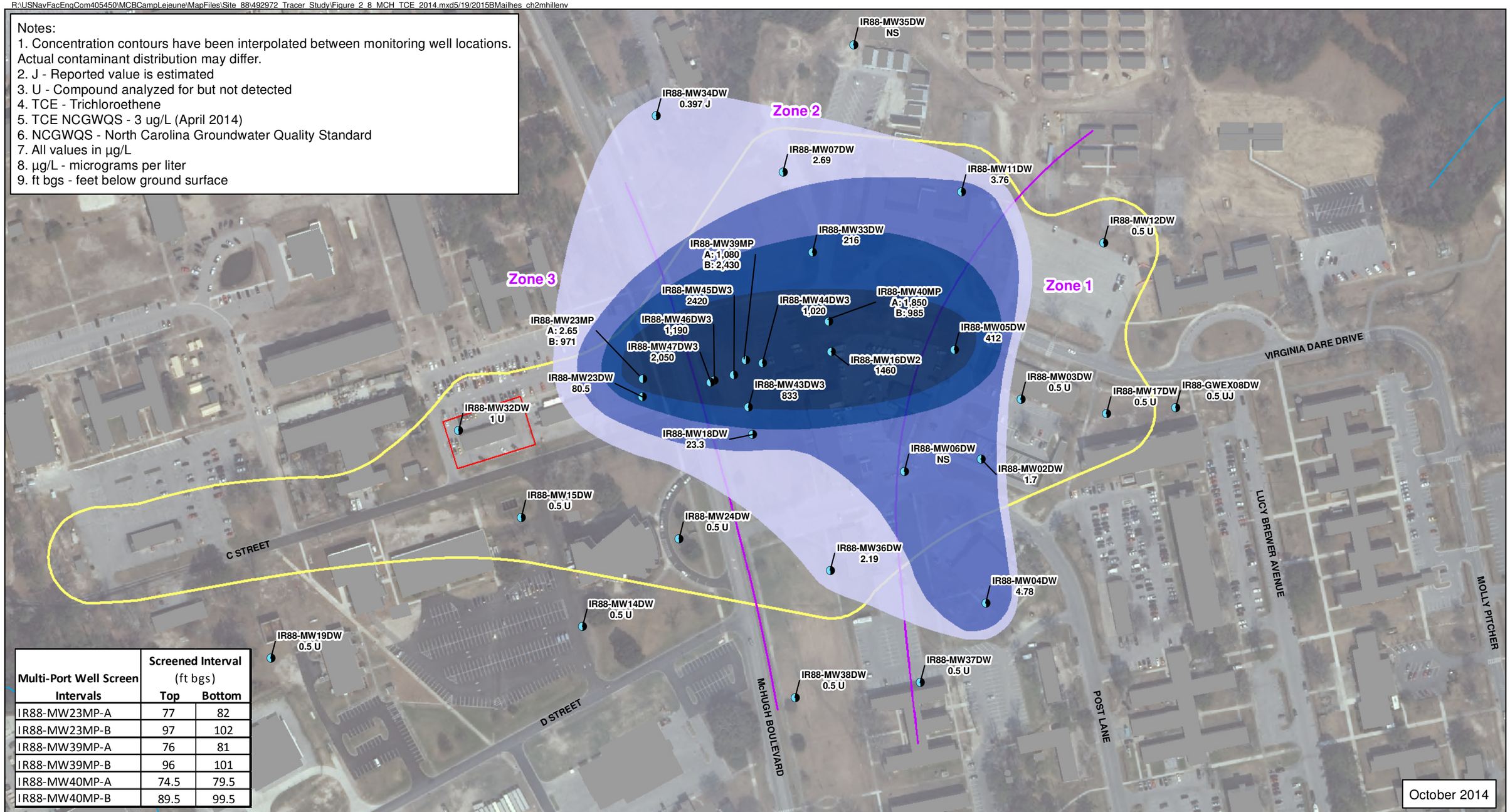
Notes:
1. Concentration contours have been interpolated between monitoring well locations. Actual contaminant distribution may differ.
2. J - Reported value is estimated
3. U - Compound analyzed for but not detected
4. TCE - Trichloroethene
5. TCE NCGWQS - 3 ug/L (April 2014)
6. NCGWQS - North Carolina Groundwater Quality Standard
7. All values in µg/L
8. µg/L - micrograms per liter
9. ft bgs - feet below ground surface




| Multi-Port Well Screen Intervals | Screened Interval (ft bgs) Top | Bottom |
|---|---|---|
| IR88-MW23MP-A | 77 | 82 |
| IR88-MW23MP-B | 97 | 102 |
| IR88-MW39MP-A | 76 | 81 |
| IR88-MW39MP-B | 96 | 101 |
| IR88-MW40MP-A | 74.5 | 79.5 |
| IR88-MW40MP-B | 89.5 | 99.5 |

**Legend**
- Middle Castle Hayne Aquifer Monitoring Well
- Surface Water Centerline
- Zone Boundary
- Former Building 25
- SWMU 615 Boundary
- Site 88 Boundary

**TCE Extent (dashed where inferred)**
- 0 µg/L - 3 µg/L
- 3 µg/L - 30 µg/L
- 30 µg/L -3 00 µg/L
- >300 µg/L

N

0 100 200 400 Feet

1 inch = 200 feet

Figure 2-8
Approximate Extent of TCE Exceedances in the MCH Aquifer (75-115 ft bgs)
Site 88 Tracer Study
MCIEAST- MCB CAMLEJ
North Carolina

CH2MHILL

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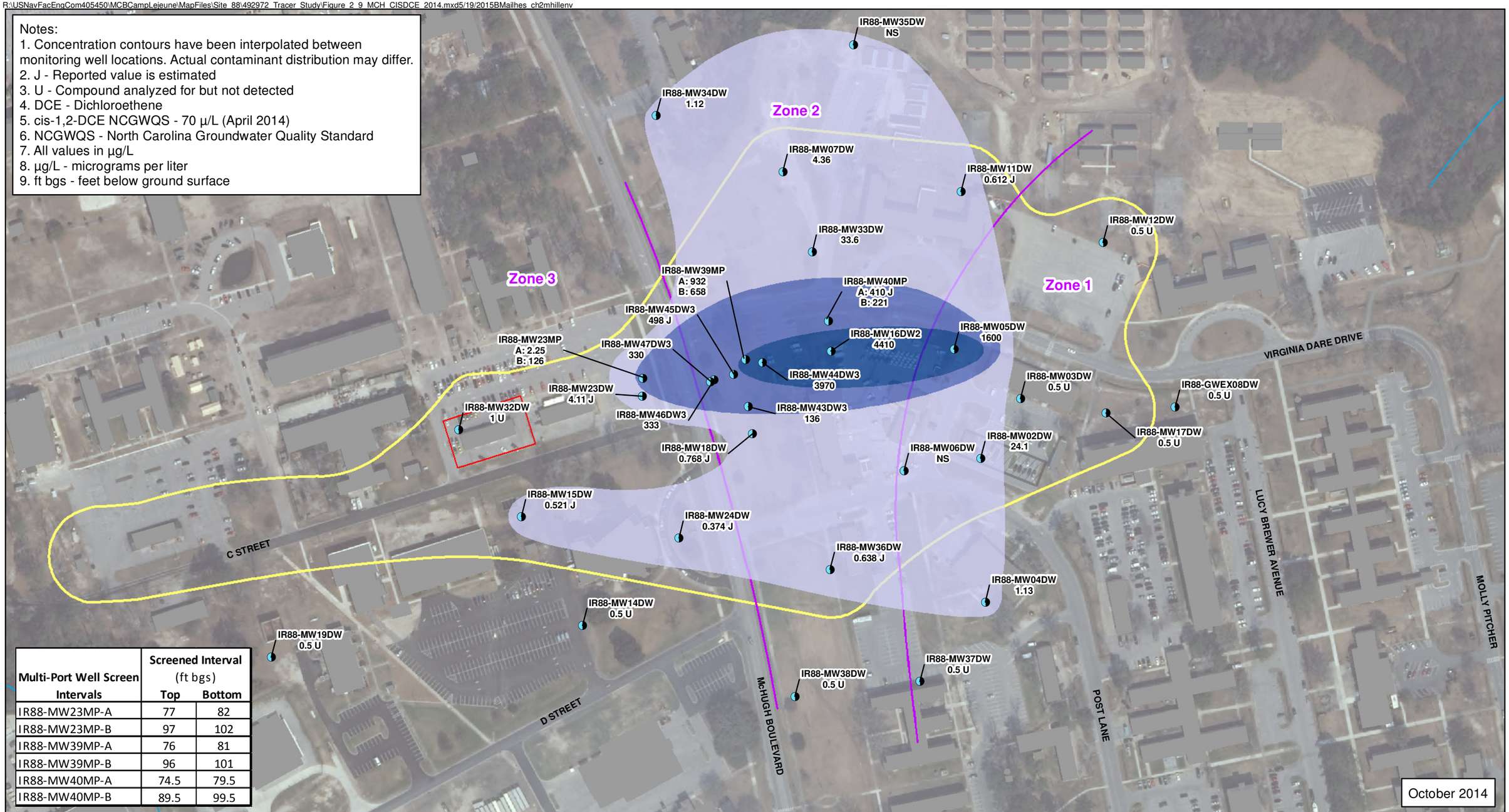


| Multi-Port Well Screen Intervals | Screened Interval (ft bgs) Top | Bottom |
|---|---|---|
| IR88-MW23MP-A | 77 | 82 |
| IR88-MW23MP-B | 97 | 102 |
| IR88-MW39MP-A | 76 | 81 |
| IR88-MW39MP-B | 96 | 101 |
| IR88-MW40MP-A | 74.5 | 79.5 |
| IR88-MW40MP-B | 89.5 | 99.5 |

**Legend**

- Middle Castle Hayne Aquifer Monitoring Well
- Surface Water Centerline
- Zone Boundary
- Former Building 25
- SWMU 615 Boundary
- Site 88 Boundary

**cis-1,2-DCE Extent (dashed where inferred)**

- 0 µg/L - 70 µg/L
- 70 µg/L - 700 µg/L
- >700 µg/L

N

0 100 200 400 Feet

1 inch = 200 feet

Figure 2-9
Approximate Extent of cis-1,2-DCE Exceedances in the MCH Aquifer (75-115 ft bgs)
Site 88 Tracer Study
MCIEAST- MCB CAMLEJ
North Carolina

CH2MHILL

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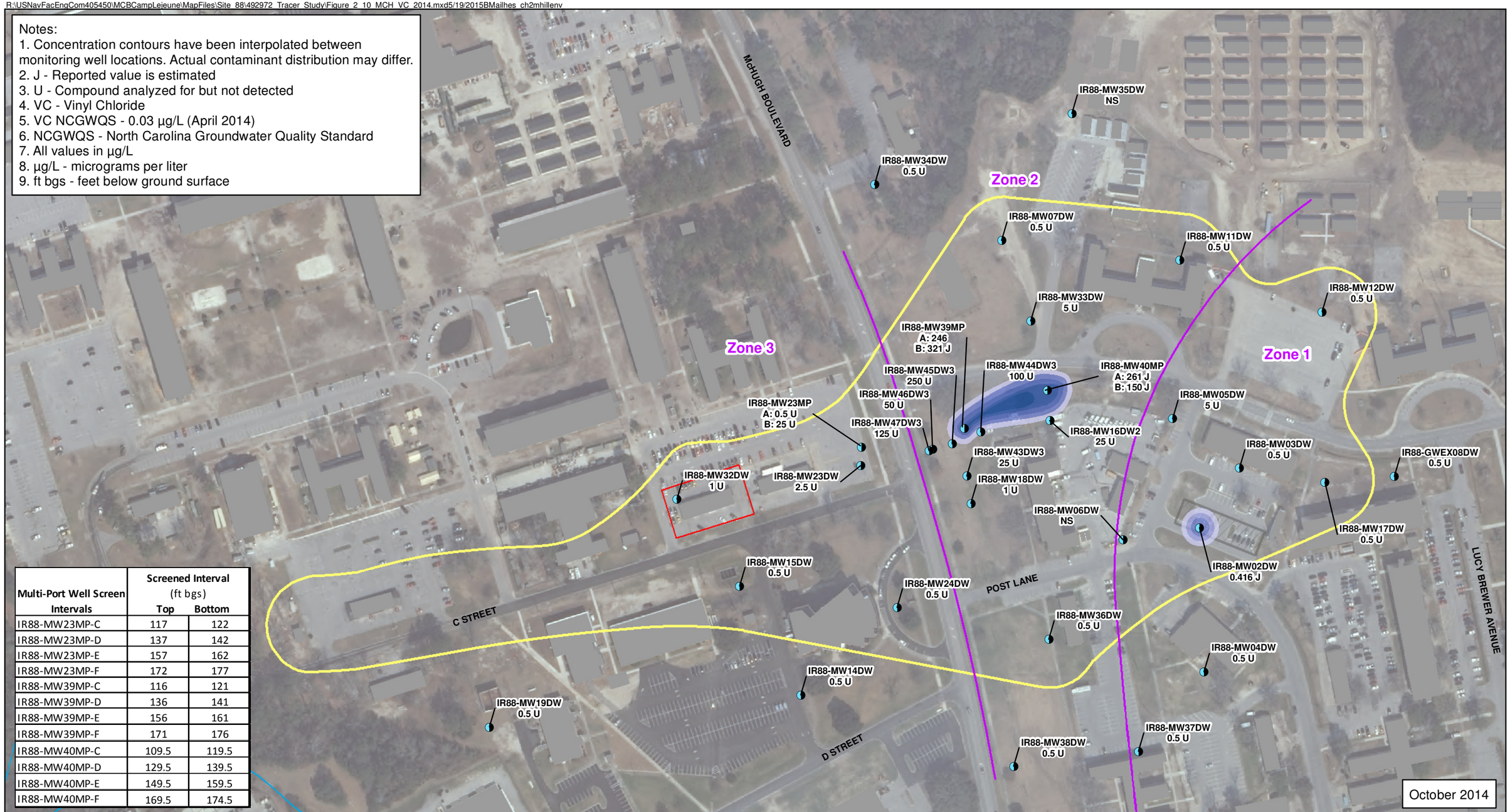
Notes:
1. Concentration contours have been interpolated between monitoring well locations. Actual contaminant distribution may differ.
2. J - Reported value is estimated
3. U - Compound analyzed for but not detected
4. VC - Vinyl Chloride
5. VC NCGWQS - 0.03 µg/L (April 2014)
6. NCGWQS - North Carolina Groundwater Quality Standard
7. All values in µg/L
8. µg/L - micrograms per liter
9. ft bgs - feet below ground surface




| Multi-Port Well Screen Intervals | Screened Interval (ft bgs) Top | Bottom |
|---|---|---|
| IR88-MW23MP-C | 117 | 122 |
| IR88-MW23MP-D | 137 | 142 |
| IR88-MW23MP-E | 157 | 162 |
| IR88-MW23MP-F | 172 | 177 |
| IR88-MW39MP-C | 116 | 121 |
| IR88-MW39MP-D | 136 | 141 |
| IR88-MW39MP-E | 156 | 161 |
| IR88-MW39MP-F | 171 | 176 |
| IR88-MW40MP-C | 109.5 | 119.5 |
| IR88-MW40MP-D | 129.5 | 139.5 |
| IR88-MW40MP-E | 149.5 | 159.5 |
| IR88-MW40MP-F | 169.5 | 174.5 |

**Legend**
- Middle Castle Hayne Aquifer Monitoring Well
- Surface Water Centerline
- Zone Boundary
- Former Building 25
- SWMU 615 Boundary
- Site 88 Boundary

**VC Extent (dashed where inferred)**
- 0 µg/L - 0.03 µg/L
- 0.03 µg/L - 0.3 µg/L
- 0.3 µg/L - 3 µg/L
- 3 µg/L - 30 µg/L
- 30 µg/L - 300 µg/L
- >300 µg/L

N

0 100 200 400 Feet

1 inch = 200 feet

Figure 2-10
Approximate Extent of VC Exceedances in the MCH Aquifer (75-115 ft bg)
Site 88 Tracer Study
MCIEAST- MCB CAMLEJ
North Carolina

CH2MHILL

SECTION 3

# Tracer Study Basis of Design

The following sections present an overview of the tracer study objectives and design basis, including the key features influencing the approach, the rationale for selection, the conceptual location and layout, and design elements.

## 3.1 Tracer Study Objectives

The Site 88 permanganate tracer study objectives are as follows:

- Evaluate the feasibility and effectiveness of ISCO using permanganate for treating COCs in groundwater in the MCH aquifer at Site 88.
- Evaluate HDD injection wells as an effective delivery method for permanganate into the deeper MCH aquifer.
- Evaluate the achieved zone of influence for permanganate injections with and without extraction/recirculation.
- Assess the effectiveness of using geophysical mapping as a means of assessing permanganate distribution following injection through a HDD well and following extraction/recirculation.
- Identify critical design parameters (permanganate dosage, injection rates, extraction/recirculation rates and injection well spacing) for the design of a full-scale ISCO treatment system in support of the FS.

## 3.2 Technology Description

### 3.2.1 In-Situ Chemical Oxidation

ISCO is an in situ technology that consists of injecting chemical oxidants into the subsurface so contaminants are oxidized into innocuous compounds. A number of chlorinated alkenes can be successfully treated via chemical oxidation. Permanganate (in a powder potassium permanganate or liquid sodium permanganate form) is one of several commercially available oxidants that can be injected into the subsurface to treat these chlorinated alkenes. With proper personal protective equipment (PPE), permanganate is safe and relatively easy to handle in the field. Permanganate was also proven to be effective at reducing PCE concentrations at Site 88 during a 2011 Pilot Study (CH2M HILL, 2011). Sodium permanganate was selected as the oxidizing agent to be used for this tracer study due to the ease of handling versus the powder oxidant form.

### 3.2.2 Horizontal Injection Wells

An HDD injection well was selected over an array of vertical wells because HDD injection wells have been successfully implemented at MCIEAST–MCB CAMLEJ, require significantly less surface infrastructure than traditional vertical injection wells especially when considered for relatively large target treatment areas, and can be installed beneath existing base infrastructure.

HDD injection wells can be installed either “blind end” (single-entry) or “continuous” (double-ended). Blind wells reduce site impact because only one access point is required. However, when they are installed using open-borehole methods, partial borehole collapse and pipe seizure can occur, which are more likely when the boring length exceeds 500 feet, or challenging lithology, such as flowing sands, is encountered. Some directional drillers have developed innovative methods to install longer blind end wells using cased well methods, but such methods are relatively expensive. Continuous wells, while increasing the total length of drilling required, can be installed less expensively over longer distances, using smaller drill rigs, due to the drilling tools and methods used. In the continuous well installation method, the drill bit is pulled back with the well materials while drilling fluids are continuously injected, thereby reducing tensile forces on the pipe, even in flowing sands. Continuous wells are also easier to rehabilitate if necessary, and the distal end can be used for monitoring. For the reasons cited above, a continuous or double-ended well configuration was selected for the subject tracer study.

### 3.2.3 Extraction/Recirculation System

A closed-loop extraction/recirculation system consists of vertical extraction wells with submersible pumps and conveyance piping used to route purged groundwater to the surface, through a booster pump, and back into the injection well(s) located hydraulically upgradient from the extraction wells. Prior to reinjection, purged groundwater will be processed through an above-ground filtration system to trap fines/solids and mitigate the potential for fouling of the injection well screen. The purpose of an extraction/recirculation system is to enhance the natural groundwater flow gradient to allow for improved distribution of chemical oxidant within the subsurface, thereby enhancing in situ treatment of COCs in groundwater.

### 3.2.4 Geophysical Mapping

A geophysical mapping technique (GeoTrax Survey) was identified as a potential technology able to evaluate the distribution of permanganate in the subsurface following injections at the Site. This technology utilizes electrical resistivity imaging to monitor for the distribution of permanganate within the deeper subsurface (UCH, MCH, and LCH aquifers). Data are collected by placing electrodes in contact with the ground. The electrodes introduce current into the subsurface and measure the resulting field. An inverse model of the data produces an electrical resistivity image that shows the synthetic distribution of resistivity that predicts values measured in the field.

In October 2014, a baseline geophysical mapping effort was conducted at Site 88 by Aestus LLC (Aestus) within the geophysical survey area depicted on **Figure 2-2**. The primary objective of the baseline geophysical mapping investigation was to provide baseline conditions to be compared with future geophysical surveys.

Site-wide groundwater sampling data were used to calibrate the results of the baseline geophysical mapping for subsurface two-dimensional modeling. The baseline geophysical mapping results indicated the following:

- Residual emulsified vegetable oil (EVO) (less than milligrams per liter [5 mg/L]) and a robust population of *Dehalococcoides* (greater than 1E5 cells per milliliter) remain within the tracer study area following a pilot study where EVO injections and bioaugmentation was conducted in 2010 (CH2M HILL, 2011). The baseline geophysical mapping data indicate that these constituents are potentially overprinting or overshadowing signals from background contaminant concentrations.
- The existing dense network of utilities within the geophysical study area potentially overshadows some contaminant or other subsurface signals (e.g., subsurface geology).

Although the presence of injectate and utility overshadowing affected the ability of the GeoTrax Surveys to identify DNAPL within the subsurface, Aestus indicated that the site-specific characteristics would not affect the ability to image resistivity changes following permanganate injections. Aestus recommended increasing the conductivity of permanganate with a nonreactive tracer material, such as sodium chloride, to increase the electrical difference and enhance the ability to detect the permanganate in subsurface. An assessment of site-specific conditions indicated that the addition of 800 mg/L of sodium chloride would result in a subsurface electric conductivity change that would be detectable to the geophysical imaging equipment. The preliminary geophysical mapping technical memorandum prepared by Aestus is included in **Appendix B**.

## 3.3 Location and Layout

In order to achieve the tracer study objectives, the tracer study will be completed in two phases. For Phase I, the key component includes the HDD injection well (**Figures 3-1** through **3-4**), and for Phase II, the key components include three vertical extraction wells and the piping and equipment required to operate the extraction/recirculation system (**Figures 3-5** and **3-6**). Factors that affected the decision for the location and layout of the tracer study system include the following:

- The HDD injection well will be placed perpendicular to the flow of groundwater, to intercept the full width of the plume which will allow the HDD injection well to be utilized during the full-scale design for ongoing treatment of impacted groundwater.

- The HDD well entry point was selected to allow sufficient setback to achieve the target HDD well depth and provide enough room for the tracer study equipment compound location and directional drilling staging area (**Figure 3-1**), while minimizing impacts to ongoing activities within the surrounding Base buildings and along roadways. In addition, Base utility poles are present at the proposed tracer study equipment compound location to provide a power drop for the injection system.
- The target depth of the HDD injection well was selected to optimize degradation of COCs within the deeper subsurface MCH aquifer (75 to 115 feet bgs) (**Figures 3-2** through **3-4**). The target depth for the HDD injection well was chosen to be 100 feet bgs since existing monitoring wells are screened at this depth, which will allow for an independent assessment of permanganate distribution in the subsurface and to verify geophysical mapping results. Samples collected from the existing monitoring well network will be inspected visually for changes in color and also field-analyzed for detectable concentrations of the tracers (permanganate and chloride). Please note that the cross-section illustrated on **Figure 3-4** is slightly upgradient and therefore portrays the plume shallower than it is along the injection transect as presented on **Figure 3-3**.
- The length of the HDD injection well screened interval was selected to be 500 feet, based on the results of the most-recent site-wide groundwater sampling conducted in October 2014 (**Figure 3-2**). The casing at the proximal end (header section) will be approximately 625 feet, to achieve the target depth of 100 feet bgs and position the wellhead near the tracer study equipment compound and directional drill rig staging area. The proximal end wellhead will be completed in a 24-inch x 60-inch access manway, set in a concrete apron. The casing at the distal end (tail section) will be approximately 450 feet long, existing in a grassy area at the southern end of the site. The distal end wellhead will be completed in a temporary 24-inch x 24-inch access manway, to be removed after the tracer study is completed, and subsequently direct buried such that it can be re-accessed if needed during implementation of the remedial action.
- The screened portion of the HDD injection well is situated parallel to the GeoTrax Survey lines that will be used to assess permanganate distribution via geophysical mapping techniques. The HDD injection well will be positioned at approximately 20, 25, and 55 feet from the three GeoTrax Survey lines to evaluate lateral distribution of permanganate to assess the accuracy and potential optimization of the assumed lateral radius of influence of 20 feet from the 2012 Draft FS (**Figure 3-2**). The data will also allow for an assessment of the vertical distribution of permanganate at each GeoTrax Survey line to assess the assumed 30-foot saturated thickness from the 2012 Draft FS.
- For the Phase II extraction/recirculation portion of the tracer study, three vertical extraction wells are proposed to be placed 180 feet from the HDD injection well, based upon the assumed required spacing of 180 feet between HDD injection wells presented in the Draft FS. Therefore, the 180-foot spacing of the proposed vertical extraction wells from the HDD injection well will allow for the assessment of whether the total number of HDD injection wells required for future remedial actions can be minimized through implementation of an extraction/recirculation system.

## 3.4 Horizontal Well Injection System Design

The proposed horizontal well injection system and permanganate dosing specifications are summarized in **Table 3-1** and discussed in the sections below.

### 3.4.1 Horizontal Injection Well Screen Design

A numerical model was used to predict flow and pressure at discrete intervals to promote relatively uniform injection rates along the entire length of the HDD injection well screened-interval. Final slot design specifications (including total open area, number of slots per foot, slot length, and modeled flow performance) are included in **Appendix C**.

The performance objective for the HDD well will be less than 1 percent skew in flow across the screens, within a flow of 0.1 to 0.15 gallon per minute per foot of screened interval. Screen slots will be cut perpendicular (“cross cut”) to the axis of the pipe in a uniform pattern around the circumference of the pipe, three rows, with 120

degrees between rows. The target inside slot length is 1.6 inches, and the target slot width is 0.020 inches, with a tolerance of 10 to 15 percent. The total target slot open area percentage is 0.151.

### 3.4.2 Horizontal Injection Well Design

The overall specification for the HDD injection well (HIW-1) is summarized in **Table 3-2** and illustrated on **Figure 3-1**. Specifications for borehole advancement, well construction, completion, and development are detailed in **Section 4**.

TABLE 3-2
HDD Injection Well Specifications
*Site 88 Tracer Study*
*MCIEAST–MCB CAMLEJ, North Carolina*

| Well ID | Entry Riser (feet) | Screen (feet) | Exit Riser (feet) | Total (feet) | Target Depth of Screen at Proximal End Measured from Ground Surface (feet bgs) | Construction Materials |
|---|---|---|---|---|---|---|
| HIW-1 | 625 | 500 | 450 | 1,575 | 100 | 4-inch Fiberglass Reinforced Epoxy(FRE) |

## 3.5 Permanganate Injection Design and Dosing

Data collected from the 2010 Treatability Study and 2011 Pilot Study, which assessed permanganate distribution and effectiveness in the UCH aquifer within Zone 2 at Site 88, provide the basis for permanganate dosing for this tracer study within the MCH aquifer of Zone 2. A summary of these studies are included below:

- **Treatability Study (CH2M HILL, 2010a):** In 2010, bench-scale treatability tests were conducted at Site 88, assessing various methods to treat site COCs in preparation for larger-scale pilot studies. One objective of the treatability tests was to evaluate the effectiveness of ISCO using permanganate for oxidizing COCs within the UCH aquifer in Zone 2. The results of the studies indicated the optimal treatment for ISCO in the UCH aquifer of Zone 2 to be approximately 1.8 g of permanganate per kilogram of dry soil.
- **Pilot Study (CH2M HILL, 2011):** From September to December 2010, a pilot study was implemented at Site 88 based on the results of the 2010 Treatability Study. ISCO using potassium permanganate was implemented via vertical injection wells for Zone 2 in the UCH aquifer near IR88-MW16IW (**Figure 2-1**) to further assess the potential effectiveness of permanganate treatment in situ, to obtain additional design parameters needed for full-scale implementation, and to mitigate offsite migration of COCs. In general, the pilot study results confirmed injection of permanganate in the UCH aquifer at Site 88 within Zone 2 to be effective. Significant findings are as follows:
    - The radius of influence (ROI) for permanganate distribution was approximately 20 feet with an average injection rate of 34 gallons per minute (gpm) into 4-inch-diameter vertical injection wells with 20 foot-screens in the UCH aquifer at approximately 55 feet bgs. The average injections pressure was 12 pounds per square inch (psi).
    - Based on the permanganate demand of 1.8 grams per kilogram (g/kg) and the targeted treatment zone size, approximately 40,000 pounds of potassium permanganate were injected. This oxidant quantity was delivered to the subsurface at a 2.5 to 4 percent concentration. The average concentrations of PCE and its daughter products was observed to decrease by 86.7 percent during the pilot study in monitoring wells within the 20-foot ROI.
    - ISCO injections were not observed to adversely affect conditions needed for microbial populations within Zone 2, corroborating results from other laboratory and field studies.

Based on the design parameters identified during the 2010 Treatability Study and 2011 Pilot Study, the required permanganate mass and solution volume for the tracer study were calculated and are summarized in **Table 3-1**. The estimated pore volume for the Phase I target tracer area is approximately 705,000 gallons, based on a lateral

radius of 20 feet, a vertical radius of 15 feet, a treatment length of 500 feet, and an estimated effective porosity of 0.2. The total sodium permanganate mass required to satisfy the soil oxidant demand and treat chlorinated solvents is approximately 42,000 pounds (at a liquid concentration of 40 percent by weight [wt]). This is based on an estimated permanganate natural oxidant demand (PNOD) of 1.8 g/kg, an assumed contact efficiency factor of 20 percent and a conservative average total COC contaminant concentration of 35 mg/L within the tracer study area. The permanganate solution will be delivered into the subsurface at a concentration of 2 percent, resulting in approximately 99,000 gallons of injectant solution which equates to approximately 14 percent of the effective pore volume.

As discussed in **Section 3.2** above, a conservative tracer sodium chloride will also be added to the injectant solution. Adding the conservative tracer will improve the probability that the injectant solution will be detected via geophysical mapping techniques in the event that permanganate is consumed prior to conducting the geophysical survey. In addition, the presence or absence of the conservative tracer via traditional monitoring in the existing network of monitoring wells, depicted on **Figure 3-1**, will provide a secondary method to assess substrate distribution if the permanganate is quickly consumed. If permanganate is consumed too quickly, a higher permanganate dosage may be warranted for the full-scale design.

## 3.6 Extraction/Recirculation System Design

The Draft FS recommended that groundwater extraction wells be considered for the full-scale remedial design to help distribute permanganate in the subsurface in a controlled manner (induced hydraulic gradients). Furthermore, the extracted groundwater can be used to mix with the permanganate for the injections, eliminating the need for supply water. To evaluate how well the treatment zone can be extended with an extraction/recirculation application and to refine design parameters for such a scenario, a Phase II (Extraction/Recirculation) portion of the tracer study will be conducted.

### 3.6.1 Hydraulic Capture Zone Calculations

A pump test was conducted in Zone 1 in support of the RI in the upper portion of the MCH aquifer at IR88-GWEX08DW (**Figure 2-2**). During the constant rate pumping test, groundwater levels were observed to decrease by 0.322 feet in observation well IR88-MW17DW, located approximately 142 feet away from extraction well IR88-GWEX08DW, when groundwater pumping rates were set to 12.5 gpm. In addition, a minor drop in groundwater levels was observed in observation well IR88-MW12DW (0.087 feet), located approximately 365 feet away.

Based on this data, calculations were performed to assess the potential hydraulic capture zone. The Steady-State Thiem Solution and an estimated capture zone width calculation for one extraction well (United States Environmental Protection Agency [USEPA], 2008) were used for this assessment, using the most conservative site-specific information available from the RI. As presented in **Table 3-3**, the Steady-State Thiem Solution results indicate that the estimated radial hydraulic capture zone around one extraction well ranges from 560 to 1,159 feet. For the one extraction well calculation method, the estimated capture zone along the central line of flow ranges from 80 to 215 feet and from 125 to 251 feet along the central line of the plume. It is assumed the actual performance will be improved with three overlapping vertical extraction wells.

Based on the pump test data and calculations performed, three extraction wells are proposed to be equally spaced at 125 feet apart, and placed 180 feet from the HDD injection well. Thus, the proposed placement of the vertical extraction wells are generally located within the estimated ranges of calculated hydraulic capture zones.

### 3.6.2 Extraction Well Submersible Pump Head Loss Calculations

To appropriately size the extraction well submersible pumps, total head losses were estimated based on the proposed location and layout of the extraction/recirculation system. As summarized in **Table 3-4**, total head losses for extracted groundwater are estimated to be approximately 114 to 122 feet of head. Extraction well submersible pumps will be designed for this range of head losses, while being able to pump one-third of the groundwater flow of the proposed injection well flow rate of 50 gpm, or 16.67 gpm each, to allow for a steady-state closed loop system.

TABLE 3-1

Tracer Study Design Summary

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

**Site 88 Aquifer Description**

| | Value | Unit |
|---|---|---|
| *Hydraulic Characteristics* | | |
| Depth of Injection Zone | 100 | ft |
| Hydraulic Gradient | 0.0014 | ft/ft |
| Hydraulic Conductivity | 7.9 | ft/day |
| Estimated Effective Porosity | 0.2 | |
| Soil Bulk Density | 115 | $lbs/ft^3$ |
| Seepage Velocity | 0.055 | ft/day |
| | 20 | ft/yr |

**Site 88 Horizontal Directionally Drilled (HDD) Injection Well Specifications**

| | Value | Unit |
|---|---|---|
| *Hydraulic Characteristics* | | |
| Depth of HDD Injection Well (HIW-1) | 100 | ft |
| Length of HDD Well Screen | 500 | ft |
| Entry Riser Length | 625 | ft |
| Exit Riser Length | 450 | ft |
| Total HDD Injection Well Length | 1,575 | ft |
| HDD Injection Well Diameter (FRE) | 4 | in |

**Phase I - Site 88 Permanganate Injection Specifications (Injection Only)**

| | Value | Unit |
|---|---|---|
| *Treatment Area Volume* | | |
| Lateral Radius of Treatment | 20 | ft |
| Vertical Radius of Treatment | 15 | ft |
| Length of Screened Interval | 500 | ft |
| Pore Volume of Treatment Zone (based on effective porosity) | 704,973 | gallons |
| *Sodium Permanganate (RemOx-L) Specifications* | | |
| Avg Total Contaminant Conc | 35 | mg/L |
| PNOD | 1.8 | g/kg |
| Effective PNOD | 20 | % |
| Calculated Oxidant Demand | 19,137 | lbs |
| Calculated RemOx-L (Total) as 40% by weight solution | 42,962 | lbs |
| | 3,759 | gallons |
| | 14.3 | 3,000-lb totes |
| **Proposed Implementation RemOx-L (Total) as 40% by weight solution** | **42,000** | **lbs** |
| **(for shipping/handling purposes)** | **3,675** | **gallons** |
| | **14** | **3,000-lb totes** |
| RemOx-L Injection Concentration | 2.0% | |
| Total Volume of Injected Fluid | 98,848 | gal |
| Effective Pore Volume Replaced | 14.0 | % |
| *Injection Specifications* | | |
| Estimated Injection Flow Rate | 0.1 | gpm per foot |
| Estimated Total Injection Flow Rate | 50 | gpm |
| Time to Complete Injection (10 hr days) | 3.3 | days |

TABLE 3-1

Tracer Study Design Summary

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

**Phase II - Site 88 Extraction/Recirculation**

| | Value | Unit |
|---|---|---|
| *Target Extraction/Recirculation Treatment Area Volume* | | |
| Lateral Extent of Treatment (Remaining Distance to Furthest Monitoring well IR88-MW46DW3) | 100 | ft |
| Vertical Extent of Treatment | 30 | ft |
| Length of Screened Interval | 500 | ft |
| Total Volume of Treatment Zone | 55,500 | cu yd |
| Pore Volume of Treatment Zone (based on effective porosity) | 2,244,000 | gallons |
| *Injection Specifications* | | |
| Estimated Injection Flow Rate | 0.1 | gpm per foot |
| Estimated Total Injection Flow Rate | 50 | gpm |
| *Extraction Well Specifications* | | |
| Number of Wells | 3 | |
| Extraction Well Diameter | 4 | in |
| Well Depth | 115 | ft |
| Screen Length | 30 | ft |
| Spacing Between Wells | 125 | ft |
| Estimated Extraction Rate per extraction well | 16.67 | gpm |
| *Recirculation* | | |
| Time to Complete Recirculation of 1 Pore Volume (assumes 24-hour operation) | 31 | days |

TABLE 3-3

**Estimated Hydraulic Capture Zone**

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

| Site 88 Middle Castle Hayne Aquifer Estimated Hydraulic Capture Zone | | |
|---|---|---|
| | Value | Unit |
| *Middle Castle Hayne Hydrogeologic Characteristics (EX08DW Pump Test Results)* | | |
| Depth of Injection Zone | 65 - 85 | ft bgs |
| Hydraulic Conductivity | 7.9 | ft/day |
| Reference Head Value ($h_0$ - MW12DW - 365 foot radial distance [R]) | 0.087 | ft |
| Head Value (h - MW17DW - 142 foot radial distance) | 0.322 | ft |
| Regional Hydraulic Gradient (MW18DW -> MW32DW) | 0.0025 | ft/ft |
| Estimated Effective Porosity | 0.2 | |
| Soil Bulk Density | 115.04 | $lbs/ft^3$ |
| Seepage Velocity | 0.101 | ft/day |
| | 36.8 | ft/yr |
| Storage Coefficient | 0.0012 | |
| Transmissivity (T) | 930 - 2,511 | $ft^2/day$ |
| *Estimated Radial Hydraulic Capture Zone - Steady-State Thiem Solution* | | |
| Estimated Drawdown ($h-h_0$) | 0.235 | ft |
| Estimated Distance to Minimal Drawdown (R) | 365 | ft |
| Transmissivity ($T_1$) - Low Range | 930 | $ft^2/day$ |
| Transmissivity ($T_2$) - High Range | 2,511 | $ft^2/day$ |
| Estimated Extraction Rate (Q) | 16.67 | gpm |
| Estimated Extraction Rate (Q) | 3,209 | $ft^3/day$ |
| Estimated Radial Hydraulic Capture Zone ($r_1$) - Low Range | 560 | ft |
| Estimated Radial Hydraulic Capture Zone ($r_2$) - High Range | 1,159 | ft |
| *Estimated Capture Zone Width Calculation - One extraction well** | | |
| Estimated Extraction Rate (Q) | 16.67 | gpm |
| Estimated Extraction Rate (Q) | 3,209 | $ft^3/day$ |
| Transmissivity ($T_1$) - Low Range | 930 | $ft^2/day$ |
| Transmissivity ($T_2$) - High Range | 2,511 | $ft^2/day$ |
| Regional Hydraulic Gradient | 0.0025 | ft/ft |
| Minimum distance to downgradient end of capture zone along the central line of the flow ($X_{min}$) | 80 | ft |
| Maximum distance to downgradient end of capture zone along the central line of the flow ($X_{max}$) | 215 | ft |
| Minimum capture zone width from the central line of the plume ($Y_{min}$) at extraction well | 125 | ft |
| Maximum capture zone width from the central line of the plume ($Y_{max}$) | 251 | ft |

*USEPA. 2008. *A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems, EPA 600/R-08/003*. January.

TABLE 3-4

**Estimated Extraction/Recirculation System Head Loss Calculations**

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

| Extraction/Recirculation System Head Loss Calculation Estimates | | |
|---|---|---|
| | Value | Unit |
| *Conveyance Piping Specifications - SDR 11 HDPE* | | |
| Pipe Diameter (D) | 2 | inches |
| | 0.05 | m |
| | 50.8 | mm |
| Pipe Area (A) | 0.002 | $m^2$ |
| Length to EX01MCH (L1) | 940 | ft |
| | 287 | m |
| Length to EX02MCH (L2) | 1065 | ft |
| | 325 | m |
| Length to EX03MCH (L3) | 1190 | ft |
| | 363 | m |
| Number of 90 degree bends | 1 | |
| *Recirculation Flow Specifications* | | |
| Estimated Extraction Rate (Q) | 16.67 | gpm |
| | 1,000 | gph |
| | 0.0011 | $m^3/s$ |
| Velocity (V) | 0.52 | m/s |
| | 1.70 | ft/s |
| *Head Loss Estimates* | | |
| *Head Losses Due to Elevation* | | |
| Elevation (Estimated from MW23DW to MW34DW) | 2.6 | ft |
| *Head Losses Due to Conveyance Piping* | | |
| Straight Pipe Friction Coefficient* | 3.13 | m/100 m |
| Head Loss Due to Conveyance Piping (L1) | 29.43 | ft |
| Head Loss Due to Conveyance Piping (L2) | 33.34 | ft |
| Head Loss Due to Conveyance Piping (L3) | 37.26 | ft |
| *Head Losses Due to 90 degree Bend Fitting* | | |
| Fitting Friction Coefficient (K) (90 degree bend - short radius elbow)** | 0.90 | ft/ft |
| Gravitational acceleration | 9.81 | $m/s^2$ |
| Head Loss Due to Fitting (90 degree bend - short radius elbow) | 0.04 | ft |
| *Head Losses Due Extraction Well Drawdown During EX08DW Pump Test**** | | |
| Extraction Well Efficiency | 10 | percent |
| Drawdown in Extraction Well During Pump Test | 19.01 | ft |
| Estimated Head Loss Due to Extraction Well Drawdown | 17.11 | ft |
| *Head Losses Due To Groundwater Elevation* | | |
| Estimated Extraction Well Drawdown | 20 | ft |
| Depth to Groundwater | 15 | ft bgs |
| Estimated Groundwater Elevation Head | 65 | ft |
| *Total Head Losses* | | |
| Total Head Loss - Conveyance Piping (L1) | 114 | ft |
| Total Head Loss - Conveyance Piping (L2) | 118 | ft |
| Total Head Loss - Conveyance Piping (L3) | 122 | ft |

*Estimated from Marley Pipe Systems. 2010. *HDPE Design Considerations - v002.*

**Welty et al.1984. *Fundamentals of Momentum, Heat, and Mass Transfer, Third Edition*.

***RI (CH2M HILL, 2008)

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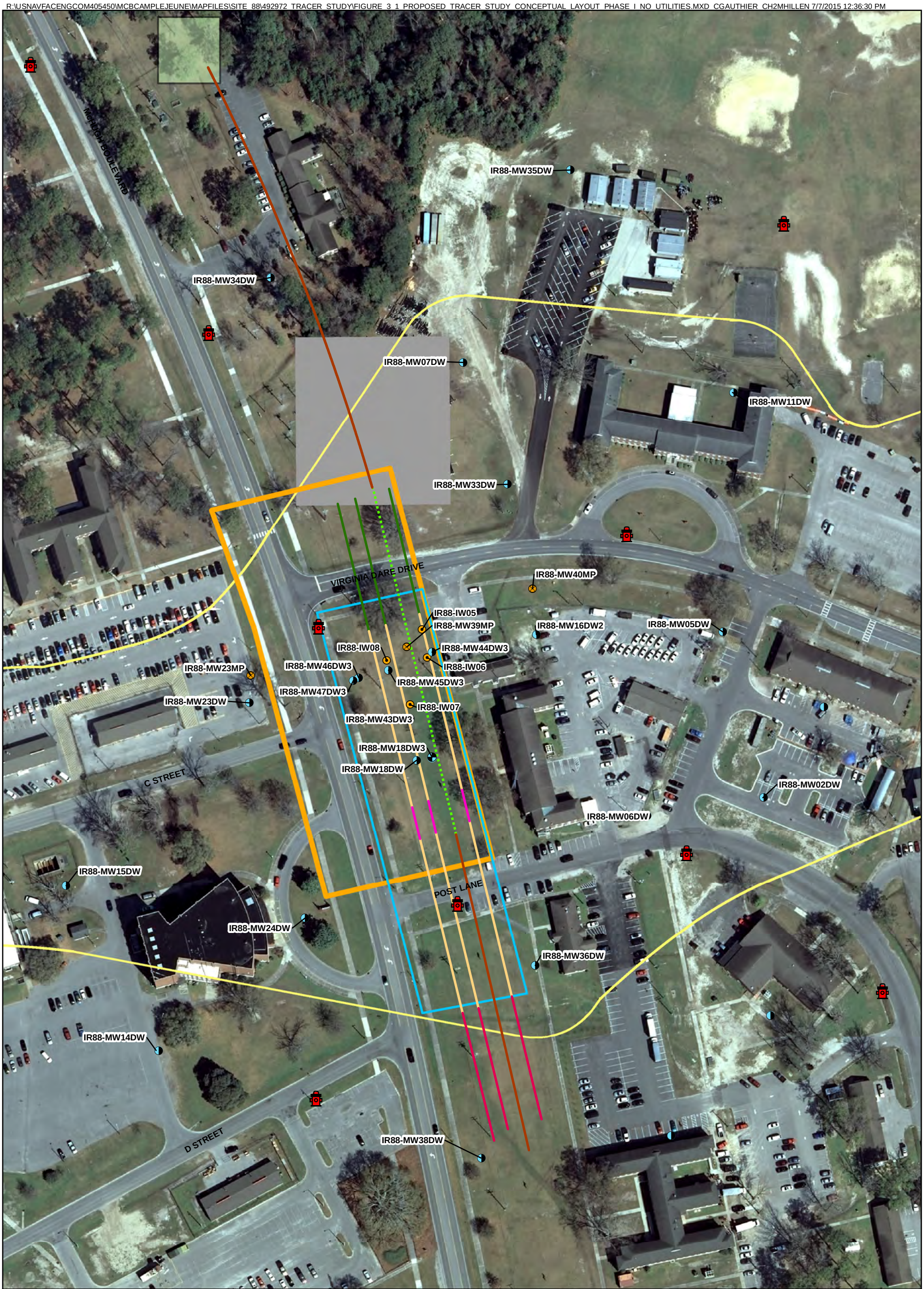


**Legend**

- Multi-Port
- Injection Well
- Middle Castle Hayne Aquifer Monitoring Well
- Lower Castle Hayne Aquifer Monitoring Well
- Fire Hydrant
- Site 88 Boundary
- Geophysical Survey Area
- Tracer Study Equipment Compound Staging
- Tracer Study Area
- Surface Water Centerline
- Proposed Horizontal Well Screen (500 feet)
- Proposed Horizontal Well Casing (625+450 feet)
- GeoTrax Survey Line

Figure 3-1
Tracer Study Conceptual Layout - Phase I
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

N

0 62.5 125 Feet

1 inch = 125 feet

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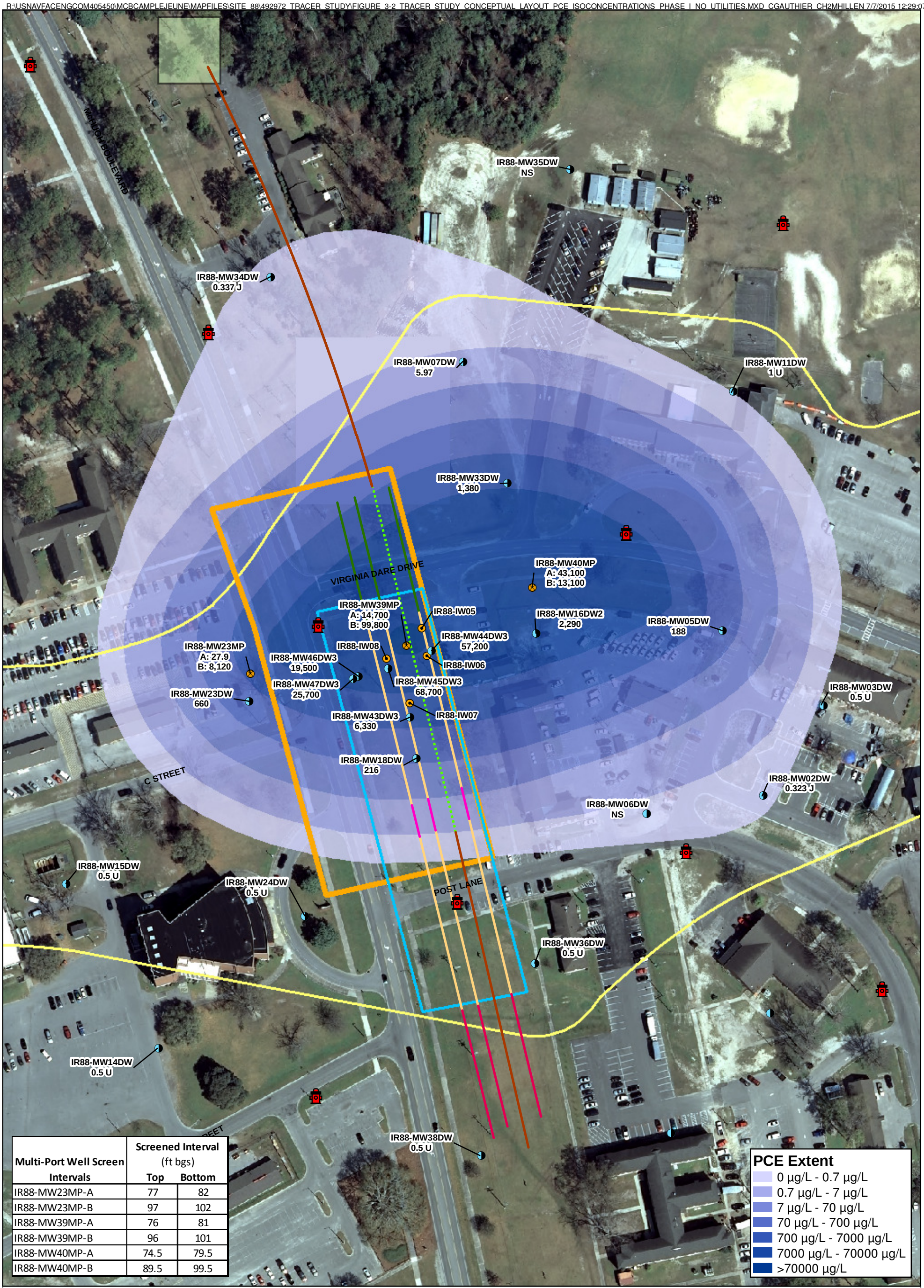


| Multi-Port Well Screen Intervals | Screened Interval (ft bgs) Top | Bottom |
|---|---|---|
| IR88-MW23MP-A | 77 | 82 |
| IR88-MW23MP-B | 97 | 102 |
| IR88-MW39MP-A | 76 | 81 |
| IR88-MW39MP-B | 96 | 101 |
| IR88-MW40MP-A | 74.5 | 79.5 |
| IR88-MW40MP-B | 89.5 | 99.5 |

**Legend**

- Multi-Port
- Injection Well
- Middle Castle Hayne Aquifer Monitoring Well
- Fire Hydrant
- Site 88 Boundary
- Geophysical Survey Area
- Tracer Study Equipment Compound Staging
- Tracer Study Area
- Surface Water Centerline
- Proposed Horizontal Well Screen (500 feet)
- Proposed Horizontal Well Casing (625+450 feet)
- GeoTrax Survey Line

N

0 62.5 125 Feet

1 inch = 125 feet

Figure 3-2
Tracer Study Conceptual Layout
and PCE Isoconcentrations - Phase I
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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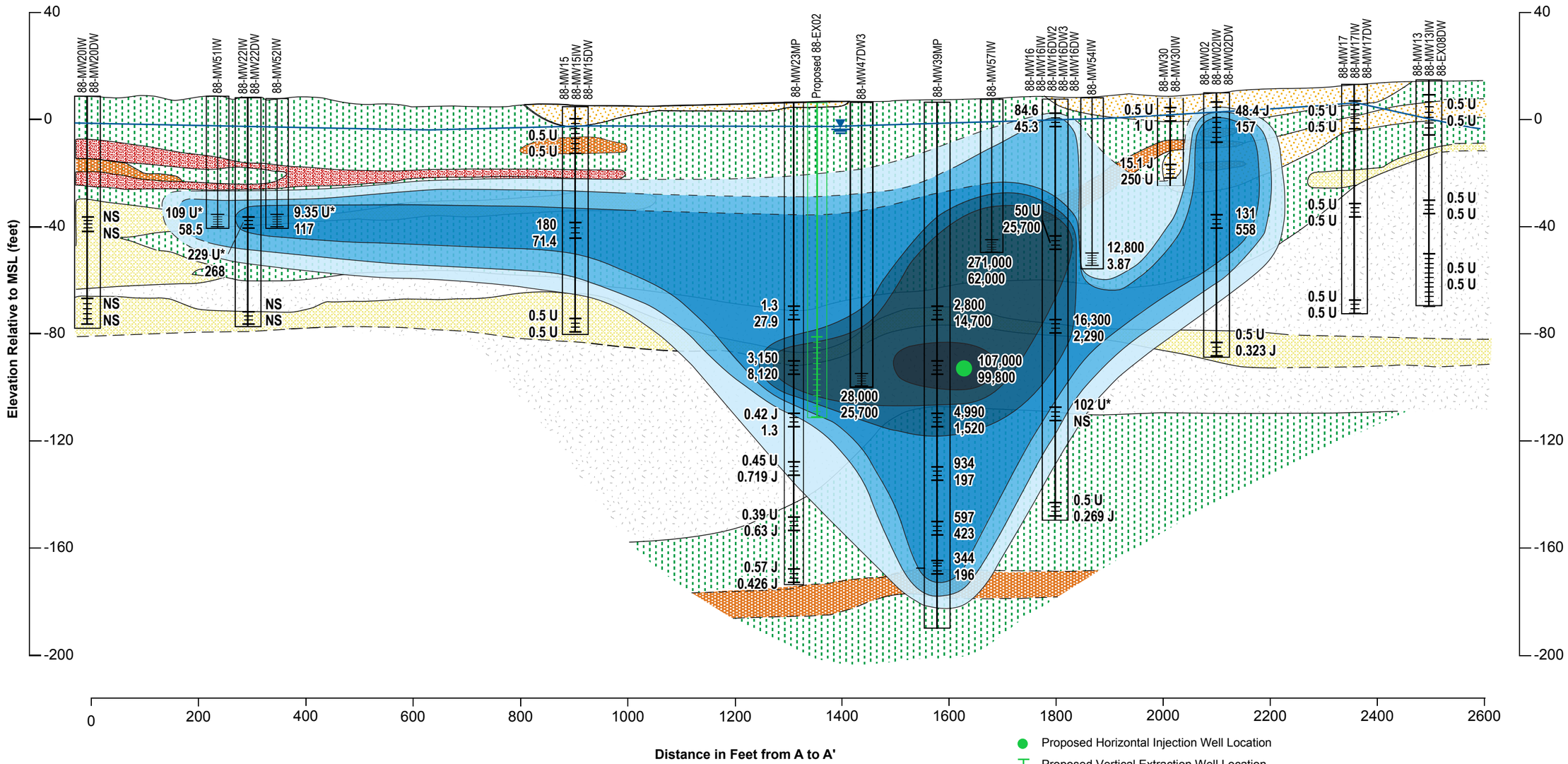


Proposed Horizontal Injection Well Location

Proposed Vertical Extraction Well Location (Optional Phase II)

PCE Concentrations shown are in µg/L
Top concentration from October 2011
Bottom concentration from October 2014

*PCE detections in wells IR88-MW16DW3, MW22IW, MW51IW, and MW52IW in October 2011 were flagged as "non-detections" due to PCE in an equipment blank. However, the concentrations are similar to previous sampling events, and are considered detections for the purposes of analysis.

**Legend**

- Clay
- Silt
- Fossiliferous Sand
- Silt/Clay
- Cemented Sand
- Screened Interval
- Sand
- Water Table Elevation

Horizontal : 1" = 200'
Vertical: 1" = 40'
V.E. = 10x

Notes:
1. The depth and thickness of the subsurface strata indicated on this section (profile) were generalized from and interpolated between test locations. Information on actual subsurface conditions applies only to the specific locations and dates indicated. Subsurface conditions and water levels at other locations may differ from conditions occurring at the indicated location.

PCE Extent
(dashed where inferred)

- 0.7 µg/L - 7 µg/L
- 7 µg/L - 70 µg/L
- 70 µg/L - 700 µg/L
- 700 µg/L - 7,000 µg/L
- 7,000 µg/L - 70,000 µg/L
- > 70,000 µg/L

Figure 3-3
Geologic Cross Section A-A'
Tetrachloroethene Concentrations
and Conceptual Layout
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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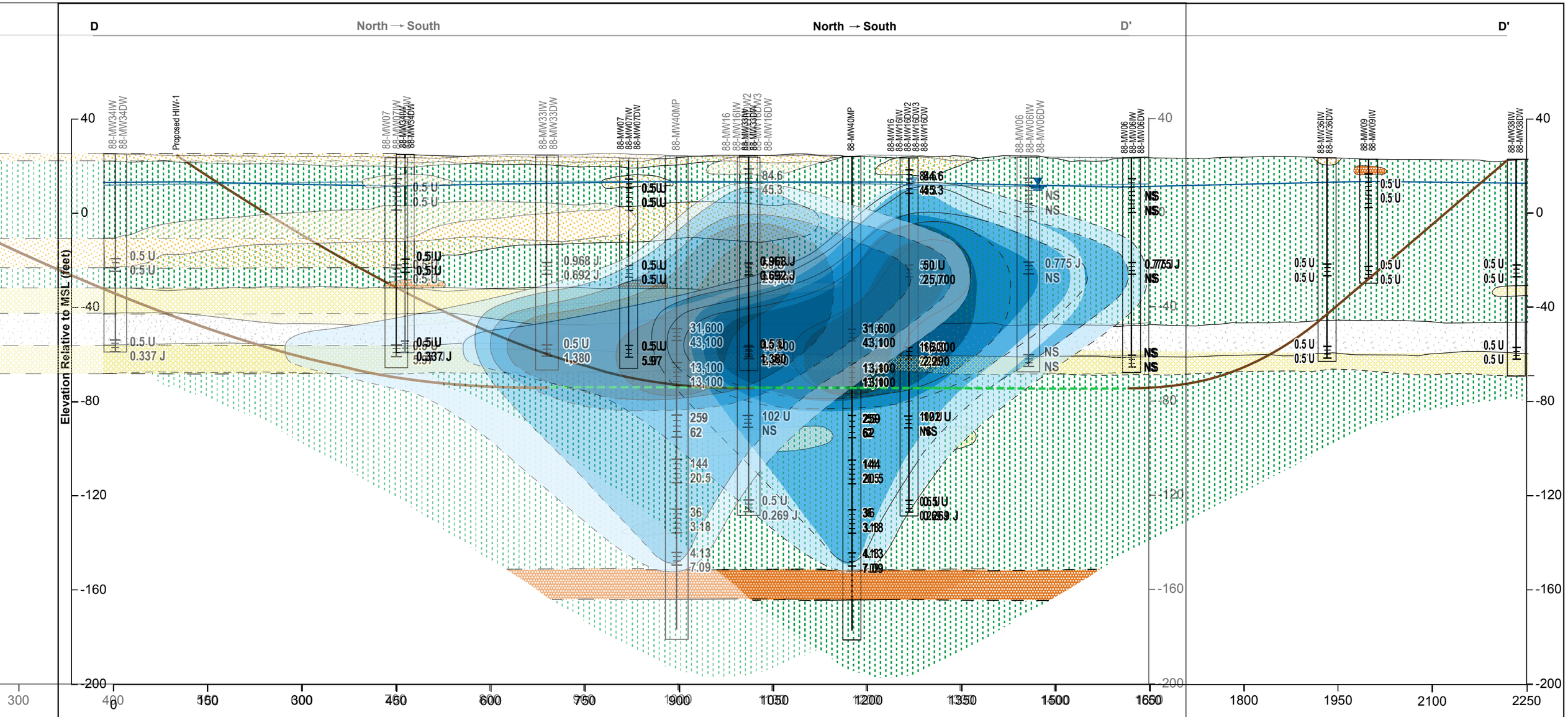


Legend

- Clay
- Silt
- Fossiliferous Sand
- Screened Interval
- Cemented Sand
- Water Table Elevation
- Sand
- NS Not Sampled

Horizontal : 1" = 100'
Vertical: 1" = 40'
V.E. = 10x

Notes:
1. The depth and thickness of the subsurface strata indicated on this section (profile) were generalized from and interpolated between test locations. Information on actual subsurface conditions applies only to the specific locations and dates indicated. Subsurface conditions and water levels at other locations may differ from conditions occurring at the indicated location.

PCE Extent (dashed where inferred)
0.7 µg/L - 7 µg/L
7 µg/L - 70 µg/L
70 µg/L - 700 µg/L
700 µg/L - 7,000 µg/L
7,000 µg/L - 70,000 µg/L

Figure 3-4
Geologic Cross Section A-A'
Tetrachloroethene Concentrations
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

Figure 3-4
Geologic Cross Section D-D'
Tetrachloroethene Concentrations
and Conceptual Layout
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

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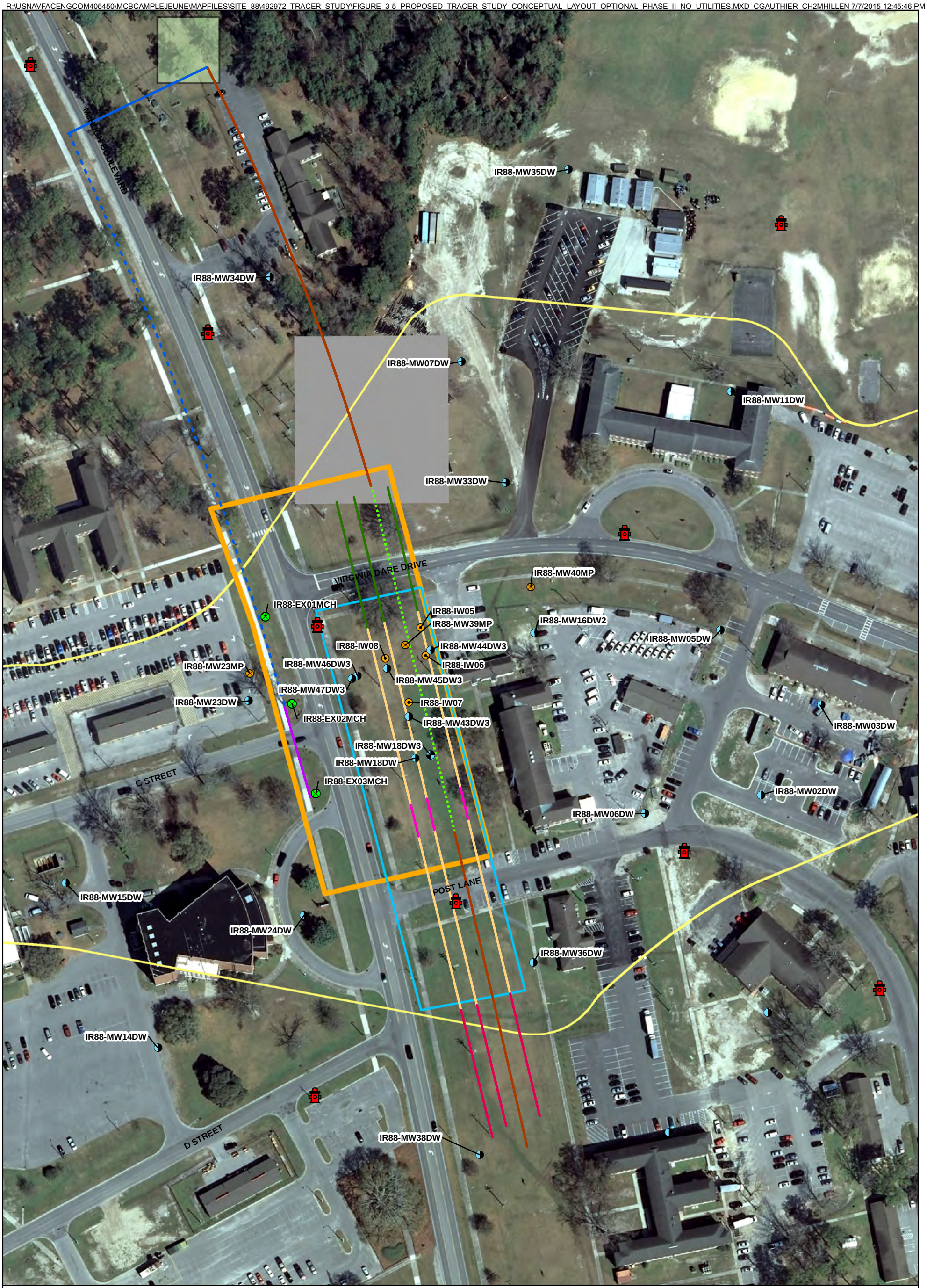


**Legend**

- Proposed Vertical Extraction Well
- Multi-Port
- Injection Well
- Middle Castle Hayne Aquifer Monitoring Well
- Lower Castle Hayne Aquifer Monitoring Well
- Fire Hydrant
- Site 88 Boundary
- Geophysical Survey Area
- Tracer Study Equipment Compound Staging
- Tracer Study Area
- Surface Water Centerline
- Proposed Horizontal Well Screen (500 feet)
- Proposed Horizontal Well Casing (625+450 feet)
- Proposed Conveyance Lines (Conventional Trenching)
- Proposed Conveyance HDD Boring- A - 200 feet
- Proposed Conveyance HDD Boring- B - 135 feet
- GeoTrax Survey Line

Figure 3-5
Tracer Study Conceptual Layout - Phase II
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

N

0 62.5 125 Feet

1 inch = 125 feet

CH2MHILL

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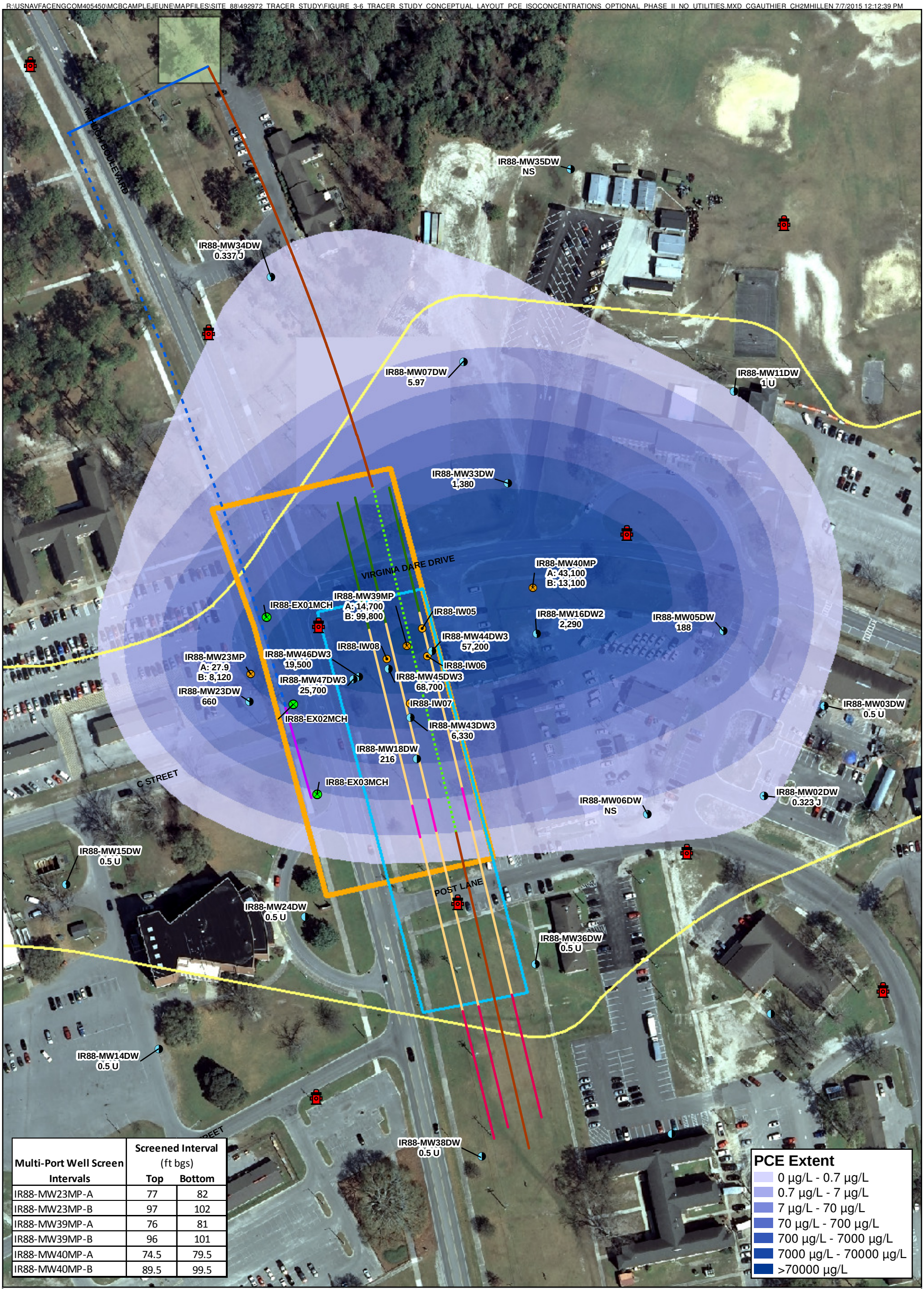


| Multi-Port Well Screen Intervals | Screened Interval (ft bgs) Top | Bottom |
|---|---|---|
| IR88-MW23MP-A | 77 | 82 |
| IR88-MW23MP-B | 97 | 102 |
| IR88-MW39MP-A | 76 | 81 |
| IR88-MW39MP-B | 96 | 101 |
| IR88-MW40MP-A | 74.5 | 79.5 |
| IR88-MW40MP-B | 89.5 | 99.5 |

**Legend**

- Proposed Vertical Extraction Well
- Multi-Port
- Injection Well
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- Tracer Study Equipment Compound Staging
- Tracer Study Area
- Surface Water Centerline
- Proposed Horizontal Well Screen (500 feet)
- Proposed Horizontal Well Casing (625+450 feet)
- Proposed Conveyance Lines (Conventional Trenching)
- Proposed Conveyance HDD Boring- A - 200 feet
- Proposed Conveyance HDD Boring- B - 135 feet
- GeoTrax Survey Line

Figure 3-6
Tracer Study Conceptual Layout and PCE Isoconcentrations - Phase II
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ
North Carolina

N

0 62.5 125 Feet

1 inch = 125 feet

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SECTION 4

# Implementation

This section presents the implementation plan for the Site 88 permanganate tracer study. To achieve the project objectives stated in **Section 3.1**, the tracer study will be conducted in two phases. The technical approach is illustrated on **Figures 3-1** through **3-6**. Key tasks associated with the tracer study are summarized below. In addition, a project schedule for the key tasks is included in **Figure 4-1**.

- For Phase I, install one double-ended, 4-inch HDD injection well with 625 feet of entry riser casing, 500 feet of screened interval at target depth of 100 feet bgs, and 450 feet of exit riser casing (**Figure 3-1**). Conduct permanganate injections and post-injection geophysical mapping to assess distribution of permanganate in the subsurface. During injections, samples will be collected from the existing monitoring well network at a minimum of every 2 hours and inspected visually for changes in color and also field-analyzed for detectable concentrations of the tracers (permanganate and chloride) to assess distribution and verify results of the geophysical mapping.
- For Phase II, install three vertical extraction wells and an associated extraction/recirculation system (**Figure 3-5**). Operate the recirculation system for 30 days and conduct post-recirculation geophysical mapping to assess whether recirculation improved distribution of permanganate in the subsurface. During system operation, routine site visits will be conducted at a minimum of two times per week, at which time, samples will also be collected from the existing monitoring well network and inspected visually for changes in color and also field-analyzed for detectable concentrations of the tracers (permanganate and chloride) to assess distribution and verify results of the geophysical mapping.
- Conduct one groundwater performance monitoring event following completion of the tracer study, to assess the overall effectiveness of the tracer study field application.
- Complete site restoration.

## 4.1 NCDENR Underground Injection Control Permit

In accordance with the rules of 15A NCAC 02T.1604, non-discharge groundwater remediation systems are groundwater treatment systems that extract and treat contaminated groundwater, including closed-loop systems using injection wells. Prior to implementation of the tracer study, an Application for Permit to Construct a Non-Discharge Groundwater Remediation System, will be submitted to the NCDENR Division of Water Resources (DWR) no less than 2 weeks prior to construction activity. A copy of this form is included in **Appendix D**.

## 4.2 Site Preparation

### 4.2.1 Drilling Area Preparation

As illustrated in **Figure 3-1**, a 90-foot by 90-foot area will be required for drilling and support operations for the drilling staging area:

- The drill rig will require an approximate 40-foot by 40-foot set-up area. IDW staging, in support of drilling and well development activities, will require an approximate 20-foot by 35-foot area. The IDW area and drill rig set-up areas will be surrounded by a silt fence to prevent migration of drilling fluids, mud, or IDW outside of the work area. All erosion and sediment controls will follow the requirements and best management practices in the 2009 NCDENR and North Carolina Agricultural Extension Service Erosion and Sediment Control Planning and Design Manual (Smolen, 1988).
- Temporary construction fencing will be placed around the work area as a safety precaution for nearby pedestrians to restrict access.

### 4.2.2 Preliminary Centerline Survey

Prior to well installation, the horizontal coordinates for points along the centerline of the HDD well will be surveyed by a North Carolina-licensed Professional Land Surveyor. Stakes or pins will be placed every 50 feet along the 1,575-foot proposed HDD well line to mark the centerline to ensure appropriate placement of the HDD injection well in relation to the existing monitoring well network and placement of GeoTrax Survey lines.

### 4.2.3 Utility Location

In advance of intrusive activities, utility locating will be conducted within 20 feet of the proposed HDD well location, within a 20-foot radius of the three proposed vertical extraction well locations (IR88-EX01MCH, IR88-EX02MCH, and IR88-EX03MCH), and within 20 feet of the proposed extraction well conveyance lines and conveyance line borings (**Figures 3-1** and **3-5**):

- A third-party professional utilities locating subcontractor will be procured to identify subsurface structures that could be impacted by drilling and HDD well installation activities. In addition, the North Carolina One Call Center (ULOCO) will be called to mark out utilities. A record of each utility mark-out ticket will be retained to document that ULOCO was contacted.
- Utilities may be identified using available as-built drawings, and field verified using geophysical instruments, conductive and inductive utility tracers and locators, air knifing, or other suitable non-destructive intrusive investigation techniques that would assist in maintaining safety during construction and the protection of the base infrastructure.
- The lateral extents of suspected subsurface utilities will be clearly marked using a combination of semi-permanent marking paint, pin flags, or stakes.

## 4.3 HDD Injection Well Installation

### 4.3.1 Installation Methods

The HDD injection well will be installed as follows:

- The HDD injection well will be installed using directional drilling methods, assuming continuous double-ended completion. The total drilling distance is estimated to be 1,575 feet to a depth of 100 feet bgs.
- Tracking and steering the drill head will be accomplished by detecting and interpreting an electromagnetic signal transmitted from the drill head during borehole advancement.
- The double-ended drilling technique that will be used to install HIW-1 is described as follows:
    - First, a pilot borehole is advanced the full distance. The profile of the borehole resembles a shallow “U” shape, with sloped “header” and “tail” sections and a center portion for the screen that is drilled as flat as possible.
    - Next, after the drill head surface penetrates the ground surface at the distal end, the drill bit is removed and a reamer tool and pull-back head is attached. The pull-back head is connected to the well materials and they are pulled back into the reamed borehole.
    - Finally, the drill rods are extracted, leaving the horizontal well in place.
- For increased strength during pull-back of the 1,575-foot long well, 4-inch diameter FRE pipe will be used, which has three to four times the tensile strength of high density polyethylene (HDPE). FRE is also compatible with sodium permanganate.
- Drilling fluids will be continuously recycled to minimize waste production, although some waste cuttings will be generated. Screened cuttings from the recycler will be temporarily stored in lined roll-off boxes. The estimated volume of waste is approximately 10 cubic yards for every 300 feet drilled. All waste will be

contained and managed in accordance with the Investigation and Remediation Waste Management Plan (WMP) (CH2M HILL, 2013a).

### 4.3.2 Development and Completion

The HDD injection well development and completion methods are as follows:

- The HDD injection well will be jetted/swabbed and purged until the development water is determined by CH2M HILL to be relatively free of sand and silt to the maximum extent practicable. Water associated with development will be contained and managed in accordance with the WMP (CH2M HILL, 2013a).
    - Installation of filter pack material is not required or recommended with directional drilling methods in most cases, however, to mitigate potential surfacing of permanganate solution, an extended length cement-bentonite grout seal will be installed to a depth of approximately 30 feet below grade
- At the proximal end of the injection well, an approximate 24-inch by 60-inch steel frame access manway, with a spring assist H-20 rated cover will be installed. The termination of the well will include a 4-inch-diameter stainless steel female (national pipe thread [NPT]) adapter fitted with a 4-inch Schedule 40 stainless-steel plug (male NPT). The manway will be set in a concrete pad, which measures at least 18-inches wide on all sides of the vault, 6-inches thick.

## 4.4 Extraction/Recirculation System Installation

### 4.4.1 Extraction Well Installation

The three vertical extraction wells will be installed via rotosonic drilling techniques by an experienced North Carolina-licensed rotosonic well driller, as follows:

- To verify the absence of underground utilities or obstructions, prior to drilling, a hand auger or post hole digger will be used to advance pilot holes encompassing the maximum outer diameter of the largest drill casing to be used to a depth of at least 5 feet bgs.
- Following verification that underground utilities or obstructions are absent, drilling will be conducted to the required depths, as summarized in **Table 4-1**, and continuous soil cores will be retrieved to allow for characterization of site lithology and screening for the presence of VOCs using a photoionization detector. Soil cuttings will be placed in a Department of Transportation (DOT) approved 55-gallon steel drum.
- Each vertical extraction well installed will consist of a 30-foot section of 4-inch 0.010-inch slot Vee-wire polyvinyl chloride (PVC) screen, connected to threaded flush-joint, Schedule 40 PVC riser to approximately 1 to 2 feet bgs for a vaulted wellhead completion. Each vault will consist of a 12-inch square steel frame access manway and connections to subsurface conveyance lines will be made using pitless adapters positioned approximately 3 feet below ground surface.

TABLE 4-1
Vertical Extraction Well Specifications
*Site 88 Tracer Study*
*MCIEAST–MCB CAMLEJ, North Carolina*

| Well Identification (ID) | Estimated Depth (feet bgs) | Screened Interval (feet bgs) | Well Diameter (inches) | Wellhead Completion |
|---|---|---|---|---|
| IR88-EX01MCH | 115 | 85-115 | 4 | Vault |
| IR88-EX02MCH | 115 | 85-115 | 4 | Vault |
| IR88-EX03MCH | 115 | 85-115 | 4 | Vault |

Development and completion methods for the three vertical extraction wells are as follows:

- Following extraction well completion, extraction wells will be developed first with a surge block and then by pumping with a submersible pump. Well development will be considered complete when visible sediment is removed. Development will not start until the last pumped grout in the well has had at least 24 hours to cure.
- Development water IDW generated will be containerized in DOT-approved 55-gallon steel drums. Drums will be staged at a vehicle-accessible location as designated by MCIEAST–MCB CAMLEJ. All waste will be contained and managed in accordance with the WMP (CH2M HILL, 2013a).
- The extraction wells will be completed with an 18-inch by 18-inch by 0.5-foot thick concrete pad, with a hinged traffic-rated vault centered in the concrete pad.
- A watertight, locking, expansion cap shall be installed on top of the PVC well casing.
- A metal name plate will be affixed to the surface completion of each extraction well that includes the well number, date of installation, size and location of screen, and total depth.

### 4.4.2 Utility Bore Drilling and Conveyance Line Installation

As depicted on **Figure 3-5**, conveyance borings are required to connect the injection system at the north side of the Site with the three proposed vertical extraction wells to the southwest:

- Two borings are required to cross underneath two main roads at the Site (McHugh Boulevard and C Street). These borings will be installed with directional drilling techniques to a depth of approximately 15 feet bgs to avoid site utilities and to minimize disruptions to traffic as follows:
    - Under McHugh Boulevard (blue colored line, “Proposed Conveyance HDD Boring A”), measuring approximately 200 feet
    - Under C Street, connecting the northernmost of southernmost vertical extraction wells (purple colored line, “Proposed Conveyance HDD Boring B”), measuring approximately 135 feet
- Two-inch diameter DR 11 HDPE conveyance piping will be pulled through HDD Borings A and B and connected to 2-inch-diameter DR 11 HDPE conveyance lines installed with conventional trenching to connect the vertical extraction wells to the recirculation system near the HIW-1 wellhead.
- All conveyance lines will be pressure tested before being capped and direct buried.
- Excess soils generated during borehole drilling and trenching will be contained and managed in accordance with the WMP (CH2M HILL, 2013a).

### 4.4.3 Extraction/Recirculation System Completion

To complete the extraction/recirculation system, the following tasks will be conducted:

- Installation of a 240-volt single-phase power source and associated electrical poles at the tracer study equipment compound and in the vicinity of the extraction wells to provide power to the booster pump and submersible extraction pumps.
- Deployment of downhole submersible extraction pumps within each vertical extraction well, with the pump intake set to 100 feet bgs. The extraction pumps will be sized to efficiently pump a minimum of 20 gpm from the extraction wells back to the recirculation trailer.
- Installation of a recirculation trailer. The primary components of the recirculation trailer include a booster pump, cartridge bag filters to remove fines from groundwater prior to reinjection to mitigate potential clogging of the injection well screen, as well as dedicated flowmeters, pressure gauges, and throttling valves for each extraction line and the line. The system will have fail-safe interlock controls, including process line pressure sensors and pressure transducers to monitor water levels.
- Plumbing of all HDPE extraction/injection line piping to a manifold and the recirculation system trailer.

A process flow diagram of the extraction/recirculation system is detailed on **Figure 4-2.**

## 4.5 Phase I Permanganate Injections

As described in **Section 3.5** and summarized in **Table 4-1**, 99,000 gallons of a 2 percent sodium permanganate solution will be introduced into the MCH aquifer via HDD injection well HIW-1. Based on an estimated 50-gpm injection rate and assuming injections will be conducted for 10 hours per day, an estimated 3 to 4 days will be needed to complete the injection event.

Sodium permanganate will be delivered to the Site in 14 260-gallon, or 3,000-pound, totes at a concentration of 40 percent by wt. The 40 percent by wt solution will be diluted to a 2 percent by wt solution using a chemical dosing pump with a small mixing tank (approximately 500-gallons), referred to hereafter as an injection trailer, to avoid requiring large mixing tanks on site. Dilution water will be obtained from a fire hydrant located approximately 350 feet southeast of the tracer study equipment compound staging area, along McHugh Boulevard, as depicted on **Figure 3-1**. The fire hydrant will be equipped with a backflow preventer or a minimum 2-foot air gap will be maintained between the hose and water vessel. Road ramps will be used to cover and protect the fire hose coming from the fire hydrant to the injection trailer. The water and sodium permanganate will simultaneously be pumped to the mixing tank at the appropriate dilution setting (1 gallon of 40 percent sodium permanganate for every 20 gallons of dilution water). Sodium chloride will be added to the mixing tank as required to achieve a subsurface concentration of 800 mg/L. The solution will be thoroughly mixed to ensure the sodium chloride is dissolved and then be pumped into the HDD injection well through a hose connected to an injection manifold that will include a flow meter and pressure gauge.

Totes of 40 percent sodium permanganate and the associated injection trailer will be placed within an above-ground secondary containment area. Spill kits will be placed within the secondary containment area in case of a leak or spill. Prior to start-up, a leak check will be conducted with water only to ensure the system is devoid of leaks prior to mixing the permanganate solution. In addition, a neutralizing solution containing equal parts water, vinegar, and dilute hydrogen peroxide will be kept on site in the event of a spill. Detailed procedures and controls regarding spill prevention and control will be included in the site-specific Health and Safety Plan (HSP). Safety data sheets for injectants permanganate and sodium chloride are included in **Appendix E**.

If necessary, a licensed electrician will be subcontracted to install electrical service to the Site.

## 4.6 Phase II Extraction/Recirculation System Operation

To evaluate whether extraction/recirculation significantly improves the zone of influence, the groundwater extraction/recirculation will be operated for approximately 30 days, assuming that operation will be conducted 24 hours per day, 7 days per week. This estimated operation time is based upon time required to extract and recirculate one pore volume while injecting at 50 gpm and extracting from each of the three vertical extraction wells at 16.67 gpm in a closed loop system operation (**Table 3-1**). Although the system will be outfitted with telemetry to provide an alert if the system shuts down unexpectedly, site visits will also be conducted at a minimum of twice per week to verify that the system is running according to design and to check for potential leaks or other issues. Additionally, operations and maintenance of the system will be conducted on an as needed basis. During site visits, personnel will also collect samples to assess for tracer distribution.

## 4.7 Permanganate Distribution Monitoring

Subsurface permanganate distribution monitoring will be assessed using two methods. The first method relies on groundwater sampling to physically confirm the presence of permanganate within existing monitoring wells located at the Site, by visibly noting the color of the sample and to test the sample for indicator parameters that the groundwater was impacted by permanganate (primarily an increase in oxidation-reduction potential and in conductivity). Samples will also be field-analyzed for tracer concentrations of both permanganate and chloride. The second method involves the use of geophysical mapping. Additionally, the groundwater sampling results will be used to confirm/verify the results of the geophysical mapping. Finally, groundwater elevation monitoring will be conducted to monitor for potential hydraulic capture zones, or areas where potential influence of the extraction/recirculation system is observed.

### 4.7.1 Groundwater Sampling

Groundwater grab sampling will be conducted during both phases of the tracer study to monitor for permanganate distribution. Monitoring will assess the zone of influence by permanganate injections and verify geophysical mapping results. Groundwater samples will be collected using a bailer or peristaltic pump. A summary of the tracer distribution sampling strategy is included in **Table 4-2**. As shown in **Table 4-2**, groundwater samples will be collected based upon their proximity to the HDD injection well. Groundwater monitoring wells located closest to the HDD injection well will be sampled initially. If groundwater appears to have a slight pink or purple color, it will be assumed that permanganate breakthrough has been achieved at that location. In addition, a field testing kit will be used to estimate the approximate permanganate concentration at that location. Samples will also be field-analyzed for chloride concentrations, since it is possible that permanganate will be quickly oxidized following injections. As sampling indicates that breakthrough has occurred, monitoring wells located further away from the HDD injection well will be sequentially added to the monitoring program.

During Phase I, samples will be collected periodically, at a minimum of every 2 hours, and as often as determined to be necessary based on field conditions. For Phase II, samples will be collected approximately twice per week during routine system checks, or more often if determined necessary based on field conditions.

### 4.7.2 Geophysical Mapping

Post-permanganate injection geophysical mapping will be conducted in the tracer study area in the same locations where the baseline geophysical mapping survey was conducted (**Figure 3-1**). Data collected during the baseline geophysical mapping survey will allow for comparison to data collected following permanganate injections. The change in subsurface conductivity due to permanganate injections allows the geophysical mapping equipment to detect the distribution patters of permanganate in the MCH aquifer.

Geophysical mapping events will be conducted as follows:

- A second round of geophysical mapping will be conducted following the Phase I permanganate injection event. Results would be compared to the baseline geophysical mapping results to assess for permanganate distribution for an injection-only scenario.

A third round of geophysical mapping will be conducted following the Phase II extraction/recirculation component of the tracer study. Results would be compared to both baseline and post-injection geophysical mapping events to evaluate any improvement to the achieved zone of influence.

## 4.8 As-built Survey

Following construction completion, an as-built survey will be conducted to record the location of the newly installed HDD injection well (IR88-HIW-1), three newly installed extraction wells (IR88-EX01MCH, IR88-EX02MCH, and IR88-EX03MCH) and the location of the conveyance lines.

## 4.9 Performance Monitoring

Performance monitoring will be conducted to assess the effectiveness of the tracer study field application following the completion of the tracer study. The most recent results from the site-wide groundwater sampling event conducted in October 2014 will serve as the baseline data to quantify the reduction in COC concentrations (when compared to post-ISCO application groundwater sampling results). Groundwater samples will also be analyzed for permanganate and chloride via field kits to assess for distribution of the injected solution.

### Performance monitoring samples

Samples will be collected from up to 20 locations within the tracer study area (**Figure 3-1**), including but not limited to, 6 monitoring wells, 1 multi-port well (with 6 discreet sampling intervals), and 4 injection wells. All of the samples will be analyzed for the site-specific COCs and field-analyzed natural attenuation indicator parameters (NAIPs) as follows:

- cVOC COCs by SW-846USEPA:
  - PCE
  - TCE
  - cis-1,2-DCE
  - trans-1,2-DCE
  - VC
- Field NAIPs:
  - Permanganate (CHEMetrics kit – Ferrous Ammonium Sulfate Method)
  - Chloride (CHEMetrics kit – Mercuric Nitrate Method)
  - Ferrous iron (Hach kit – Phenanthroline Method)
  - Nitrate/nitrite (Hach kit – Cadmium Reduction/Diazotization Method)
  - Specific conductivity (Water Quality Meter – Methods 2510, USEPA 120.1)
  - pH/Oxidation-Reduction Potential (Water Quality Meter – Method 2580)
  - Temperature (Water Quality Meter – USEPA 170.1)
  - Turbidity (USEPA Method 180.1)

Groundwater samples will be collected using low flow techniques in accordance with the *Groundwater Sampling and Analysis Plan, Pilot Studies Site 88 – Operable Unit No. 15, Marine Corps Base Camp Lejeune, Jacksonville, North Carolina* (CH2M HILL, 2010b).

Groundwater sampling results will be compared to North Carolina Groundwater Quality Standards and the results will be incorporated into the Draft Final FS.

### Sampling Equipment Decontamination and IDW Management

All non-disposable sampling equipment will be decontaminated immediately after each use in accordance with the *Groundwater Sampling and Analysis Plan, Pilot Studies Site 88 – Operable Unit No. 15, Marine Corps Base Camp Lejeune, Jacksonville, North Carolina* (CH2M HILL, 2010b). All IDW resulting from the low-flow sampling at Site 88 will be contained in 5-gallon buckets and transported for disposal at the wastewater treatment plant located at Lot 203 on Piney Green Road, in accordance with the WMP (CH2M HILL, 2013a). Disposable equipment,

including personal protective equipment, polyethylene tubing, paper towels, and latex gloves, will be disposed of as ordinary solid waste.

If purge water contains unspent permanganate, a neutralizing solution containing equal parts water, vinegar, and dilute hydrogen peroxide will be used to neutralize the solution prior to disposal.

## 4.10 Site Restoration

Following completion of the tracer study, the surface area disturbed by the system construction will be restored by patching to match the adjacent ground surfaces. Restoration activities will also include removing the equipment compound from the site. The HDD injection well and vertical extraction wells will remain in place for potential use as part of the remedial action.

TABLE 4-2

Tracer Distribution Sampling Summary

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

| Well ID | Well Depth (ft bgs) | Diameter (inches) | Screened Interval (ft bgs) Top | Bottom | Depth to Groundwater* | Color | Conductivity | pH | Oxidation-Reduction Potential | Permanganate | Chloride | Grouping** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upper Middle Castle Hayne Aquifer** | | | | | | | | | | | | |
| IR88-MW18DW | 22.59 | 85 | 2 | 80 | X | X | X | X | X | X | X | 2 |
| IR88-MW39MP-A | 81 | NA | 76 | 81 | | X | X | X | X | X | X | 1 |
| **Lower Middle Castle Hayne Aquifer** | | | | | | | | | | | | |
| IR88-IW05 | 110 | 4 | 90 | 110 | X | X | X | X | X | X | X | 1 |
| IR88-IW06 | 110 | 4 | 90 | 110 | | X | X | X | X | X | X | 1 |
| IR88-IW07 | 110 | 4 | 90 | 110 | | X | X | X | X | X | X | 1 |
| IR88-IW08 | 110 | 4 | 90 | 110 | X | | | | | | | |
| IR88-MW39MP-B | 101 | NA | 96 | 101 | | X | X | X | X | X | X | 1 |
| IR88-MW43DW3 | 100 | 2 | 95 | 100 | | X | X | X | X | X | X | 2 |
| IR88-MW44DW3 | 100 | 2 | 95 | 100 | X | X | X | X | X | X | X | 2 |
| IR88-MW45DW3 | 100 | 2 | 95 | 100 | | X | X | X | X | X | X | 3 |
| IR88-MW46DW3 | 100 | 2 | 95 | 100 | | X | X | X | X | X | X | 4 |
| IR88-MW47DW3 | 100 | 2 | 95 | 100 | X | X | X | X | X | X | X | 4 |
| IR88-EX01MCH | 115 | 4 | 85 | 115 | | X | X | X | X | X | X | 5 |
| IR88-EX02MCH | 115 | 4 | 85 | 115 | | X | X | X | X | X | X | 5 |
| IR88-EX03MCH | 115 | 4 | 85 | 115 | | X | X | X | X | X | X | 5 |
| **Upper Lower Castle Hayne Aquifer** | | | | | | | | | | | | |
| IR88-MW18DW3 | 120 | 2 | 115 | 120 | X | X | X | X | X | X | X | 3 |
| IR88-MW39MP-C | 121 | NA | 116 | 121 | | X | X | X | X | X | X | 1 |

**Notes:**

ft bgs - feet below ground surface

*Gauging would be conducted during injections and extraction/recirculation operations to assess potential hydraulic influence

**Groupings based upon how far sample location is from injection well. Sampling will initially focus on existing monitoring wells located closest to the injection well, and move out laterally as breakthrough is observed:

- Group 1: Initial group of wells to monitor; located within 20 feet of the HDD injection well
- Group 2: Wells selected for monitoring once breakthrough is observed in nearest Group 1 monitoring wells; located within 20 to 30 feet of the HDD injection well
- Group 3: Wells selected for monitoring once breakthrough is observed in nearest Group 2 monitoring wells, likely during Phase II; located within 30 to 40 feet of the HDD injection well
- Group 4: Wells selected for monitoring once breakthrough is observed in nearest Group 3 monitoring wells, likely during latter portion of Phase II; located within 80 to 90 feet of the HDD injection well
- Group 5: Extraction wells will be monitored for breakthrough during the latter portion of Phase II; located 180 feet from the HDD injection well

| ID | Task Name | Duration | Start | Finish | Predecesso |
|---|---|---|---|---|---|
| 1 | **Site 88 Tracer Test** | **315 days** | **Mon 3/2/15** | **Fri 5/13/16** | |
| 2 | **Work Plan** | **119 days** | **Mon 3/2/15** | **Thu 8/13/15** | |
| 3 | Work Planning | 60 days | Mon 3/2/15 | Fri 5/22/15 | |
| 4 | Draft Work Plan - Partnering Team Review | 30 days | Mon 5/25/15 | Fri 7/3/15 | 3 |
| 5 | Respond to Comments | 12 days | Mon 7/6/15 | Tue 7/21/15 | 4 |
| 6 | Comment Resolution | 7 days | Wed 7/22/15 | Thu 7/30/15 | 5 |
| 7 | Final Work Plan | 10 days | Fri 7/31/15 | Thu 8/13/15 | 6,4,5 |
| 8 | **Phase I - Permanganate Injections** | **34 days** | **Tue 9/8/15** | **Fri 10/23/15** | |
| 9 | Utility Locating/Centerline Survey | 4 days | Tue 9/8/15 | Fri 9/11/15 | 7FS+17 day |
| 10 | HDD Well Installation and Development | 15 days | Mon 9/14/15 | Fri 10/2/15 | 9 |
| 11 | Permanganate Injections | 10 days | Mon 10/5/15 | Fri 10/16/15 | 10 |
| 12 | Post-Injection Geophysical Mapping | 5 days | Mon 10/19/15 | Fri 10/23/15 | 11 |
| 13 | **Phase II - Extraction/Recirculation** | **64 days** | **Tue 9/8/15** | **Fri 12/4/15** | |
| 14 | Utility Locating | 1 day | Tue 9/8/15 | Tue 9/8/15 | 7FS+17 day |
| 15 | Vertical Extraction Well Installation and Development | 8 days | Wed 9/9/15 | Fri 9/18/15 | 14 |
| 16 | Extraction/Recirculation System Construction | 15 days | Mon 9/21/15 | Fri 10/9/15 | 15 |
| 17 | Extraction/Recirculation System Operation | 25 days | Mon 10/26/15 | Fri 11/27/15 | 12 |
| 18 | Post-Recirculation Geophysical Mapping | 5 days | Mon 11/30/15 | Fri 12/4/15 | 17 |
| 19 | Post-Recirculation Performance Monitoring | 5 days | Mon 11/30/15 | Fri 12/4/15 | 17 |
| 20 | **Sample Management** | **60 days** | **Mon 12/7/15** | **Fri 2/26/16** | |
| 21 | Lab Analysis | 30 days | Mon 12/7/15 | Fri 1/15/16 | 18 |
| 22 | Data Validation | 15 days | Mon 1/18/16 | Fri 2/5/16 | 21 |
| 23 | Data Management | 15 days | Mon 2/8/16 | Fri 2/26/16 | 22 |
| 24 | **Technical Memorandum** | **70 days** | **Mon 2/8/16** | **Fri 5/13/16** | |
| 25 | Draft TM | 30 days | Mon 2/8/16 | Fri 3/18/16 | 23FS-15 da |
| 26 | Draft TM - Base and Navy Review | 15 days | Mon 3/21/16 | Fri 4/8/16 | 25 |
| 27 | Draft TM - Partnering Team Review | 15 days | Mon 4/11/16 | Fri 4/29/16 | 26 |
| 28 | Final TM (Final date may vary - TM to be submitted as an Appendix to Draft Final FS) | 10 days | Mon 5/2/16 | Fri 5/13/16 | 27 |

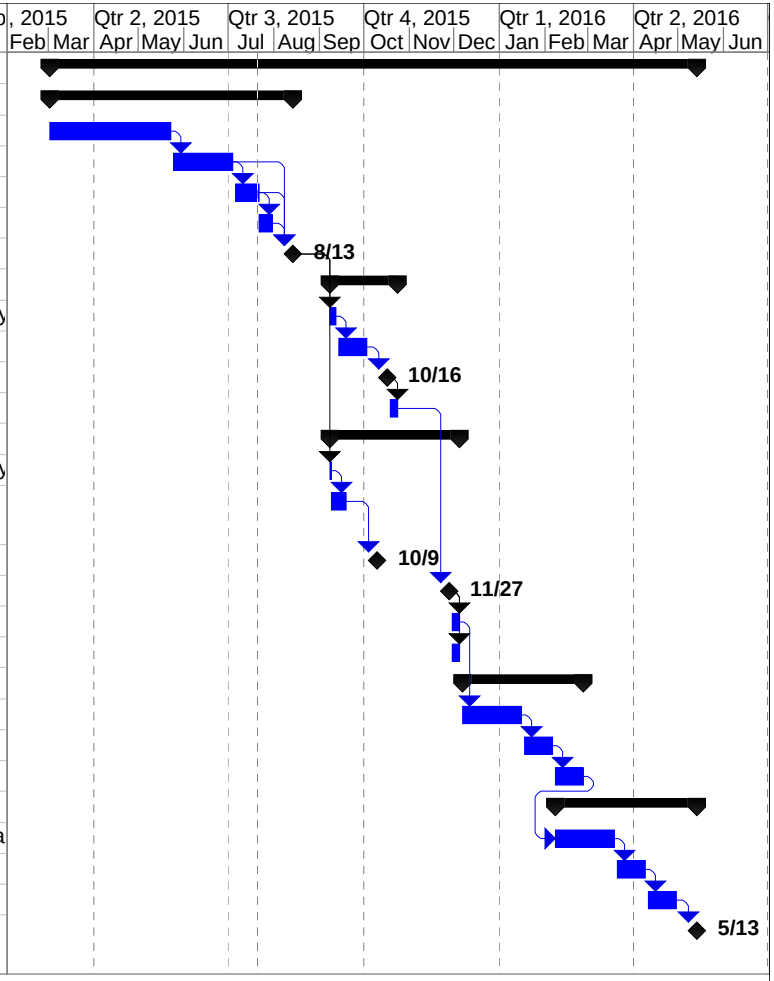
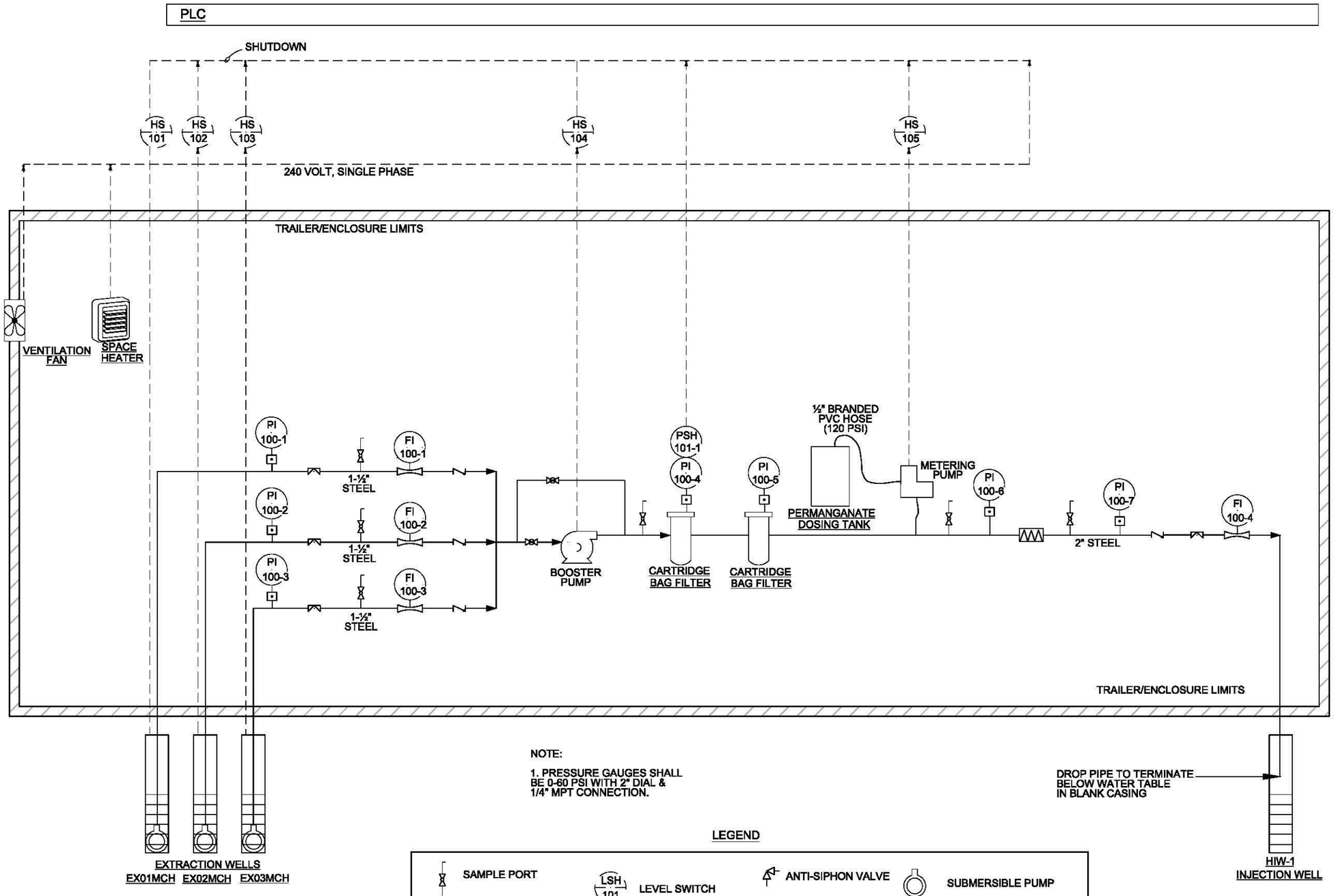



Figure 4-1 - Project Schedule
Site 88 Tracer Study
MCIEAST-MCB CAMLEJ, North Carolina

| | | | | | |
|---|---|---|---|---|---|
| Task | | Inactive Milestone | | Finish-only | |
| Split | | Inactive Summary | | External Tasks | |
| Milestone | | Manual Task | | External Milestone | |
| Summary | | Duration-only | | Progress | |
| Project Summary | | Manual Summary Rollup | | Deadline | |
| External Tasks | | Manual Summary | | | |
| External Milestone | | Start-only | | | |




NOTE:

1. PRESSURE GAUGES SHALL BE 0-60 PSI WITH 2" DIAL & 1/4" MPT CONNECTION.

FIGURE 4-2
PROCESS FLOW DIAGRAM
SITE 88 TRACER STUDY
MCIEAST-MCB CAMLEJ
NORTH CAROLINA

CH2MHILL

TARHEEL\PROJ\EBL\NAVY CLEAN\CAMP LEJEUNE\CAMPLEJ\CADD\SITE 88\PROCESS_FLOW_DIAGRAM_SITE88.DGN

SECTION 5

# Reporting

Following completion of the permanganate tracer study, the results will be compiled and reported in a technical memorandum which will be included as an appendix to the Draft Final FS. The technical memorandum will summarize the field activities, present the analytical and geophysical mapping results, provide boring logs and well construction details, and evaluate the overall effectiveness of the tracer study for assessing the feasibility of this technology in the Draft Final FS.

SECTION 6

# References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# Appendix A
# Analytical Data Tables

TABLE A-1

**Exceedances in the MCH Aquifer (75-115 ft bgs)**

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

| **Station ID** | **NCGWQS (April 2013)** | IR88-GWEX08DW | IR88-MW02DW | IR88-MW03DW | IR88-MW04DW | IR88-MW05DW | IR88-MW06DW | IR88-MW07DW | IR88-MW07DW | IR88-MW11DW | IR88-MW12DW | IR88-MW14DW | IR88-MW15DW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | | IR88-GWEX08DW-14D | IR88-GW02DW-14D | IR88-GW03DW-14D | IR88-GW04DW-14D | IR88-GW05DW-14D | IR88-GW06DW-04D | IR88-GW07DW-14D | IR88-GW07DWD-14D | IR88-GW11DW-14D | IR88-GW12DW-14D | IR88-GW14DW-14D | IR88-GW15DW-14D |
| **Sample Date** | | 10/25/14 | 10/23/14 | 10/22/14 | 10/24/14 | 10/25/14 | 10/16/04 | 10/23/14 | 10/23/14 | 10/22/14 | 10/23/14 | 10/23/14 | 10/22/14 |
| **Chemical Name** | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| **Volatile Organic Compounds (µg/l)** | | | | | | | | | | | | | |
| Benzene | 1 | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 5 U | 10 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U |
| cis-1,2-Dichloroethene | 70 | 0.5 U | 24.1 | 0.5 U | 1.13 | 1,600 | 57 | 4.36 | 4.3 | 0.612 J | 0.5 U | 0.5 U | 0.521 J |
| Naphthalene | 6 | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 5 U | NA | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U |
| Tetrachloroethene | 0.7 | 0.5 U | 0.323 J | 0.5 U | 0.5 U | 188 | 10 U | 5.97 | 5.63 | 0.5 U | 0.5 U | 0.5 U | 0.5 U |
| trans-1,2-Dichloroethene | 100 | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 8.65 J | 3 J | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U |
| Trichloroethene | 3 | 0.5 UJ | 1.7 | 0.5 U | 4.78 | 412 | 70 | 2.69 | 2.65 | 3.76 | 0.5 U | 0.5 U | 0.5 U |
| Vinyl chloride | 0.03 | 0.5 U | 0.416 J | 0.5 U | 0.5 U | 5 U | 10 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U |

**Notes:**

Bold box indicates exceedance of NCGWQS (April 2013)

NA - Not analyzed

D - Compound identified in an analysis at a secondary dilution factor

J - Analyte present, value may or may not be accurate or precise

U - The material was analyzed for, but not detected

UJ - Analyte not detected, quantitation limit may be inaccurate

cells/ml - Cells per milliliter

gc/ml - Gene copies per milliliter

mg/l - Milligrams per liter

µg/l - Micrograms per liter

TABLE A-1

**Exceedances in the MCH Aquifer (75-115 ft bgs)**

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

| **Station ID** | **NCGWQS (April 2013)** | IR88-MW16DW2 | IR88-MW17DW | IR88-MW18DW | IR88-MW18DW2 | IR88-MW18DW3 | IR88-MW19DW | IR88-MW20DW | IR88-MW21DW | IR88-MW22DW | IR88-MW23DW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | | IR88-GW16DW2-14D | IR88-GW17DW-14D | IR88-GW18DW-14D | IR88-GW18DW2-14D | IR88-GW18DW3-14D | IR88-GW19DW-14D | IR88-GW20DWD-07C | IR88-GW21DW-07C | IR88-GW22DW-07C | IR88-GW23DW-14D | IR88-GW23DWD-14D |
| **Sample Date** | | 10/23/14 | 10/23/14 | 10/22/14 | 10/22/14 | 10/21/14 | 10/23/14 | 08/08/07 | 08/12/07 | 08/09/07 | 10/22/14 | 10/22/14 |
| **Chemical Name** | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Volatile Organic Compounds (µg/l)** | | | | | | | | | | | | |
| Benzene | 1 | 25 U | 0.5 U | 1 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 5 U | 2.5 U |
| cis-1,2-Dichloroethene | 70 | 4,410 | 0.5 U | 0.768 J | 0.5 U | 0.5 U | 0.5 U | 0.5 UJ | 0.5 UJ | 0.5 U | 3.82 J | 4.11 J |
| Naphthalene | 6 | 25 U | 0.5 U | 1 U | 0.5 U | 0.5 U | 0.5 U | NA | NA | NA | 5 U | 2.5 U |
| Tetrachloroethene | 0.7 | 2,290 | 0.5 U | 216 | 0.5 U | 0.602 J | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 660 | 569 |
| trans-1,2-Dichloroethene | 100 | 25 U | 0.5 U | 1 U | 0.5 U | 0.5 U | 0.5 U | 0.5 UJ | 0.5 UJ | 0.5 U | 5 U | 2.5 U |
| Trichloroethene | 3 | 1,460 | 0.5 U | 23.3 | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 80.5 | 73.3 |
| Vinyl chloride | 0.03 | 25 U | 0.5 U | 1 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 5 U | 2.5 U |

**Notes:**

Bold box indicates exceedance of NCGWQS (April 2013)

NA - Not analyzed

D - Compound identified in an analysis at a secondary dilution factor

J - Analyte present, value may or may not be accurate or precise

U - The material was analyzed for, but not detected

UJ - Analyte not detected, quantitation limit may be inaccurate

cells/ml - Cells per milliliter

gc/ml - Gene copies per milliliter

mg/l - Milligrams per liter

µg/l - Micrograms per liter

TABLE A-1

**Exceedances in the MCH Aquifer (75-115 ft bgs)**

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

| **Station ID** | **NCGWQS (April 2013)** | IR88-MW23MP | | IR88-MW24DW | IR88-MW32DW | IR88-MW33DW | IR88-MW34DW | IR88-MW35DW | | IR88-MW36DW | IR88-MW37DW | IR88-MW38DW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | | IR88-GW23MP-A-14D | IR88-GW23MP-B-14D | IR88-GW24DW-14D | IR88-GW32DW-14D | IR88-GW33DW-14D | IR88-GW34DW-14D | IR88-GW35DW-11D | IR88-GW35DWD-11D | IR88-GW36DW-14D | IR88-GW37DW-14D | IR88-GW38DW-14D |
| **Sample Date** | | 10/22/14 | 10/22/14 | 10/23/14 | 10/25/14 | 10/23/14 | 10/24/14 | 10/15/11 | 10/15/11 | 10/23/14 | 10/24/14 | 10/24/14 |
| **Chemical Name** | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **Volatile Organic Compounds (µg/l)** | | | | | | | | | | | | |
| Benzene | 1 | 0.5 U | 25 U | 0.5 U | 1 U | 5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U |
| cis-1,2-Dichloroethene | 70 | 2.25 | **126** | 0.374 J | 1 U | 33.6 | 1.12 | 14.2 | 14.4 | 0.638 J | 0.5 U | 0.5 U |
| Naphthalene | 6 | 0.5 U | 25 U | 0.5 U | 1 U | 5 U | 0.5 U | NA | NA | 0.5 U | 0.5 U | 0.5 U |
| Tetrachloroethene | 0.7 | **27.9** | **8,120** | 0.5 U | 1 U | **1,380** | 0.337 J | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U |
| trans-1,2-Dichloroethene | 100 | 0.5 U | 25 U | 0.5 U | 1 U | 5 U | 0.5 U | NA | NA | 0.5 U | 0.5 U | 0.5 U |
| Trichloroethene | 3 | 2.65 | **971** | 0.5 U | 1 U | **216** | 0.397 J | 0.5 U | 0.5 U | 2.19 | 0.5 U | 0.5 U |
| Vinyl chloride | 0.03 | 0.5 U | 25 U | 0.5 U | 1 U | 5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U | 0.5 U |

**Notes:**

**Bold box indicates exceedance of NCGWQS (April 2013)**

NA - Not analyzed

D - Compound identified in an analysis at a secondary dilution factor

J - Analyte present, value may or may not be accurate or precise

U - The material was analyzed for, but not detected

UJ - Analyte not detected, quantitation limit may be inaccurate

cells/ml - Cells per milliliter

gc/ml - Gene copies per milliliter

mg/l - Milligrams per liter

µg/l - Micrograms per liter

TABLE A-1

**Exceedances in the MCH Aquifer (75-115 ft bgs)**

*Site 88 Tracer Study*

*MCIEAST-MCB CAMLEJ*

*North Carolina*

| **Station ID** | **NCGWQS (April 2013)** | IR88-MW39MP | | IR88-MW40MP | | IR88-MW43DW3 | IR88-MW44DW3 | IR88-MW45DW3 | IR88-MW46DW3 | | IR88-MW47DW3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample ID** | | IR88-GW39MP-A-14D | IR88-GW39MP-B-14D | IR88-GW40MP-A-14D | IR88-GW40MP-B-14D | IR88-GW43DW3-14D | IR88-GW44DW3-14D | IR88-GW45DW3-14D | IR88-GW46DW3-14D | IR88-GW46DW3D-14D | IR88-GW47DW3-14D |
| **Sample Date** | | 10/21/14 | 10/21/14 | 10/23/14 | 10/23/14 | 10/21/14 | 10/21/14 | 10/21/14 | 10/21/14 | 10/21/14 | 10/21/14 |
| **Chemical Name** | | | | | | | | | | | |
| | | | | | | | | | | | |
| **Volatile Organic Compounds (µg/l)** | | | | | | | | | | | |
| Benzene | 1 | 50 U | 250 U | 250 U | 100 U | 25 U | 250 U | 250 U | 100 U | 50 U | 125 U |
| cis-1,2-Dichloroethene | 70 | 932 | 658 | 410 J | 221 | 136 | 3,970 | 498 J | 329 | 333 | 330 |
| Naphthalene | 6 | 50 U | 250 U | 250 U | 100 U | 25 U | 100 U | 250 U | 100 U | 50 U | 125 U |
| Tetrachloroethene | 0.7 | 14,700 | 99,800 | 43,100 | 13,100 | 6,330 | 57,200 | 68,700 | 13,500 | 19,500 | 25,700 |
| trans-1,2-Dichloroethene | 100 | 50 U | 250 U | 250 U | 100 U | 25 U | 100 U | 250 U | 100 U | 50 U | 125 U |
| Trichloroethene | 3 | 1,080 | 2,430 | 1,850 | 985 | 833 | 1,020 | 2,420 | 1,190 | 1,330 | 2,050 |
| Vinyl chloride | 0.03 | 246 | 321 J | 261 J | 150 J | 25 U | 100 U | 250 U | 100 U | 50 U | 125 U |

**Notes:**

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NA - Not analyzed

D - Compound identified in an analysis at a secondary dilution factor

J - Analyte present, value may or may not be accurate or precise

U - The material was analyzed for, but not detected

UJ - Analyte not detected, quantitation limit may be inaccurate

cells/ml - Cells per milliliter

gc/ml - Gene copies per milliliter

mg/l - Milligrams per liter

µg/l - Micrograms per liter

# Appendix B
# Baseline Geophysical Mapping Technical Memorandum

# PRE-INJECTION INTERIM REPORT

# GEOTRAX SURVEY™
# INJECTION MONITORING PROJECT

## SITE 88
## MCIEAST-MCB CAMLEJ
## NORTH CAROLINA, USA

**May 7, 2015**

**Aestus Project No. 14-114-09**

**Prepared for:**

**CH2M HILL**
**14120 Ballantyne Corporate Place, Suite 200**
**Charlotte, NC 28277**

**Prepared by:**

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## EXECUTIVE SUMMARY

Aestus, LLC (Aestus) performed its GeoTrax Survey™ subsurface imaging at Site 88 at MCIEAST-MCB CAMLEJ (Site 88) located in Jacksonville, North Carolina. This high-resolution subsurface geophysical mapping technology is being used in a phased approach to help assess the distribution of permanganate solution that will be injected into the subsurface via a horizontal well and distributed via a recirculation system.

This report provides the results of the pre-injection subsurface imaging work. Conclusions relative to permanganate distribution in the subsurface will be summarized in Aestus' forthcoming Post-Injection Report that will be submitted following post-injection field work, currently anticipated to be performed in summer 2015.

### Scope of Work

Aestus' scope of work for this project was to use our subsurface imaging technology to scan the earth's subsurface (i.e., to depths of ~184 feet) at three transect locations selected jointly by CH2M Hill and Aestus (see Figure PV-1). These transects were located immediately downgradient of the planned horizontal injection well location shown on Figure PV-1, such that Aestus can perform pre and post- injection imaging of in-situ chemical oxidation compounds.

In-situ monitoring of injectate is accomplished by performing a "differencing" analysis on GeoTrax Survey™ pre and post-injection subsurface image data to effectively visualize distribution of injectate (i.e., highlight zones of the subsurface that have changed electrical signatures due to the presence of injectate). This process is more robust than standard site characterization work (i.e., uses the non-transient version of this technology) and is therefore more schedule, labor, and equipment-intensive. The primary differences include:

- Electrode stakes must remain in place (undisturbed) for the duration of the monitoring project
- Additional data acquisition and processing time is required

Additionally, the nature of injection monitoring work requires two (potentially three) mobilizations by Aestus to perform the following data acquisition events along the same exact transect line locations. The anticipated work phases and schedule estimates for pending work are listed below:

1. **Phase I:** Pre-Injection Surveys; acquire pre-injection baseline images ***(October 2014)***
2. **Phase II:** Post-Injection Surveys**;** track injectate following injection ***(Summer 2015)***
3. **Phase III:** Post-Recirculation Surveys**;** track injectate following recirculation **(Summer 2015; if this phase of work is ultimately authorized by CH2M Hill)**

This phased process will be useful in optimizing both the horizontal well design and evaluating the effectiveness of the permanganate injections. Follow up confirmation borings may be required at one or more phase to confirm the electrical signatures of the injectates identified by Aestus if the data provided by the existing monitoring well network is found to be insufficient (i.e., existing wells not at the optimum location or screened at the required depth).


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## Results of Pre-Injection Field Work

Aestus' geophysical survey work yielded high quality/high resolution two-dimensional (2-D) electrical resistivity images of the subsurface at Site 88 from the locations shown on Figure PV-1. The final 2-D survey images (see Figures 1 through 3) are presented in one custom (site specific) color contouring scheme as discussed below in Section 6.1 (Development of Site Specific Color Contouring Scheme) of this report.

## Interim Conclusions Following Pre-Injection Field Work

Aestus offers the following interim conclusions, which are discussed in more detail in Section 7.0 of this report:

1. Aestus has determined that the pre-injection imaging data collected during field work in October 2014 meets our quality standards and will provide an acceptable baseline set of images to use for comparison to the post-injection images.
2. Aestus will provide conclusions related to distribution of injected permanganate solution in our forthcoming Post-Injection Interim Report. Post-injection imaging work is currently scheduled for the summer months of 2015.
3. Aestus' imagery indicates that previous vertical injection work at Site 88 appears to have affected and readily flowed within the zone between approximately 50 and 100 feet BGS (see further discussion in Section 7.3.2). Therefore CH2M Hill may want to focus on this zone with the horizontal injection well.
4. It is important that the planned horizontal injection well be placed such that Aestus' downgradient survey lines can detect injectate migrating in a reasonable project timeframe as a function of the Site 88 groundwater gradient and/or injection pressures. **Please see related recommendations in Section 8.1 and 8.2.**
5. Blue colored zones (10 to 75 Ohm-m) <u>below</u> the top of the Castle Haynes Aquifer (yellow dashed line in Figures 1 through 3) occur laterally between 0 and 400 feet from Electrode 1 in all three survey images, and likely correspond to the presence of 2010 ISCO injectate.
6. Subsurface zones with resistivity values of < 10 Ohm-m (purple colored zones) <u>above</u> ~125' AMSL are anomalous and likely due to signatures from bioactivity. Typical geologic formations tend to have resistivity values higher than 10 Ohm-m and Aestus expects this would be true for Site 88 where the geology is predominantly sandy.
7. Darker brown high zones (>1000 Ohm-m) <u>below</u> the Castle Hayne Formation (yellow dashed line in images) have higher resistivity values than expected for this site, and could potentially reflect zones with DNAPL-related impacts and/or zones with coarser grained and/or more cemented geology (see graphic below and Figure 1). These anomalous zones detected by Aestus exist in areas with no proximate monitoring well data. Confirmation drilling would be required to verify the cause of these anomalous zones.
8. Site biogeochemical conditions (i.e., from previous ISCO work and/or bioactivity) and/or metallic utility signatures may be partially or fully masking a potential DNAPL signature in some areas (see discussion of hierarchy of electrical signatures in Section 2.3.2 and Conclusions in Section 7.3.4 ).


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# LIST OF ACRONYMS

| | |
|---|---|
| AGI | Advanced Geosciences, Inc. (2121 Geoscience Dr., Austin, TX 78726, USA) |
| AMSL | Above Mean Sea Level |
| AST | Aboveground Storage Tank |
| BGS | Below Ground Surface |
| COC | Contaminant of Concern |
| CSM | Conceptual Site Model |
| DNAPL | Dense Non-aqueous Phase Liquid |
| EC | Electrical conductivity, mS/cm (millisiemens per centimeter) |
| ERD | Enhanced Reductive Dechlorination |
| ERI | Electrical Resistivity Imaging |
| EVO | Emulsified Vegetable Oil |
| ISCO | In-situ Chemical Oxidation |
| ORP | Oxidation-reduction potential, mV (millivolts) |
| PCE | Tetrachloroethene |
| PIDs | Reading from a Photoionization Detector, ppm (parts per million) |
| TCE | Trichloroethene |
| UST | Underground storage tank |
| VC | Vinyl Chloride |
| VOC | Volatile Organic Compound |
| 3-D | Three-dimensional model visualizations produced by RockWorks™ 15 software (RockWare® Inc., 2221 East St. #1, Golden, CO 80401, USA) |


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# 1.0 PROJECT OVERVIEW

Aestus, LLC (Aestus) performed its GeoTrax Survey™ subsurface imaging at Site 88 at MCIEAST-MCB CAMLEJ (Site 88) located in Jacksonville, North Carolina. This high-resolution subsurface geophysical mapping technology is being used in a phased approach to help assess the distribution of permanganate solution that will be injected into the subsurface via a horizontal well and distributed via a recirculation system in the context of a permanganate tracer study.

GeoTrax Survey™ data can also be used in most cases to help identify subsurface locations where dense non-aqueous phase liquids (DNAPL) are present in the subsurface and to optimize injection well locations. However, for this project the primary focus is mapping distribution of injectate as site logistical and access constraints prevent Aestus from performing its' typical grid layout for site characterization work, and the horizontal injection well location needed to be selected in advance, to be able to properly locate our transect lines at a downgradient location (see Figure PV-1). To the extent possible, Aestus will offer interpretations based on our geophysical data regarding contaminant distribution and recommendations for injection well depth targets.

Aestus' imaging technology provides tremendous data density (thousands of proprietary electrical resistivity imaging samples at a resolution of approximately 2.5 meters horizontally and vertically) in a 2-D plane for site characterization, which overcomes the inherent limitation of standard approaches using only one-dimensional data points (via borings/monitoring wells) installed without the benefit of imaging targets. These image data were integrated with historical data to develop a better understanding of the subsurface at Site 88.

This report outlines the activities and results of Phase I (pre-injection surveys).

## 1.1 Project Objectives

The project objectives of this investigation program were to use Aestus' imaging technology to assist CH2M Hill with the following over-all project goals:

1. Help assess the distribution of permanganate solution that will be injected into the subsurface via a horizontal well and distributed via a recirculation system (via ~3 vertical extraction wells) for a permanganate tracer study
2. Assist CH2M Hill with confirming the target location and depth of the planned horizontal injection well shown in Figure PV-1
3. To the extent possible, use the pre-injection imagery to help CH2M Hill interpret subsurface locations where dense non-aqueous phase liquids (DNAPL) are present in the subsurface and/or other site characterization issues of interest.

## 1.2 Site Location and Description

Site 88 is located near the intersection of McHugh Boulevard and Virginia Dare Drive, at MCIEAST-MCB CAMLEJ located in Jacksonville, North Carolina.


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### *1.2.1 Site Background*

The following site background information is summarized from documents provided to Aestus by CH2M Hill:

- Site 88 has a groundwater contaminant plume dominated by chlorinated solvents as the primary COC. A dry cleaning facility located within building 25, which operated from the 1940s to 2004, contributed to the chlorinated solvent plume.
- Initially, five 750-gallon underground storage tanks (USTs) were installed north of the building to store Varsol™.
- 1970s: One 150-gallon above-ground storage tank (AST) was installed to store the Varsol™ replacement, PCE, in the vicinity of the original USTs. The tank was used until 1995. Former employees reported that used PCE was disposed of in floor drains.
- December 1986 and March 1995, self-contained dry cleaning machines were installed which eliminated the need for PCE storage.
- November 1995: Both the USTs and AST were removed.
- August 2004: The dry cleaning building was demolished.

### *1.2.2 Site Geology and Hydrogeology*

The geology and hydrogeology at Site 88 are important factors that control movement of COC and the planned injectate, and also are critical in the interpretation of the subsurface imaging data. There are four principal formations underlying the vicinity of Site 88 (listed from shallowest to deepest):

1. Undifferentiated sediments/surficial aquifer consisting of fine sand and silt
2. Belgrade Formation/Castle Hayne semi-confining unit consisting of clayey silt and silty clay (~5-7 ft thickness, discontinuous)
3. River Bend Formation /upper Castle Hayne aquifer consisting of much more dense, sand with silt and shells (~55-60' BGS)
4. Castle Hayne Formation/middle & Lower Castle Hayne (>~60' BGS)

The main aquifer has a groundwater surface at ~80 feet BGS, and consists of fine to medium sand with silt and clay. Also, shallow groundwater is found at ~10-12 feet BGS, with a downward vertical gradient.

## 1.3 Scope of Work

Aestus' scope of work for this project was to use our subsurface imaging technology to scan the earth's subsurface (i.e., to depths of ~184 feet) at three transect locations selected jointly by CH2M Hill and Aestus (see Figure PV-1). These transects were located immediately downgradient of the planned horizontal injection well (see Figure PV-1) such that Aestus can perform pre and post- injection imaging of in-situ chemical oxidation compounds.


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The final electrode spacing and resulting survey line length and imaging depth at Site 88 are shown in the legend on Figure PV-1 and are also listed in Table 1. The end electrode land survey coordinates are summarized in Table 2. The distance along each survey line from Electrode 1 is provided in Table 3.

Figure PV-1 also shows the location and orientation (i.e., the green ends of the survey lines represent Electrode 1 and the red ends represent Electrode 56) of the surveys performed at Site 88. As shown in Figure PV-1, the survey transects extend from the field north of Virginia Dare Drive to the southeast and end in the field located northwest of Building 6. The ground surface of the site is primarily grassy, though some electrode stakes were installed in Virginia Dare Drive, Post Lane, and the parking lot to the west of Building 3.

Aestus land surveyed the locations of the GeoTrax Survey™ lines using our total station and established Site 88 control points with known coordinate system and datum. The imaging data were integrated with historical drilling data to help guide horizontal well placement.

### 1.4 Project Schedule

The nature of injection monitoring work requires two (potentially three) mobilizations by Aestus to perform the following data acquisition events along the same exact transect line locations:

4. **Phase I:** Pre-Injection Surveys; acquire pre-injection baseline images
5. **Phase II:** Post-Injection Surveys**;** track injectate following injection
6. **Phase III:** Post-Recirculation Surveys**;** track injectate following recirculation (if this phase of work is ultimately authorized by CH2M Hill)

A detailed timeline for project work completed to date is shown below:

- October 21 through 26, 2014: Phase I data acquisition field work
- November 13, 2014: Aestus submit preliminary figures and technical memorandum with interim pre-injection data
- November 17, 2014: Discuss preliminary results with CH2M Hill via Aestus hosted web conference
- January 13, 2015: Received comments on Draft Pre-Injection Interim Report submittal from CH2M Hill
- February through April, 2015; Aestus field questions from CH2M Hill regarding geophysical QC data provided
- April 23, 2015: This Pre-Injection Interim Report is being submitted to CH2M Hill

Initially, injection work was planned for February 2015. Currently it is anticipated that CH2M Hill's injection activities and Phase II post-injection monitoring work by Aestus will be performed during the summer of 2015.


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## 2.0 METHODOLOGY

This section provides an overview of the technology used and a general description of the data acquisition, data processing and interpretation processes, with special reference to features and activities specific to the Site 88 project

### 2.1 GeoTrax Survey™ Technology Overview

Aestus' uses a non-intrusive proprietary form of electrical resistivity imaging (ERI) technology to scan the subsurface of environmentally impacted sites for a variety of anomalies, including those associated with dense and light non-aqueous phase liquids (DNAPLs/LNAPLs) and related dissolved phase contamination. This technology has been successfully used for a number of other applications including mapping geology, locating other subsurface environmental impacts, leaking pipelines, buried tanks, landfill and burial pit boundaries, and presence or absence of contaminant transport channels/preferential migration pathways. The use of this technology for Injection Monitoring (i.e., transient monitoring via imagery over time) is discussed in more detail below in Section 2.2.

Electrical resistivity measurements have been used since the 1830's to interpret the earth. Electrical resistivity imaging (ERI) works by imparting an electrical current into the ground, and then measuring voltage at one or more other locations along a straight survey line/transect. Based on these data, the apparent resistivity of subsurface materials is calculated using Ohm's Law. These measurements are then inverted to provide measurements of model resistivity or true resistivity at regular points. For this report, these data will be referred to as resistivity data or electrical resistivity data.

Similar to a single pixel in a digital photo, a single resistivity measurement does not yield significant information. However, modern ERI acquisition instruments combined with modern computer processing speeds facilitate hundreds or thousands of resistivity measurements in a short timeframe. These measurements are performed along a survey alignment and are subsequently used to produce a two-dimensional (2-D) electrical image (analogous to a CAT-scan in the medical industry) of the subsurface that graphically illustrates the presence or absence of subsurface anomalies and provides quantitative measurements of the subsurface resistivity. The 2-D continuous images help minimize interpolation between 1-D data points such as soil borings or wells, and assist in confirming or redefining conceptual site models.

Aestus' technology is based on conventional electrical resistivity imaging (ERI) techniques developed decades ago in its original form. However, we have worked with Oklahoma State University (OSU) to vastly improve the core technology specifically for use in the environmental industry. Aestus is currently the sole worldwide licensee of trade secret intellectual property from OSU that provides proprietary data collection algorithms and processing software to achieve higher data quality and ultimately increased image quality, relative to standard ERI approaches. The higher sensitivity provided by GeoTrax Survey™ is required to adequately image complex environmental sites and perform transient imaging to detect injectates. Aestus collects our data using established quality control (QC) protocols as discussed in Section 4.0 of this report.


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## 2.2 GeoTrax Survey™ Used for Injection Monitoring (Transient Monitoring)

Aestus' imaging technology has been used successfully to perform monitoring of in-situ chemical oxidation injectate distribution. Transient monitoring allows Aestus to perform a "differencing" analysis on pre and post-injection subsurface image data, to effectively visualize distribution of injectate (i.e., highlight zones of the subsurface that have changed electrical signatures due to the presence of injectate). This process is more robust than standard site characterization work using this technology and is more schedule, labor, and equipment-intensive as electrode stakes must remain in place (undisturbed) for the duration of the monitoring project, and additional data acquisition and processing time is required. Multiple mobilizations are also required for certain projects.

## 2.3 Technology Limitations

As with any technology, GeoTrax Survey™ has some limitations which are discussed below.

### *2.3.1 Metallic Interference*

If imaging is performed overtop of an extensive grounding grid (such as is sometimes found at electrical substations for instance), this metallic grid can effectively blank out our survey images. In addition, when surveying immediately adjacent and parallel to buried metallic pipelines; some degree of interference may be experienced to metallic interference. Aestus attempts to maintain a 15-foot (4.6 m) buffer zone rule when surveying parallel to metallic pipelines. Under certain conditions (e.g., geology dependent, etc.), Aestus can successfully image within the 15' foot (4.6 m) buffer zone.

Historically, Aestus has been able to achieve project objectives by selectively working around known buried pipeline locations to achieve high quality survey images and avoid interference from buried metallic pipelines. Should a survey be performed perpendicular to a buried metallic pipeline, the pipe sometimes shows up in the image as a conductive anomaly and can cause a narrow conductive shadow to the bottom of the survey image. In this situation, the survey image on either side of the pipeline location is intact with good data quality.

### *2.3.2 Calibration of Electrical Imagery to Analytical Data Is Required*

Because Aestus' imaging technology is not a quantitative analytical chemical sampling tool, it does not immediately identify or quantify the chemical, geological, and biological (bioactivity) composition of anomalies detected. Additionally, most environmental sites on which we acquire data have regulatory drivers that are chemical concentration based.

Therefore, Aestus employs our GeoTrax Viz™ data integration process (see Sections 2.6 and 2.7) to integrate historical and follow-up confirmation drilling data with our 2-D images and 3-D visualization model. This process allows Aestus to use these other lines of evidence to effectively "convert" or calibrate the electrical signatures back to the subsurface features of interest to our clients, such as physical (geology signatures), chemical (contamination presence/absence and relative concentration), and biological signatures (indicating potential presence/absence of bioactivity). The data integrated for calibration and interpretation purposes typically includes but is not limited to boring logs, analytical sample data, and fluid level measurements.


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Aestus is often successful at developing a semi-quantitative relationship between subsurface resistivity values and concentrations of contaminants. As the site complexity increases with multiple signals present from bioactivity, remediation attempts, and the other potential signals listed below, developing these semi-quantitative relationships become more challenging.

1. Soil and rocks (geology/lithology)
2. Groundwater (quality/chemistry)
3. Presence of contamination (e.g., NAPLs, aqueous phase impacts, etc.)
4. Remedial action fluids and/or their effects (e.g., injectates, or chemistry shifts that occur as a result of injectates)
5. Biological activity (biomass and related groundwater chemistry shifts)
6. Effects of metallic utility lines

The above item Nos. 3, 4, 5, and 6 can often partially or fully "overprint" signatures of underlying geology. This "overprinting" is normally acceptable because identifying contamination and issues relative to remedial attempts and presence/absence of bioactivity is helpful information and the drilling data helps constrain the geological contacts and variability. Aestus' robust data integration process helps parse out issues of interest relative to project objectives.

#### *2.3.3 Confirmation Drilling Typically Required*

Once calibrated to the subject site, the GeoTrax Survey™ images are normally a very powerful tool to accurately predict locations and often times relative concentrations (and/or NAPL saturation) of contamination in subsurface soils. In cases when our images show subsurface features/anomalies that are not part of the existing site conceptual model, additional confirmation boring data may be required to correctly redefine the site conceptual model. Additional confirmation borings, should they be required, are limited in number because the imagery provides specific drilling targets and therefore facilitate a very focused confirmation drilling program.

#### *2.3.4 Special Considerations for Injection Monitoring (Transient Monitoring)*

When performing injection monitoring, Aestus' experience is that it is important to use dedicated electrode stakes that do not move between pre and post injection monitoring activities. Additionally it is important to minimize the duration of time between pre and post injection imaging to avoid other subsurface changes over time showing up in the differenced images designed to show injectate as the only material change over time between the two imaging events.

### 2.4 Geophysical Survey Data Acquisition Activities

Three survey transects were performed at Site 88 for Phase I data acquisition, performed between October 21 and October 26, 2014.. Dedicated electrodes (i.e., left in place between imaging events) were utilized so that these exact electrode positions may be used for subsequent Phase II and Phase III data acquisition and to facilitate higher-precision "difference" processing.


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Fifty-six (56) equally-spaced electrodes were placed at a 5.0 m (16.4 feet) spacing (see Figure PV-1). This yielded a total line length of ~902 feet (~275 m) and total survey depth of ~120 feet (~36.5 m). The lines were configured roughly parallel to each other with a north-northwest to south-southeast orientation.

Aestus personnel collected field notes of site features (e.g. roads, utility crossings, and monitoring well locations) proximate to electrode locations. These data were posted to Figures 1 through 3 during our GeoTrax Viz™ 2-D data integration work. Additionally, site features and electrode geospatial locations (including elevation data) were land surveyed by Aestus personnel to properly position site data into Aestus' GeoTrax Viz™ three-dimensional (3-D) visualization model. The electrode elevation data were also utilized as topographic correction for the geophysical data processing for each survey image.

### 2.5 Data Processing

Once data collection was completed, raw data files collected by the SuperSting R8 earth resistivity meter were transferred to the Aestus field laptop for an initial QC review to verify proper data collection. The raw data files were then transferred to Aestus' home office staff for topographic correction and full data processing. Topographic correction for each data file was achieved by creating a terrain file with the distance in meters to each land surveyed electrode along with the elevation of each land surveyed electrode in meters (land survey data collected by Aestus field crew using a Topcon total station).

### 2.6 Historical Data Integration onto 2-D Subsurface Images

Aestus reviewed available Site 88 data provided by our client, and used our GeoTrax Viz™ process to incorporate the following historical site characterization data onto our 2-D survey images as shown in the Figures section of this report:

- Site features from field notes (Aestus' field crew)
- Monitoring well construction
- Boring log data
- PID data from soil borings
- Groundwater analytical data
- Groundwater quality parameter data
- Groundwater level data
- Historical ERD injection records
- Bio parameter data

It is important to understand that not all of these data sets integrated into 2-D are exactly aligned <u>temporally and/or spatially</u> and interpretations of integrated data should be account for this issue.


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## 2.7 Historical & Subsurface Image Data Integration into 3-D

To assist ourselves and our clients' with visualizing the subsurface images as they relate to one another, Aestus used data collected from our 2-D imaging process to generate a 3-D representation of these data in the subsurface of Site 88. We and our clients typically find that the results of the 3-D visualization work are very helpful in providing a more complete and somewhat simplified understanding of the survey data/images, ultimately yielding a better understanding of subsurface issues at a given site. The 3-D visualizations are also very useful in explaining site conceptual models and features to both technical and non-technical stakeholders.

To allow viewing of our survey images to scale in 3-D space, Aestus developed a technique to import and properly position and scale the survey images in 3-D drawing space and relative to the site base map using Rockworks™ 3-D visualization software. Although the perspective 3-D views resulting from these efforts are based on 2-D data sets (i.e., the individual electrical resistivity image data was not collected in 3-D during the survey work), Aestus has a higher confidence in our approach relative to the conventional approach of using only 1-D monitoring well data points and the resulting interpolations between these discrete points.

For Aestus' 3-D visualization work, thousands of field data points (collected in 2-D) were used as input to develop the 3-D perspective views. Other data imported into Aestus' 3-D model for Site 88 include but are not limited to the following:

- Transect locations and identification labels
- Vertical 2-D subsurface images
- Horizontal elevation slices (though GeoTrax Survey™ data)
- Site monitoring wells
- Historical injection wells
- Aerial photo(s)
- Various aerial photos and site maps (provided by Aestus' client)
- Utility information
- Groundwater level data
- Analytical data from groundwater samples

It is important to understand that not all of these data sets integrated into 3-D are exactly aligned <u>temporally and/or spatially</u> and interpretations of integrated data should be account for this issue.

Because the 3-D visualization work performed by Aestus was extensive and many different views of these data can be generated using this tool, it is not practical to provide all of these views as part of the hardcopy report. However, Aestus is providing a copy of our 3-D model files for viewing by our client's personnel using a free viewer provided by Rockworks™. This data and instructions on downloading and using the free viewer software are contained in Electronic Appendix E-3 to this report.


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## 3.0 EQUIPMENT USED

Aestus LLC used the following geophysical and project support equipment during Phase I operations at Site 88.

| Type | Manufacturer | Use |
|---|---|---|
| Supersting R8IP | Advanced Geosciences, Inc.; 2121 Geoscience Dr., Austin, TX 78726, USA | Earth Resistivity Meter; ERI data acquisition |
| Supersting R8IP | Same as above | Backup instrument |
| AGI Switchbox 56 | Same as above | Resistivity data acquisition |
| AGI Switchbox 56 | Same as above | Backup instrument |
| Topcon GPT-3007W | Topcon Positioning Systems, Inc., 400 National Drive, Livermore, CA 94550, USA | Geospatial data acquisition |
| Electrode Cables | Proseismic; 5291 Langfield Rd, Houston, TX 77040 | Resistivity data acquisition |
| Traffic Cones | Various | Traffic control |
| Traffic Ramps | Yellow Jacket Cable Protectors; 2350 East Central Ave. Durante, CA 91010 | Protect cables in road crossings |
| Rotary Hammer | Bosch | Drill holes for electrode stakes in concrete/asphalt |
| Equipment Trailer | Wells Cargo | Equipment mobilization/storage |
| Temporary Electrode Stakes | n/a | Resistivity data acquisition |
| Permanent Electrode Stakes | n/a | Resistivity data acquisition |


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# 4.0 QUALITY CONTROL

Aestus is focused on delivering a work product based on high quality data. For this Site 88 project, understanding injectate distribution in the subsurface as it relates to updating the overall conceptual site model (CSM), is dependent upon accurate geophysical data. This section discusses the QC tests and data files collected to verify that data of acceptable quality was collected from the site.

## 4.1 Quality Control (QC) Tests

To verify that our GeoTrax Survey™ data is accurate and collected in accordance with industry standard levels of care, Aestus utilizes several QC tests recommended by the manufacturer of the geophysical survey instrumentation (i.e., Advanced Geosciences, Inc.), prior to data collection in the field. The below QC tests are run at the beginning of each work day. If any issues with the equipment are discovered during any one of the tests, Aestus' backup equipment is used and compromised instruments are sent to the manufacture for diagnostics and repair. Each of the QC tests is discussed in detail below.

### *4.1.1 Receiver Test*

The Receiver Test verifies that the geophysical equipment is functioning properly by utilizing a test box with a known resistance to verify that all of the SuperSting R8 receivers are working correctly. A Receiver Test is completed at the start of each day and as needed otherwise should troubleshooting become necessary during the work day.

### *4.1.2 Switchbox Relay Test*

The switchbox contains two relays per electrode. The Switchbox Relay Test ensures that both relays for each electrode are functioning properly. A Switchbox Relay Test is completed at the start of each day and as needed otherwise should troubleshooting become necessary during the work day.

### *4.1.3 Cable Test*

The switchbox also has two multiplexers per electrode to set that electrode as P1-P9. The cable test goes through and sets each P line and verifies each mux connection is solid for every electrode. A Cable Test is completed at the start of each day and as needed otherwise should troubleshooting become necessary during the work day.

### *4.1.4 Contact Resistance Test*

The Contact Resistance test checks to make sure that each electrode and electrode stake has good electrical contact with the earth by measuring the resistance between each electrode, starting with electrodes 1 and 2, then 2 and 3, and so on until the last pair of electrodes 55 and 56 are tested. If measurements of some electrode locations are higher than what the average value is for the rest of the electrodes, the high electrodes can either be advanced farther into the ground and/or sprayed with salt water to increase the electrical contact with the earth at these locations (occasionally, Aestus uses a bentonite slurry to enhance contact, particularly in dry materials such as coarser gravel). The Contact Resistance Test can then be rerun to check any electrodes that were adjusted to attempt to achieve better contact with the earth.


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This procedure is done before each survey is run, and is repeated until the contact resistance for each electrode is at an acceptable level (typically < 2000 Ohms as Aestus' goal, although this can be site dependent).

### 4.2 Non-Proprietary Raw Data Files

Aestus and Oklahoma State University have worked together since 2001, and have developed intellectual property that is used to collect and process electrical resistivity imaging (ERI; also referred to by some as ERT) data differently from the standard methods. These proprietary advancements (branded commercially as Aestus' GeoTrax Survey™ since 2003) were made specifically for the environmental site characterization industry because industry experience indicates that standard ERI does not have enough sensitivity to consistently and accurately detect contaminants in the subsurface such as LNAPL, DNAPL, and dissolved phase impacts.

Although GeoTrax Survey™ technology was developed originally for environmental site characterization, OSU and Aestus are on the cutting edge of using our proprietary ERI to image injectates (i.e., the purpose of this Site 88 project) as our data indicate that standard ERI methods are also typically not sensitive enough for this objective.

Due to our use of trade secret intellectual property (IP) that Aestus has developed on its own as well as that licensed exclusively to Aestus by Oklahoma State University, we are contractually bound to maintain this IP as trade secret. This scenario is typically unsatisfying for the geophysicist community that is accustomed to fully understanding traditional geophysical methods that have been in existence for decades (since the 1930s) and which are typically public domain technologies and not protected intellectual property.

Aestus understands this concern and we therefore also collect non-proprietary raw data files (typically standard dipole-dipole array) so that our clients are able to verify that we collected real data at the site be able to confirm data quality. These data files are provided in Electronic Appendix E-4.


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## 5.0 RESULTS

Aestus' geophysical survey work yielded high quality/high resolution two-dimensional (2-D) electrical resistivity images of the subsurface at Site 88 from the locations shown on Figure PV-1. The final 2-D survey images (see Figures 1 through 3) are presented in one custom (site specific) color contouring scheme as discussed below in Section 6.1 (Development of Site Specific Color Contouring Scheme) of this report.

Site photos taken during Aestus' field work are provided as Electronic Appendix E-1. The GeoTrax Survey™ XYZR data output files containing geo-referenced (i.e., X, Y, and Z coordinate data) resistivity (R) data sets that were used to color contour the abovementioned survey images are provided as Electronic Appendix E-2 included with this report. These XYZR data were also used to generate a select few horizontal elevation slices through the domain surveyed by Aestus (see 3-D visualization model provided as Electronic Appendix E-3).

For a select few sites, either the GeoTrax Survey™ 2-D images or data from a site monitoring well network will provide the data required to fulfill the project objectives and develop a solid conceptual site model. However, for most sites, Aestus' experience indicates that data integration of the geophysical images and conventional site investigation data (i.e., from monitoring wells, soil borings, etc.) into a 3-D visualization model is necessary to interpret the collective data sets, develop a useful conceptual site model, and fulfill the project objectives. The following section of this report discusses data interpretation for Site 88.


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## 6.0 DATA INTERPRETATION

Aestus believes that the end goal of environmental site characterization work is to use all available data collected at a site to visualize the Earth's subsurface in 3-D and understand the distribution of contamination at a site, as well as other factors that affect the site (bioactivity, preferential pathways, geology, injectate distribution, etc.) as they relate to overall project objectives. This process is most useful if the end result provides a conceptual site model that is more objective (i.e., and therefore less subjective), based on multiple data sets or lines of evidence, and is relatively easy to understand by the various project stakeholders.

As discussed previously in Sections 2.6 and 2.7, Aestus integrated our geophysical survey data with other available site data to help Aestus effectively "convert" or calibrate our electrical resistivity data back to chemical, physical and biological site parameters of interest to our clients. Historical site data are incorporated into this framework in addition to Aestus' electrical resistivity data and any follow-up confirmation drilling/sampling data (if/when available).

This process assists Aestus in developing the most appropriate color contouring scheme(s) for the electrical resistivity data that best highlight zones of interest in the subsurface (e.g., contaminated versus clean conditions). Because each site that Aestus' images is different electrically due to varying hydrogeology, types and concentrations of contaminants, etc., this is an iterative process that is very site specific.

### 6.1 Development of Site Specific Custom Color Contouring Scheme

Upon completion of the data processing work discussed in Section 2.5 of this report, the resistivity data set <u>is fixed and is not modified</u> from that point forward. However, Aestus does modify the color contouring scheme(s) used to effectively contour these data (i.e., show various ranges of resistivity detected at the site using different colors) to allow us and our clients to understand what the data means relative to properties of the subsurface that are of foremost interest to Aestus' clients (i.e., contaminant distribution, geology, presence of biological activity, etc.). The color modification process is similar to re-contouring a topographic map (i.e., the elevation points never change, but the contour interval is altered to produce different maps highlighting various features or ranges of resistivity).

For the Site 88 project, the custom color contouring scheme used for this Pre-Injection Interim Report is shown on Figures 1 through 4.

### 6.2 Discussion of Multiple Color Schemes in 3-D

On some sites, Aestus finds that it is helpful to isolate certain resistivity ranges to more easily explain certain interpretations of subsurface features. As discussed in Section 2.5, the data is never modified once it is processed; only color contours representing electrical resistivity ranges are changed. Typical color contouring schemes shown in the 3-D visualization model are described below:

1. **<u>Statistical Color Scheme:</u>** This color scheme assigns each of 20 ranges of resistivity (i.e., "bins") a unique color; the resistivity ranges are determined statistically and includes 5% of the data points in each "bin". A spectrum of cool (purple) to warm (red) colors is used.


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2. **Custom Site Specific Color Scheme:** This color scheme highlights both the low end (i.e., highly conductive end) of the resistivity scale in blue and uses brown colors to highlight resistive anomalous zones detected.
3. **High Resistivity Only Range**: Color contouring scheme highlighting relatively higher resistivity anomalous zones. This color scheme focuses on the high end (i.e., resistive end) of the resistivity scale and uses brown and orange colors to highlight resistivity anomalies.
4. **Low Resistivity (High Conductivity) Only Range:** Color contouring scheme highlighting low resistivity anomalous zones. This color scheme focuses on the low end of the resistivity scale (i.e., conductive end) and uses blue and purple colors to highlight conductive anomalies.


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# 7.0 CONCLUSIONS

Aestus' pre-injection interim report stage conclusions are provided below relative to each of the project objectives discussed in Section1.1.

The below conclusions are offered based on Aestus' experience and professional judgment. As with all environmental assessment work, these conclusions are reached with a certain acceptable degree of uncertainty, due to the possibility that relevant subsurface conditions may exist beyond the scope of this investigation.

## 7.1 Assess Distribution of Injected Permanganate Solution

Aestus has determined that the pre-injection imaging data collected during field work in October 2014 meets our quality standards and will provide an acceptable baseline set of images to use for comparison to the post-injection images. Although the data was somewhat noisy in certain areas due to potential metallic utility interference, Aestus believes that this will not be a material issue since this project is relying on determining changes in electrical resistivity over time as discussed below.

Aestus will provide conclusions related to distribution of injected permanganate solution in our forthcoming Post-Injection Interim Report. As a function of the injection monitoring methodology, post-injection imaging is required for Aestus to interpret injectate distribution. Post-injection imaging work is currently scheduled for summer 2015.

CH2M Hill is advised that the forthcoming post-injection images may not appear substantially different to the naked eye if the same resistivity scale is used to color contour both image sets. Differencing data processing will use resistivity data from both pre and post injection images to calculate and plot the percent change in electrical resistivity between the two image sets. Aestus anticipates that the plot of percent change in resistivity will represent zones where injectate has crossed the image plane.

## 7.2 Optimize Location/Depth of Horizontal Injection Well

Aestus' imagery indicates that previous vertical injection work appears to have impacted and readily flowed within the zone between approximately 50 and 100 feet BGS (see further discussion in Section 7.3.2). Therefore CH2M Hill may want to focus on this zone with the horizontal injection well.

It is important that the injection well be placed such that Aestus' downgradient survey lines can detect injectate migrating in a reasonable project timeframe as a function of the Site 88 groundwater gradient and/or injection pressures. Please see related recommendations in Section 8.1 and 8.2.


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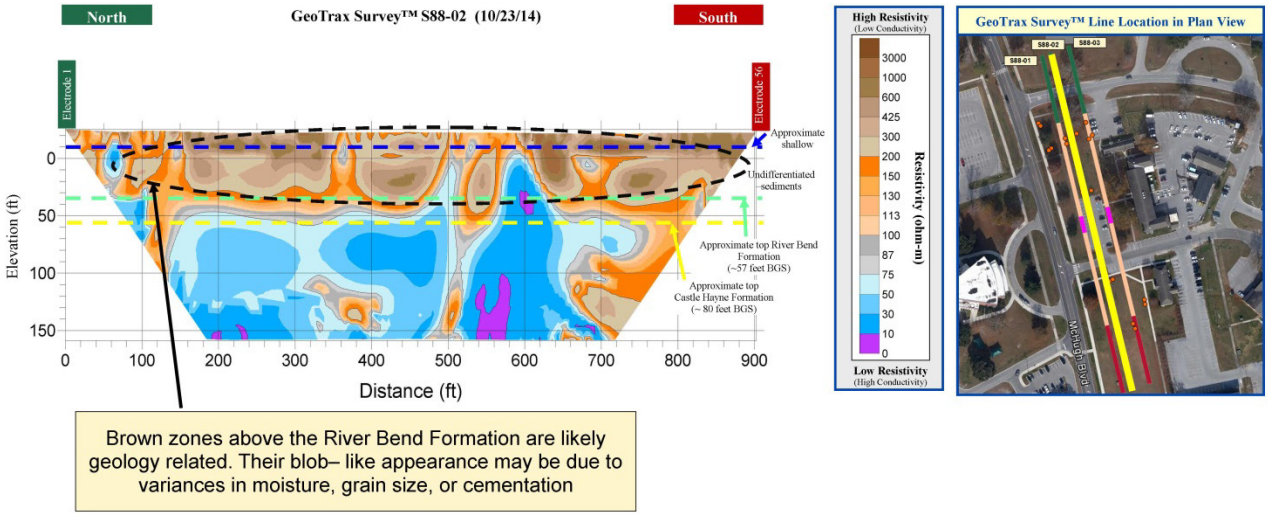
## 7.3 Provide Additional Site Characterization Information

Aestus is providing the below interim stage (following pre-injection imaging) conclusions relative to the various signals that can be detected by GeoTrax Survey™ (see 2.3.2). Site 88 has all possible signals including contaminants, injectate, and metallic utilities, making data interpretation more challenging.

These conclusions have been reached using only historical site drilling and sampling data for correlation with Aestus' electrical imagery. Potentially anomalous zones detected by Aestus exist in areas with no proximate monitoring well data. Therefore, the cause of these anomalous zones will remain unknown unless targeted confirmation drilling and sampling is performed.

### *7.3.1 Geology*

The shallower light brown colored zones (> 200 Ohm-m) above the top of the River Bend Semi-Confining Unit (green dashed line in images) are believed to be representative primarily of geology (see graphic below and Figures 1through 3). The variability of resistivity values in these brown zones likely indicates changes in soil grain size, moisture content and/or degree of cementation. Differences in cementation were noted in boring logs from the site (see IW06 and IW05 on image S88-03 in Figure 3).





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### *7.3.2 Injectate and Metallic Utilities*

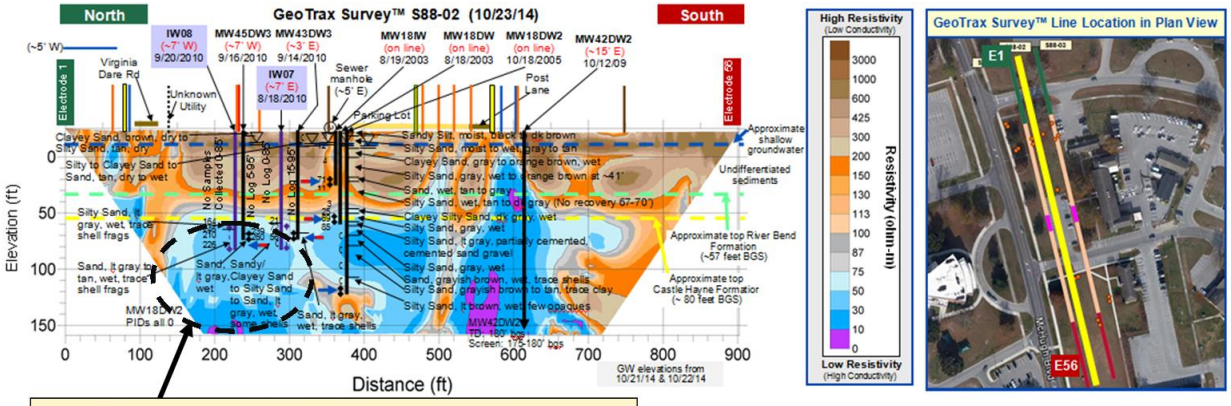
An enhanced reductive dechlorination (ERD) pilot study was conducted at the site in 2010 and consisted of injections of emulsified vegetable oil (EVO) via vertical injection wells. Additionally, the utility locate work performed during the first couple of field days showed that more utilities existed than previously was known (Note: this is common for a military base site as some utility locations are on a need to know basis only and may not appear on site utility maps). Aestus slightly adjusted the locations of our survey lines, to the extent possible, to minimize the effects of buried metallic utilities.

Upon reviewing our survey data, we believe that electrically conductive signatures from injectate and metallic utilities were detected by our imaging process as discussed below. Aestus does not anticipate that the presence of injectate or metallic utilities will prevent successful imaging of future injections, as the differencing process will likely account for this issue.

Blue colored zones (10 to 75 Ohm-m) **below** the top of the Castle Haynes Aquifer (yellow dashed line in graphic below and Figures 1 through 3) occur laterally between 0 and 400 feet from Electrode 1 and likely correspond to the presence of residual injectate from 2010. The vertical injection wells are colored dark purple on the figures, and their labels are a lighter purple on the images. This conclusion is based on two observations from the integrated data sets:

- Injection wells are screened in the Castle Hayne formation, and are coincident with blue zones in the Castle Hayne Formation (see graphic below, and Figures 1 through 3)

- Resistivity values for sand and silty sand are typically higher than 10-75 Ohm-m, and therefore there is likely a condition in the subsurface causing the resistivity value to be decreased (i.e., presumably the injectate from 2010)

- 


Blue zones below the Castle Hayne Formation are coincident with injection well locations; and are likely caused by the 2010 injections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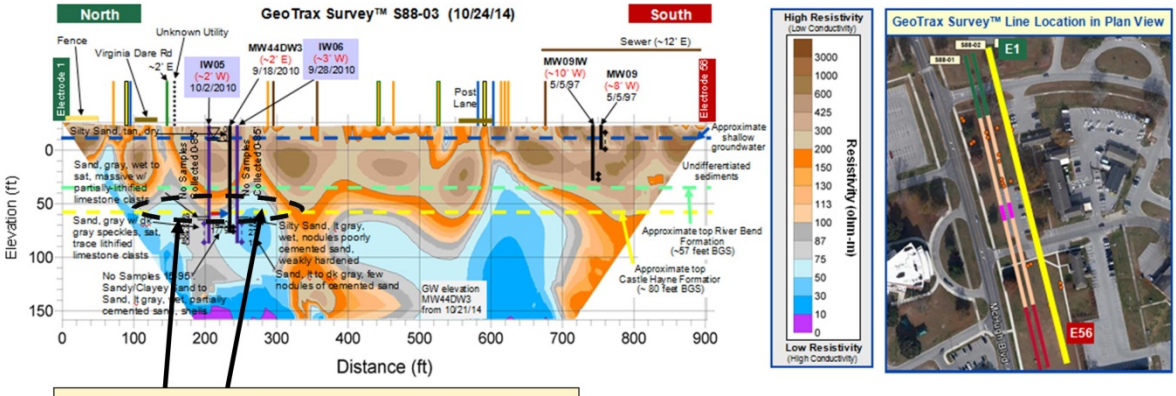
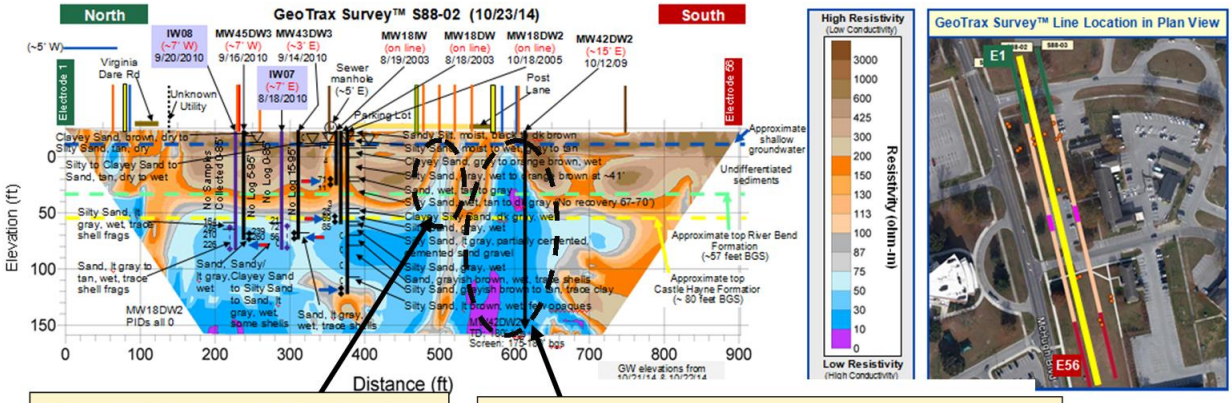
Areas between 10 and 75 Ohm-meters of resistivity (blue zones) **above** the top of the Castle Haynes Aquifer (yellow dashed line in images) are likely associated with either:

1. The potential presence of injectate (see graphic below and Figure 3)




Blue zones above the Castle Hayne Formation in this area are likely are likely caused by the 2010 injections

2. Influence from utilities (e.g. potentially leaking water lines). In some cases, influence from utilities can extend into the Castle Hayne Formation, and may be caused in part by metallic interference (see graphic below and Figure 2).




Some blue zones above the Castle Hayne Formation appear to be influenced by utilities

Some utility influence can extend below the Castle Hayne Formation, and may be caused in part by metallic interference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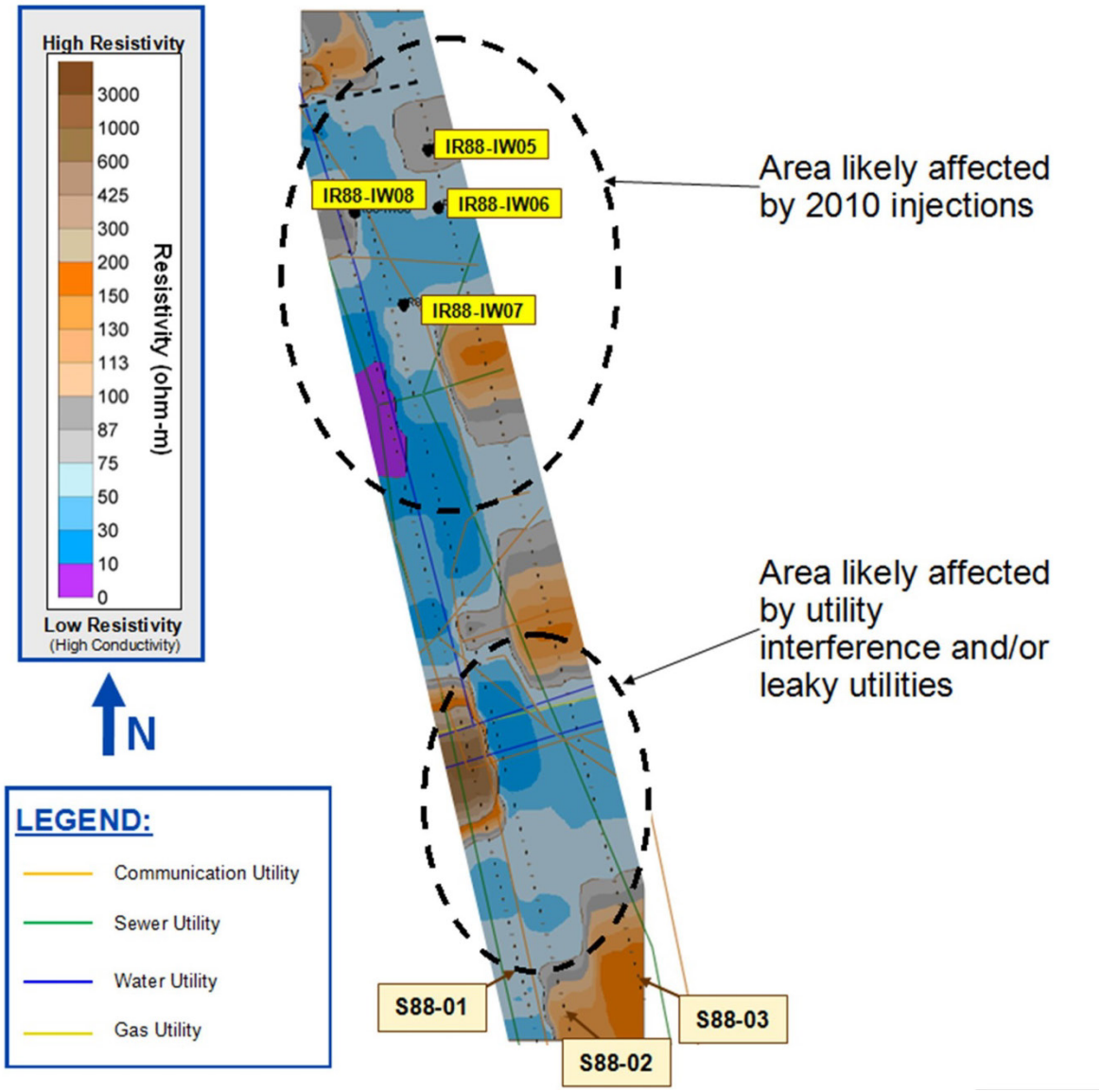
The interpreted horizontal distribution of 2010 injectate impacts versus utility impacts is shown on the graphic below and on Figure 5. This graphic is a screen shot from Aestus' 3D visualization model showing a horizontal elevation slice through the imaging data at 77' AMSL (~100' BGS).





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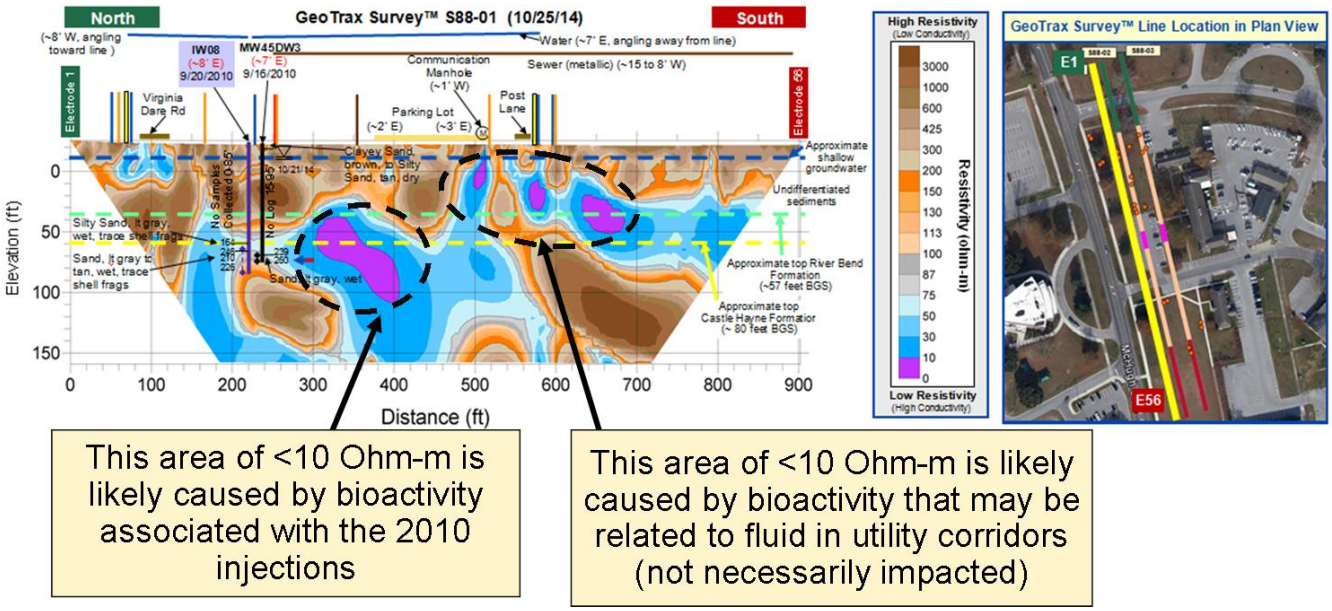
### *7.3.3 Bioactivity*

Aestus suspects that subsurface zones with resistivity values of < 10 Ohm-m (purple colored zones) above ~125' AMSL are anomalous and likely due to signatures from bioactivity. Typical geologic formations tend to have resistivity values higher than 10 Ohm-m and Aestus expects this would be true for Site 88 where the geology is predominantly sandy.

It should be noted that although both bioactivity and metallic utility interference are electrically conductive anomalous signatures, they can be differentiated from each other based on geometry or shape of the anomaly. Specifically, anomalies related to utilities typically start at or just below ground surface and are vertically oriented (see example in Section 7.3.2). They also typically correspond to known metallic utility locations in Aestus field notes and/or project maps. Aestus theorizes that bioactivity can sometimes be enhanced near utility corridors in which case a combined signature can be present.





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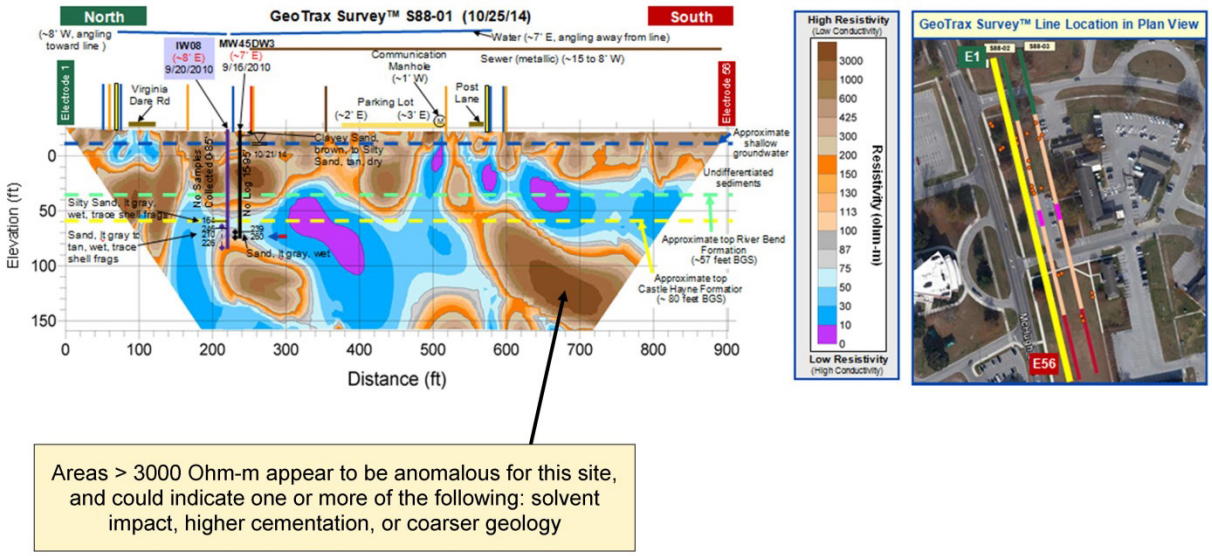
### *7.3.4 DNAPL-Related Impacts*

Assuming DNAPL still exists at Site 88 and has not dissolved into groundwater over time, its presence as a primary electrical signature in the pre-injection imagery is not fully obvious as it is for many other sites. Aestus' interpretation at this time is that site biogeochemical conditions (i.e., from previous ISCO work and/or bioactivity) and/or metallic utility signatures may be partially or fully masking a potential DNAPL signature in some areas (see above conclusions and discussion of hierarchy of electrical signatures in Section 2.3.2).

However, darker brown zones (>1000 Ohm-m) **below** the Castle Hayne Formation (yellow dashed line in images) have higher resistivity values than expected for this site, and could potentially reflect zones with DNAPL-related impacts and/or zones with coarser grained and/or more cemented geology (see graphic below and Figure 1).




Areas > 3000 Ohm-m appear to be anomalous for this site, and could indicate one or more of the following: solvent impact, higher cementation, or coarser geology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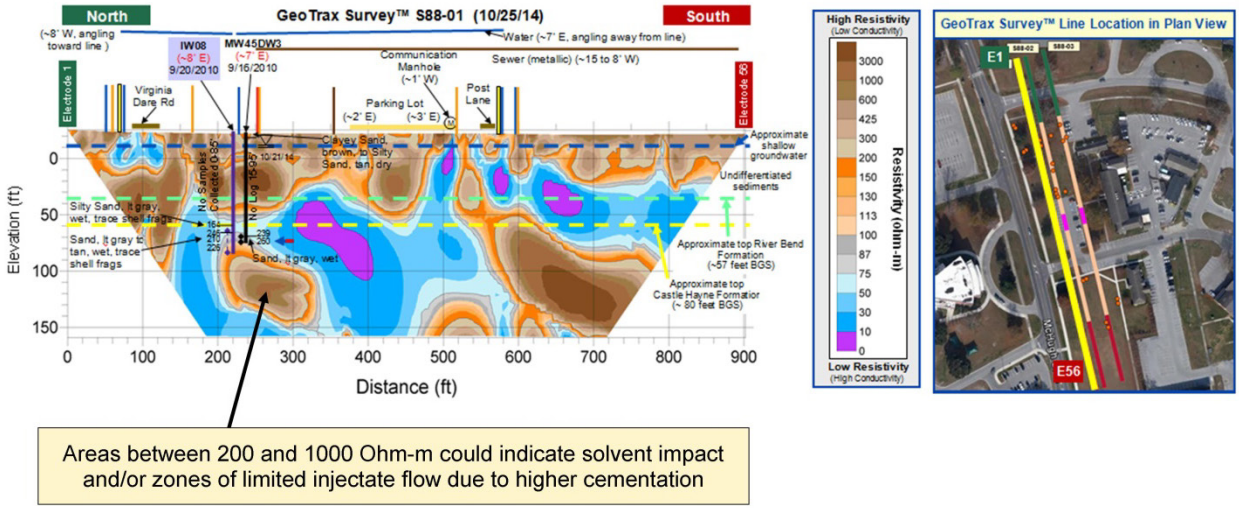
Medium brown colored zones (200 to 1,000 Ohm-m) **<u>beneath</u>** the Castle Haynes Formation (yellow dashed line in images) may potentially be areas where injectate did not flow due to higher cementation in the subsurface, or may potentially have DNAPL-related impacts (see graphic below and Figure 1).




The above conclusions have been reached using only historical site drilling and sampling data for correlation with Aestus' electrical imagery. The abovementioned anomalous zones detected by Aestus exist in areas with no proximate monitoring well data. Therefore, the cause of these anomalous zones will remain unknown unless targeted confirmation drilling and sampling is performed.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# 8.0 RECOMMENDATIONS

This section provides Aestus' recommendations moving forward, based on the results and conclusions developed from our work.

## 8.1 Meeting to Discuss Injection Well Placement and Injectate Specifications

We recommend that CH2M Hill and Aestus collaborate via a web conference in the near future to discuss plans for injection well location, length, and depth. It is important that the injection well be placed such that not too much time is required for Aestus' downgradient survey lines can detect injectate migrating as a function of the Site 88 groundwater gradient.

Aestus and CH2M Hill have previously discussed potentially "spiking" the injectate with a benign salt or other tracer to amplify the shift in conductivity/resistivity thereby assisting Aestus with detection of the injectate. Aestus recommends that the injectate specifications also be discussed in this meeting.

## 8.2 Planning for Phase II Post Injection GeoTrax Survey™ Work

Prior to the commencement of Phase II, Aestus suggests that CH2M Hill and Aestus discuss the type of injectate planned and the potential for spiking the injectate with chloride. Spiking the injectate with chloride will make the injectate more conductive, providing a higher degree of contrast between the subsurface and injectate. Since injectate from 2010 is apparent in the Phase I surveys, a higher degree of contrast for the planned injection work is highly beneficial to achieving the project objective goal of imaging the future injectate.

## 8.3 3-D Visualization Model Review

To be able to fully understand the GeoTrax Survey™ data collected and visualize it in a robust manner in 3-D, Aestus recommends that the reader use the provided free 3-D visualization model viewer to look at these areas more closely on-screen and from different perspectives as screen captures (i.e. imported into Figure 5) from the 3-D visualization model of the site do not provide as complete of an understanding of the available site data. Additionally, the resolution of these hardcopy figures is lower than reviewing the model on a computer monitor screen.

## 8.4 Web Conference Review

Because this report discusses a complex site and multiple data sets encompassing thousands of field data points, Aestus believes that CH2M Hill personnel may benefit from a web conference meeting to further review this report together, field questions, and assist in conveying understanding of conclusions based on this work. Aestus would be pleased to attend and contribute to such a meeting if deemed helpful by CH2M Hill.

## 8.5 Follow-up Confirmation Drilling

While not originally anticipated as part of this injection monitoring project, should CH2M Hill desire to more fully understand the cause of potentially anomalous zones detected by Aestus that exist in areas without proximate monitoring well data, targeted confirmation drilling and sampling would provide more certainty.


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# TABLES

# Table 1
## Electrode Spacing, Survey Line Length, and Survey Depth
## Site 88 at MCIEAST-MCB CAMLEJ
## North Carolina, USA

| Survey ID | Electrode Spacing (m) | Survey Line Length (ft) | Image Depth (ft) |
|---|---|---|---|
| S88-01 | 5.00 | 902 | 180 |
| S88-02 | 5.00 | 902 | 180 |
| S88-03 | 5.00 | 902 | 180 |



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# Table 2
# GeoTrax Survey™ End Electrode Land Survey Coordinates
# Site 88 at MCIEAST-MCB CAMLEJ
# North Carolina, USA

| Survey ID | Coordinate System and Datum[1] | Electrode 1 | | | Electrode 56 | | |
|---|---|---|---|---|---|---|---|
| | | Easting (ft) | Northing (ft) | Elevation (ft) | Easting (ft) | Northing (ft) | Elevation (ft) |
| S88-01 | UTM Zone 18N | 284,621.25 | 3,839,213.11 | 7.76 | 284,684.94 | 3,838,945.95 | 6.67 |
| S88-02 | | 284,625.92 | 3,839,215.27 | 7.69 | 284,692.02 | 3,838,948.37 | 6.86 |
| S88-03 | | 284,640.81 | 3,839,221.33 | 7.85 | 284,707.40 | 3,838,954.59 | 7.20 |

**Notes:**

RESERVED SECTION; no notes for this project.



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# Table 3
# Distance Along Survey Line from Electrode No. 1 (5.0 m Spacing)
# Site 88 at MCIEAST-MCB CAMLEJ
# North Carolina, USA

| 5 meter spacing | | | | | |
|---|---|---|---|---|---|
| ***Electrode*** | ***Meters*** | ***Feet*** | ***Electrode*** | ***Meters*** | ***Feet*** |
| **1** | 0.00 | 0 | **29** | 140.00 | 459 |
| **2** | 5.00 | 16 | **30** | 145.00 | 476 |
| **3** | 10.00 | 33 | **31** | 150.00 | 492 |
| **4** | 15.00 | 49 | **32** | 155.00 | 509 |
| **5** | 20.00 | 66 | **33** | 160.00 | 525 |
| **6** | 25.00 | 82 | **34** | 165.00 | 541 |
| **7** | 30.00 | 98 | **35** | 170.00 | 558 |
| **8** | 35.00 | 115 | **36** | 175.00 | 574 |
| **9** | 40.00 | 131 | **37** | 180.00 | 591 |
| **10** | 45.00 | 148 | **38** | 185.00 | 607 |
| **11** | 50.00 | 164 | **39** | 190.00 | 623 |
| **12** | 55.00 | 180 | **40** | 195.00 | 640 |
| **13** | 60.00 | 197 | **41** | 200.00 | 656 |
| **14** | 65.00 | 213 | **42** | 205.00 | 673 |
| **15** | 70.00 | 230 | **43** | 210.00 | 689 |
| **16** | 75.00 | 246 | **44** | 215.00 | 705 |
| **17** | 80.00 | 262 | **45** | 220.00 | 722 |
| **18** | 85.00 | 279 | **46** | 225.00 | 738 |
| **19** | 90.00 | 295 | **47** | 230.00 | 755 |
| **20** | 95.00 | 312 | **48** | 235.00 | 771 |
| **21** | 100.00 | 328 | **49** | 240.00 | 787 |
| **22** | 105.00 | 344 | **50** | 245.00 | 804 |
| **23** | 110.00 | 361 | **51** | 250.00 | 820 |
| **24** | 115.00 | 377 | **52** | 255.00 | 837 |
| **25** | 120.00 | 394 | **53** | 260.00 | 853 |
| **26** | 125.00 | 410 | **54** | 265.00 | 869 |
| **27** | 130.00 | 427 | **55** | 270.00 | 886 |
| **28** | 135.00 | 443 | **56** | 275.00 | 902 |

* NOTE: All Surveys have a 5.0 m electrode spacing.



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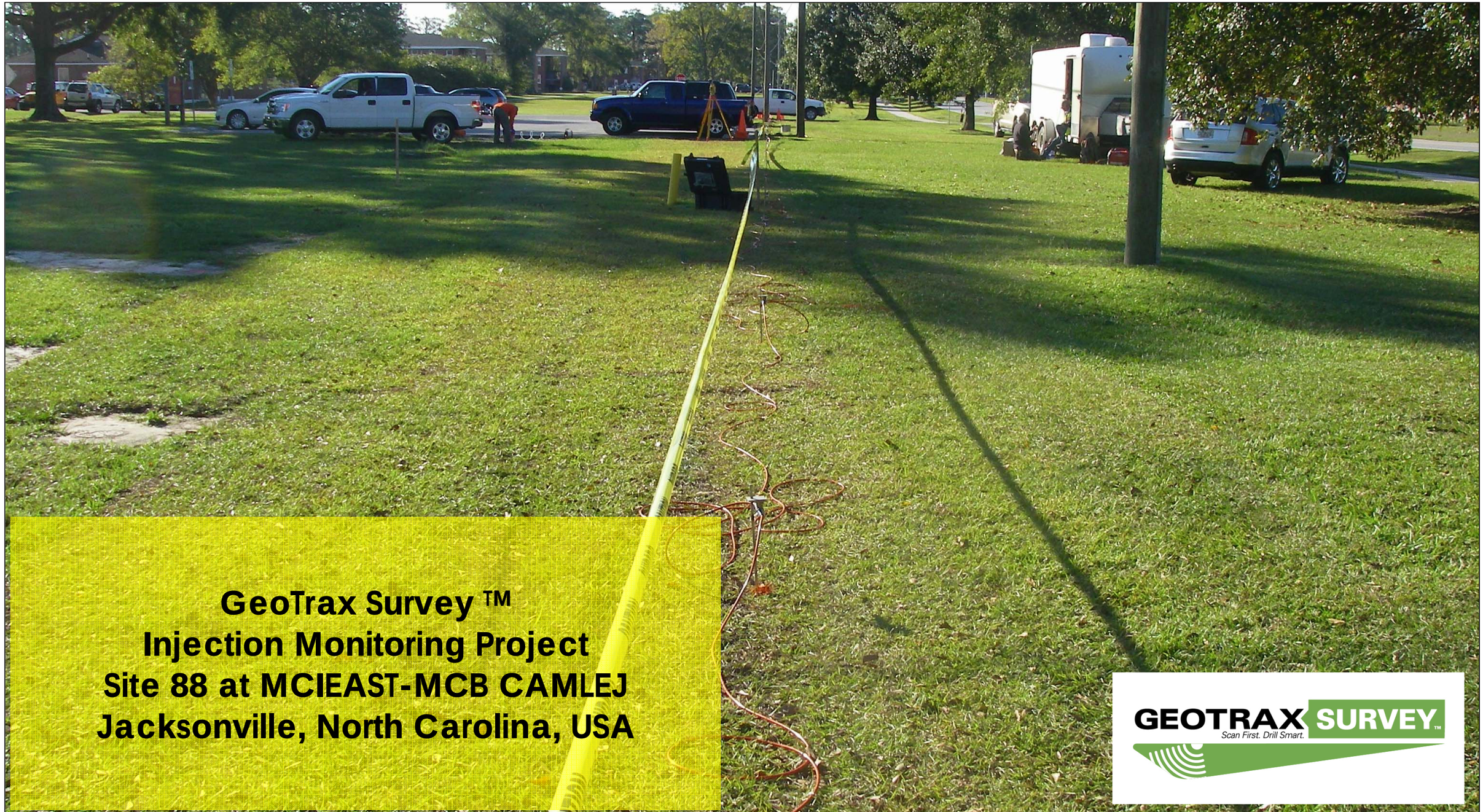
# FIGURES



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| | |
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| QC By: | MAS |
| Approved By: | SWM |
| Date: | 05-07-15 |
| Project No.: | 14-114-09 |

**GeoTrax Survey™ Injection Monitoring**
**Site 88 at MCIEAST-MCB CAMLEJ**
**Jacksonville, North Carolina, USA**

**PRE-INJECTION INTERIM REPORT**

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FIGURE

**TITLE PAGE**

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# Legend and Symbols

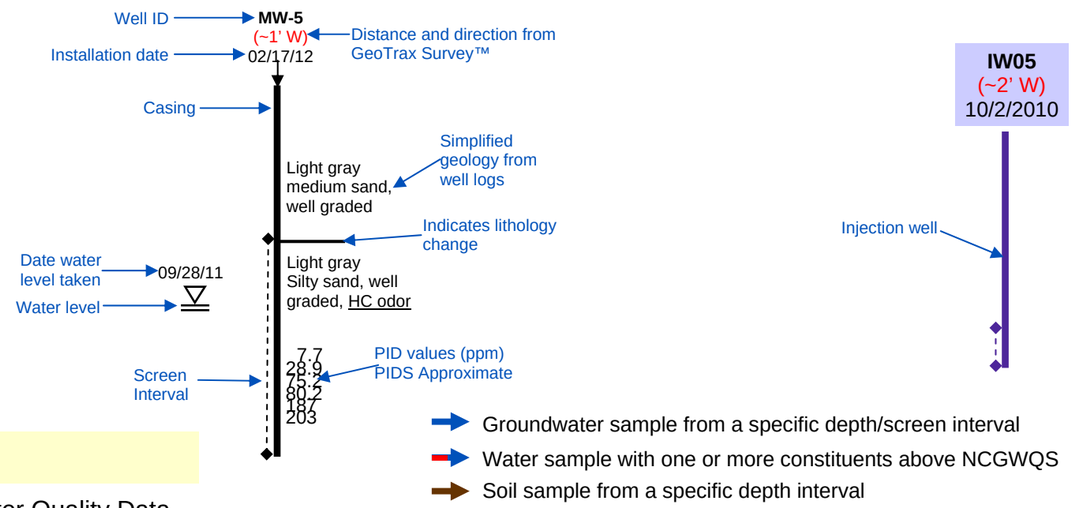
**(for reference when reviewing all Figures)**

Indicates various site features which are labeled accordingly on the figures

## Utilities

Phone/ Communication | Sewer | Electric | Gas | Water | Storm Drain | Fiber Optic | Unknown Utility | Manhole

## Monitoring Well Explanation




## Analytical Data

| Groundwater Sample Results | | |
|---|---|---|
| Well | | MW45DW3 |
| Sample Date | | 10/12/2011 |
| *Parameters (µg/L)* | Standards (µg/L) | |
| PCE | 0.7 | **122,000** |
| TCE | 3 | **2,670** |
| cis-1,2-DCE | 70 | **601 J** |
| Vinyl Chloride | 0.03 | 500 U |

| Groundwater Quality Sample Results | | |
|---|---|---|
| Well | | MW45DW3 |
| Sample Date | | 10/12/2011 |
| *Parameters* | *Units* | |
| Temperature | °C | 19.99 |
| Conductivity | mS/cm | 0.379 |
| DO | mg/L | 0.11 |

| General Microbial Analyses | |
|---|---|
| Well | MW45DW3 |
| Sample Date | 10/12/2011 |
| *Parameters (CELLS/ML)* | |
| Dehalobacter | 5,300 = |
| Dehalococcoides | 0.5 < |
| Desulfuromonas | 45,600 = |

| Semi-Volatile Organic Compounds | |
|---|---|
| Well | MW45DW3 |
| Sample Date | 10/12/2011 |
| *Parameters (mg/L)* | |
| Acetate | 0.11 |
| Butyrate | 0.05 U |
| Formic Acid | 0.12 |

| Zone 2 ERD Injection Record | | |
|---|---|---|
| Well | | IW08 |
| Sample Date | | 2010* |
| *Injectate* | *Units* | |
| EVO (SRS™, 6.4%) & Sodium bicarbonate (700 mg/L) | Gal | 1,488 |
| Mass of EVO (SRS™) | lbs | 11,965 |
| TSI-DC Bioaugmentation Culture™ (5E10 cells/mL) | L | 10.3 |

Groundwater and Soil Analytical Data and Groundwater Quality Data Parameters for Wells Near GeoTrax Surveys™. Data provided by CH2MHILL.

**Bold**: Constituent concentration exceeds North Carolina Groundwater Quality Standard (NCGWQS, January 2010)

Data precedes GeoTrax™ Survey for Groundwater Quality Data

DC Dehalococcoides ethenogenes
ERD Enhanced reductive de-chlorination
EVO (SRS™) Emulsified vegetable oil substrate (carbon source)
MCL Maximum contaminant level
NS Not sampled
TSI Terra Systems Inc.
CELLS/ML Cells per milliliter
U The material was analyzed for but not detected
J Analyte present. Value may or may not be accurate or precise
UJ Analyte not detected, quantitation limit may be inaccurate
D Compound identified in an analysis at a secondary dilution factor.
DJ NO MATCHING QUALIFIER DEFINITION FOUND IN LOOKUP LIST
< Less than (value shown)

**General Notes:**

1. *Locations of site features on Figures (e.g., utilities, wells, etc.) are approximate*


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FIGURE
LS-1

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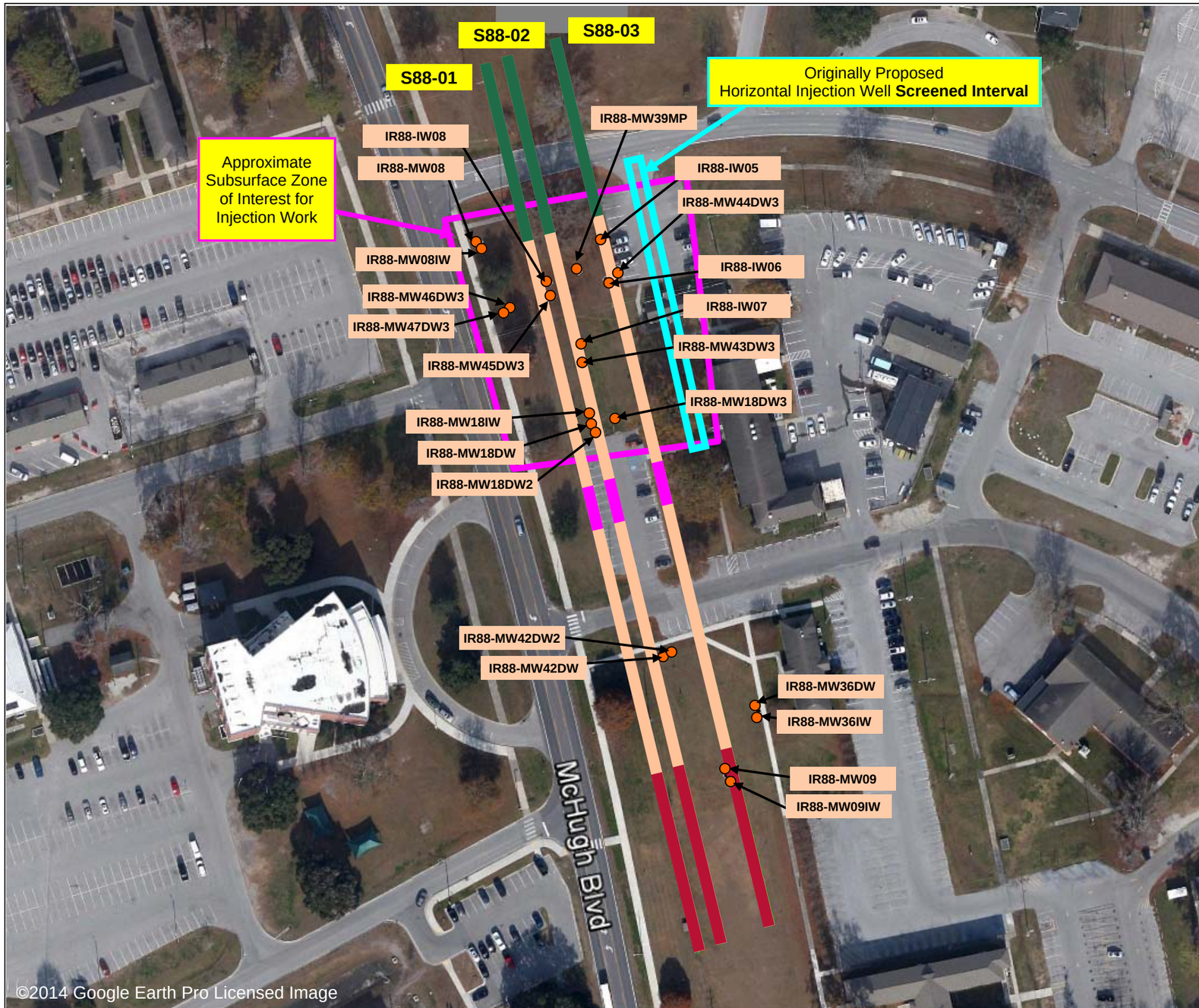


## LEGEND:

Electrode 1 — Electrode 56

**GeoTrax Survey™**
**Orientation and Designation**

S88-01

**5.00 Meter** Electrode Spacing
Survey Line ~902 feet Long (~275 m)
Image Depth ~184 feet (~56 m)

IR88-MW43DW3 Historical Monitoring and Injection Well Locations

Instrument Location at Center of Pink Line (pink box)

**Full depth of trapezoidal shaped image exists in center orange zone; partial depth in green and red zones**

N

0 250 500
feet


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| Approved By: | SWM |
| Date: | 05-07-15 |
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**GeoTrax Survey™ and Historical Monitoring & Injection Well Locations**
**Site 88 at MCIEAST-MCB CAMLEJ**
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FIGURE
PV-1

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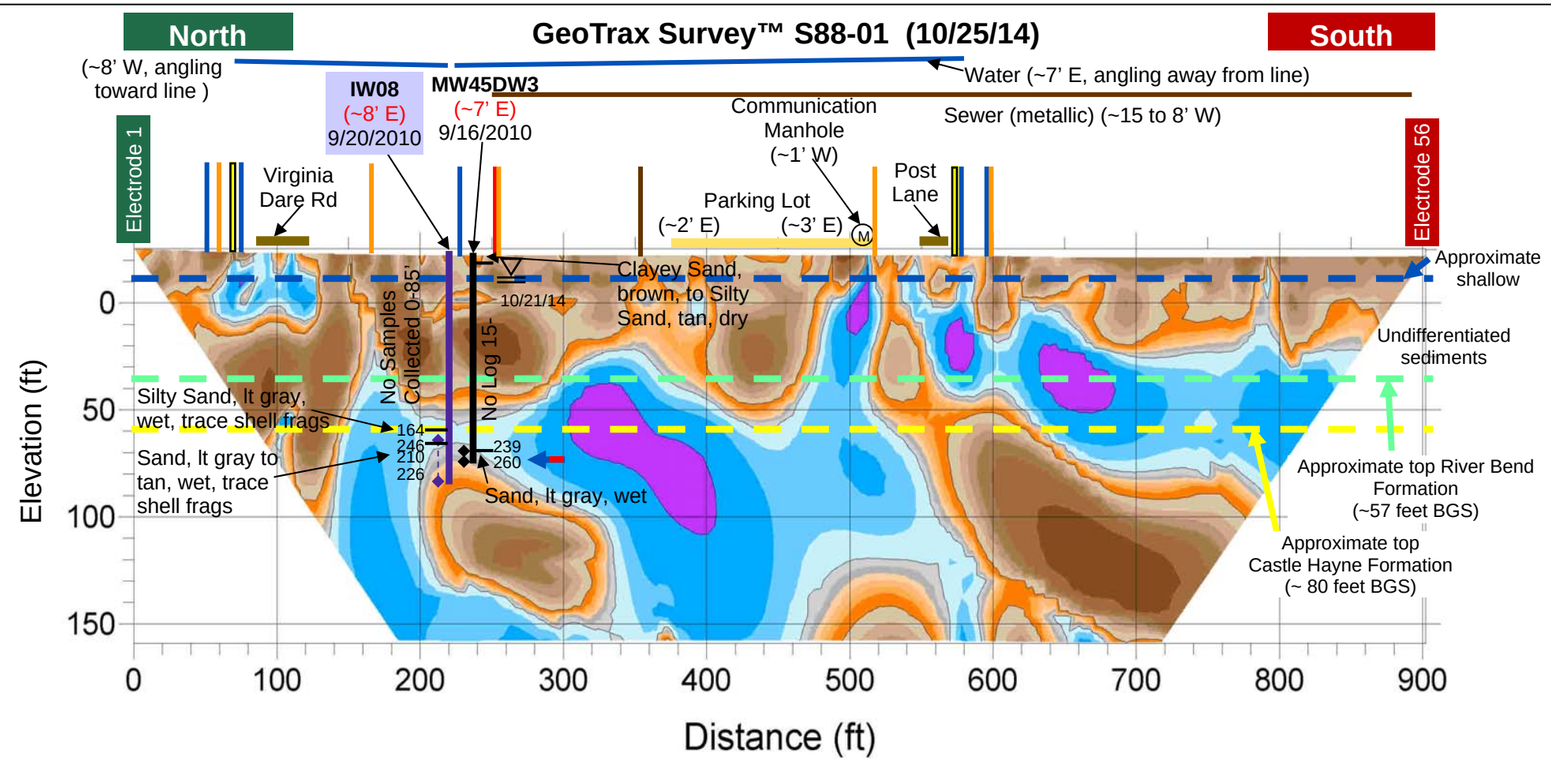


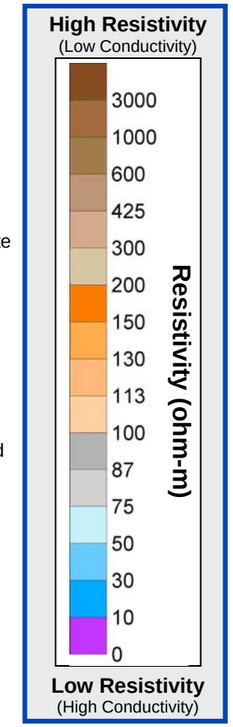


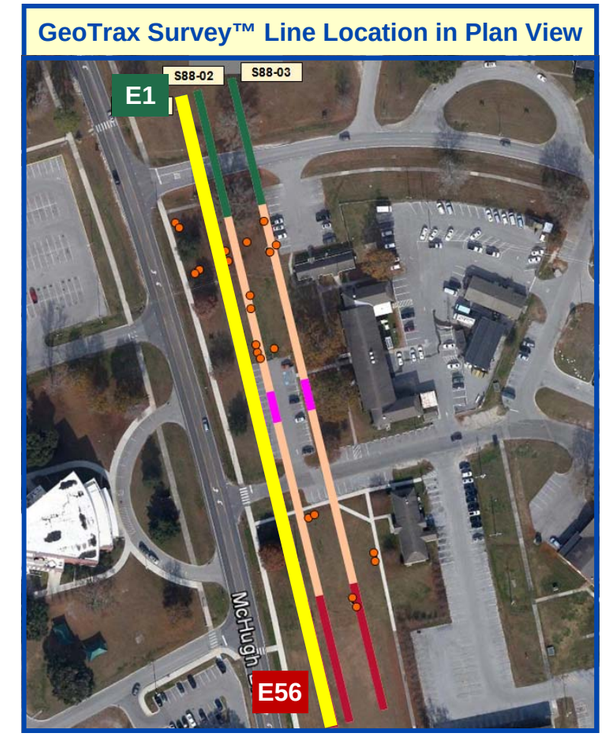


| Groundwater Sample Results | | |
|---|---|---|
| Well | | MW45DW3 |
| Sample Date | | 10/21/14 |
| *Parameters (µg/L)* | Standards (µg/L) | |
| PCE | 0.7 | **68,700 D** |
| TCE | 3 | **2,420 D** |
| cis-1,2-DCE | 70 | **498 DJ** |
| VC | 0.03 | 250 U |
| trans-1,2-DCE | | 250 U |

| Groundwater Quality | | |
|---|---|---|
| Well | | MW45DW3 |
| Sample Date | | 10/21/14 |
| *Parameters* | *Units* | |
| Temperature | ºC | 19.77 |
| Conductivity | mS/cm | 0.377 |
| DO | mg/L | 0.7 |
| ORP | mV | -100 |
| pH | S.U. | 7.69 |

| General Microbial Analyses | |
|---|---|
| Well | MW45DW3 |
| Sample Date | 10/21/2014 |
| *Parameters (CELLS/ML)* | |
| BAV1 R-Dase | 0.5 U |
| Dehalococcoides | 1.3 |
| VC R-Dase | 0.5 U |

| Zone 2 ERD Injection Record | | |
|---|---|---|
| Well | | IW08 |
| Sample Date *More precise injection date not provided | | 2010* |
| *Injectate* | *Units* | |
| EVO (SRS™, 6.4%) & Sodium bicarbonate (700 mg/L) | gal | 1,488 |
| Mass of EVO (SRS™) | lb | 11,965 |
| TSI-DC Bioaugmentation Culture™ (5E10 cells/mL) | L | 10.3 |
| Anaerobic water (Sodium sulfite 0.003 lb/gal) | gal | 5,000 |
| Anaerobic water | gal | 10,000 |

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FIGURE
1

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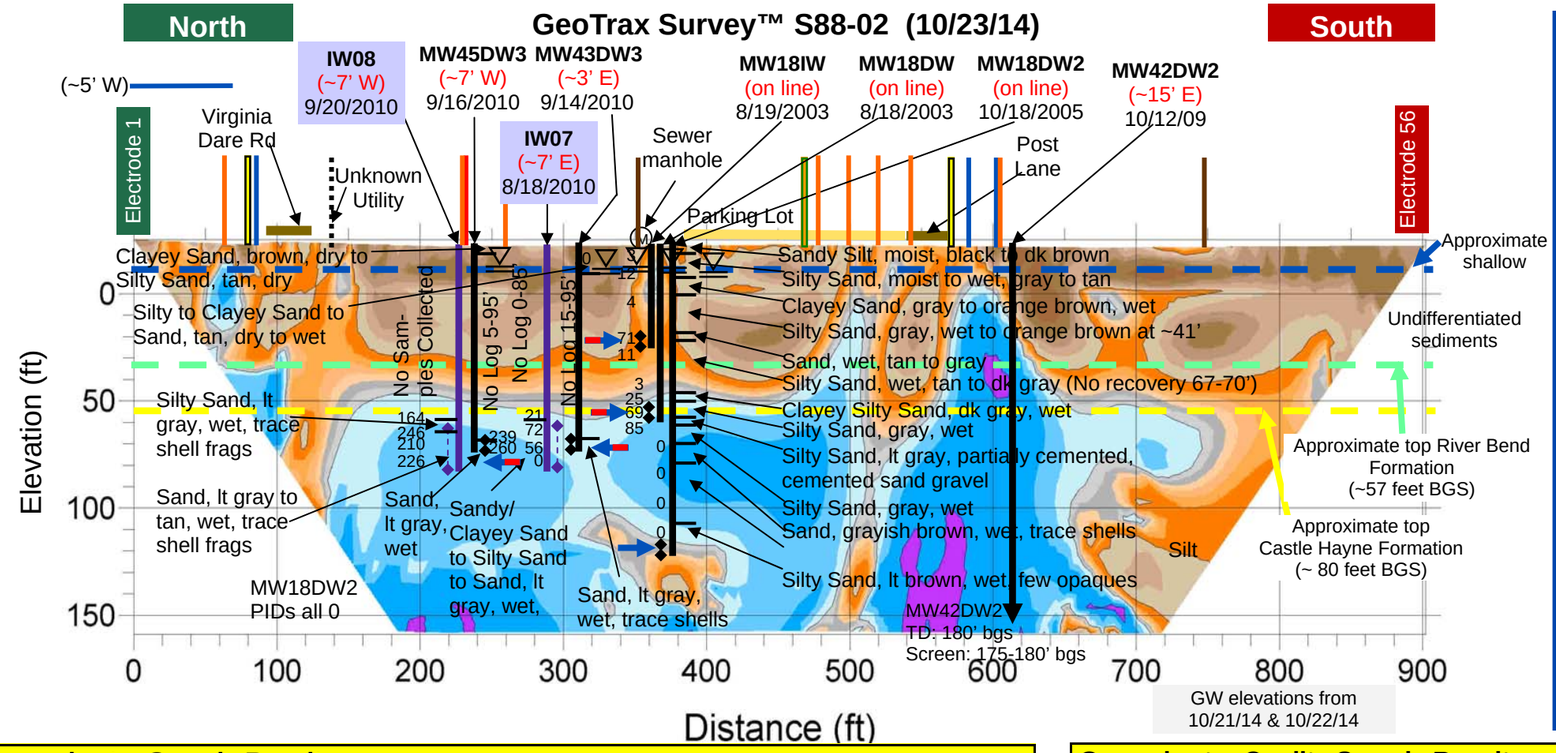


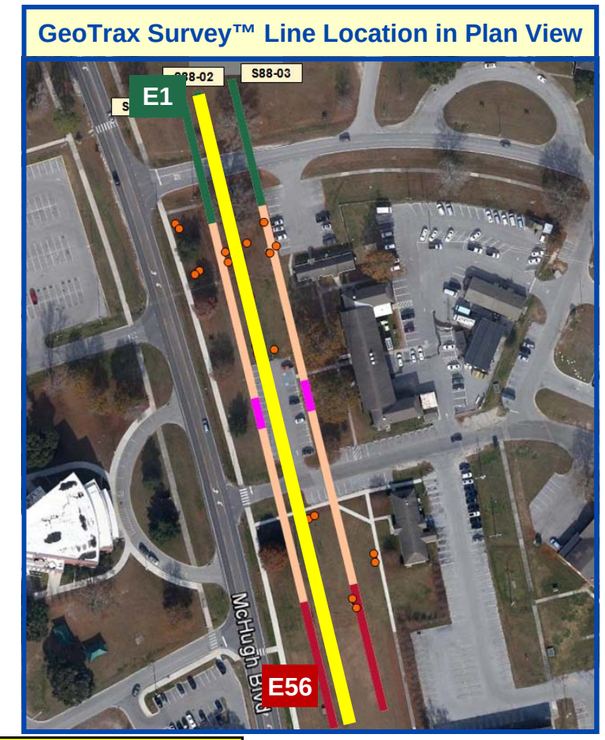


## Groundwater Sample Results

| Well | | MW45DW3 | MW43DW3 | MW18IW | MW18DW | MW18DW2 | MW42DW2 |
|---|---|---|---|---|---|---|---|
| Sample Date | | 10/21/14 | 10/21/14 | 10/21/14 | 10/22/14 | 10/22/14 | |
| *Parameters (µg/L)* | Standards (µg/L) | | | | | | |
| PCE | 0.7 | **68,700 D** | **6,330 D** | **28.9** | **216 D** | 0.5 U | No Data Provided/ Not Sampled |
| TCE | 3 | **2,420 D** | **833 D** | 0.501 J | **23.3 D** | 0.5 U | |
| cis-1,2-DCE | 70 | **498 DJ** | **136 D** | 0.6 J | 0.768 DJ | 0.5 U | |
| VC | 0.03 | 250 U | 25 U | 0.5 U | 1 U | 0.5 U | |
| trans-1,2-DCE | | 250 U | 25 U | 0.5 U | 1 U | 0.5 U | |

## General Microbial Analyses

| Well | MW45DW3 | Not Sampled |
|---|---|---|
| Sample Date | 10/21/2014 | MW43DW3 |
| *Parameters (CELLS/ML)* | | MW18IW |
| BAV1 R-Dase | 0.5 U | MW18DW |
| Dehalococcoides | 1.3 | MW18DW2 |
| VC R-Dase | 0.5 U | MW42DW2 |

## Groundwater Quality Sample Results

| Well | | MW45DW3 | MW43DW3 | MW18IW | MW18DW | MW18DW2 | MW42DW2 |
|---|---|---|---|---|---|---|---|
| Sample Date | | 10/21/14 | 10/21/14 | 10/21/14 | 10/22/14 | 10/22/14 | 10/27/2009 |
| *Parameters* | *Units* | | | | | | |
| Temperature | ºC | 19.77 | 21.37 | 21.28 | 17.48 | 19.79 | 20.59 |
| Conductivity | mS/cm | 0.377 | 0.36 | 0.2 | 0.404 | 0.229 | 0.364 |
| DO | mg/L | 0.7 | 1.84 | 2.21 | 4.59 | 1.38 | 0.11 |
| ORP | mV | -100 | -60.3 | 170.3 | 137.6 | 101.8 | -176 |
| pH | S.U. | 7.69 | 12.22 | 4.26 | 8.1 | 7.8 | 8.21 |

## Zone 2 ERD Injection Record

| Well | | IW08 | IW07 |
|---|---|---|---|
| Sample Date *More precise injection date not provided | | 2010* | 2010* |
| *Injectate* | *Units* | | |
| EVO (SRS™, 6.4%) & Sodium bicarbonate (700 mg/L) | gal | 1,488 | 1,695 |
| Mass of EVO (SRS™) | lb | 11,965 | 16,639 |
| TSI-DC Bioaugmentation Culture™ (5E10 cells/mL) | L | 10.3 | 17 |
| Anaerobic water (Sodium sulfite 0.003 lb/gal) | gal | 5,000 | 5,000 |
| Anaerobic water | gal | 10,000 | 10,000 |

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FIGURE
2

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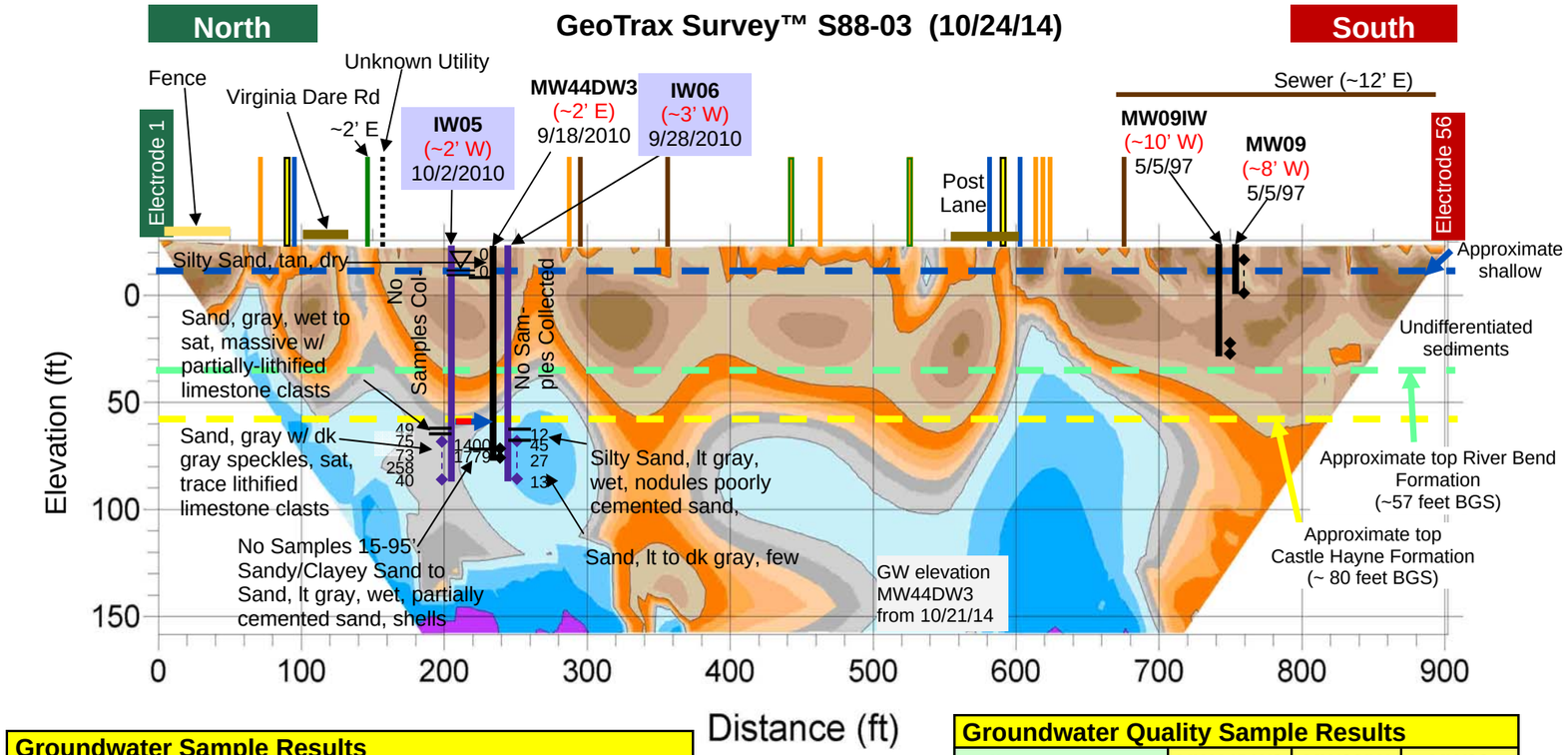


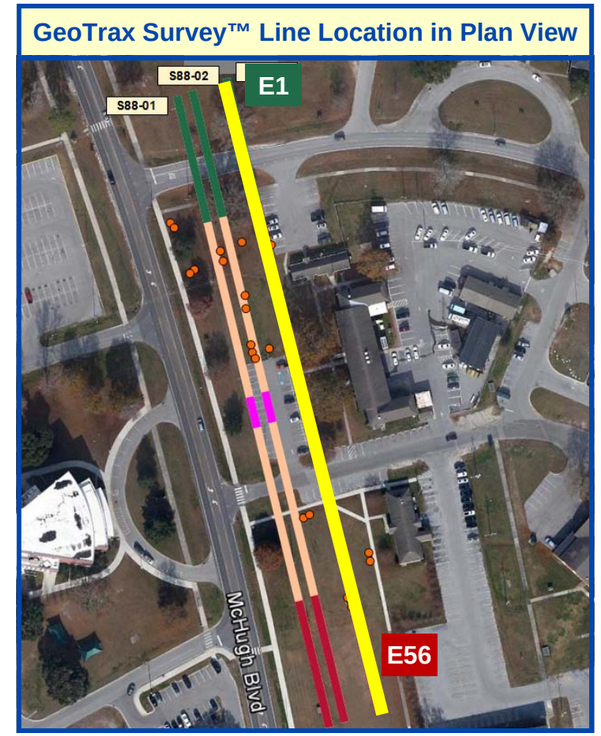


## Groundwater Sample Results

| Well | | MW44DW3 | MW09IW | MW09 |
|---|---|---|---|---|
| Sample Date | | 10/21/14 | | |
| *Parameters (µg/L)* | Standards (µg/L) | | | |
| PCE | 0.7 | **57,200 D** | No Data Provided / Not Sampled | |
| TCE | 3 | **998 D** | | |
| cis-1,2-DCE | 70 | **3,860 D** | | |
| VC | 0.03 | 250 U | | |
| trans-1,2-DCE | | 250 U | | |

## General Microbial Analyses

| Well | MW44DW3 | MW09IW | MW09 |
|---|---|---|---|
| Sample Date | | | |
| *Parameters (CELLS/ML)* | | | |
| BAV1 R-Dase | No Data Provided/ Not Sampled | | |
| Dehalococcoides | | | |
| VC R-Dase | | | |

## Groundwater Quality Sample Results

| Well | | MW44DW3 | MW09IW | MW09 |
|---|---|---|---|---|
| Sample Date | | 10/21/14 | 8/12/2007 | 8/12/2007 |
| *Parameters* | *Units* | | | |
| Temperature | ºC | 21.15 | 20.06 | 22.39 |
| Conductivity | mS/cm | 0.468 | 0.148 | 0.052 |
| DO | mg/L | 5.38 | 0.09 | 6.20 |
| ORP | mV | 118.1 | 68.0 | 251 |
| pH | S.U. | 9.32 | 5.50 | 4.25 |

## Zone 2 ERD Injection Record

| Well | | IW05 | IW06 |
|---|---|---|---|
| Sample Date *More precise injection date not provided | | 2010* | 2010* |
| *Injectate* | *Units* | | |
| EVO (SRS™, 6.4%) & Sodium bicarbonate (700 mg/L) | gal | 1,783 | 1,608 |
| Mass of EVO (SRS™) | lb | 14,339 | 12,940 |
| TSI-DC Bioaugmentation Culture™ (5E10 cells/mL) | L | 10.3 | 10.3 |
| Anaerobic water (Sodium sulfite 0.003 lb/gal) | gal | 5,000 | 5,000 |
| Anaerobic water | gal | 10,000 | 6,765 |

GEOTRAX VIZ™ Data Integration. 3D Visualization.


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7 Red Oak Road
Wilmington, DE 19806

2605 Dotsero Court
Loveland, CO 80538

6005 West 19th Avenue
Stillwater, OK 74074


Scale: NTS unless specified
QC By: MAS
Approved By: SWM
Date: 05-07-15
Project No.: 14-114-09

**GeoTrax Viz™ 2-D Data Integration**
**Site 88 at MCIEAST-MCB CAMLEJ**
**Jacksonville, North Carolina, USA**

# PRE-INJECTION INTERIM REPORT

*Prepared for*
CH2MHILL

FIGURE
3

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*More precise injection date not provided

# Representative Site Photos*

*** All site photos included as an electronic appendix to this report**


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7 Red Oak Road
Wilmington, DE 19806

2605 Dotsero Court
Loveland, CO 80538

6005 West 19th Avenue
Stillwater, OK 74074


| | |
|---|---|
| Scale: | NTS unless specified |
| QC By: | MAS |
| Approved By: | SWM |
| Date: | 05-07-15 |
| Project No.: | 14-114-09 |

**Photos of GeoTrax Survey™ Transect Locations**
**Site 88 at MCIEAST-MCB CAMLEJ**
**Jacksonville, North Carolina, USA**

**PRE-INJECTION INTERIM REPORT**

*Prepared for*

CH2MHILL

FIGURE

4

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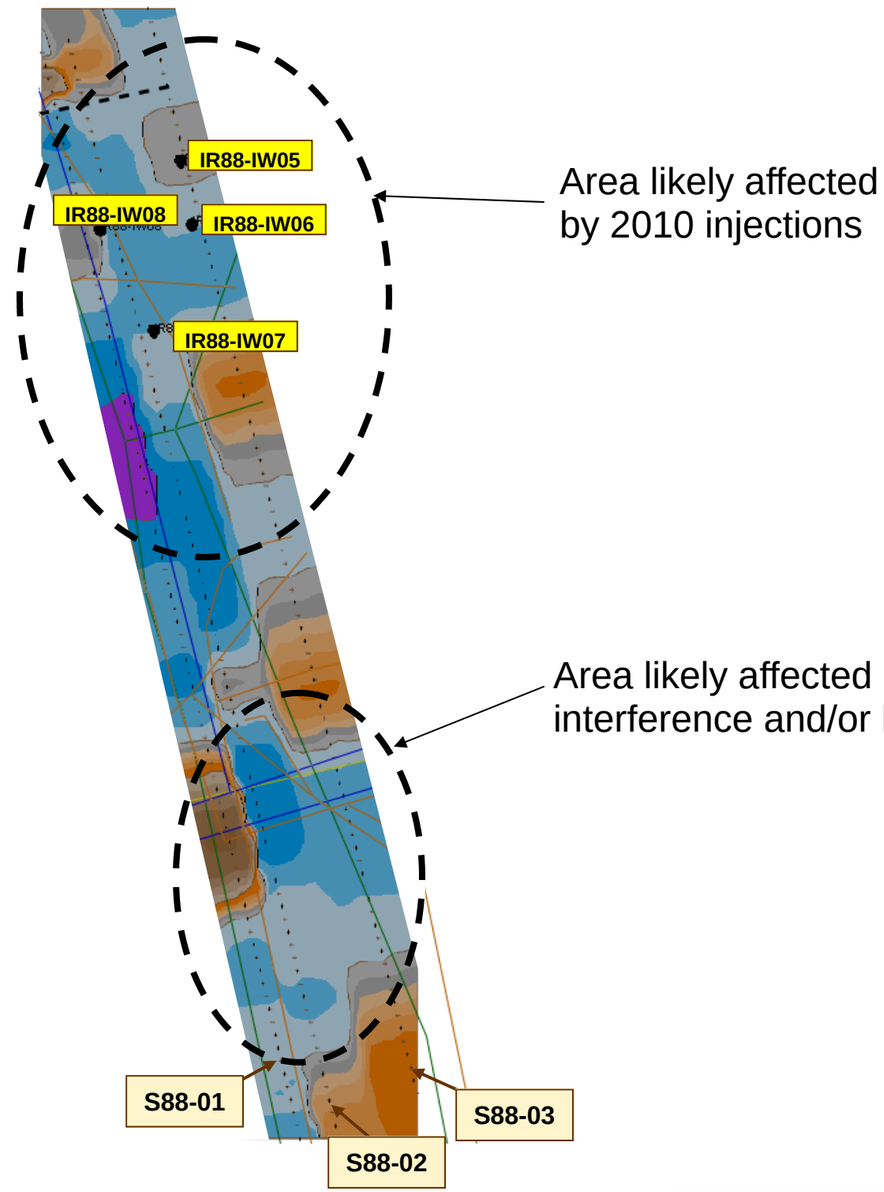
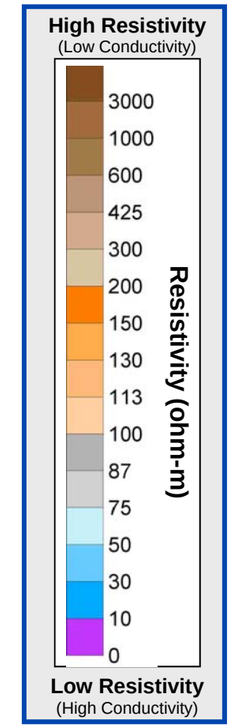
## GeoTrax Survey™ Horizontal Elevation Slice at 77' AMSL (~100' BGS) with Utilities Showing 2010 Injectate Extent




**LEGEND:**

- Communication Utility
- Sewer Utility
- Water Utility
- Gas Utility

N

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| | | | |
|---|---|---|---|
| Aestus Aestus, LLC<br>1.888.GEO.TRAX<br>www.aestusllc.com | 7 Red Oak Road<br>Wilmington, DE 19806<br>2605 Dotsero Court<br>Loveland, CO 80538<br>6005 West 19th Avenue<br>Stillwater, OK 74074 | Scale: NTS unless specified<br>QC By: MAS<br>Approved By: SWM<br>Date: 05-07-15<br>Project No.: 14-114-09 | GeoTrax Viz™ 3-D Data Integration & Visualization Perspective View<br>Site 88 at MCIEAST-MCB CAMLEJ<br>Jacksonville, North Carolina, USA<br>**PRE-INJECTION INTERIM REPORT** |

*Prepared for* CH2MHILL

FIGURE 5

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# Appendix A

# Aestus' GeoTrax Survey™ Field Notes

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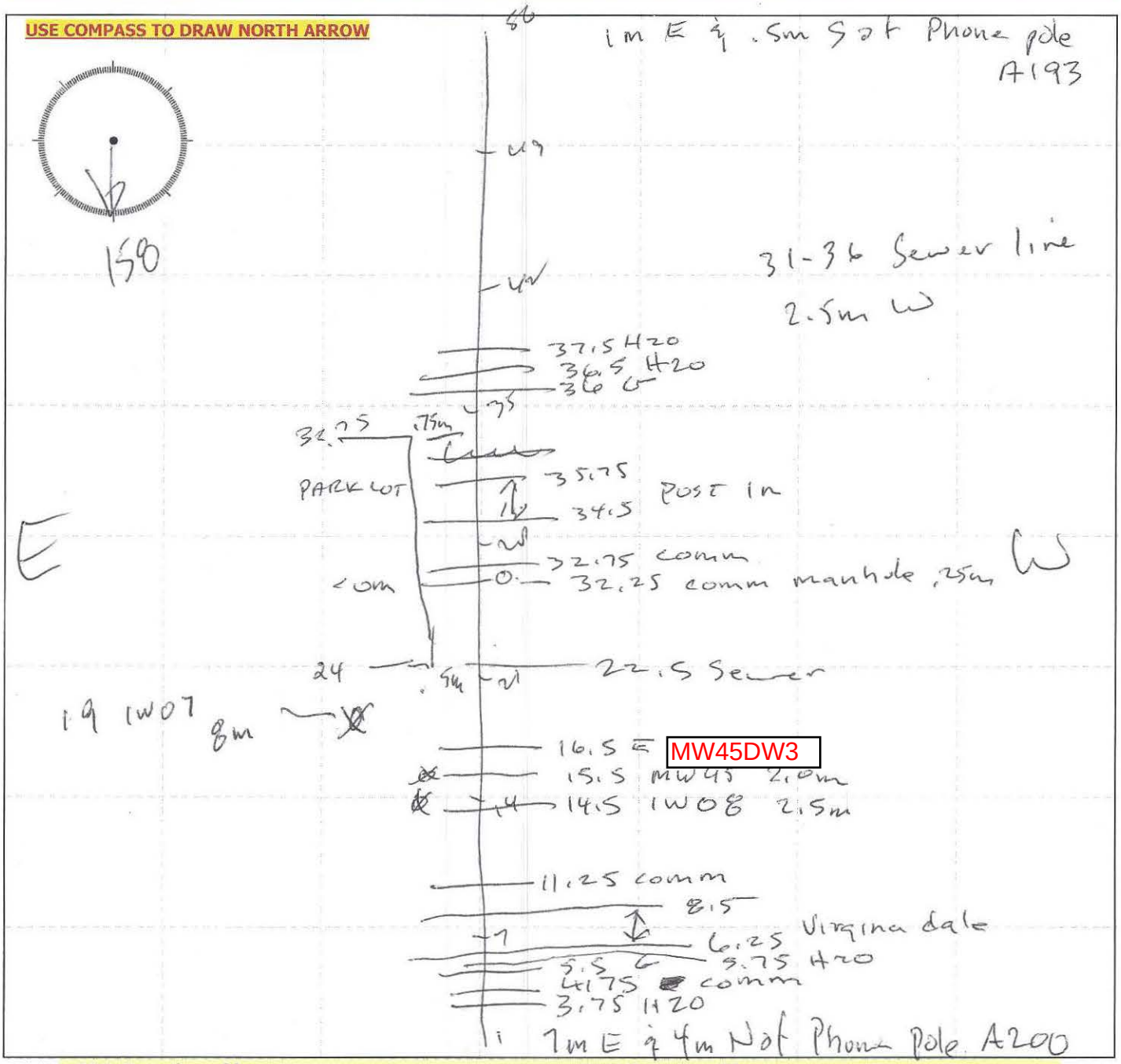
**File Name** | S | 8 | 8 | 0 | 1 | VQ |

Project Name Site 88, Camp Lejeune, NC

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling

**USE COMPASS TO DRAW NORTH ARROW**




| GPS Coords. | N: | GPS Coords | N: |
|---|---|---|---|
| Electrode #1 | W: | Electrode #56 | W: |
| | Accuracy: | | Accuracy: |

**Aestus GeoTrax Survey™ Data Acquisition Field Notes**

**File Name** S 8 8 0 1 JK

Project Name Site 88, Camp Lejeune, NC

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)** **"Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | 7m E ¼ 4m N of Phone Pole A200 | 29 | |
| 2 | | 30 | |
| 3 .75 | $H_2O$ | 31 | Sewer line 2.5m W (metallic) |
| 4 .75 | Comm | 32 .75 | Park Lot .75m E 32.25 Comm manhole .25m W |
| 5 .5 | G 5.75 $H_2O$ | 33 32.75 | Comm |
| 6 .25 | Virginia dale Road | 34 .5 | Post Lane |
| 7 | | 35 .75 | |
| 8 .5 | | 36 | G 36.5 $H_2O$ |
| 9 | | 37 .5 | $H_2O$ |
| 10 | | 38 | |
| 11 .25 | Comm | 39 | |
| 12 | | 40 | |
| 13 | | 41 | |
| ~~14~~ .5 | IW08 2.5m E | 42 | |
| ~~15~~ .5 | MW45DW3 2.0m E | 43 | |
| 16 .5 | E | 44 | |
| 17 | | 45 | |
| 18 | | 46 | |
| ~~19~~ | IW07 8m E | 47 | |
| 20 | | 48 | |
| 21 | | 49 | |
| 22 .5 | Sewer | 50 | |
| 23 | | 51 | |
| 24 | Park Lot .5m E | 52 | |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | |
| 28 | | 56 | |

**Aestus GeoTrax Survey™ Data Acquisition Field Notes**

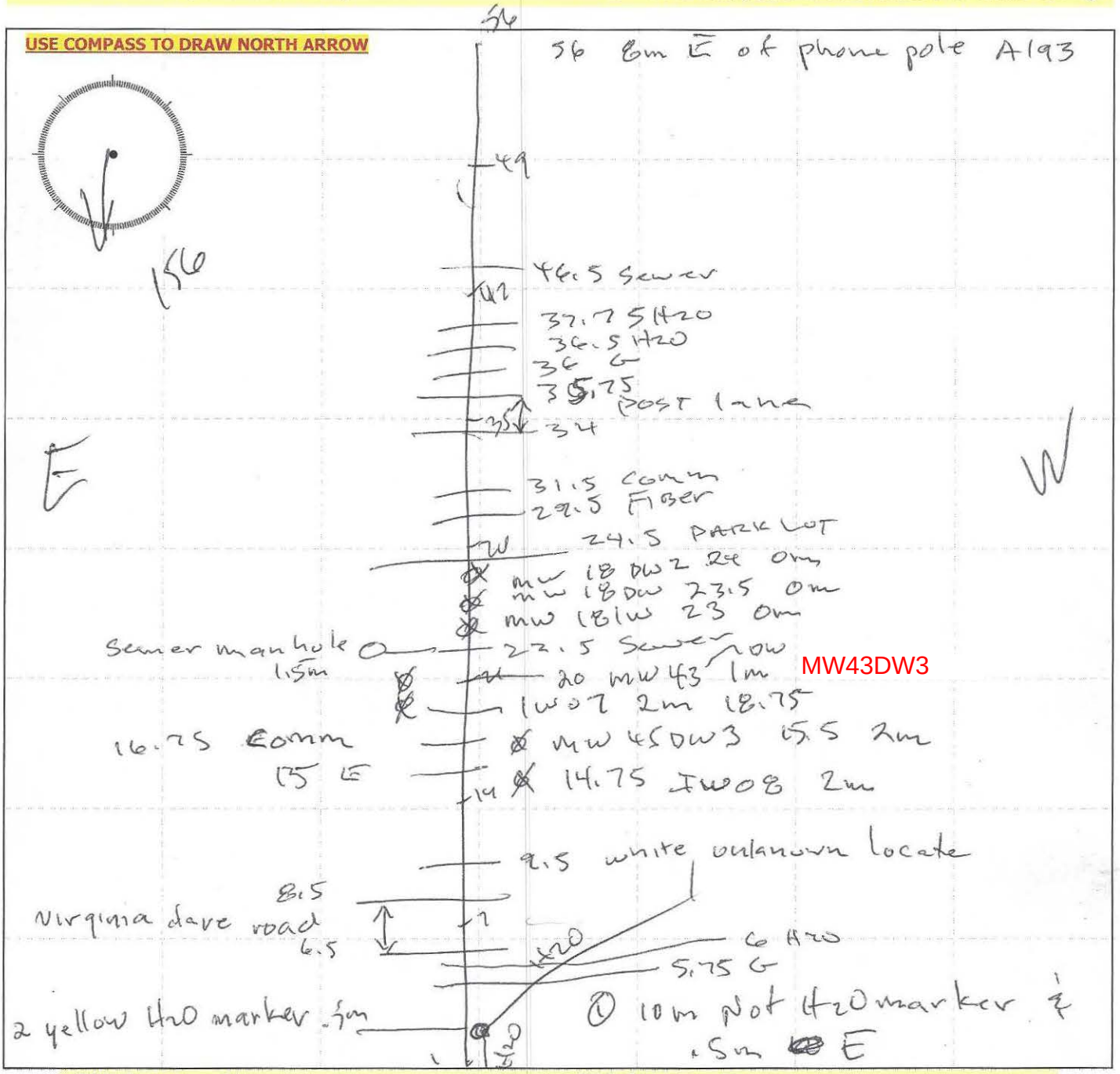
**File Name** | S | 8 | 8 | D | 2 | VK |

Project Name Site 88, Camp Lejeune, NC

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling

**USE COMPASS TO DRAW NORTH ARROW**




| GPS Coords. | N: | GPS Coords | N: |
|---|---|---|---|
| Electrode #1 | W: | Electrode #56 | W: |
| | Accuracy: | | Accuracy: |

**Aestus GeoTrax Survey™ Data Acquisition Field Notes**

**File Name** S 8 8 0 2 VQ

Project Name Site 88, Camp Lejeune, NC

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)** **"Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | 10m N of H2O marker & .5m E | 29 .5 | F.O. |
| 2 | yellow H2O marker .5m W | 30 | |
| 3 | | 31 .5 | Comm |
| 4 | | 32 | |
| 5 .75 | G | 33 | |
| 6 | H2O 6.5 W virginia dale Road | 34 | Post lane |
| 7 | ↓ | 35 .75 | ↓ |
| 8 | ↓ 8.5 | 36 | G 36.5 H2O |
| 9 .5 | unknown locate | 37 .75 | H2O |
| 10 | | 38 | |
| 11 | | 39 | |
| 12 | | 40 | |
| 13 | | 41 | |
| 14 .75 | FW08 2m W | 42 | |
| ~~15~~ | E 15.5 MW45DW3 2m W | 43 | |
| 16 .75 | Comm | 44 | |
| 17 | | 45 | |
| ~~18~~ .75 | FW07 2m E | 46 .5 | Sewer |
| 19 | | 47 | |
| ~~20~~ | MW43 1m E | 48 | |
| 21 | | 49 | |
| 22 .5 | Sewer w/ manhole 1.5m E | 50 | |
| ~~23~~ | MW 18W 0m 23.5 18W 0m | 51 | |
| ~~24~~ | 18DW2 0m PARKLOT | 52 | |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | |
| 28 | | 56 | 8m E of Photopole A193 |

MW43DW3

**Aestus GeoTrax Survey™ Data Acquisition Field Notes**

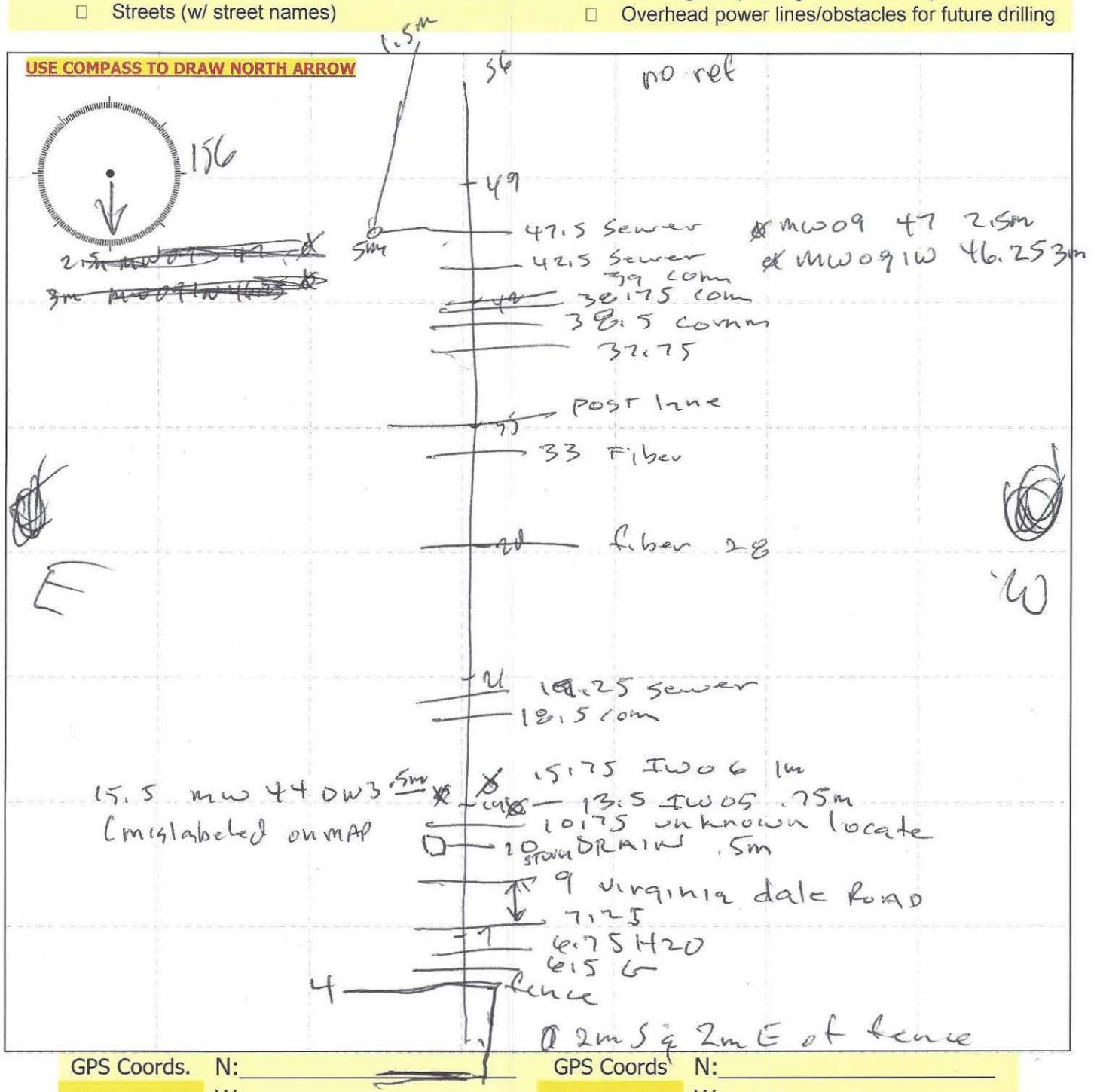
**File Name** S 8 8 0 3 VQ

Project Name Site 88, Camp Lejeune, NC

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling

**USE COMPASS TO DRAW NORTH ARROW**




| GPS Coords. | N: | GPS Coords | N: |
|---|---|---|---|
| Electrode #1 | W: | Electrode #56 | W: |
| | Accuracy: | | Accuracy: |

**Aestus GeoTrax Survey™ Data Acquisition Field Notes**

mw 44 is labeled as mw 46 on map

**File Name** S 8 8 0 3 v4

Project Name Site 88, Camp Lejeune, NC

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)** **"Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | 2m S & 2m E of fence | 29 | |
| 2 | | 30 | |
| 3 | | 31 | |
| 4 | fence 0m | 32 | |
| 5 | | 33 | FO |
| 6.5 | 6.75 H2O | 34 | |
| 7.25 | Virginia dale Road | 35 | Post lane |
| 8 | | 36 | |
| 9 | | 37.75 | 3 |
| 10 | Storm drain .5m E 10.75 unknown locate | 38.5 | Comm 38.75 comm 39 comm |
| 11 | | 39 | |
| 12 | | 40 | |
| 13.5 | FW05 .75m W | 41 | |
| 14 | | 42.5 | Sewer |
| ~~15.5~~ | ~~mw 44 DW3 .5m W~~ | 43 | |
| 15.5 | ~~mw 44~~ .5m E, 15.75 FW06 1m W | 44 | |
| 17 | MW44DW3 | 45 | |
| 18.5 | Comm | 46.25 | mw 09 1m W |
| 19.25 | Sewer | 47.5 | Sewer 47 mw09 3.5m W |
| 20 | | 48 | |
| 21 | | 49 | |
| 22 | | 50 | |
| 23 | | 51 | |
| 24 | | 52 | |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | |
| 28 | fiber optic (FO) | 56 | |

# Appendix B

# Daily Instrument QC Logs

Aestus
Aestus, LLC

# QC Test Log for Aestus GeoTrax Survey™ Instrumentation

**Day of Week (circle one):** *Mon Tue Wed Thu Fri Sat Sun* **Date:** 10 / 21 / 2014 **Tested By** *(initials)*: RP

| Instrument Name | Quality Control Test Name | Result Specifics | Pass/Fail (circle one) | Failure Specifics/ Other Comments | Corrective Measures Taken If QC Test Failed |
|---|---|---|---|---|---|
| | | | | | |
| Supersting R8 (Aestus Owned) | Receiver Test (target = 0.5Ω) | Ω range = 1.45 - 5.04 | (Pass) Fail | | |
| Supersting R8 (backup instrument) | Receiver Test (target = 0.5Ω) | Ω range = 4.96 - 5.00 | (Pass) Fail | | |
| | | | | | |
| Switchbox (56 Electrode; Aestus owned) | Relay Test | | (Pass) Fail | | |
| Switchbox (56 Electrode; backup Instrument) | Relay Test | | Pass Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Cable Test | | (Pass) Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Contact Resistance Test[1] | | | | |
| 1st survey line run today | Contact Resistance Test[1] | Low Ω= 1.1 and High Ω= 3.4 | Pass Fail | | |
| 2nd survey line run today | Contact Resistance Test[1] | Low Ω= 1.5 and High Ω= 3.4 | Pass Fail | | |
| 3rd survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 4th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 5th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| | | | | | |
| | | | | | |
| If having problems with any of the above tests, then test the following: | | | | | |
| Check output voltage of SuperSting R8 Power Supply or 12V DC battery | Power supply voltage | | Pass Fail | | |
| Check patch cords from Supersting R8 to Switchbox(es) | Patch cord integrity | | Pass Fail | | |
| Check gender bender cable (typically at 29-56 end of switchbox) | Gender bender integrity | | Pass Fail | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

recorded readings in thousands of Ohms
recorded readings in thousands of Ohms

Aestus, LLC

# QC Test Log for Aestus GeoTrax Survey™ Instrumentation

**Day of Weekcircle one):** *Mon Tue Wed Thu Fri Sat Sun* **Date:** 10 / 22 / 14 **Tested By** *(initials)*: [illegible]

| Instrument Name | Quality Control Test Name | Result Specifics | Pass/Fail (circle one) | Failure Specifics/ Other Comments | Corrective Measures Taken If QC Test Failed |
|---|---|---|---|---|---|
| | | | | | |
| Supersting R8 (Aestus Owned) | Receiver Test (target = 0.5Ω) | Ω range = | Pass Fail | | |
| Supersting R8 (backup instrument) | Receiver Test (target = 0.5Ω) | Ω range = 476-501 | Pass Fail | | |
| | | | | | |
| Switchbox (56 Electrode; Aestus owned) | Relay Test | | Pass Fail | | |
| Switchbox (56 Electrode; backup Instrument) | Relay Test | | Pass Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Cable Test | | Pass Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Contact Resistance Test[1] | | | | |
| 1st survey line run today | Contact Resistance Test[1] | Low Ω= 1.0 and High Ω= 2.1 | Pass Fail | | |
| 2nd survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 3rd survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 4th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 5th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| | | | | | |
| | | | | | |
| If having problems with any of the above tests, then test the following: | | | | | |
| Check output voltage of SuperSting R8 Power Supply or 12V DC battery | Power supply voltage | | Pass Fail | | |
| Check patch cords from Supersting R8 to Switchbox(es) | Patch cord integrity | | Pass Fail | | |
| Check gender bender cable (typically at 29-56 end of switchbox) | Gender bender integrity | | Pass Fail | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

recorded readings in thousands of Ohms



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Aestus, LLC

# QC Test Log for Aestus GeoTrax Survey™ Instrumentation

**Day of Week (circle one):** *Mon Tue Wed (Thu) Fri Sat Sun* **Date:** 10 / 23 / 14 **Tested By** *(initials)* [illegible]

| Instrument Name | Quality Control Test Name | Result Specifics | Pass/Fail (circle one) | Failure Specifics/ Other Comments | Corrective Measures Taken If QC Test Failed |
|---|---|---|---|---|---|
| | | | | | |
| Supersting R8 (Aestus Owned) | Receiver Test (target = 0.5Ω) | Ω range = | Pass Fail | | |
| Supersting R8 (backup instrument) | Receiver Test (target = 0.5Ω) | Ω range = 4.7 - 5.1 | (Pass) Fail | | |
| | | | | | |
| Switchbox (56 Electrode; Aestus owned) | Relay Test | | Pass Fail | | |
| Switchbox (56 Electrode; backup Instrument) | Relay Test | | (Pass) Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Cable Test | | (Pass) Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Contact Resistance Test[1] | | | | |
| 1st survey line run today | Contact Resistance Test[1] | Low Ω= 1.10 and High Ω= 2.40 | Pass Fail | | |
| 2nd survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 3rd survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 4th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 5th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| | | | | | |
| | | | | | |
| If having problems with any of the above tests, then test the following: | | | | | |
| Check output voltage of SuperSting R8 Power Supply or 12V DC battery | Power supply voltage | | Pass Fail | | |
| Check patch cords from Supersting R8 to Switchbox(es) | Patch cord integrity | | Pass Fail | | |
| Check gender bender cable (typically at 29-56 end of switchbox) | Gender bender integrity | | Pass Fail | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

recorded readings in thousands of Ohms



Aestus
Aestus, LLC

# QC Test Log for Aestus GeoTrax Survey™ Instrumentation

**Day of Weeк (circle one):** *Mon Tue Wed Thu (Fri) Sat Sun* **Date:** 10 / 24 / 14 **Tested By** *(initials)*: [illegible]

| Instrument Name | Quality Control Test Name | Result Specifics | Pass/Fail (circle one) | Failure Specifics/ Other Comments | Corrective Measures Taken If QC Test Failed |
|---|---|---|---|---|---|
| | | | | | |
| Supersting R8 (Aestus Owned) | Receiver Test (target = 0.5Ω) | Ω range = | Pass Fail | | |
| Supersting R8 (backup instrument) | Receiver Test (target = 0.5Ω) | Ω range = 474 - .481 | (Pass) Fail | | |
| | | | | | |
| Switchbox (56 Electrode; Aestus owned) | Relay Test | | Pass Fail | | |
| Switchbox (56 Electrode; backup Instrument) | Relay Test | | (Pass) Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Cable Test | | (Pass) Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Contact Resistance Test[1] | | | | |
| 1st survey line run today | Contact Resistance Test[1] | Low Ω= 9.0 and High Ω= 4.9 | (Pass) Fail | SSO3T | |
| 2nd survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 3rd survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 4th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 5th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| | | | | | |
| | | | | | |
| If having problems with any of the above tests, then test the following: | | | | | |
| Check output voltage of SuperSting R8 Power Supply or 12V DC battery | Power supply voltage | | Pass Fail | | |
| Check patch cords from Supersting R8 to Switchbox(es) | Patch cord integrity | | Pass Fail | | |
| Check gender bender cable (typically at 29-56 end of switchbox) | Gender bender integrity | | Pass Fail | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

recorded readings in thousands of Ohms



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Aestus, LLC

# QC Test Log for Aestus GeoTrax Survey™ Instrumentation

**Day of Week (circle one):** *Mon Tue Wed Thu Fri Sat Sun* **Date:** 10/25/14 **Tested By** *(initials)*: GN

| Instrument Name | Quality Control Test Name | Result Specifics | Pass/Fail (circle one) | Failure Specifics/ Other Comments | Corrective Measures Taken If QC Test Failed |
|---|---|---|---|---|---|
| | | | | | |
| Supersting R8 (Aestus Owned) | Receiver Test (target = 0.5Ω) | Ω range = | Pass Fail | | |
| Supersting R8 (backup instrument) | Receiver Test (target = 0.5Ω) | Ω range = 1.7 - 5.1 | Pass Fail | | |
| | | | | | |
| Switchbox (56 Electrode; Aestus owned) | Relay Test | | Pass Fail | | |
| Switchbox (56 Electrode; backup Instrument) | Relay Test | | Pass Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Cable Test | | Pass Fail | | |
| | | | | | |
| Resistivity electrode cables (surface layout for GeoTrax Survey™) | Contact Resistance Test[1] | | | | |
| 1st survey line run today | Contact Resistance Test[1] | Low Ω= 2.17 and High Ω= 4.4 | Pass Fail | | |
| 2nd survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 3rd survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 4th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| 5th survey line run today | Contact Resistance Test[1] | Low Ω=____ and High Ω=____ | Pass Fail | | |
| | | | | | |
| | | | | | |
| If having problems with any of the above tests, then test the following: | | | | | |
| Check output voltage of SuperSting R8 Power Supply or 12V DC battery | Power supply voltage | | Pass Fail | | |
| Check patch cords from Supersting R8 to Switchbox(es) | Patch cord integrity | | Pass Fail | | |
| Check gender bender cable (typically at 29-56 end of switchbox) | Gender bender integrity | | Pass Fail | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

recorded readings in thousands of Ohms



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# Electronic Appendices

*(Sent via email with report transmittal)*

| | |
|---|---|
| Electronic Appendix E-1 | Site Photographs |
| Electronic Appendix E-2 | XYZR GeoTrax Survey™ Data Output Files |
| Electronic Appendix E-3 | 3-D Visualization Model and Free Viewer Software |
| Electronic Appendix E-4 | Raw Data Files for Client QC (collected w/ standard ERI method) |

Aestus
Aestus, LLC

# Appendix C
# HDD Injection Well Screen Design Package

# Design Report for Horizontal Injection Well, Permanganate Tracer Study Site 88 Marine Corps Installations East, Camp LeJeune, NC, REV01

*Prepared For*

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# 1.0 Introduction

The installation and operation of a horizontal injection wells is planned for the permanganate injection at Site 88, Marine Corps Installations East – Marine Corps Base Camp LeJeune, North Carolina (Site). Losonsky & Associates Inc. was retained by CH2M HILL to provide a Design Report for this project. The purpose of the Design Report is to provide the screen design for the horizontal well planned for the project, supported by technical and engineering information. Information used in the preparation of this Design Report was provided to Losonsky & Associates by CH2M HILL.

This revision, REV01, was issued to adjust the design for changes in well completion material, at the request of CH2MHILL.

## *1.1 Horizontal Injection Wells*

A permanganate solution will be injected at a rate of 50 gpm into horizontal wells HIW-1. The screen section will be 500 ft long, so that the well will inject at a unit flow rate of 0.1 gpm/ft. The horizontal screen will be placed 100 ft below ground surface (bgs). The target zone is the middle Castle Hayne aquifer, primarily a fine silty sand with some dense partially cemented zones.

## *1.2 Scope of Work and Assumptions*

The objective of the proposed horizontal injection system is to inject a permanganate solution below the water table at the Site in order for the purpose of in situ chemical oxidation. CH2M HILL provided the following information used by Losonsky & Associates to design the system:

- Maps and schematic cross sections showing the locations of the proposed horizontal injection wells and subsurface hydrostratigraphy,
- Water level information, and
- Operational parameters of the permanganate injection system.

The primary engineering goal of the design effort is to achieve nearly uniform injection along the screened section of the horizontal well, with less than 1 percent skew, given site-specific hydrogeologic characteristics, and the intended conditions of operation of the injection system. Generally uniform flow distribution along the screen is necessary in order to affect the entire target treatment zone. The design is based on experience and output of fluid dynamics simulation models, which determine the appropriate slotting configuration needed to produce acceptably uniform flow along the screened sections of the proposed horizontal injection well.

Losonsky & Associates has not visited the Site, and has not performed any field investigations. In preparing this design, Losonsky & Associates relied upon data and information provided by CH2M HILL.

# 2.0 Well Placement Design

The horizontal injection well will be directionally drilled using a jetting tool to drill a pilot hole, which may be enlarged and completed with one or more reaming operations by the directional drilling rig. The horizontal wells will be entry-exit wells, with an *entry riser section* between the entry point, or wellhead, and the beginning of the *screen section*, and an *exit riser section* terminating at an exit point at the surface.

The horizontal distance, or displacement, between the proximal end of the well screen and the wellhead is the *step-back distance*, or *horizontal displacement*, and the linear length of the well measured from the entry point to the end of the well is the *measured depth* (MD) of the well. *True vertical depth* (TVD) is measured at any point along the well path vertically to the underlying portion of the well. The *header length* includes both the riser and any surface conveyance piping from the wellhead to the equipment enclosure containing the injection equipment.

## *2.1 Well Paths and Well Depths*

The well path of the horizontal injection well is designed to inject permanganate solution into the targeted water-bearing sand unit. The horizontal well is designed to intersect a target plume areas beneath Site 88, taking full advantage of the zone of influence of the horizontal injection well, based on the results of subsurface testing conducted by others. The placement of the horizontal well reflects COC distribution and subsurface hydrostratigraphy, as determined by CH2M HILL.

## *2.2 Well Geometry*

The horizontal well will have the following lengths:

- HIW-1: approximately 1575 ft total length, consisting of:
  - 625 ft entry riser,
  - 500 ft of screen
  - approximately 450 ft exit riser

The riser length is rounded to the nearest ft. The depth of the screen section of the horizontal well will be 100 ft bgs throughout the screen section, from the proximal end to the distal end.

Conveyance piping is assumed to be either of inconsequential length, or have sufficiently large diameter to preclude significant effect on frictional head losses. This design report is based on pressure at the injection wellhead.

# 3.0 Well Completion Design

Key elements of well completion include the well diameter, well materials, and screen slotting configuration. Filter pack is not recommended for horizontal wells in general, and is not recommended for the planned horizontal injection wells at the Site.

## *3.1 Well Diameter and Well Materials*

Modeling and operation of horizontal remediation wells over the past twenty-five years indicates that for typical operating flow rates and total pipe lengths in the range of 100 to 1000 ft, a well diameter of 3 or 4 inches generally avoids significant frictional head loss or pressure drop. The well will be installed as an entry-exit well using installation methods that are viable for up to 4-inch diameter pipe. Based on head loss calculations and pipe availability, 4-inch diameter, fiberglass reinforced epoxy (FRE) pipe was selected for the horizontal injection well. The 4-inch FRE pipe has a nominal outside diameter (OD) of 4.5 inches, and an average inside diameter (ID) of 3.9 inches. This design accounts for head losses in the 4-inch FRE riser pipe and screen section of the well.

## *3.2 Well Screen*

The design of the injection well specifies the open area of the well screen that will allow uniform injection of permanganate into the formation. The mechanical analysis consists of three basic elements: pipe flow, orifice (slot) flow, and formation flow. The analysis consists of iterative calculations along the well screen, generating key mechanical parameters:

- Pressure or head along the screen,
- Flow through the screened pipe, and
- Injection of permanganate fluid into the formation.

The analysis uses an iterative computational process to determine the degree of uniformity of flow along the well screen, calculated with an acceptable margin of error and without violating laws of fluid mechanics. The design goal is to provide uniform injection of permanganate into the formation, within acceptable tolerance ranges. The injection well analysis simulates permanganate solution moving through the riser, along the screen, through slots and into the formation. The results are used to determine the necessary open area along the well screen, and to indicate how the open area needs to vary along the screen in order to achieve an acceptable degree of uniformity of flow.

### 3.2.1 Input Parameters

The analysis depends on the following pipe specifications and hydrogeologic parameters:

- Injection rate
- Mass flow rate of the injection stream
- Inner diameter of the well pipe
- Outer diameter of the well pipe

- Pipe roughness factor
- Hydraulic conductivity of the formation
- Thickness of the target zone
- Length of the header pipe
- Elevation of the inlet of the header pipe
- Elevation of the outlet of the header pipe
- Changes in elevation of the screened section, if any (none for the modeled well)
- Viscosity of the injected fluid
- Temperature of the extracted or injected fluid
- Orifice coefficient for the screen slots
- Time to reach equilibrium flow in the subsurface soil formations

The analysis can be used to help specify optimal operating conditions for a horizontal well. Field tests can be used to identify hydrogeologic input parameters, and to define appropriate operational ranges for injection pressures and flow rates that will effectively deliver permanganate solution to the target saturated zone.

### 3.2.2 Pipe Flow

The calculation of frictional head losses in the pipe is applied to both the header pipe and to each element of the screened section. Bernoulli's equation solves for total head in terms of fluid pressure and velocity:

$$h = z(x) + \frac{p(x)}{\rho g} + \frac{V(x)^2}{2g} \qquad (3\text{-}1)$$

In Equation 3-1, $h$ is the total head along a streamline, $p$ is the pressure, $V$ is the average fluid velocity, $\rho$ is the fluid density, $z$ is the pipe elevation, and $g$ is gravitational acceleration. According to Bernoulli's equation, energy is conserved and the total head remains constant, so that gravity head or pressure head can be converted into velocity.

Viscous fluids convert mechanical energy, or head, into heat along the pipe wall. To account for this loss of head, the viscous head is added to the Bernoulli equation:

$$h = z + \frac{p}{\rho g} + \frac{V^2}{2g} + \int_{x_0}^{x} \frac{f}{D} \frac{V(\tilde{x})^2}{2g} d\tilde{x} \qquad (3\text{-}2)$$

In the right-hand term in Equation 3-2, $D$ is the pipe diameter, $x$ is the coordinate in the direction of flow, and $f$ is a proportionality term called the *friction factor*. Viscous head, the right-hand term in Equation 3-2, absorbs energy yielded by pressure head, velocity, and gravity. The total head still remains constant.

The pressure at a point along the pipe is derived by integrating the viscous head equation:

$$p_B = p_A - \rho g\left(\Delta z + f\frac{L}{D}\frac{V^2}{2g}\right) \qquad (3\text{-}3)$$

In Equation (3-3), $p_A$ and $p_B$ represent pressure at two points along the pipe, and $\Delta z$ is the change in pipe elevation.

The friction factor, $f$, is a function of the Reynolds Number and pipe roughness. The Reynolds Number, $R$, characterizes the pipe flow in terms of turbulent or laminar flow, where $R$ less than 2000 represents laminar flow in pipes and R greater than 2000 represents turbulent flow. The Reynolds number is defined as:

$$R = \frac{\rho V D}{\mu} \qquad (3\text{-}4)$$

where $\mu$ is the dynamic viscosity of the fluid.

The roughness of the pipe, $e$, is the average size of any ribs, bumps, or protrusions on the inside wall of the pipe. The ratio $e/D$ is called the relative roughness. For laminar flow, the friction factor equals $64/R$. For turbulent flow, the friction factor is determined empirically. The Moody Chart for pipe flow plots a series of solutions to the following empirical equation:

$$\frac{1}{\sqrt{f}} = -2\cdot\log\left(\frac{e/D}{3.7} + \frac{2.51}{R\sqrt{f}}\right) \qquad (3\text{-}5)$$

The Moody Chart is used for curve-fitting to determine the friction factor for a specific fluid flowing through a given pipe under known flow conditions.

### 3.2.3 Orifice Flow

The slots of a well screen constitute orifices through which the fluid can flow into the screened pipe. The intended effect of permanganate injection is for the liquid to exit the screen through the slots at a uniform rate along the length of the screen. An orifice is a

more constricted channel for flow than the pipe containing the orifice. The pressure of the fluid drops as it flows through the orifice and out of the pipe.

Orifice flow equations are derived from Bernoulli's equation, which are valid if the fluid speed is sufficiently slower than the speed of sound (less than mach 0.3). Based on Bernoulli's equation, the flow across a circular orifice is:

$$\Delta p = p_1 - p_2 = \frac{1}{2}\rho V_2^{\,2} - \frac{1}{2}\rho V_1^{\,2} \qquad (3\text{-}6)$$

where $p_1$ and $p_2$ represent fluid pressure immediately upstream and downstream of the orifice. Substituting cross sectional areas for the velocities, $V$, in Equation 3-6 with the volumetric flow rate, $Q$, yields the orifice flow equation:

$$Q = C_d \sqrt{\frac{2\Delta p}{\rho}} \frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \qquad (3\text{-}7)$$

In Equation 3-7, $C_d$ is the *discharge coefficient* that accounts for the flow-reducing effects of viscosity and turbulence, which convert kinetic flow energy into heat. The cross sectional area, $A_2$, downstream of the orifice is too complex to be described directly. Instead, the *flow coefficient*, $C_f$, is defined in order to simplify the orifice flow equation:

$$Q = C_f A_o \sqrt{\frac{2\Delta p}{\rho}} \qquad (3\text{-}8)$$

In Equation 3-8, $A_o$ is the cross-sectional area of the orifice.

The flow coefficient, $C_f$, is determined empirically using curve-fitting. Its values range from 0.6 to 0.9 for most orifices. The flow coefficient varies as a function of the orifice size, the pipe diameter, and the Reynolds Number.

For noncircular orifices, the *hydraulic diameter* is used in the flow equations. For a rectangular orifice with sides of length *a* and *b*, the hydraulic diameter equals four times the hydraulic radius. The hydraulic radius equals the area of the slot divided by the twice

the sum of the side lengths of the orifice. For example, for slots with a 100:1 ratio of length to width, the correction factor applied to the slot area is 32.5.

### 3.2.4 Porous Media Flow

Flow of fluid to or from the porous formation through the horizontal well is governed by equations related to Darcy's Law and the Laplace Equations for mass balance. A wide range of solutions for those equations have been developed in the hydrogeologic literature to describe flow to and from wells, including solutions specific to horizontal wells, presented by Joshi (1991), Losonsky and Beljin (1992), Beljin and Losonsky (1992), and Losonsky & Beljin (1994). The analysis was performed using such solutions.

# 4.0 Injection Well Analysis Results

This section presents the results of the mechanical analysis of permanganate injection in the subsurface, based on known site hydrogeologic conditions. Results are presented for the horizontal well proposed for the Site, with screen and riser lengths as specified in Section 2.2, and pipe diameter as specified in Section 3.1.

## *4.1 Well HIW-1*

Well HIW-1 will be used to inject permanganate at a rate of 50 gpm into the water bearing sand unit at a depth of 100 ft bgs. The proximal end of the well screen will be separated from the wellhead by 625 ft of riser pipe. The well will be completed with 4-inch FRE pipe, and it will have a 500-ft long screen section. The screen will be slotted with the calculated uniform open area that will produce evenly distributed flow along the entire screen, within less than 1 percent of the target unit flow rate.

### 4.1.1 Injection Rate for Well HIW-1

**Figure 1** shows the permanganate injection rate per foot of screen in cubic ft per minute (cfm) per foot of well screen for well HIW-1 operating at 39 psi. The unit injection rate along the horizontal screen will be approximately 0.013 cfm per foot (0.1 gpm) throughout the horizontal screen, for a total flow rate of 50 gpm. The injection rate will change by less than 1 percent along the horizontal well screen.

The unit injection rate measured in pounds (lbs) per hour per foot of screen in well HIW-1 is shown in **Figure 2** for the well operating at 36 psi at the wellhead. The well injects approximately 50 lbs permanganate solution per hour per foot of screen. **Figure 3** shows the cumulative injection rate as a percentage of total injection in well HIW-1.

### 4.1.2 Screen Open Area in Well HIW-1

The numerical flow simulation indicates that flow will distribute evenly if the open area in well HIW-1 is constant along the entire screen, but properly matched to the flow rate and pipe diameter. The optimal open area is 0.175 percent, achieved with a constant slot configuration that includes 1.6-inch long slots with an aperture of 0.016 inch.

# 5.0 Slot Configuration

The open area specified by the design can be achieved with any slot configuration that distributes slots around the circumference of the well, and maintains consistent slot length, slot width, and slot distribution as prescribed by the design. Well HIW-1 has uniform open area along its entire screen section. **Table 1** provides guidance for the configuration of slots that will provide the specified open area for the horizontal well using the specified slot dimensions. **Table 1** presents suggested slot configurations for transverse slots, cut perpendicular to the axis of the pipe, as is customary with traditional slotted well screens and required for this project. Transverse slots are typically used in blind well installations.

## *5.1 Slot Aperture*

Slot aperture of 0.016 inch is acceptable for the injection well screened in a poorly graded (well sorted) sand unit. The wells may be used for various injections in the future, and could be used for extraction as well if needed, given the slot aperture of 0.016 inch. Consistent 0.016 inch slots can be cut into 4-inch FRE pipe.

## *5.2 Slot Length*

Slot length of 1.6 inch on the ID of the pipe is specified because it allows good distribution of slots over the surface of the pipe. Arranging the slots in 3 rows leaves approximately 3.4 inches of pipe surface between slots within each row, assuming a 6-inch collar remains unslotted at both ends of each 20-ft section of FRE pipe (**Table 1**). The end-to-end distance between slots in adjacent rows covers approximately 2.5 inches of pipe surface on the ID of the pipe. Using 3 rows of slots provides good distribution of slots around the circumference of the pipe and does not cause excessive loss of pipe strength. Maximum strength can be preserved if slots in adjacent rows are staggered. Consistent 1.6 inch long slots can be cut into 4-inch FRE without unusual difficulty.

# 6.0 Summary and Recommendations

Mechanical analysis of flow through the planned horizontal permanganate injection well HIW-1 indicates that a constant open area, created along its screen section using 0.016-inch wide slots that are 1.6 inch long on the ID of the pipe, will produce even flow distribution under the intended flow rates and pressures.

Horizontal injection well HIW-1 will be completed with 4-inch FRE pipe. Slots in the FRE screen will be transverse, cut perpendicular to the axis of the pipe. The required open area will be achieved with three rows of slots. Slots length will be 1.6 inch and slot aperture will be 0.016 inch. The slots will be separated evenly along the length of the pipe, and slots in adjacent rows will be staggered, if possible, in order to minimize the loss of pipe strength due to slotting. The number of slots per row in each 20-foot stick of the FRE pipe will be as follows:

- HIW-1 (4-inch diameter FRE):
    - 0-500 feet: 129 slots distributed in 3 rows of 67 slots that are 1.6 inch long and 0.016 inch wide

The separation between slots in each row of slots will be approximately 3.4 inch. Separation between slots may change depending on the width of solid, unslotted collar at the ends of the 20-foot FRE pipe sections. Spacing between rows will leave approximately 2.5 inches of uncut FRE on the pipe ID. Any adjustments to the slot configuration must preserve the slot dimensions and the total open area per 20-foot section of pipe, so that the percent open area reflects the design.

Slots in adjacent rows should be staggered if possible to improve the distribution of slots, and to reduce the loss of cross-sectional area of pipe. This will maximize pipe strength and contribute to successful horizontal well installation and operation.

The conceptual design presented in this report is intended to provide specific guidelines for the installation of the horizontal injection well. Subsurface conditions, site logistics, space and equipment requirements of the drilling contractor; and manufacturing constraints of pipe and screen suppliers may influence the final as-built condition of the horizontal well.

# 7.0 References

Joshi, S.D., 1991, Horizontal Well Technology, Pennwell Publishing Co., Tulsa, Oklahoma, 535 pp.

Losonsky, G., and Beljin, M.S., 1992, *Horizontal wells in subsurface remediation, in Proceedings of HMC-South Conference*, Hazardous Materials Controls Research Institute, February 1992, New Orleans, pp. 75-80.

Beljin, M.S., and Losonsky, G., 1992, HWELL: *A horizontal well model, in Proceedings of Conference on Solving Ground Water Problems with Models*, International Ground Water Modeling Center and the Association of Ground Water Scientist and Engineers, February 1992, Dallas, pp. 45-54.

Losonsky, G., and Beljin, M.S., 1994, Horizontal wells for subsurface pollution control, in Handbook of Process Engineering for Pollution Control and Waste Management, Wise, D.L., and Trantolo, D.J., eds., Chapter 30, Marcel-Decker, Inc., New York, pp. 619-633.

# TABLES

# TABLE 1 Rev01

## Horizontal Injection Well, Camp LeJeune Site 88, NC

### Target Slot Configurations for 4 Inch FRE Screen Pipe*

### 0.016 Inch Slot Aperture, 1.6 Inch Slot Length

| Zone | Section of Screen | Slot Length | Slot Width | Length of Stick | Slots per Stick | Rows of Slots per Stick | Slots per Row per Stick | Open Area per Stick | Screen ID | Screen OD | ID Area per Stick | Open Area | Width of Collar at Each End of Stick | ID Row Spacing (Around Pipe) of Trans-verse Slots | Spacing (Along Pipe) of Trans-verse Slots |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FEET | INCH | INCH | FEET | | | | SQR INCH | INCH | INCH | SQR INCH | % | INCH | INCH | INCH |
| **Injection Well HIW-1, 500 Feet of Screen, 20-Foot Sections of 4-Inch FRE Pipe** | | | | | | | | | | | | | | | |
| **1** | 0-500 | 1.6 | 0.016 | 20.0 | 201 | 3 | 67 | 5.1456 | 3.900 | 4.50 | 2940.53 | 0.175 | 6.00 | 2.484 | 3.438 |

***Slot configuration can be adjusted to accommodate manufacturing requirements; slot dimensions and open area per stick must be preserved**

# FIGURES

**FIGURE 1. Injection rate (cfm/foot of screen) in Well HIW-1, Camp LeJeune Site 88**
**4 in FRE: 500 ft screen, 625 ft riser. Operation: 39 psi, 50 gpm**

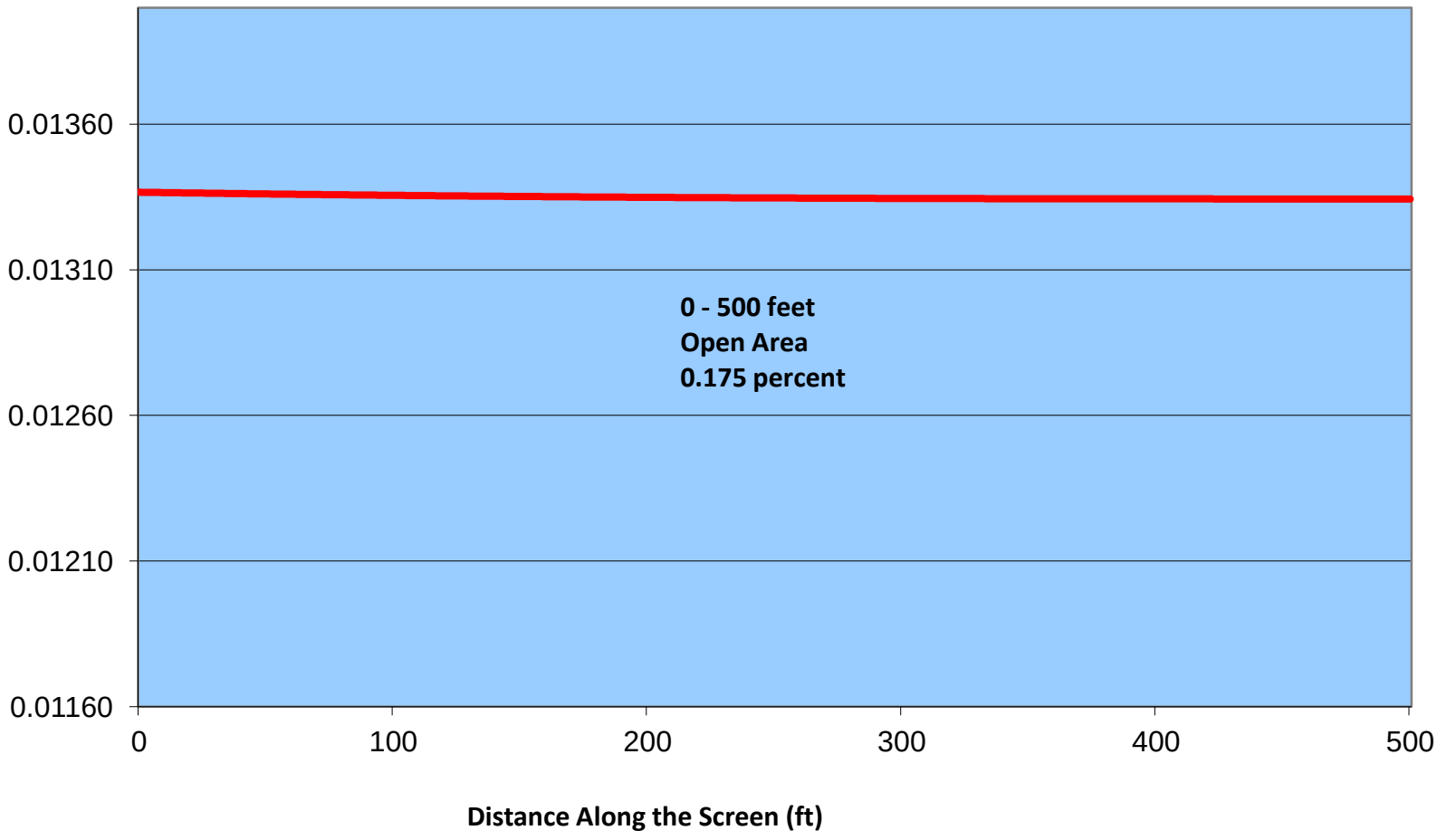


**FIGURE 2. Injection rate (lb/hr/foot of screen) in Well HIW-1, Camp LeJeune Site 88**
**4 in FRE: 500 ft screen, 625 ft riser. Operation: 39 psi, 50 gpm**

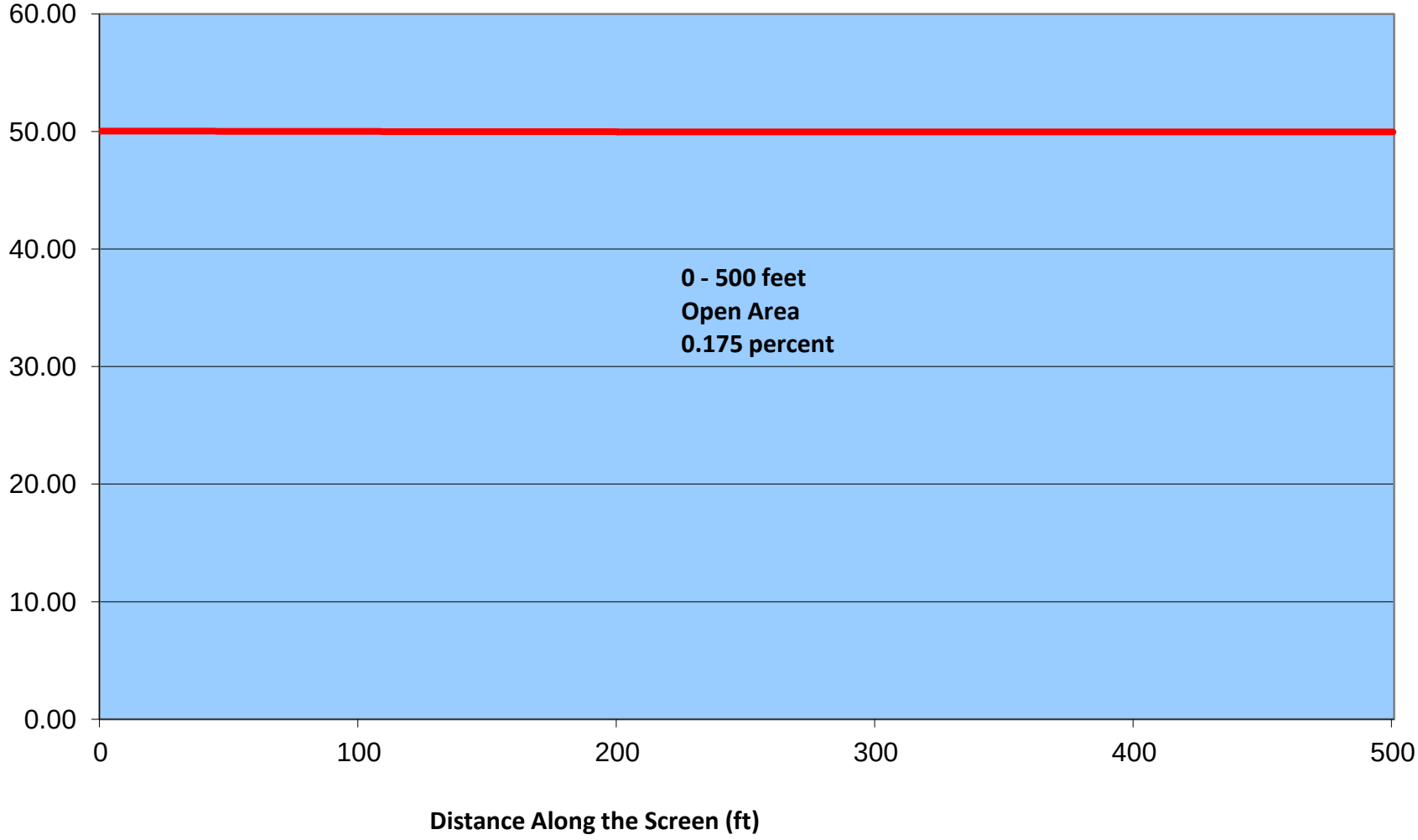
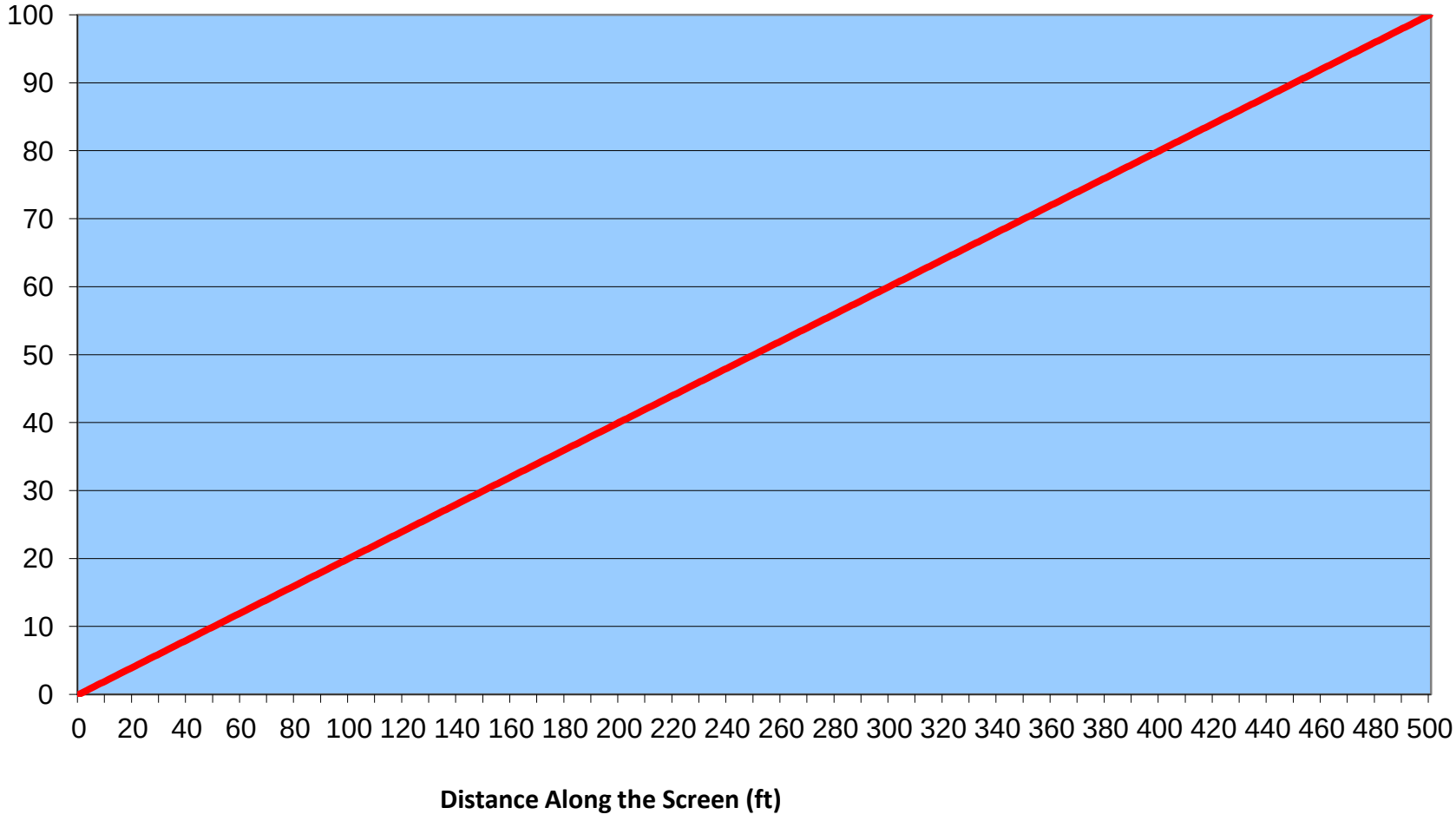


**FIGURE 3. Cumulative injection rate (percent of total) in Well HIW-1, Camp LeJeune Site 88**
**4 in FRE: 500 ft screen, 625 ft riser. Operation: 39 psi, 50 gpm**



# Appendix D
# NCDENR Non-Discharge Groundwater Remediation Permit Application Form

State of North Carolina

Department of Environment and Natural Resources - Division of Water Resources

# *Non-Discharge Groundwater Remediation Permit Application Form*

THIS APPLICATION PACKAGE WILL NOT BE ACCEPTED UNLESS ALL APPLICABLE ITEMS ARE INCLUDED

## ***APPLICATION INFORMATION***

| | |
|---|---|
| Application Date: | May 2015 |
| Application Type: | New Project |
| * New Projects – DWQ to assign application # | |
| ** Renewals/Modifications – Enter Permit # | |
| Fee Submitted: (*refer to fee schedule at* http://portal.ncdenr.org/web/wq/aps/lau/fees) | Not Applicable under CERCLA Exclusion |

* For new projects: complete this page, signature page, and supply all attachments.
** For renewals: complete this page and signature page.
For modifications: complete this page, signature page, and supply relevant attachments.

| | |
|---|---|
| Applicant's Name (*specify the name of the municipality, corporation, individual, etc.*): | Mr. John Townson |
| Owner or Signing Official's Name and Title (*person legally responsible for the facility and its compliance*): | Director of Environmental Management Division |
| Mailing Address: | G-F/EMD/EQB; 12 Post Lane |
| Telephone Number: | 910-451-7693 |
| Email Address: | |
| Facility Name (*name of the project site; be consistent throughout application package*): | *Site 88, Operable Unit No. 15, Marine Corps Installations East - Marine Corps Base Camp Lejeune (MCIEAST-MCB CAM LEJ)* |
| Physical Address: | G-F/EMD/EQB; 12 Post Lane |
| County: | Onslow |
| Geographic Coordinates: | 3839153.42 N; 284648.62 E (NAD1983; UTM/Zone 18N) |
| Contact Person (*who can answer questions about application*): | Jessica High |
| Telephone Number: | 704-543-3263 |
| Email Address: | Jessica.High@ch2m.com |

***ATTACHMENTS***

***Applicable information listed below is included in the attached Permanganate Tracer Study Work Plan, Site 88, Operable Unit No. 15, Marine Corps Installations East – Marine Corps Base Camp Lejeune, North Carolina (CH2M HILL, 2015). Applicable sections, tables, figures are provided for each section below.***

**A. Site Description and Incident Information**. As specified in 15A NCAC 02T .1604(a), the applicant must briefly describe the site, noting pertinent site information including:

(1) Contaminant(s) of concern,
(2) Source(s) and date(s) of the contaminant release,
(3) Remedial actions to date,
(4) Current land use,
(5) Potential receptors, and
(6) Incident number and name of oversight agency.

**Required information is documented in the attached Work Plan, specifically Section 2.**

**B. Soils Evaluation**. As specified in 15A NCAC 02T .1604(b), for systems with proposed discharge within seven feet of land surface and above the seasonal high water table, a soil evaluation of the disposal site shall be provided to the Division by the applicant. If required by G.S. 89F, a soil scientist shall submit this evaluation. This evaluation shall be presented in a report that includes the following components:

(1) Field description of soil profile. Based on examinations of excavation pits or auger borings, the following parameters shall be described by individual diagnostic horizons to a depth of seven feet below land surface or to bedrock:
   (A) Thickness of the horizon;
   (B) Texture;
   (C) Color and other diagnostic features;
   (D) Structure;
   (E) Internal drainage;
   (F) Depth, thickness, and type of restrictive horizon(s);
   (G) pH;
   (H) Cation exchange capacity; and
   (I) Presence or absence and depth of evidence of any seasonal high water table.
(2) Recommendations concerning annual and instantaneous loading rates of liquids, solids, other wastewater constituents and amendments. Annual hydraulic loading rates shall be based on in-situ measurement of saturated hydraulic conductivity in the most restrictive horizon.

**This information is NOT APPLICABLE since discharge will not be within 7 feet of land surface, but at 100 feet below land surface**.

**C. Hydrogeologic Evaluation**. As specified in 15A NCAC 02T .1604(c), a hydrogeologic evaluation of the disposal site shall be provided to the Division by the applicant. This evaluation shall be conducted to a depth that includes the depth of existing contamination and the total depth of the injection well(s) or infiltration gallery(ies). This evaluation shall be based on borings for which the numbers, locations, and depths are sufficient to define the components of the hydrogeologic evaluation. In addition to borings, other techniques may be used to investigate the subsurface conditions at the site. These techniques may include geophysical well logs, surface geophysical surveys, and tracer studies. This evaluation shall be presented in a report that includes the following components:

(1) A description of the regional and local geology and hydrogeology;
(2) A description, based on field observations of the site, of the site topographic setting, streams, springs and other groundwater discharge features, drainage features, existing and abandoned wells, rock outcrops, and other features that may affect the movement of the contaminant plume and treated wastewater;
(3) Changes in lithology underlying the site;
(4) Depth to bedrock and occurrence of any rock outcrops;
(5) The hydraulic conductivity, transmissivity, and storativity (specific yield if unconfined aquifer) of the affected aquifer(s);
(6) Depth to the seasonal high water table;
(7) A discussion of the relationship between the affected aquifers of the site to local and regional geologic and hydrogeologic features; and
(8) A discussion of the groundwater flow regime of the site focusing on the relationship of the plume and remediation system to groundwater receptors, groundwater discharge features, and groundwater flow media.

**Required information is documented in the attached Work Plan, specifically Sections 1 and 2.**

**D. Demonstration of Hydraulic Control**. As specified in 15A NCAC 02T .1604(d), computer modeling or predictive calculations based on site-specific conditions shall be provided to the Division by the applicant to demonstrate that operation of the system will not cause or contribute to:

(1) The migration of contaminants into previously uncontaminated areas, and
(2) A violation of the groundwater standards specified in 15A NCAC 02L .0202 at the compliance boundary as described in 15A NCAC 02L .0107.

**Required information is documented in the attached Work Plan, specifically using predictive calculations based on site-specific conditions outlined in Sections 3.6.1, Figures 3-1 through 3-6, and Table 3-3.**

**E. Maps and Cross-Sections**. As specified in 15A NCAC 02T .1604(e), site plans or maps shall be provided to the Division by the applicant depicting the location, orientation, and relationship of facility components including:

(1) A scaled map of the site, with site-specific topographic contour intervals and showing all facility-related structures and fences within the treatment, storage and disposal areas;

(2) Locations of all test auger borings or inspection pits;

(3) The location of all wells (including usage and construction details if available), designated wellhead protection areas, streams (ephemeral, intermittent, and perennial), springs, lakes, ponds, other surface drainage features, and any other site activities or features that may involve possible exposure to contamination within 500 feet of all waste treatment, storage, and disposal sites;

(4) Setbacks specified in 15A NCAC 02T .1606;

(5) Delineation of property boundaries, review boundaries, and compliance boundaries;

(6) The horizontal and vertical extent of the contaminant plume for each of the contaminants of concern, including isoconcentration lines and plume cross-sections;

(7) Cross-sections depicting soil and rock layers and features to a depth including the depth of existing contamination and the total depth of the injection wells or infiltration galleries; and

(8) Hydrologic features such as potentiometric surface / water table contours and the direction of groundwater flow.

**Required information is documented in the attached Work Plan, specifically Tables 2-2, 3-2, 4-1, and Figures 1-2, 2-2 through 2-10, and 3-1 through 3-6.**

**F. Engineering Design Documents**. As specified in 15A NCAC 02T .1604(f), the following documents shall be provided to the Division by the applicant:

(1) Engineering plans for the entire system, including treatment, storage, application, and disposal facilities and equipment except those previously permitted unless they are directly tied into the new units or are critical to the understanding of the complete process;

(2) Specifications describing materials to be used, methods of construction, and means for ensuring quality and integrity of the finished product; and

(3) Plans that include construction details of recovery, injection, and monitoring wells and infiltration galleries.
NOTE: Recovery and monitoring wells shall be constructed in accordance with the requirements of 15A NCAC 02C .0108. Injection wells shall be constructed in accordance with the requirements of 15A NCAC 02C .0225(g).

**Required information is documented in the attached Work Plan, specifically Sections 3, 4, and 5, Tables 3-1, 3-2, 4-1, and Figures 3-1, 3-5, and 4-2.**

**G. Operating and Monitoring Plans**. As specified in 15A NCAC 02T .1604(g), an operation and monitoring plan shall be provided to the Division by the applicant. These documents shall be specific to the site and include:

(1) The operating plan shall include:
   (A) The operating schedule including any periodic shut-down times,
   (B) Required maintenance activities for all structural and mechanical elements,
   (C) All consumable and waste materials with their intended source and disposal locations,
   (D) Restrictions on access to the site and equipment, and
   (E) Provisions to ensure the quality of the treated effluent and hydraulic control of the system at all times when any portion of the system ceases to function.

(2) If injection wells are to be used then the operating plan shall also include:
   (A) The proposed average and maximum daily rate and quantity of injectant;
   (B) The average maximum injection pressure expressed in units of pounds per square inch (psi); and
   (C) The total or estimated total volume to be injected.

(3) The monitoring plan shall be prepared in accordance with 15A NCAC 02T .1607 and include:
   (A) The monitoring well(s) that will be sampled,
   (B) The constituent(s) for which those samples will be analyzed, and
   (C) The schedule for sampling.

**Required information is documented in the attached Work Plan, specifically Sections 4.6, 4.7, and 4.9, Figure 4-1, and Table 3-1.**

**H. *In Situ* Remediation Additives**. The following shall be provided to the Division by the applicant if the remediation system includes additives to promote remediation *in situ*:

*NOTE: Approved injectants can be found online at http://portal.ncdenr.org/web/wq/aps/gwpro. All other substances must be reviewed by the Division of Public Health, Department of Health and Human Services as required by 15A NCAC 02C .0225(a). Contact the UIC Program for more information (Ph# 919-807-6464).*

(1) MSDS, concentration at the point of injection, and percentage if present in a mixture with other injectants;
(2) A description of the rationale for selecting the injectants and concentrations proposed for injection, including an explanation or calculations of how the proposed injectant volumes and concentrations were determined;
(3) A description of the reactions between the injectants and the contaminants present including specific breakdown products or intermediate compounds that may be formed by the injection;
(4) A summary of results if modeling or testing was performed to investigate the injectant's potential or susceptibility for biological, chemical, or physical change in the subsurface; and
(5) An evaluation concerning the development of byproducts of the injection process, including increases in the concentrations of naturally occurring substances. Such an evaluation shall include the identification of the specific byproducts of the injection

process, projected concentrations of byproducts, and areas of migration as determined through modeling or other predictive calculations.

**Required information is documented in the attached Work Plan, specifically Section 3, Table 3-1, and Appendix E.**

**Professional Engineer's Certification:**

Name and Complete Address of Engineering Firm: CH2M HILL, Inc.

14120 Ballantyne Corporate Place, Suite 200

City: Charlotte State: NC Zip: 28277

Telephone Number: (704) 543-3263 Fax Number: (704) 544-4041

I, Jessica M. High, attest that this application for the Site 88, Operable Unit No. 15 Permanganate Tracer Study Non-Discharge Groundwater Remediation Permit has been reviewed by me and is accurate and complete to the best of my knowledge. I further attest that to the best of my knowledge the proposed design has been prepared in accordance with the applicable regulations. Although certain portions of this submittal package may have been developed by other professionals, inclusion of these materials under my signature and seal signifies that I have reviewed this material and have judged it to be consistent with the proposed design.

North Carolina Professional Engineer's Seal, Signature, and Date:

**Applicant's Certification (signing authority must be in compliance with 15A NCAC 2T .0106(b) and (c)):**

I, _____, attest that this application for

_____

has been reviewed by me and is accurate and complete to the best of my knowledge. I understand that if all required parts of this application are not completed and that if all required supporting information and attachments are not included, this application package will be returned to me as incomplete.

Signature _____ Date _____

SEND TWO COPIES OF THE COMPLETE APPLICATION PACKAGE, INCLUDING ALL SUPPORTING INFORMATION AND MATERIALS, TO THE FOLLOWING ADDRESS:

**DWR - AQUIFER PROTECTION SECTION**
**1636 MAIL SERVICE CENTER**
**RALEIGH, NORTH CAROLINA 27699-1636**

**TELEPHONE NUMBER: (919) 807-6464**

# Appendix E
# Safety Data Sheets

# SAFETY DATA SHEET

## 1. Identification

| | |
|---|---|
| **Product identifier** | **RemOx® L ISCO Reagent** |
| **Other means of identification** | Not available. |
| **Recommended use** | Liquid oxidant recommended for applications that require a concentrated permanganate solution. |
| **Recommended restrictions** | Use in accordance with supplier's recommendations. |

**Manufacturer / Importer / Supplier / Distributor information**

| | |
|---|---|
| **Manufacturer/Supplier** | CARUS CORPORATION |
| **Address** | 315 Fifth Street,<br>Peru, IL 61354, USA |
| **Telephone** | 815 223-1500 - All other non-emergency inquiries about the product should be directed to the company |
| **E-mail** | salesmkt@caruscorporation.com |
| **Website** | www.caruscorporation.com |
| **Contact person** | Dr. Chithambarathanu Pillai |
| **Emergency Telephone** | For Hazardous Materials [or Dangerous Goods] Incidents ONLY<br>(spill, leak, fire, exposure or accident), call CHEMTREC at<br>CHEMTREC®, USA: 001 (800) 424-9300<br>CHEMTREC®, Mexico (Toll-Free - must be dialed from within country):<br>01-800-681-9531<br>CHEMTREC®, Other countries: 001 (703) 527-3887 |

## 2. Hazard(s) identification

| | | |
|---|---|---|
| **Physical hazards** | Oxidizing liquids | Category 2 |
| **Health hazards** | Acute toxicity, oral | Category 4 |
| | Skin corrosion/irritation | Category 1B |
| | Serious eye damage/eye irritation | Category 1 |
| | Specific target organ toxicity, single exposure | Category 3 respiratory tract irritation |
| **OSHA defined hazards** | Not classified. | |

**Label elements**

| | |
|---|---|
| **Signal word** | Danger |
| **Hazard statement** | May intensify fire; oxidizer. Harmful if swallowed. Causes severe skin burns and eye damage. May cause respiratory irritation. |
| **Precautionary statement** | |
| **Prevention** | Keep away from heat. Take any precaution to avoid mixing with combustibles. Keep/Store away from clothing//combustible materials. Use only outdoors or in a well-ventilated area. Do not breathe mist or vapor. Wear protective gloves/protective clothing/eye protection/face protection. Do not eat, drink or smoke when using this product. Wash thoroughly after handling. |
| **Response** | In case of fire: Use water for extinction. If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If on skin (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower. Wash contaminated clothing before reuse. If swallowed: Rinse mouth. Do NOT induce vomiting. If inhaled: Remove person to fresh air and keep comfortable for breathing. |
| **Storage** | Store locked up. Store in a well-ventilated place. Keep container tightly closed. |
| **Disposal** | Dispose of contents/container in accordance with local/regional/national/international regulations. |
| **Hazard(s) not otherwise classified (HNOC)** | Not classified. |

| | | |
|---|---|---|
| **Environmental hazards** | Hazardous to the aquatic environment, acute hazard | Category 1 |
| | Hazardous to the aquatic environment, long-term hazard | Category 1 |

**Supplemental information**

**Hazard symbol**

**Hazard statement** Very toxic to aquatic life with long lasting effects.

**Precautionary statement**

**Prevention** Avoid release to the environment.

**Response** Collect spillage.

## 3. Composition/information on ingredients

**Mixtures**

| Chemical name | CAS number | % |
|---|---|---|
| Sodium permanganate | 10101-50-5 | 36 - 40 |

**Composition comments** All concentrations are in percent by weight unless ingredient is a gas. Gas concentrations are in percent by volume.

## 4. First-aid measures

**Inhalation** If breathing is difficult, remove to fresh air and keep at rest in a position comfortable for breathing. Remove victim to fresh air and keep at rest in a position comfortable for breathing. Move to fresh air. For breathing difficulties, oxygen may be necessary. Call a physician or poison control center immediately. Get medical attention immediately. Call a physician if symptoms develop or persist. Get medical attention if symptoms persist.

**Skin contact** Take off immediately all contaminated clothing. (Caution: Solution may ignite certain textiles). Immediately flush skin with plenty of water. Get medical attention immediately. Wash contaminated clothing before reuse.

Contact with skin may leave a brown stain of insoluble manganese dioxide. This can be easily removed by washing with a mixture of equal volume of household vinegar and 3% hydrogen peroxide, followed by washing with soap and water.

**Eye contact** Immediately flush with plenty of water for up to 15 minutes. Remove any contact lenses and open eyelids wide apart. Continue rinsing. Get medical attention immediately.

**Ingestion** Immediately rinse mouth and drink plenty of water. Never give anything by mouth to a victim who is unconscious or is having convulsions. Do not induce vomiting. If vomiting occurs, keep head low so that stomach content doesn't get into the lungs. Get medical attention immediately.

Before using, read Material Safety Data Sheet (MSDS) for this product. Rinse container at least three times to an absence of pink color before disposing.

**Most important symptoms/effects, acute and delayed** Contact with this material will cause burns to the skin, eyes and mucous membranes. Corrosive effects. Irritation of eyes and mucous membranes. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. May cause temporary blindness and severe eye damage. Permanent eye damage including blindness could result. Show this safety data sheet to the doctor in attendance.

**Indication of immediate medical attention and special treatment needed** Provide general supportive measures and treat symptomatically. In case of shortness of breath, give oxygen. Decomposition products are alkaline. Brown stain is insoluble manganese dioxide.

**General information** In the case of accident or if you feel unwell, seek medical advice immediately (show the label where possible). If you feel unwell, seek medical advice (show the label where possible). Ensure that medical personnel are aware of the material(s) involved, and take precautions to protect themselves. For personal protection, see Section 8 of the MSDS. Show this safety data sheet to the doctor in attendance. Wash contaminated clothing before reuse.

## 5. Fire-fighting measures

**Suitable extinguishing media** Flood with water from a distance, water spray or fog.

**Unsuitable extinguishing media** The following extinguishing media are ineffective: Dry chemical. Foam. Carbon dioxide ($CO_2$). Halogenated materials.

**Specific hazards arising from the chemical** May intensify fire; oxidizer. May ignite combustibles (wood, paper, oil, clothing, etc.). Contact with incompatible materials or heat (135 ºC / 275 ºF) could result in violent exothermic chemical reaction. Oxidizing agent, may cause spontaneous ignition of combustible materials. By heating and fire, corrosive vapors/gases may be formed.

**Special protective equipment and precautions for firefighters** Self-contained breathing apparatus and full protective clothing must be worn in case of fire. Selection of respiratory protection for firefighting: follow the general fire precautions indicated in the workplace.

**Fire-fighting equipment/instructions**

Move container from fire area if it can be done without risk. Cool containers exposed to flames with water until well after the fire is out. Prevent runoff from fire control or dilution from entering streams, sewers, or drinking water supply. Dike fire control water for later disposal. Water runoff can cause environmental damage.

## 6. Accidental release measures

**Personal precautions, protective equipment and emergency procedures**

Keep unnecessary personnel away. Keep upwind. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Avoid inhalation of vapors and contact with skin and eyes. Wear protective clothing as described in Section 8 of this safety data sheet. Local authorities should be advised if significant spillages cannot be contained.

**Methods and materials for containment and cleaning up**

Keep combustibles (wood, paper, oil, etc.) away from spilled material. Should not be released into the environment. This product is miscible in water.

Large Spills: Stop leak if possible without any risk. Dike the spilled material, where this is possible. Proceed with either of the following two options depending upon the size of the spill and the availability of the neutralizing agents:

Option # 1: Dilute to approximately 6% with water, and then reduce with sodium thiosulfate, a bisulfite or ferrous salt solution. The bisulfite or ferrous salt may require some dilute sulfuric acid (10% w/w) to promote reduction. Neutralize with sodium carbonate to neutral pH, if acid was used. Decant or filter and deposit sludge in approved landfill. Where permitted, the sludge may be drained into sewer with large quantities of water.

Option # 2: Absorb with inert media like diatomaceous earth or inert floor dry, collect into a drum and dispose of properly. Do not use saw dust or other incompatible media. Disposal of all materials shall be in full and strict compliance with all federal, state, and local regulations pertaining to permanganates.

To clean contaminated floors, flush with abundant quantities of water into sewer, if permitted by federal, state, and local regulations. If not, collect water and treat as described above. Cover with reducing agent (e.g. sodium bisulphite/thiosulphate or a ferrous salt plus 2M $H_2SO_4$). Transfer to container with water and neutralize with soda ash. Otherwise, absorb spill with vermiculite or other inert material, then place in a container for chemical waste. Do not use sawdust or other combustible material. Following product recovery, flush area with water. Prevent product from entering drains.

Small Spills: Cover with reducing agent (e.g. sodium bisulphite/thiosulphate or a ferrous salt plus 2M $H_2SO_4$). Transfer to container with water and neutralize with soda ash. Clean surface thoroughly to remove residual contamination.

Never return spills in original containers for re-use. Never return spills in original containers for re-use.

**Environmental precautions**

Do not allow to enter drains, sewers or watercourses. Contact local authorities in case of spillage to drain/aquatic environment.

## 7. Handling and storage

**Precautions for safe handling**

Take any precaution to avoid mixing with combustibles. Keep away from clothing and other combustible materials. Do not get this material in your eyes, on your skin, or on your clothing. Do not breathe mist or vapor. If clothing becomes contaminated, remove and wash off immediately. Spontaneous ignition may occur in contact with cloth or paper. When using, do not eat, drink or smoke. Good personal hygiene is necessary. Wash hands and contaminated areas with water and soap before leaving the work site. Avoid release to the environment.

**Conditions for safe storage, including any incompatibilities**

Store locked up. Keep container tightly closed and in a well-ventilated place. Store in a cool, dry place. Store away from incompatible materials (See Section 10). Follow applicable local/national/international recommendations on storage of oxidizers. Store in accordance with NFPA 430 requirements for Class II oxidizers.

## 8. Exposure controls/personal protection

**Occupational exposure limits**

No exposure limits noted for ingredient(s).

**US. OSHA Table Z-1 Limits for Air Contaminants (29 CFR 1910.1000)**

| Components | Type | Value |
|---|---|---|
| Sodium permanganate (CAS 10101-50-5) | Ceiling | 5 mg/m3 |

**US. ACGIH Threshold Limit Values**

| Components | Type | Value | Form |
|---|---|---|---|
| Sodium permanganate (CAS 10101-50-5) | TWA | 0.1 mg/m3 | Inhalable fraction. |
| | | 0.02 mg/m3 | Respirable fraction. |

**US NIOSH Pocket Guide to Chemical Hazards: Recommended exposure limit (REL)**

| Components | Type | Value | Form |
|---|---|---|---|
| Sodium permanganate (CAS 10101-50-5) | TWA | 1 mg/m3 | Fume. |

**US NIOSH Pocket Guide to Chemical Hazards: Short Term Exposure Limit (STEL)**

| Components | Type | Value | Form |
|---|---|---|---|
| Sodium permanganate (CAS 10101-50-5) | STEL | 3 mg/m3 | Fume. |

**Biological limit values** No biological exposure limits noted for the ingredient(s).

**Exposure guidelines** Follow standard monitoring procedures.

**Appropriate engineering controls** Provide adequate general and local exhaust ventilation. An eye wash and safety shower must be available in the immediate work area.

**Individual protection measures, such as personal protective equipment**

**Eye/face protection** Wear safety glasses with side shields (or goggles). Wear face shield if there is risk of splashes.

**Skin protection**

**Hand protection** Wear chemical-resistant, impervious gloves. Use protective gloves made of: Rubber or plastic. Suitable gloves can be recommended by the glove supplier.

**Other** Wear appropriate chemical resistant clothing. Rubber or plastic apron.

**Respiratory protection** In case of inadequate ventilation or risk of inhalation of vapors, use suitable respiratory equipment. In the United States of America, if respirators are used, a program should be instituted to assure compliance with OSHA 29 CFR 1910.134.

**Thermal hazards** Wear appropriate thermal protective clothing, when necessary.

**General hygiene considerations** When using, do not eat, drink or smoke. Keep from contact with clothing and other combustible materials. Remove and wash contaminated clothing promptly. Wash hands before breaks and immediately after handling the product. Handle in accordance with good industrial hygiene and safety practice.

## 9. Physical and chemical properties

**Appearance** Dark purple liquid.

**Physical state** Liquid.

**Form** Aqueous solution.

**Color** Dark purple.

**Odor** Odorless.

**Odor threshold** Not available.

**pH** 5 - 8

**Melting point/freezing point** < 24.8 °F (< -4 °C)

**Initial boiling point and boiling range** > 213.8 °F (> 101 °C)

**Flash point** Does not flash.

**Evaporation rate** As water.

**Flammability (solid, gas)** Not applicable.

**Upper/lower flammability or explosive limits**

**Flammability limit - lower (%)** Not applicable.

**Flammability limit - upper (%)** Not applicable.

**Vapor pressure** 760 mm Hg (105 °C)

**Vapor density** Not available.

**Relative density** 1.37 - 1.4 (20 °C) ( Water = 1)

**Solubility(ies)** Miscible with water.

**Partition coefficient (n-octanol/water)** Not available.

**Auto-ignition temperature** Not available.

**Decomposition temperature** Not available.

**Viscosity** Not available.

**Other information**

| | |
|---|---|
| **Explosive properties** | Not explosive. Can explode in contact with sulfuric acid, peroxides and metal powders. |
| **Oxidizing properties** | Strong oxidizing agent. |

## 10. Stability and reactivity

| | |
|---|---|
| **Reactivity** | The product is non-reactive under normal conditions of use, storage and transport. |
| **Chemical stability** | Stable at normal conditions. |
| **Possibility of hazardous reactions** | Contact with combustible material may cause fire. Can explode in contact with sulfuric acid, peroxides and metal powders. |
| **Conditions to avoid** | Contact with incompatible materials or heat (135 °C / 275 °F) could result in violent exothermic chemical reaction. |
| **Incompatible materials** | Acids. Peroxides. Reducing agents. Combustible material. Metal powders. |
| **Hazardous decomposition products** | By heating and fire, corrosive vapors/gases may be formed. Contact with hydrochloric acid liberates chlorine gas. |

## 11. Toxicological information

**Information on likely routes of exposure**

| | |
|---|---|
| **Ingestion** | Causes digestive tract burns. Harmful if swallowed. Ingestion causes burns of the upper digestive and respiratory tracts. |
| **Inhalation** | May cause irritation to the respiratory system. |
| **Skin contact** | Causes severe skin burns. |
| **Eye contact** | Causes serious eye damage. |
| **Symptoms related to the physical, chemical and toxicological characteristics** | Contact with this material will cause burns to the skin, eyes and mucous membranes. Permanent eye damage including blindness could result. |

**Information on toxicological effects**

| | |
|---|---|
| **Acute toxicity** | Causes severe skin burns and eye damage. Causes burns. Harmful if swallowed. Health injuries are not known or expected under normal use. Harmful if swallowed. |

| **Components** | **Species** | **Test Results** |
|---|---|---|
| Potassium permanganate (CAS 7722-64-7) | | |
| **Acute** | | |
| *Dermal* | | |
| LD50 | Rat | 2000 mg/kg |
| *Oral* | | |
| LD50 | Rat | 2000 mg/kg |

Toxicity data are not available for sodium permanganate. Toxicity is expected to be similar to that of potassium permanganate.

| | |
|---|---|
| **Skin corrosion/irritation** | Causes severe skin burns. |
| **Serious eye damage/eye irritation** | Causes serious eye damage. |
| **Respiratory sensitization** | Not classified. |
| **Skin sensitization** | Not classified. |
| **Germ cell mutagenicity** | Not classified. |
| **Carcinogenicity** | Not classified. |
| **Reproductive toxicity** | Not classified. |
| **Specific target organ toxicity - single exposure** | May cause irritation of respiratory tract. |
| **Specific target organ toxicity - repeated exposure** | Not classified. |
| **Aspiration hazard** | Not classified. |
| **Further information** | Chronic effects are not expected when this product is used as intended. Prolonged exposure, usually over many years, to manganese oxide fume/dust can lead to chronic manganese poisoning, chiefly affecting the central nervous system. |

## 12. Ecological information

| | |
|---|---|
| **Ecotoxicity** | Very toxic to aquatic life with long lasting effects. |

| Components | | Species | Test Results |
|---|---|---|---|
| Potassium permanganate (CAS 7722-64-7) | | | |
| **Aquatic** | | | |
| Fish | LC50 | Bluegill (Lepomis macrochirus) | 2.7 mg/l, 96 hours, static |
| | | | 2.3 mg/l, 96 hours, flow through |
| | | | 2.3 mg/l, 96 hours |
| | | | 1.8 - 5.6 mg/l |
| | | Carp (Cyprinus carpio) | 3.16 - 3.77 mg/l, 96 hours |
| | | | 2.97 - 3.11 mg/l, 96 hours |
| | | Goldfish (Carassius auratus) | 3.3 - 3.93 mg/l, 96 hours, static |
| | | Milkfish, salmon-herring (Chanos chanos) | > 1.4 mg/l, 96 hours |
| | | Rainbow trout (Oncorhynchus mykiss) | 1.8 mg/l, 96 hours |
| | | | 1.08 - 1.38 mg/l, 96 hours |
| | | | 0.77 - 1.27 mg/l, 96 hours |
| | | Rainbow trout,donaldson trout (Oncorhynchus mykiss) | 0.275 - 0.339 mg/l, 96 hours |

Toxicity data are not available for sodium permanganate. Toxicity is expected to be similar to that of potassium permanganate.

**Persistence and degradability** Expected to be readily converted by oxidizable materials to insoluble manganese oxide.

**Bioaccumulative potential** Potential to bioaccumulate is low.

**Mobility in soil** The product is miscible with water. May spread in water systems.

**Mobility in general** The product is miscible with water. May spread in water systems.

**Other adverse effects** None known.

## 13. Disposal considerations

**Disposal instructions** Dispose of contents/container in accordance with local/regional/national/international regulations.

**Local disposal regulations** Rinse container at least three times to an absence of pink color before disposing.

**Hazardous waste code** D001: Ignitable waste
The Waste code should be assigned in discussion between the user, the producer and the waste disposal company.

**Waste from residues / unused products** Do not allow this material to drain into sewers/water supplies. Dispose of in accordance with local regulations.

**Contaminated packaging** Since emptied containers may retain product residue, follow label warnings even after container is emptied. Rinse container at least three times to an absence of pink color before disposing. Empty containers should be taken to an approved waste handling site for recycling or disposal.

## 14. Transport information

**DOT**

**UN number** UN3214
**UN proper shipping name** Permanganates, inorganic, aqueous solution, n.o.s. (Sodium permanganate)
**Transport hazard class(es)** 5.1
**Subsidiary class(es)** -
**Packing group** II
**Environmental hazards**
**Marine pollutant** Yes
**Special precautions for user** Read safety instructions, SDS and emergency procedures before handling.
**Special provisions** 26, 353, IB2, T4, TP1
**Packaging exceptions** 152
**Packaging non bulk** 202
**Packaging bulk** 242

**IATA**

**UN number** UN3214
**UN proper shipping name** Permanganates, inorganic, aqueous solution, n.o.s. (Sodium permanganate)
**Transport hazard class(es)** 5.1
**Subsidiary class(es)** -
**Packaging group** II
**Environmental hazards** Yes
**Labels required** 5.1
**ERG Code** 5L

**Special precautions for user** Read safety instructions, SDS and emergency procedures before handling.

**IMDG**

| | |
|---|---|
| **UN number** | UN3214 |
| **UN proper shipping name** | PERMANGANATES, INORGANIC, AQUEOUS SOLUTION, N.O.S. (Sodium permanganate) |
| **Transport hazard class(es)** | 5.1 |
| **Subsidiary class(es)** | - |
| **Packaging group** | II |
| **Environmental hazards** | |
| **Marine pollutant** | Yes |
| **Labels required** | 5.1 |
| **EmS** | F-H, S-Q |
| **Special precautions for user** | Read safety instructions, SDS and emergency procedures before handling. |

**Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code** This substance/mixture is not intended to be transported in bulk.

## 15. Regulatory information

**US federal regulations** This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.
All components are on the U.S. EPA TSCA Inventory List.

CERCLA/SARA Hazardous Substances - Not applicable.

Drug Enforcement Administration (DEA) (21 CFR 1310.02 (b) 8: List II chemical.

**TSCA Section 12(b) Export Notification (40 CFR 707, Subpt. D)**

Not regulated.

**US. OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)**

Not listed.

**CERCLA Hazardous Substance List (40 CFR 302.4)**

Sodium permanganate (CAS 10101-50-5) LISTED

**Superfund Amendments and Reauthorization Act of 1986 (SARA)**

**Hazard categories** Immediate Hazard - Yes
Delayed Hazard - No
Fire Hazard - Yes
Pressure Hazard - No
Reactivity Hazard - No

**SARA 302 Extremely hazardous substance** No

**SARA 311/312 Hazardous chemical** Yes

**SARA 313 (TRI reporting)**

| Chemical name | CAS number | % by wt. |
|---|---|---|
| Sodium permanganate | 10101-50-5 | 36 - 40 |
| Potassium permanganate | 7722-64-7 | 2 |

**Other federal regulations**

**Clean Air Act (CAA) Section 112 Hazardous Air Pollutants (HAPs) List**

Sodium permanganate (CAS 10101-50-5)

**Clean Air Act (CAA) Section 112(r) Accidental Release Prevention (40 CFR 68.130)**

Not regulated.

**Safe Drinking Water Act (SDWA)** Not regulated.

**Drug Enforcement Administration (DEA). List 2, Essential Chemicals (21 CFR 1310.02(b) and 1310.04(f)(2) and Chemical Code Number**

Sodium permanganate (CAS 10101-50-5) 6588

**Drug Enforcement Administration (DEA). List 1 & 2 Exempt Chemical Mixtures (21 CFR 1310.12(c))**

Sodium permanganate (CAS 10101-50-5) 15 % wt

**DEA Exempt Chemical Mixtures Code Number**

Sodium permanganate (CAS 10101-50-5) 6588

**Food and Drug Administration (FDA)** Not regulated.

**US state regulations** This product does not contain a chemical known to the State of California to cause cancer, birth defects or other reproductive harm.

**US. Massachusetts RTK - Substance List**

Not regulated.

**US. New Jersey Worker and Community Right-to-Know Act**

Sodium permanganate (CAS 10101-50-5) 500 lbs

**US. Pennsylvania RTK - Hazardous Substances**

Not regulated.

**US. Rhode Island RTK**

Sodium permanganate (CAS 10101-50-5)

**US. California Proposition 65**

**US - California Proposition 65 - Carcinogens & Reproductive Toxicity (CRT): Listed substance**

Not listed.

**International Inventories**

| Country(s) or region | Inventory name | On inventory (yes/no)* |
|---|---|---|
| Australia | Australian Inventory of Chemical Substances (AICS) | Yes |
| Canada | Domestic Substances List (DSL) | No |
| Canada | Non-Domestic Substances List (NDSL) | Yes |
| China | Inventory of Existing Chemical Substances in China (IECSC) | Yes |
| Europe | European Inventory of Existing Commercial Chemical Substances (EINECS) | Yes |
| Europe | European List of Notified Chemical Substances (ELINCS) | No |
| Japan | Inventory of Existing and New Chemical Substances (ENCS) | Yes |
| Korea | Existing Chemicals List (ECL) | Yes |
| New Zealand | New Zealand Inventory | Yes |
| Philippines | Philippine Inventory of Chemicals and Chemical Substances (PICCS) | Yes |
| United States & Puerto Rico | Toxic Substances Control Act (TSCA) Inventory | Yes |

*A "Yes" indicates this product complies with the inventory requirements administered by the governing country(s).
A "No" indicates that one or more components of the product are not listed or exempt from listing on the inventory administered by the governing country(s).

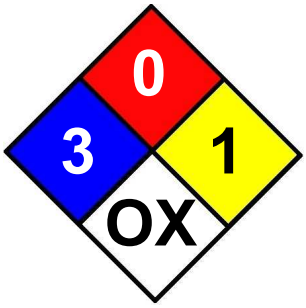
## 16. Other information, including date of preparation or last revision

**Issue date** 27-November-2013

**Revision date** -

**Version #** 01

**NFPA Ratings**




**References**

HSDB® - Hazardous Substances Data Bank
Registry of Toxic Effects of Chemical Substances (RTECS)
EPA: AQUIRE database
NLM: Hazardous Substances Data Base
US. IARC Monographs on Occupational Exposures to Chemical Agents
IARC Monographs. Overall Evaluation of Carcinogenicity
National Toxicology Program (NTP) Report on Carcinogens
ACGIH Documentation of the Threshold Limit Values and Biological Exposure Indices

**Disclaimer**

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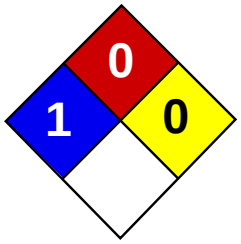


| | |
|---|---|
| Health | 1 |
| Fire | 0 |
| Reactivity | 0 |
| Personal Protection | E |

# Material Safety Data Sheet
## Sodium chloride MSDS

## Section 1: Chemical Product and Company Identification

**Product Name:** Sodium chloride

**Catalog Codes:** SLS3262, SLS1045, SLS3889, SLS1669, SLS3091

**CAS#:** 7647-14-5

**RTECS:** VZ4725000

**TSCA:** TSCA 8(b) inventory: Sodium chloride

**CI#:** Not applicable.

**Synonym:** Salt; Sea Salt

**Chemical Name:** Sodium chloride

**Chemical Formula:** NaCl

**Contact Information:**

**Sciencelab.com, Inc.**
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

**CHEMTREC (24HR Emergency Telephone), call:** 1-800-424-9300

**International CHEMTREC, call:** 1-703-527-3887

**For non-emergency assistance, call:** 1-281-441-4400

## Section 2: Composition and Information on Ingredients

**Composition:**

| Name | CAS # | % by Weight |
|---|---|---|
| Sodium chloride | 7647-14-5 | 100 |

**Toxicological Data on Ingredients:** Sodium chloride: ORAL (LD50): Acute: 3000 mg/kg [Rat.]. 4000 mg/kg [Mouse]. DERMAL (LD50): Acute: >10000 mg/kg [Rabbit]. DUST (LC50): Acute: >42000 mg/m 1 hours [Rat].

## Section 3: Hazards Identification

**Potential Acute Health Effects:** Slightly hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

**Potential Chronic Health Effects:**
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. Repeated or prolonged exposure is not known to aggravate medical condition.

## Section 4: First Aid Measures

**Eye Contact:**

Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. Get medical attention.

**Skin Contact:**
Wash with soap and water. Cover the irritated skin with an emollient. Get medical attention if irritation develops. Cold water may be used.

**Serious Skin Contact:** Not available.

**Inhalation:**
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention if symptoms appear.

**Serious Inhalation:** Not available.

**Ingestion:**
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Loosen tight clothing such as a collar, tie, belt or waistband. Get medical attention if symptoms appear.

**Serious Ingestion:** Not available.

## Section 5: Fire and Explosion Data

**Flammability of the Product:** Non-flammable.

**Auto-Ignition Temperature:** Not applicable.

**Flash Points:** Not applicable.

**Flammable Limits:** Not applicable.

**Products of Combustion:** Not available.

**Fire Hazards in Presence of Various Substances:** Not applicable.

**Explosion Hazards in Presence of Various Substances:**
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

**Fire Fighting Media and Instructions:** Not applicable.

**Special Remarks on Fire Hazards:** When heated to decomposition it emits toxic fumes.

**Special Remarks on Explosion Hazards:**
Electrolysis of sodium chloride in presence of nitrogenous compounds to produce chlorine may lead to formation of explosive nitrogen trichloride. Potentially explosive reaction with dichloromaleic anhydride + urea.

## Section 6: Accidental Release Measures

**Small Spill:**
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

**Large Spill:**
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

## Section 7: Handling and Storage

**Precautions:**
Keep locked up.. Do not ingest. Do not breathe dust. Avoid contact with eyes. Wear suitable protective clothing. If ingested, seek medical advice immediately and show the container or the label. Keep away from incompatibles such as oxidizing agents, acids.

**Storage:** Keep container tightly closed. Keep container in a cool, well-ventilated area. Hygroscopic

## Section 8: Exposure Controls/Personal Protection

**Engineering Controls:**
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

**Personal Protection:**
Splash goggles. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

**Personal Protection in Case of a Large Spill:**
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

**Exposure Limits:** Not available.

## Section 9: Physical and Chemical Properties

**Physical state and appearance:** Solid. (Solid crystalline powder.)

**Odor:** Slight.

**Taste:** Saline.

**Molecular Weight:** 58.44 g/mole

**Color:** White.

**pH (1% soln/water):** 7 [Neutral.]

**Boiling Point:** 1413°C (2575.4°F)

**Melting Point:** 801°C (1473.8°F)

**Critical Temperature:** Not available.

**Specific Gravity:** 2.165 (Water = 1)

**Vapor Pressure:** Not applicable.

**Vapor Density:** Not available.

**Volatility:** Not available.

**Odor Threshold:** Not available.

**Water/Oil Dist. Coeff.:** Not available.

**Ionicity (in Water):** Not available.

**Dispersion Properties:** See solubility in water.

**Solubility:**
Easily soluble in cold water, hot water. Soluble in glycerol, and ammonia. Very slightly soluble in alcohol. Insoluble in Hydrochloric Acid.

## Section 10: Stability and Reactivity Data

**Stability:** The product is stable.

**Instability Temperature:** Not available.

**Conditions of Instability:** Incompatible materials, high temperatures.

**Incompatibility with various substances:** Reactive with oxidizing agents, metals, acids.

**Corrosivity:** Not considered to be corrosive for metals and glass.

**Special Remarks on Reactivity:**
Hygroscopic. Reacts with most nonnoble metals such as iron or steel, building materials (such as cement) Sodium chloride is rapidly attacked by bromine trifluoride. Violent reaction with lithium.

**Special Remarks on Corrosivity:** Not available.

**Polymerization:** Will not occur.

## Section 11: Toxicological Information

**Routes of Entry:** Inhalation. Ingestion.

**Toxicity to Animals:**
WARNING: THE LC50 VALUES HEREUNDER ARE ESTIMATED ON THE BASIS OF A 4-HOUR EXPOSURE. Acute oral toxicity (LD50): 3000 mg/kg [Rat.]. Acute dermal toxicity (LD50): >10000 mg/kg [Rabbit]. Acute toxicity of the dust (LC50): >42000 mg/m3 1 hours [Rat].

**Chronic Effects on Humans:** MUTAGENIC EFFECTS: Mutagenic for mammalian somatic cells. Mutagenic for bacteria and/or yeast.

**Other Toxic Effects on Humans:** Slightly hazardous in case of skin contact (irritant), of ingestion, of inhalation.

**Special Remarks on Toxicity to Animals:** Lowest Published Lethal Dose (LDL) [Man] - Route: Oral; Dose: 1000 mg/kg

**Special Remarks on Chronic Effects on Humans:**
Causes adverse reproductive effects in humans (fetotoxicity, abortion, ) by intraplacental route. High intake of sodium chloride, whether from occupational exposure or in the diet, may increase risk of TOXEMIA OF PREGNANCY in susceptible women (Bishop, 1978). Hypertonic sodium chloride solutions have been used to induce abortion in late pregnancy by direct infusion into the uterus (Brown et al, 1972), but this route of administration is not relevant to occupational exposures. May cause adverse reproductive effects and birth defects in animals, particularly rats and mice (fetotoxicity, abortion, musculoskeletal abnormalities, and maternal effects (effects on ovaries, fallopian tubes) by oral, intraperitoneal, intraplacental, intrauterine, parenteral, and subcutaneous routes. While sodium chloride has been used as a negative control n some reproductive studies, it has also been used as an example that almost any chemical can cause birth defects in experimental animals if studied under the right conditions (Nishimura & Miyamoto, 1969). In experimental animals, sodium chloride has caused delayed effects on newborns, has been fetotoxic, and has caused birth defects and abortions in rats and mice (RTECS, 1997). May affect genetic material (mutagenic)

**Special Remarks on other Toxic Effects on Humans:**
Acute Potential Health Effects: Skin: May cause skin irritation. Eyes: Causes eye irritation. Ingestion: Ingestion of large quantities can irritate the stomach (as in overuse of salt tablets) with nausea and vomiting. May affect behavior (muscle spasicity/contraction, somnolence), sense organs, metabolism, and cardiovascular system. Continued exposure may produce dehydration, internal organ congestion, and coma. Inhalation: Material is irritating to mucous membranes and upper respiratory tract.

## Section 12: Ecological Information

**Ecotoxicity:** Not available.

**BOD5 and COD:** Not available.

**Products of Biodegradation:**
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

**Toxicity of the Products of Biodegradation:** The product itself and its products of degradation are not toxic.

**Special Remarks on the Products of Biodegradation:** Not available.

## Section 13: Disposal Considerations

**Waste Disposal:**
Waste must be disposed of in accordance with federal, state and local environmental control regulations.

## Section 14: Transport Information

**DOT Classification:** Not a DOT controlled material (United States).

**Identification:** Not applicable.

**Special Provisions for Transport:** Not applicable.

## Section 15: Other Regulatory Information

**Federal and State Regulations:** TSCA 8(b) inventory: Sodium chloride

**Other Regulations:** EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.

**Other Classifications:**

**WHMIS (Canada):** Not controlled under WHMIS (Canada).

**DSCL (EEC):**
R40- Possible risks of irreversible effects. S24/25- Avoid contact with skin and eyes.

**HMIS (U.S.A.):**

**Health Hazard:** 1

**Fire Hazard:** 0

**Reactivity:** 0

**Personal Protection:** E

**National Fire Protection Association (U.S.A.):**

**Health:** 1

**Flammability:** 0

**Reactivity:** 0

**Specific hazard:**

**Protective Equipment:**
Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Splash goggles.

## Section 16: Other Information

**References:**
-Hawley, G.G.. The Condensed Chemical Dictionary, 11e ed., New York N.Y., Van Nostrand Reinold, 1987. -SAX, N.I. Dangerous Properties of Indutrial Materials. Toronto, Van Nostrand Reinold, 6e ed. 1984. -The Sigma-Aldrich Library of Chemical Safety Data, Edition II.

**Other Special Considerations:** Not available.

**Created:** 10/11/2005 12:33 PM

**Last Updated:** 05/21/2013 12:00 PM

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