FINAL REPORT

Analysis of Long-Term Performance of Zero-Valent Iron Applications

ESTCP Project ER-201589

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14. ABSTRACT
This project involves the assessment of long-term performance of ZVI both as a source-zone treatment and as a barrier treatment for chlorinated volatile organic compounds (VOCs). This document details the field activities and data evaluation that were conducted in support of this project. The project approach consisted of a desktop review and field assessment. The field assessment was conducted at two selected sites. The first site was a Zero-valent Iron (ZVI) permeable reactive barrier (PRB) for plume control assessment at Allegany Ballistics Laboratory (ABL) Site 5. The other was at St. Louis Ordnance Plant Operable Unit 1 (OU1), where ZVI was introduced by soil-mixing in a source area.

15. SUBJECT TERMS
permeable reactive barrier, PRB, Allegany Ballistics Laboratory, ABL, St. Louis Ordnance Plant, zero-valent iron, ZVI, chlorinated volatile organic compounds, chlorinated VOCs, source-zone treatment, barrier treatment, groundwater,

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LIST OF ABBREVIATIONS

°C	degrees Celsius
µg/g	micrograms per gram
µg/L	micrograms per liter
1,1,2,2-PCA	1,1,2,2-tetrachloroethane
ABL	Allegany Ballistics Laboratory
AFB	Air Force Base
Al	aluminum
amsl	above mean se level
ATK	ATK Tactical Systems Company LLC
AVS	acid-volatile sulfur
bgs	below ground surface
btoc	below top of casing
Ca	calcium
CH2M	CH2M HILL, Inc.
cm/s	centimeters per second
CO_2	carbon dioxide
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DPT	direct push technology
EDS	energy-dispersive x-ray spectroscopy
ESTCP	Environmental Security Technology Certification Program
EtnC	alkene monooxygenase
EtnE	epoxyalkane transferase
eV	electron-volt
EXWC	Engineering and Expeditionary Warfare Center
Fe	iron
FeO	ferrous oxide
ft	feet

ft/d	feet per day
GOCO	government-owned, contractor-operated
IDW	investigation-derived waste
ITRC	Interstate Technology and Regulatory Council
lb	pound/pounds
MCL	maximum contaminant level
mg/L	milligrams per liter
mL	milliliter
mS/cm	milliSiemens per centimeter
mV	millivolt
NA	not applicable
NAVFAC	Naval Facilities Engineering Command
ND	not detected
NGS	next generation sequencing
NR	not recorded
NS	not sampled
NTU	nephelometric turbidity unit
OHSU	Oregon Health and Science University
ORP	oxidation/reduction potential
OU	Operable Unit 1
PCE	tetrachloroethene (perchloroethene)
PDF	Powder Diffraction File
PHE	phenol hydroxylase
PMMO	particulate methane monooxygenase
PRB	permeable reactive barrier
PVC	polyvinyl chloride
RDEG	toluene monooxygenase 2
RPM	remedial project manager
SANG	Savannah Air National Guard
SEM	scanning electron microscopy

SiO_2	silicon dioxide
SMMO	soluble methane monooxygenase
SOP	standard operating procedure
SWMU	Solid Waste Management Unit
TCE	trichloroethene
TOC	total organic carbon
TOD	toluene dioxygenase
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
VC	vinyl chloride
VOC	volatile organic compound
XANES	x-ray absorption near edge structure
XRD	x-ray diffraction
ZVI	zero-valent iron

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1.0 INTRODUCTION

Environmental Security Technology Certification Program (ESTCP) Project Number ER-201589-PR, Analysis of Long-Term Performance of Zero-valent Iron (ZVI) Applications (the project), involves the assessment of long-term performance of ZVI applications both as a source-zone treatment and as a barrier treatment for chlorinated volatile organic compounds (VOCs).

This project was completed through both desktop review and field investigations. The results of the desktop review were previously detailed in *Analysis of Long-term Performance of Zero-valent Iron Treatment at Nine Sites* (CH2M HILL, Inc. [CH2M] and Naval Facilities Engineering and Expeditionary Warfare Center [NAVFAC EXWC], 2016) (see **Appendix A**) and are summarized in the background section of this report. The remaining portions of the document detail the performance objectives, field activities and data evaluation that were conducted in support of the field study portion of the project. The recommendations in the report consider both phases of the project (desktop and field study).

Field data were collected at Allegany Ballistics Laboratory (ABL), located in Rocket Center, West Virginia, and the former St. Louis Ordnance Plant Operable Unit 1 (OU1), located in St. Louis, Missouri. Geochemical, contaminant concentration, mineralogical, reactivity, and hydraulic data were collected and evaluated for each site to determine the long-term efficacy of the ZVI treatments implemented at these sites and to assess the remaining active degradation mechanisms at each site.

1.1 BACKGROUND

1.1.1 ZVI Technology Background

ZVI technologies have been incorporated into remedies at many contaminated groundwater sites since the mid-1990s. ZVI applications began with their use in permeable reactive barriers (PRBs), the first of which was installed at Intersil Site, a private industrial site in Sunnyvale, California, in 1994. This PRB now has a history of more than 20 years. However, long-term monitoring data from this and other early sites (e.g., Denver Federal Center) have generally been sparse, either because these were private sites with limited interest in the mechanism behind the outcome, or because the sites moved on to supplement the PRBs with other remedies. ESTCP was in the forefront of evaluating the long-term performance of granular-particle-sized ZVI PRBs through projects such as CU-199907 (ESTCP, 2002). The Interstate Technology and Regulatory Council (ITRC) prepared a well-received *Technical/Regulatory Guidance Permeable Reactive Barrier: Technology Update* (2011) that identified issues related to long-term performance of PRBs. Among the key issues the ITRC guidance identified are the lack of conclusive evidence of a clean front emerging on the downgradient side of PRBs, uncertainty of the role of precipitates (e.g., oxides, carbonates, sulfides) forming on ZVI surfaces, and the lack of verification of hydraulic performance (groundwater flow through the PRB) as key questions that still needed to be answered for the technology.

In the early 2000s, another door opened to ZVI technologies when nano-scale, micro-scale, and granular ZVI began to be injected into dense non-aqueous phase liquid (DNAPL) source zones by a variety of processes, such as pneumatic fracturing, hydraulic fracturing, and augering. The United States Navy conducted a study of the short-term performance of injected ZVI in source zones (Naval Facilities Engineering Command [NAVFAC] Engineering Service Center, 2005). They found that the governing factor for success in an injected application was the ratio of ZVI mass to soil mass in the target treatment zone. At optimal ZVI:soil ratios, considerable decline in oxidation/reduction potential (ORP) of the aquifer to -400 millivolts (mV) was observed, leading to desirable abiotic reactions that led to compounds such as trichloroethene (TCE) degrading to acetylene through the β-elimination pathway. Many of the short-term studies reviewed during the Navy's 2005 evaluation ended at approximately 6 months, with the aquifer ORP beginning to rebound to -200 mV, at which point reduction of TCE continued through biodegradation, but with the generation of some cis-1,2-dichloroethene (cis-1,2-DCE) and vinyl chloride (VC).

As part of the *Analysis of Long-term Performance of Zero-valent Iron Treatment at Nine Sites* (CH2M and NAVFAC EXWC, 2016) a desk top review of existing data was completed as part of the first phase of this project. This review indicated reduced ZVI reactivity a few years after treatment (higher dissolved oxygen [DO] and ORP, reduced contaminant degradation rate, and evidence of movement from an abiotic degradation pathway to a biological reductive dechlorination pathway [increased generation of daughter products]). The second phase of the project involved fieldwork to confirm these findings.

1.1.2 Results of Desktop Study

The following sites were evaluated during the desktop review to assess long-term performance trends of ZVI based on existing data and to select the field study sites:

- PRB Sites
  - ABL Site 5, Rocket Center, West Virginia
  - Boeing Michigan Aeronautical Research Center OT-16, Joint Base McGuire-Dix-Lakehurst, New Hanover Township, New Jersey
- Injection Sites
  - St. Julien's Creek Annex Site 21, Chesapeake, Virginia
  - Naval Surface Warfare Center White Oak Site 13, White Oak, Maryland
  - Savannah Air National Guard (SANG) Base, Site 8, Garden City, Georgia
- Soil Mixing Sites
  - Arnold Air Force Base (AFB), Solid Waste Management Unit (SWMU) 16, Manchester, Tennessee
  - United States Army Corps of Engineers (USACE) St. Louis Ordnance Plant OU1, St. Louis, Missouri
  - Marine Corps Base Camp Lejeune Site 89, Jacksonville, North Carolina
  - Naval Support Facility Indian Head Site 17, Indian Head, Maryland

A summary of results for each site is provided as **Table 1-1**.

Table 1-1. Nine Site Summary of ZVI Treatment Performance

Site Name	Primary Contaminants and Highest Baseline Concentration(s)	Groundwater Velocity (feet per year [ft/year])	ZVI Dosage (pounds [lbs] ZVI/lb soil)	Conclusions and Comments
PRB Sites				
ABL Site 1	TCE: 110µg/L	293	40 percent - 8+50 mesh Envirometal ZVI/60 percent sand PRB (trenched)	Reductions of 70% were observed downgradient of the PRB. pH downgradient of the PRB continues to increase (a positive indicator of continued flow through the PRB). ORP has returned to near baseline levels in downgradient wells, but is still lower than in upgradient wells. Other geochemisty parameters (e.g., sulfate) do not indicate highly reducing conditions.
McGuire OT-16	TCE: 400 µg/L	376	0.5 percent Hepure ZVI, injected PRB using Ferox (nitrogen) process	Average reduction of 33% was observed, based on wells within, downgradient, and crossgradient of the PRB. No generation of daughter products was observed. Minimal and short-lived changes in field parameters (pH, ORP, DO) were observed. No changes in hydraulic characteristics were observed.
Injection Sites				
St. Julien's Creek Site 21	TCE: 12,500 µg/L	72	0.8 percent Hepure ZVI using Ferox	ZVI injections were very effective in reducing all chlorinated VOCs to levels at or near MCLs in all monitoring wells within the ZVI treatment areas. A 96% reduction in total VOCs was observed. Geochemical changes and concentration trends indicate mechanisms behind the chlorinated VOC reductions are both β-elimination and reductive dechlorination. Elevated pH and alkalinity remain in treatment areas. Indicators of reducing conditions, such as sulfide, have returned to near baseline levels. Arsenic concentrations have increased significantly.

Table 1-1. Nine Site Summary of ZVI Treatment Performance

Site Name	Primary Contaminants and Highest Baseline Concentration(s)	Groundwater Velocity (feet per year [ft/year])	ZVI Dosage (pounds [lbs] ZVI/lb soil)	Conclusions and Comments
White Oak Site 13	1,1,2,2-tetrachloroethane 1,1,2,2-PCA: 946 µg/L TCE: 535 µg/L cis-1,2-DCE: 755 µg/L trans-1,2-DCE: 148 µg/L	35	0.2 percent (on-site) 0.4 percent (off-site) Hepure ZVI injected using Ferox	ZVI was effective in reducing concentrations of chlorinated VOCs by ~85% in the two treated areas (on- and off-site). Efficacy was inconsistent from location to location, particularly in the on-site treatment area. Highly reducing conditions were achieved in only one well and clean up goals were only attained in two treatment area wells. Inconsistent treatment in the on-site area was noted and may be a result of a lower dose used in that area, varying redox conditions across the site or possible sorbed mass in the source zone resulting in continued back diffusion following treatment.
SANG Site 8	cis-1,2-DCE: 1,200 µg/L	37	0.4 percent Hepure ZVI injected using Ferox	Concentrations of chlorinated VOCs in monitoring wells within the treatment area were reduced to less than MCLs (~99.4%). Because concentrations were already decreasing as a result of previous treatments in the area, it is uncertain the degree to which the ZVI contributed to site clean-up. pH increased following treatment, and DO was maintained at levels less than 1 mg/L throughout most of the post-treatment monitoring period. ORP was also reduced, but not to levels ideal for abiotic reduction of chlorinated ethenes.

Table 1-1. Nine Site Summary of ZVI Treatment Performance

Site Name	Primary Contaminants and Highest Baseline Concentration(s)	Groundwater Velocity (feet per year [ft/year])	ZVI Dosage (pounds [lbs] ZVI/lb soil)	Conclusions and Comments
Mixing Sites				
Arnold AFB SWMU 16	TCE: 5,616 µg/L	81	0.2-percent (injections) 0.8-percent ZVI (mixing)	Substantial decreases of TCE were observed in the source area as well as in downgradient wells. Nitrate was also effectively treated with ZVI. Strongly reducing conditions were not achieved at this site and significant generation of daughter products occurred. This, in conjunction with movement of contaminants, resulted in an overall increase of total VOCs at the site. Daughter products produced did not subsequently degrade.
St. Louis Ordnance Depot OU1	Tetrachloroethene (PCE): 36,100 µg/L	No aquifer testing completed	1-percent ZVI – mixed with no clay addition or water	Concentrations of chlorinated VOCs in monitoring wells within the treatment area and the downgradient area were reduced to less than the site clean-up goal of 21,000 µg/L (average reduction of 99.8%) . Highly reducing conditions favorable for β-elimination were achieved in the mixing area. Some evidence of reductive dechlorination was also observed. pH increased and DO was maintained at levels less than 1 mg/L throughout post-treatment monitoring period in the soil-mixing area. DO was also reduced to less than 1 mg/L during most rounds of downgradient well monitoring. Some reduction in concentrations downgradient also occurred.
Camp Lejeune Site 89	1,1,2,2-PCA: 110,000 µg/L TCE: 490,000 µg/L cis-1,2-DCE: 140,000 µg/L trans-1,2-DCE: 26,000 µg/L VC: 3,400 µg/L	17-55	2-percent ZVI, 3-percent bentonite mixture	Concentrations were reduced by >99.9% in all treatment area wells (in most cases to less than laboratory detection levels). No rebound of VOCs was observed. ORP was reduced to -711 mV. DO was also reduced and pH increased, but some rebound of these parameters has occurred.

Table 1-1. Nine Site Summary of ZVI Treatment Performance

Site Name	Primary Contaminants and Highest Baseline Concentration(s)	Groundwater Velocity (feet per year [ft/year])	ZVI Dosage (pounds [lbs] ZVI/lb soil)	Conclusions and Comments
Indian Head Site 17	TCE: 870,000 µg/L cis-1,2-DCE: 170,000 µg/L VC: 14,000 µg/L	43-400	1-percent ZVI, ZVI/bentonite slurry	Concentrations were reduced by >99%, to levels just greater than MCLs. Highly reducing conditions were achieved in the mixing area. pH increased following treatment, DO was reduced to levels less than 1 mg/L. No rebound of contaminants was observed.

Notes:

1,1,2,2-PCA = 1,1,2,2-tetrachloroethane

MCL = maximum contaminant level

The amount of performance data available for the ZVI treatment systems varied widely between sites. In most cases, the amount of upgradient, treatment zone, and downgradient data was suitable for compliance assessments but was less optimal or insufficient for conducting a comprehensive evaluation of performance. Nevertheless, some general conclusions were made from the desktop study.

The degree of VOC degradation achieved by the various ZVI treatment systems varied from as little as 33 percent to nearly 100 percent. The greatest degree of VOC treatment was achieved within ZVI soil mixing zones and was more effective with increasing ZVI dose (ZVI to soil ratio). Baseline ORP was also a factor, with sites already under reducing conditions at the time of treatment performing slightly better than sites under oxidizing conditions. Evidence of degradation through the sequential reductive dechlorination pathway was found at all the injected ZVI treatment systems, downgradient of one PRB, and at two of the four soil mixing sites. The least amount of evidence for the reductive dechlorination pathway was found at Camp Lejeune Site 89 (dose of 2 percent) and Indian Head Site 17 (dose of 1 percent) where the β-elimination pathway appeared to dominate. A summary of dose, initial ORP, lowest ORP achieved, percent reduction in contaminant concentration, and daughter product generation is provided as **Table 1-2**.

Table 1-2. Nine Site Analysis ZVI Design Metrics and Performance

Site	Iron Dose (ZVI:soil mass ratio)	Initial ORP (millivolts [mV])[1]	Lowest ORP Achieved During Treatment (mV)[1]	Percent Reduction/ Increase in Concentrations[1]	Generation of Daughter Products Observed	If Yes, with or without subsequent Reductions
ABL Site 5	40*	128	-212	-70.7%	Yes (but may be due to migration)	Without
McGuire OT-16	0.5	19.92	-501.4	-33%	No	NA
St. Julien's Creek Site 21	0.8	-2.8 to 128.5	-418.1	-96.3%	Yes	With
White Oak Site 13	0.2 (onsite) /0.5 (offsite)	-1 to 328	-303	-58.6% (onsite)/-85.6% (offsite)	Yes	With
SANG Site 8	0.4	-68 to -143	-184.9	-99.4%	Yes	With
Arnold Air Force Base SWMU 16	0.2	79-151	-205	+397%	Yes	Without
St. Louis Ordnance Depot OU1	1	98.7-232	-400	-99.8%	Yes	With (source area)
Camp Lejeune Site 89	2	-71 to -51	-711	-99.99%	No	NA
Indian Head Site 17	1	-54 to 123	-308	-99.98%	No	NA

Notes:

* Based iron: sand ratio in PRB

[1] Treatment Area, or downgradient for the ABL PRB

NA = not applicable

Downgradient geochemical changes in groundwater quality most frequently observed include increases in pH and decreases in ORP, DO and other terminal electron acceptors (e.g., sulfate). Dissolved iron was commonly noted to increase following treatment. At the only site where arsenic data were available (St. Julien’s Creek Site 21), arsenic concentrations increased considerably in ZVI treatment areas, a possible result of mobilization due to reducing conditions. Microbial data were not available post-treatment at any of the nine sites evaluated.

Rebound of geochemical conditions to baseline levels generally took over a year, with some sites not reaching baseline conditions at the time of this study. However, conditions optimal for β-elimination were generally not observed 5-12 years following treatment. **Table 1-3** shows time to ORP rebound for each site evaluated.

Table 1-3. Nine Site Analysis ORP Time to Rebound

Site	Time to ORP Rebound in Treatment Area (days)	Time to ORP Rebound in Downgradient Wells (days)
ABL Site 5	N/A	1461
McGuire OT-16	151	609
St. Julien's Creek Site 21	1826	NA
White Oak Site 13 (on site)	NA*	NA
White Oak Site 13 (off site)	NA*	NA
Savannah ANG Site 8	NA*	NA
Arnold Air Force Base SWMU 16	304	1,218
St. Louis Ordnance Depot OU1	1673	915
Camp Lejeune Site 89	426	NA
Indian Head Site 17	NR	NR

Notes:

*Time to rebound not calculated for White Oak and Savannah ANG as ORP results are still decreasing as of the most recent sampling event

NR indicates baseline data not recorded

ABL Site 5 was identified as the preferred PRB site for field study because the remedy for this site was the more effective of the PRB sites and the trenched wall configuration was ideal for collection of remaining iron. St. Louis Ordnance Plant OU1 was selected as the preferred source area treatment site because the remedy was highly effective (average concentration reduction of 99.8%) and no clay was mixed with the ZVI, making it possible to attribute all reductions in concentrations to ZVI treatment rather than sorption.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overarching objective of this demonstration is to evaluate the long-term effectiveness of ZVI groundwater remedies with respect to reactivity, hydraulic performance, and mechanisms of action. Following completion of the desktop study, two field test sites were evaluated to achieve the overarching project objective: one PRB Site (ABL) and one soil mixing site (former St. Louis Ordnance Plant). Specific objectives for the field efforts at each site are listed below.

1.2.1 Specific PRB Site Objectives

1. Evaluate the current reactivity of the ZVI
2. Evaluate the hydraulic flow characteristics of the PRB
3. Evaluate abiotic and biological degradation processes that are occurring in the vicinity of the PRB

1.2.2 Specific Source Area (Soil Mixing Site) Objectives

1. Evaluate the current reactivity of the ZVI
2. Evaluate hydraulic flow characteristics within the mixing area and outside of the mixing area

3. Evaluate abiotic and biological degradation processes that are occurring within the source treatment area

1.3 REGULATORY DRIVERS

Based on 40 Code of Federal Regulations §300.430(f)(4)(ii), "if a remedial action is selected that results in hazardous substances, pollutants, or contaminants remaining at the site above levels that allow for unlimited use and unrestricted exposure, the lead agency shall review such action no less often than every five years after initiation of the selected remedial action." The five-year review process requires an assessment of whether the existing remedy is functioning as intended, and if the remedy is not determined to be functioning as intended, an assessment of recommended additional actions is prepared (United States Environmental Protection Agency [USEPA], 2001). The results of this study are intended to help the Department of Defense end users, regulators, and other stakeholders better assess of functionality of ZVI remedies as part of the five-year review process and during other remedy optimization efforts.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

2.1.1 Zero-valent Iron Technology Development and Application

Metal-based reductive chemistry was first used to dechlorinate VOCs in the late 1970s and was designed as a possible treatment for metals-laden industrial wastewater streams (Sweeny, 1980). Utilization of this technology to treat contaminated groundwater, primarily through application of ZVI, took off in the 1990s. In 1994, the first full-scale commercial PRB was approved for use in the State of California by the San Francisco Regional Water Quality Control Board, and in 1994, the first "chemical treatment wall" was identified as the preferred alternative in a Somersworth Municipal Landfill, Somersworth, New Hampshire Record of Decision (USEPA, 1994). The USEPA guidance document *Permeable Reactive Barrier Technologies for Contaminant Remediation* (1998) made performance and compliance monitoring recommendations for PRB sites. A source area at a former manufacturing facility in Fairfield, New Jersey was also treated with granular iron and sand backfill that same year (ITRC, 2005). This represented a different application for ZVI in comparison with the downgradient barrier approaches previously employed. In the 2000s, technology advances including microscale and nanoscale ZVI materials, use of bimetallic coatings, biological enhancements, and improved application technologies such as injection and soil mixing with stabilizing agents allowed for more effective source area treatment. More remedies were implemented which involved direct treatment of source areas with ZVI.

In the early 2000s, evaluations of PRBs installed in the 1990s indicated formation of a number of mineral species on iron surfaces in PRBs, including insoluble species like calcium carbonates, iron carbonates, and iron hydroxides. Additionally, precipitates that conduct electrons, such as magnetite and carbonate green sand, were shown to form (Wilkin at al., 2003). Column studies completed by Zhang and Gillham (2005) demonstrated a 7 percent loss of porosity due to mineral precipitates. Additionally, these column tests showed the iron reactivity rate of decline occurred more rapidly than a loss of permeability. In Technical/Regulatory Guidelines *Permeable Reactive Barriers: Lessons Learned/New Directions* (ITRC, 2005), ITRC made additional recommendations for performance monitoring of PRBs and source zone treatments and specified some areas for further investigation at source treatment sites. These included the longevity of the iron as a function of amount and size, potential for loss of iron due to unproductive reactions, the potential for biologically mediated reactions, ability to treat DNAPL, migration of DNAPL resulting from injection, ability to address contaminants in low permeability layers, and optimal performance monitoring approaches. In Technical/Regulatory Guidelines *Permeable Reactive Barrier: Technology Update* (2011), ITRC identified areas for further research including studies needed to better understand what geochemical phases become important or become inactive as the iron ages and changes hydraulic characteristics of the aquifer over time. While the USEPA and ITRC guidance documents have recommended specific performance monitoring procedures including coring for precipitate build-up evaluation and tests for permeability alterations, in the interest of cost-savings, monitoring at most ZVI-treatment sites has generally focused on compliance with groundwater standards.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Data from nine ZVI sites were evaluated to better assess the advantages and limitations of the technology for remediation of sites with VOC contamination. Based on the results of the desktop study (**Appendix A**, the following advantages were noted:

2.2.1 Advantages Identified in Desktop Review Phase of Project

- Significant dose-dependent VOC concentration reductions were observed at most sites evaluated, in some cases without the generation of daughter products, indicating degradation through the β-elimination pathway
- Greatest VOC concentration reductions were generally observed at soil-mixing sites
- Evidence of degradation through the sequential reductive dechlorination pathway was also found at all of the injected ZVI treatment systems, downgradient of one PRB, and at two of the four soil mixing sites reviewed
- Reducing conditions generally remained for years after treatment
- Most sites reviewed did not show VOC rebound to baseline levels at the time the desktop review was completed, which was in most cases more than 5 years following treatment

2.2.2 Disadvantages Identified in Desktop Review Phase of Project

- Microscale ZVI cannot be injected using methods commonly used for liquid phase reagents – it must be fractured into the formation or mixed in using augers; delivery by fracturing may not achieve uniform reagent delivery throughout the aquifer and was generally not as effective as ZVI treatment through mixing
- Longevity of the ZVI may not be adequate to fully treat some VOC source zones
- Contact with contaminants is key – treatment efficacy was often limited by ZVI emplacement access restrictions due to infrastructure (buildings and utilities) and terrain
- Treatment is dependent on initial site conditions, with sites already under reducing conditions performing better

2.2.3 Advantages Identified During Field Phase of the Project

- Some reactivity of iron remained many (5-11) years following treatment, as indicated by lower than baseline ORP, presence of iron precipitates favorable for continued abiotic degradation (e.g., magnetite), reactivity with resazurin, and geochemical and microbial changes across both treatment areas indicating reducing conditions are present within the treatment areas.
- No changes in groundwater flow characteristics were noted which would impact remedy effectiveness at either field study site.
- No rebound of VOC concentrations was noted at either field study site over time, indicating long-term efficacy of treatment
- Presence of anaerobic reductive dechlorinating bacteria at the St. Louis site in addition to aerobic ethenotrophs and cometabolizers capable of VC degradation supports continued degradation potential.

2.2.4 Disadvantages Identified During the Field Phase of the Project

- Concentrations downgradient of the treatment areas at both sites were higher than within the treatment areas; while this was known or suspected prior to treatment at both sites, it highlights the value of additional monitoring points before design and following treatment.
- Some reductions in reactivity, formation of precipitates on ZVI, and weathering of ZVI to other iron species was observed; however, given the 11- and 5-year lifetime of these remedies, this was not entirely unexpected.

2.3 TECHNOLOGY DEVELOPMENT

This study did not involve development of a new technology, but rather involved evaluation of long-term performance of an existing technology. The desired outcome of the project was the generation of a tool kit of best practices for optimal design and performance monitoring of ZVI remedies. These best practices are provided in Section 9 of this report.

3.0 PERFORMANCE OBJECTIVES

The overall objective of the field demonstration portion of this project was to evaluate the long-term performance of ZVI applications at a PRB site and a soil mixed/injection source area treatment site to develop a design and performance monitoring tool kit for remedial project managers (RPMs). The technical objective of this project was to collect biogeochemical, mineralogical, and potentiometric data to evaluate the effectiveness of ZVI at each site, its influence on the microbial community, and its impact on hydraulic conditions. Performance objectives for data discussed in Section 5 are tabulated in **Table 3-1**.

Table 3-1. Performance Objectives

Performance Objective	Data Requirements	Performance Criteria	Results
Quanitative Objectives			
Assess continued zero valent iron (ZVI) influence on geochemistry and contaminant chemistry	Groundwater and field measurements were collected from 12 wells at theABL permeable reactive barrier (PRB) and seven wells at the St. Louis soil mixing site. The samples were analyzed for site contaminants, total and dissolved metals, total organic carbon (TOC), chloride, fluoride, nitrate, nitrite, sulfide, sulfate, phosphate, alkalinity, hardness, sulfide, ammonia, methane, ethane, ethene, and acetylene. Field measurements including pH, DO, and oxidation/reduction potential (ORP) were also collected.	Recognition of horizontal geochemical changes along the flow path through the ZVI application area.	Geochemical differences (changes in ORP, DO, pH, and anions and other geochemical indicators) were noted within the St. Louis Operable Unit 1 (OU1) treatment area in comparison to outside of the treatment area, consistent with continued abiotic reactions. Similar observations were made in one of the two transects downgradient of the PRB at ABL Site 5. Highly reducing conditions were observed in some portions of both of the test sites. A clean front was observed across one transect at the PRB site. Additionally, in the location within the mixing site which was monitored before and after treatment, no rebound was observed. Data indicated continued ZVI effectiveness.

Table 3-1. Performance Objectives

Performance Objective	Data Requirements	Performance Criteria	Results
Determine the current degree of ZVI reactivity	Evaluate reactivity of remaining iron material through acidification and hydrogen generation, and resazurin dye testing.	Reacted ZVI material from the application areas will be compared against unreacted control material and background reference soil samples. Reacted ZVI will show more reducing capacity than background soil samples.	Reactivity analysis was completed using acidification and hydrogen generation as well as with resazurin testing for the St. Louis site and indicated low presence of ZVI (<0.04% of sample dry mass) in the mixing area. However, 100% reactivity to resazurin was observed in mixing area soil/iron in comparison to little reactivity in surrounding soils, indicating potential for continued abiotic reactions. Due to laboratory availability, this testing was not completed on ABL samples.
Qualitative Objectives			
Determine the degree of mineralization of the ZVI	ZVI samples in two locations in the former St. Louis Ordnance Plant soil mixing area and at four locations (two upgradient and two downgradient) at the ABL PRB were collected to allow for analyses by scanning electron microscopy, x-ray diffraction (XRD), thermogravimetric, x-ray absorption spectroscopy, and carbon/sulfur analyses to determine particle morphology, size, composition, mineral identification, and iron oxidation states and bonding environments.	The remaining iron observed will be ZVI, bivalent or mixed valence iron precipitates (magnetite, iron carbonate hydroxide, iron sulfide, and green rust). Extrapolate individual sample results and consider other findings to draw conclusions about long-term performance of the ZVI application area.	XRD, x-ray absorption near edge structure (XANES) spectroscopy, magnetic susceptibility, magnetic separation, hydrogen production, and energy dispersive line scans across identified iron particles indicated very little ZVI remaining in the cores collected at both sites. However, magnetite and hematite were observed at ABL, while magnetite was dominant with some goethite (observed in XANES) at St. Louis. Magnetite may still facilitate abiotic reactions. Mineral precipitates (calcium carbonate and iron oxide) were observed coating the iron particles in the upgradient portion of the ABL PRB, but were not significant enough to interfere with hydraulic performance of the PRB. Overall data indicate some passivation of the ZVI treatments at both sites, although degradation is still likely to be occurring through secondary reactivity and possibly by ZVI present in areas not represented by the samples analyzed. Due to laboratory availability, the downgradient portion of the PRB at ABL was not evaluated and the sample sets at both sites were very limited.

Table 3-1. Performance Objectives

Performance Objective	Data Requirements	Performance Criteria	Results
Assess microbial community changes due to ZVI application	Nine groundwater samples at the ABL PRB site and seven at the St. Louis soil mixing site were collected for Next Generation Sequencing (NGS) and QuantArray-Chlor analysis.	Recognition of horizontal microbial changes along the flow path through the ZVI application area.	Differences in microbial populations downgradient of (at the ABL PRB) and within the treatment area (at the St. Louis site) were noted. While dechlorinating microbial populations at the ABL site (reductive dechlorinators, ethenotrophs capable of dechlorination, and cometabolizers) were not impacted by the presence of the wall, sulfur oxidizing bacteria (Sulfurimonas) were found in abundance just downgradient of the wall, but not in other areas of the site, indicating some continued impact of the wall on site microbiology. At the St. Louis site, populations of reductive dechlorinators capable of at least partial dechlorination of trichloroethene (TCE) (such as Dehalogenimonas sp.) were enhanced in the treatment area, but Dehalococcoides sp. functional genes associated with complete dechlorination were generally absent. NGS data were indicative of significant changes in microbial populations in the mixing area (e.g. higher populations of Firmicutes), supporting geochemical data indicating long-term continuing impacts from ZVI at the site.
Determine if ZVI application changed groundwater flow	Wells within the monitoring network were surveyed as necessary and gauged to assess flow direction. Slug tests were performed within and outside of the ZVI-treated area at the source area treatment site.	Groundwater potentiometric elevations were used to distinguish hydraulic flow near ZVI application. Hydraulic conductivity was assessed within and outside of the iron treated area to determine if changes occurred as a result of treatment.	No significant changes (mounding, diversion around the wall, etc.) were noted in the groundwater flow at the ABL site. At the St. Louis site, flow patterns were difficult to discern because of differences in well-screen intervals. Similar hydraulic conductivity values were measured within and outside of the treatment area at St. Louis Ordnance Plant during slug testing, indicating minimal impacts to hydraulic characteristics from ZVI treatment.

Table 3-1. Performance Objectives

Performance Objective	Data Requirements	Performance Criteria	Results
Develop pre- and post-treatment data requirements for RPM tool kit	Field data were evaluated in consideration of the desktop review performed as the first phase of this project.	Based on data evaluation, prepare summary of most useful information for RPM to design and monitor ZVI applications, distribute to Navy RPMs, and solicit feedback.	Recommended best practices are included in Section 9.

4.0 SITE DESCRIPTION

4.1 SITE LOCATION AND HISTORY: ABL SITE 5, ROCKET CENTER, WEST VIRGINIA

The following sections describe site histories at the two selected demonstration sites, ABL Site 5 and the former St. Louis Ordnance Plant OU1.

4.1.1 Site History – ABL Site 5

ABL is a U.S. Navy-owned, contractor-operated (ATK Tactical Systems Company LLC [ATK]) research, development, testing, and production facility for solid propellants and motors used for ammunition, rockets, and armaments. The facility is located in Mineral County in the northeastern part of West Virginia, along the West Virginia and Maryland border (**Figure 4-1**). The facility lies between the North Branch Potomac River to the north and west, and Knobly Mountain to the south and east. The land surrounding the ABL facility is primarily rural agricultural and forest. ABL consists of about 1,634 acres of land with about 350 buildings. The facility is divided into two distinct operating plants, Plant 1 and Plant 2. Plant 1 is the government-owned, contractor-operated (GOCO) facility owned by the Navy and leased to ATK by the Naval Sea Systems Command through a Facilities Use Contract. It occupies about 1,577 acres in area (including a large undeveloped area). Plant 2, owned and operated by ATK, occupies the remaining 57 acres.

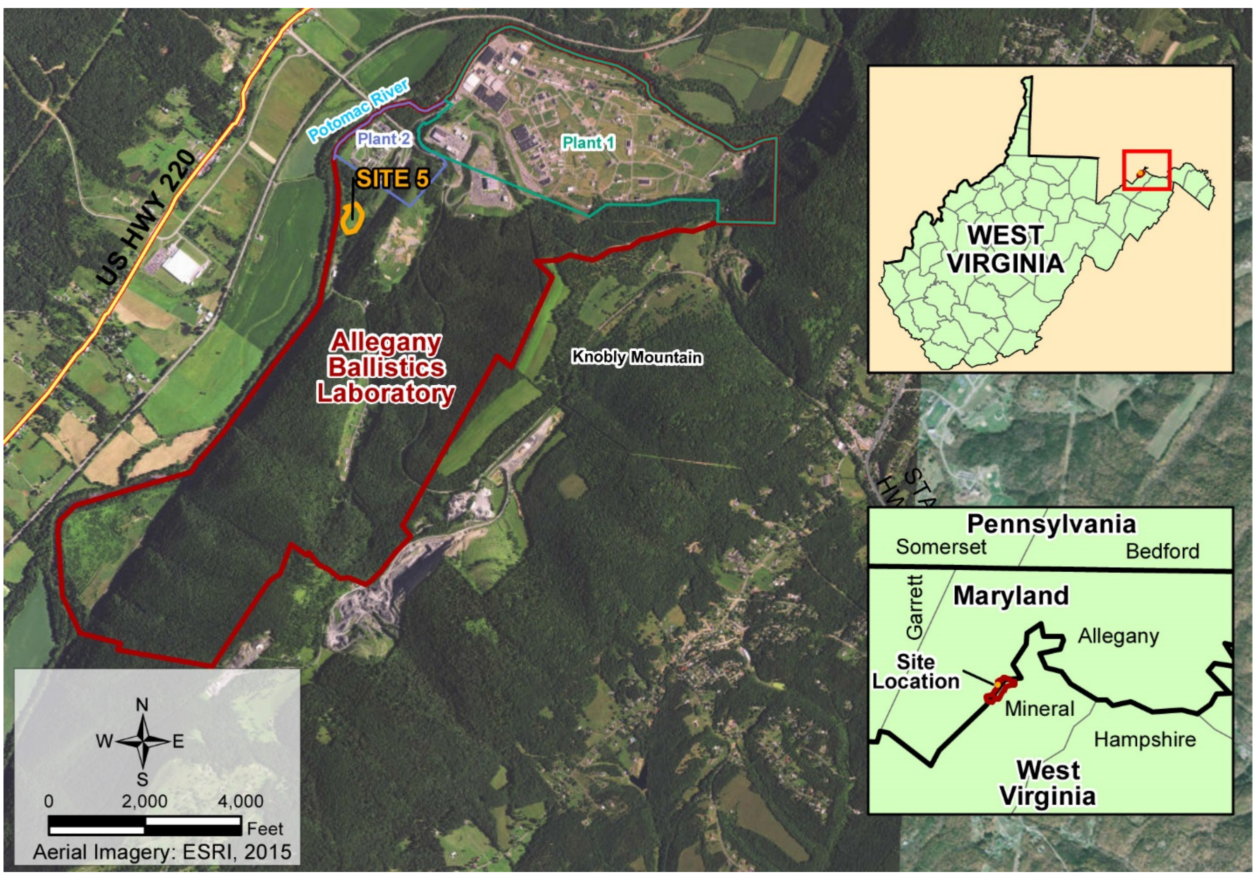

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Figure 4-1. ABL Site 5 Location Map

Site 5 is a former landfill on the GOCO portion of the facility. The landfill operated from the early 1960s to 1985, accepting wastes generated by ABL that were deemed to be inert. Inert wastes were defined as wastes not contaminated with explosives nor generated at an area on the facility where explosives were managed. Wastes reported to have been disposed of at Site 5 include drums that previously contained tetrachloroethene (PCE), methylene chloride, and acetone; fluorescent tubes (potential mercury source); unknown laboratory and photographic chemicals; fiberglass and other resin-coated fibers; metal and plastic machining wastes; and construction and demolition debris (CH2M, 2003). The landfill covers 1.3 acres and was capped in 1997.

4.1.2 Physical and Hydrogeologic Setting – ABL Site 5

Site 5 is located on a terrace above the North Branch Potomac River. The Site 5 topography gently slopes toward the North Branch Potomac River, then becomes steeper immediately adjacent to the river. Site 5 is underlain by unconsolidated alluvial deposits of fill, silty clay, and clayey gravel (alluvium) and predominantly shale bedrock. The depth to bedrock at Site 5 is approximately 15 to 20 feet below ground surface (bgs). Depth to shallow groundwater is between 1 to 12 feet bgs. Shallow (alluvial) groundwater flow is northwestward, subparallel to the river (**Figure 4-2**). Alluvial groundwater velocity downgradient of the landfill was estimated to be 0.81 foot per day, or 293 feet per year. Groundwater level data in the vicinity of the wall collected as part of this investigation is summarized in Section 5.

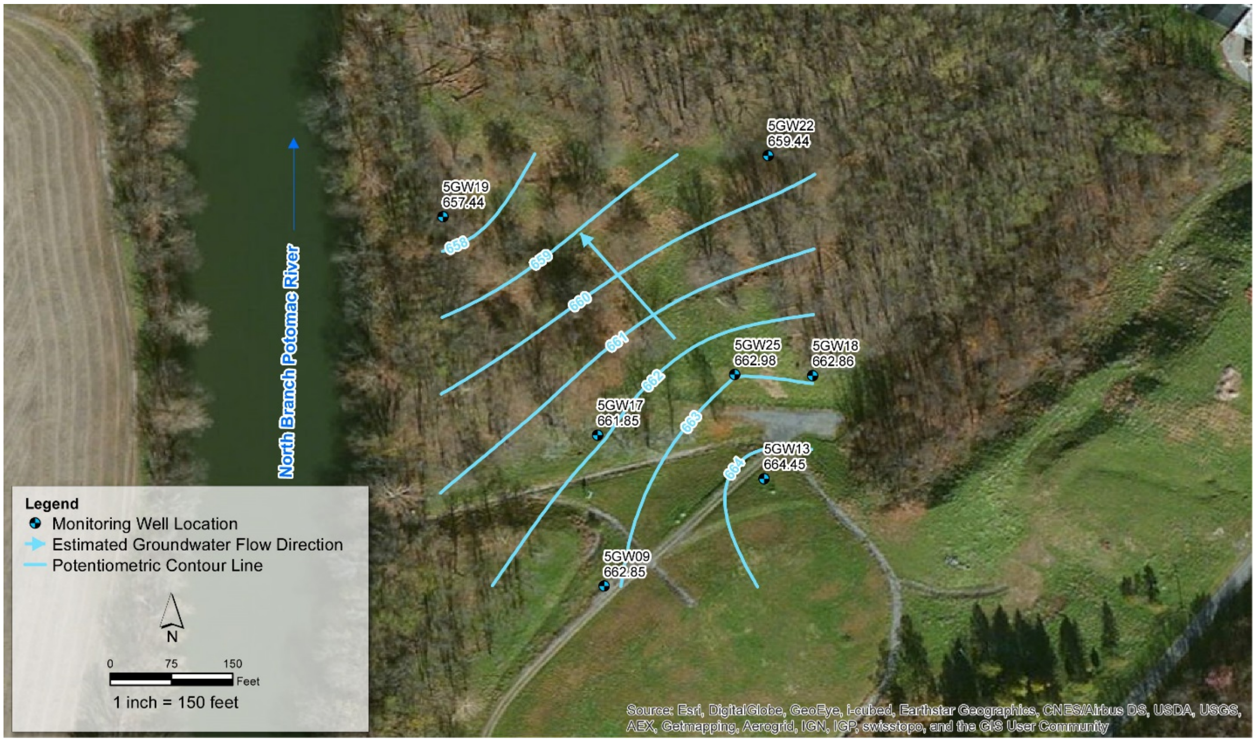

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Figure 4-2. ABL Site 5 Groundwater Contour Map (August 2012)

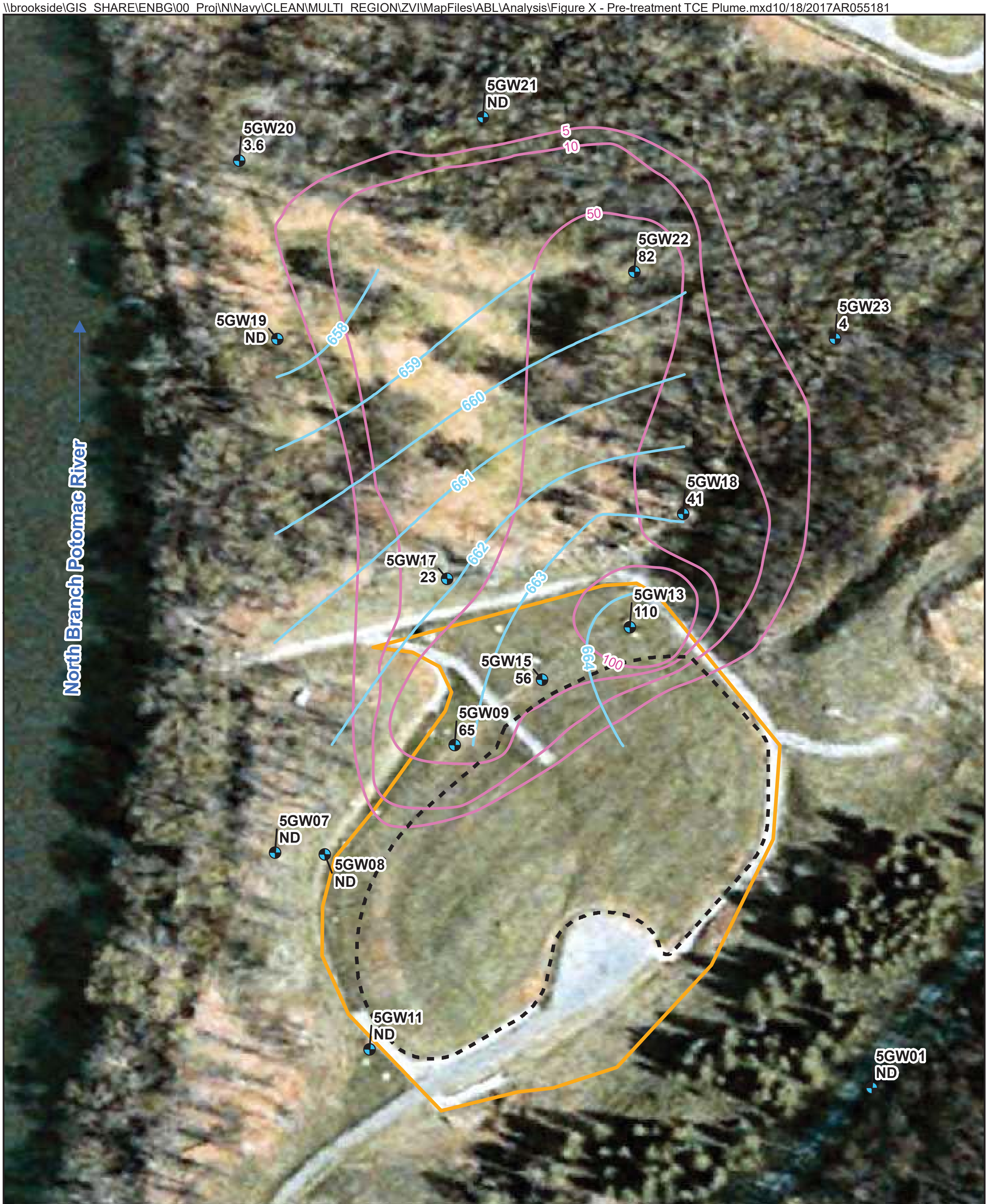
4.1.3 Contaminant Distribution – ABL Site 5

The highest historical TCE concentrations at ABL Site 5 have been in the 100 to 150 micrograms per liter (µg/L) range, on the downgradient edge of the landfill boundary within the alluvium. The dissolved phase TCE plume in the alluvial aquifer originated within the landfill, and prior to the installation of the PRB, extended over 700 feet downgradient toward the North Branch of the Potomac River (**Figure 4-3**); while groundwater flow is to the north-northwest, the contaminant plume extends mostly northward. The landfill and resultant groundwater contaminant plume are located in a former meander bend of the river. The depositional environment (i.e., paleochannel) likely has more influence on the contaminant migration then the groundwater potentiometric gradient, resulting in this discrepancy. While TCE has been detected in wells installed in the fractured shale bedrock, detections in these wells have been sporadic and have typically not exceeded the maximum contaminant level (MCL) of 5 µg/L. TCE daughter products (cis-1,2-DCE, VC) have also been detected in groundwater, but have not exceeded their respective MCLs of 70 and 2 µg/L (CH2M, 2013).

4.1.4 ZVI Treatment Summary – ABL Site 5

In June 2006, in order to address the migration of TCE from the landfill towards the Potomac River, a 200-foot-long, 2-foot-wide, and 17- to 21.5-foot-deep PRB was installed through the alluvial aquifer and keyed into the bedrock (**Figure 4-4**) at the downgradient edge of the landfill. A trench was excavated nominally 24 inches wide and up to 21.5 feet deep, depending on the elevation of the bedrock. As the trench was excavated, a biopolymer slurry was added to the trench for side wall support. A total of 357,000 pounds (lb) of ZVI (EnviroMetal Technologies Inc. CC-1004 [-8+50 mesh] manufactured by Connelly GPM, Inc.) were mixed with 536,000 lb of sand that was then added to the excavation for completion. The trench was then covered with a 6-ounce geotextile, and a 3-foot-deep clay cap was placed over top of the barrier. While the required residence time for treatment of the ZVI only required a 7-inch-thick PRB based on initial calculations (AGVIQ and CH2M, 2006), the wall was constructed to be 2 feet thick due to trenching limitations. The remedy for TCE in the portion of the plume already downgradient of the PRB at the time of installation was identified as monitored natural attenuation (CH2M, 2013).

\\brookside\GIS_SHARE\ENBG\00_Proj\N\Navy\CLEAN\MULTI_REGION\ZVI\MapFiles\ABL\Analysis\Figure X - Pre-treatment TCE Plume.mxd10/18/2017AR055181



Legend

- Monitoring Well Location
- Site Boundary
- Installation Boundary
- Plume Line
- Landfill Boundary
- Groundwater Elevation Contour (ft amsl)

Note:
Data contoured represents TCE concentrations collected between 1994 and 2000, highest value in this date range was selected.

N

0 75 150
Feet

Imagery Source: ©2003, Google

Figure 4-3
Pre-treatment TCE Plume
Allegany Ballistics Laboratory
Rocket Center, West Virginia

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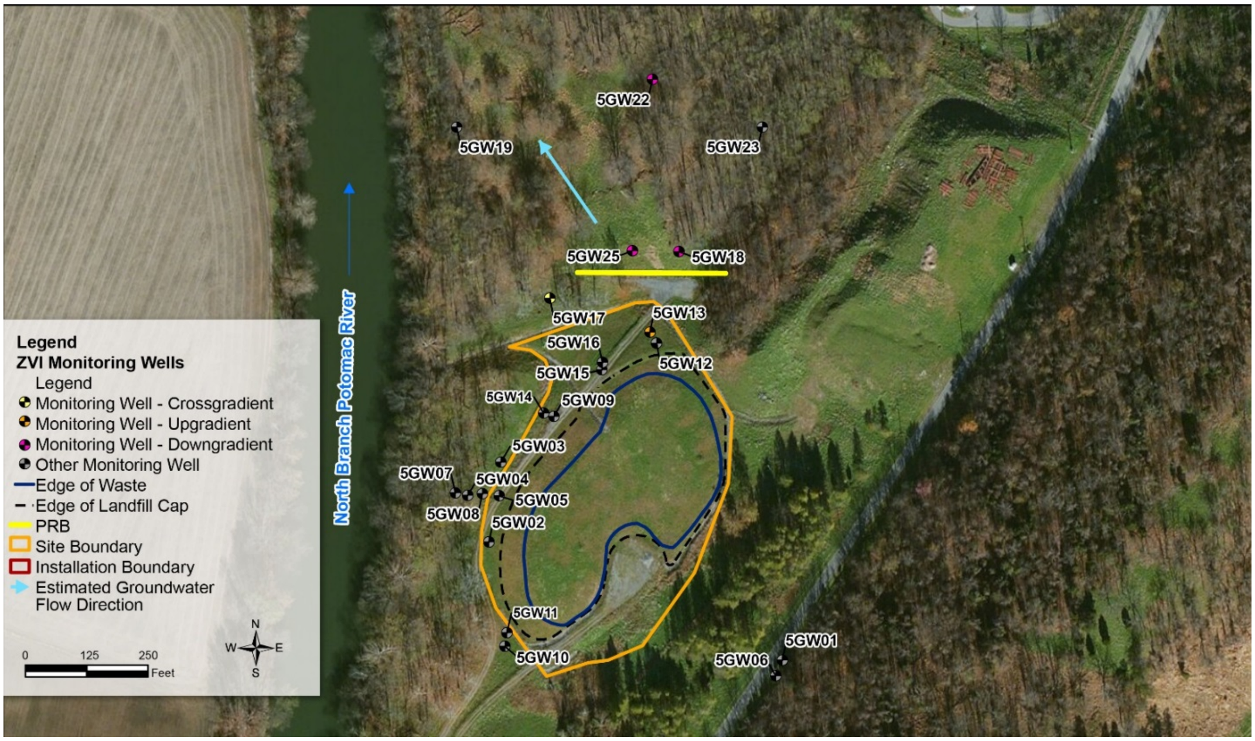

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Figure 4-4. ABL Site 5 Treatment Area

4.2 SITE LOCATION AND HISTORY: FORMER ST. LOUIS ORDNANCE PLANT OU1, ST. LOUIS, MISSOURI

4.2.1 Site History – Former St. Louis Ordnance Plant OU1

The former St. Louis Ordnance Plant is located on the western boundary of the city limits of St. Louis (**Figure 4-5**). The St. Louis Ordnance Plant operated from 1941 to 1945 as a small arms ammunition production facility. The plant was divided into two areas designated No. 1 (east of Goodfellow Boulevard) and No. 2 (west of Goodfellow Boulevard). The former Hanley Area consists of the 14.68 acres at the northeastern end of Plant Area No. 2 at the intersection of Stratford Avenue and Goodfellow Boulevard (**Figure 4-5**). The processes there consisted of the blending of primary explosives and incendiary compounds, and the tracer charging of .30- and .50-caliber projectiles as part of the assembly of the final product. Powder wells installed in 1941 received wastewater from buildings and magazines until 1945. The powder wells provided sediment collection before discharge to the sanitary sewer. The former Hanley Area takes its name from Hanley Industries, Inc., which leased the area in 1959 and conducted operations there through 1979. Hanley used the site for research, development, manufacture, and testing of various explosives. Over that time, Hanley produced specialty ordnance and non-ordnance devices for the U.S. military and the National Aeronautics and Space Administration. Hanley used most of the buildings to load detonators and primers and to mix explosives. Explosives were dried in magazines by leaving cans of explosives exposed to the air, and a lead azide reactor was operated in one of the magazines, the location of which is unknown. Hanley reportedly did not use the powder wells or sumps on the property for wastewater disposal (USACE, 2010).

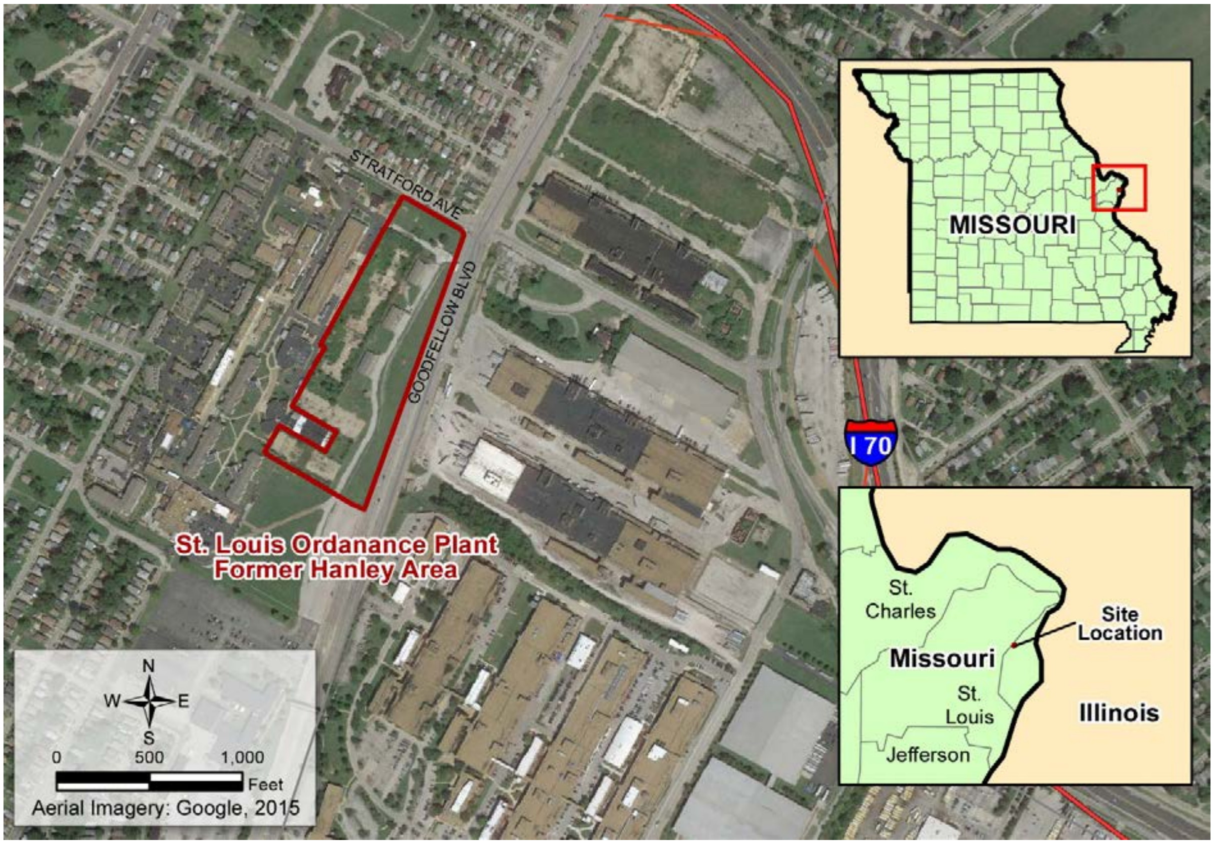

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Figure 4-5. Former St. Louis Ordnance Plant OU1 Site Location Map

The site ground surface consists of paved areas and landscaped vegetation. The site is completely fenced (partially with iron fencing and the remaining with a 6-foot-tall chain link fence). The site contains underground rooms (former basements and bunkers), tunnels for service utilities, and a combined underground wastewater and stormwater collection system. The underground structures are still intact. Most other buildings have been demolished or are currently only used for storage. Building 219G is occupied during business hours (USACE, 2010).

4.2.2 Physical and Hydrogeologic Setting – Former St. Louis Ordnance Plant OU1

Overburden soils at the former St. Louis Ordnance Plant site consist primarily of clay. Fill material including gravel, concrete rubble, brick debris, and sand has been observed in portions of the site as deep as 11 feet. A layer of interbedded clay and silt is observed between roughly 20 to 25 feet bgs in the north part of the former Hanley Area. A hard, dry, completely weathered shale is present beneath the clay (USACE, 2010). The thickness of the weathered shale ranges from 6 to 12 feet in boreholes advanced to depths at which the competent bedrock is encountered. Groundwater is present within more permeable silt and clay lenses that are locally discontinuous within the upper clay unit. Depth to groundwater is generally between 3 and 10 feet bgs. Saturated conditions are not observed within the weathered shale beneath the clay unit. Groundwater is encountered in a 6-inch saturated coal layer within the competent shale zone. Groundwater within the coal does not appear to be connected to groundwater in the discontinuous silt and clay lenses. Based on previous investigations groundwater in the silt and clay generally flows from the south and west to the east-northeast (**Figure 4-6**).

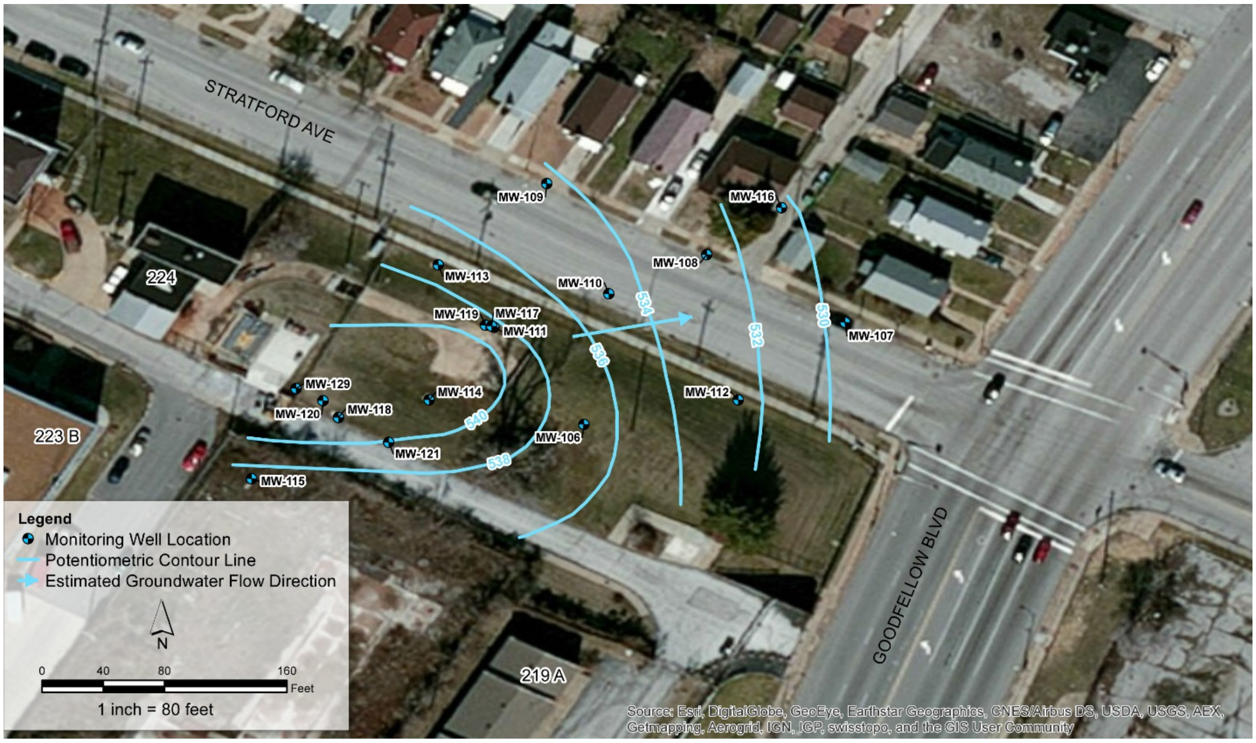

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Figure 4-6. Former St. Louis Ordnance Plant OU1 Groundwater Contour Map (April 2015)

4.2.3 Contaminant Distribution – Former St. Louis Ordnance Plant OU1

Dissolved-phase groundwater contamination was identified in three distinct plumes containing one or more chlorinated VOCs at the site. Only one of these plumes was treated with ZVI. Consequently, the remainder of this nature and extent description is focused on that area, designated as Plume A. Plume A consisted of elevated concentrations of PCE, TCE, and cis-1,2-DCE, with PCE at a maximum concentration of 43,300 µg/L. The plume originates on the north side of a parking lot near a sewer system. A former building (220) was previously located in this area and is suspected to have been the source. The presence of TCE and cis-1,2-DCE may be attributed to reductive dechlorination of PCE. There is no historical record of a single large spill, but sporadic discharge of small quantities of spent product is assumed to have occurred. **Figure 4-7** illustrates the areal extent of total VOC concentrations in and around the treatment area prior to the Remedial Action. The depth of groundwater contamination extends from the water table (3 to 10 feet bgs) to the weathered shale interface at roughly 26 to 28 feet bgs.

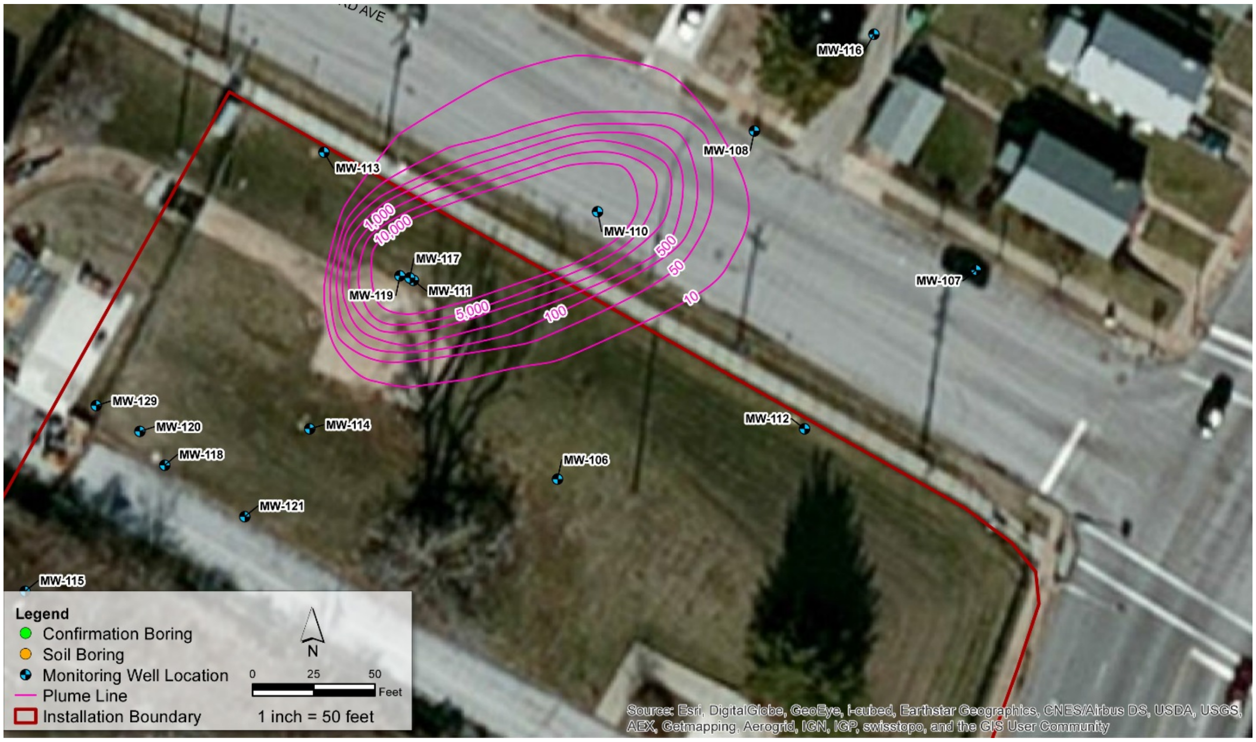

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Figure 4-7. Former St. Louis Ordnance Plant OU1 Total VOC Plume (December 2011)

4.2.4 ZVI Treatment Summary – Former St. Louis Ordnance Plant OU1

In March 2012, soil mixing was performed to reduce PCE concentrations in groundwater below the active treatment remediation goal of 21,000 µg/L. ZVI soil mixing occurred over an area of 1,491 square feet to an average depth of 25 feet, for a total treatment volume of 1,383 cubic yards of soil. The treatment depth was based on the depth to the weathered shale bedrock. To mix the soil, ZVI was placed directly into an open borehole advanced to the depth of each column. The column was then mixed using an auger 5 feet in diameter.

An estimated 659 pounds of contaminant mass were present in the subsurface within the treatment area: 23 pounds dissolved in groundwater and 636 pounds adsorbed to soil. The mass of contaminants dissolved in groundwater and adsorbed to the soil was estimated based on various site assumptions including estimated porosity (0.25), soil density (1.5 tons per cubic yard), average concentrations of PCE detected in soil (169 milligrams per kilogram, and maximum concentrations of PCE in groundwater (43,300 µg/L). Based on those calculations and a factor of safety of 25, a minimum ZVI dosage of 0.6 percent by mass was determined to be needed to effectively treat PCE in groundwater and adsorbed to soil. A remediation dosage of 1 percent ZVI, by mass of soil, was used. Twenty-two tons of ZVI were incorporated into 1,383 cubic yards of soil. Five hundred pounds of ZVI was introduced into each of 88 soil mixing columns (**Figure 4-8**) to distribute the ZVI evenly throughout the treatment area. Soil mixing was conducted without adding water (CH2M, 2012).

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Figure 4-8. Former St. Louis Ordnance Plant OU1 Treatment Area and Wells

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

This section provides details regarding the conceptual experimental design, site characterization activities, and data analysis associated with the technology demonstration performed at ABL Site 5 and former St. Louis Ordnance Plant OU1.

5.2 BASELINE CHARACTERIZATION

Because this project involves evaluation of existing remedies and not testing of a new technology, baseline measurements are not applicable. However, the following sections describe activities completed in preparation for fieldwork. Fieldnotes for this work are included in **Appendix B**.

5.2.1 Utility Location

Prior to completing intrusive activities, utilities were located at each site and a dig permit was obtained to avoid damage to existing underground utilities. Underground Detective provided locating services for the former St. Louis Ordnance Plant site. Accumark provided locating services for the ABL site. No underground utilities requiring movement of sample locations proposed in the Demonstration Plan for this project (NAVFAC EXWC and CH2M, 2016) were noted at either site. At the ABL site, Accumark also used a metal detector to mark the outside of the PRB at the site to assist in accurate placement of sample locations relative to the PRB.

5.3 FIELD TESTING

5.3.1 ZVI Sampling – ABL Site 5

Profile samples of ZVI across the PRB at ABL were collected using direct push technology (DPT) drilling technology in locations shown on **Figure 5-1**. Pilot holes were installed prior to completion of cores collected for laboratory analysis to allow for logging of the ZVI contact with the native soil. Cores were collected by beginning at the ground surface and advancing the 2-inch-diameter DPT drive point diagonally into the wall. All points were completed with the boring started 5 feet from the center line of the wall. Drilling methods were adjusted to ensure the wall interface was encountered at a 67-degree angle as shown on **Figure 5-2**. The angle at which the core barrel was positioned relative to the ground was measured frequently during drilling. Because of some shifting of the angle during coring, adjustments were made in some cases to begin the core at an angle of up to 70 degrees to achieve the desired 67 degrees at depth. Once a pilot hole was installed and logged, two additional borings were completed within 1 to 2 feet of the pilot hole parallel to the wall for the purpose of collecting cores for laboratory analysis (**Figure 5-1**). The depth on the diagonal at which the iron was encountered varied from one core to the next, even when cores were only a foot or two away from one another and approached the wall at the same angle, indicating possible inconsistencies in the wall thickness. Depths on the diagonal at which iron was encountered in each core and soil descriptions are included in **Table 5-1**.

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Figure 5-1. DPT Boring Locations, ABL Site 5

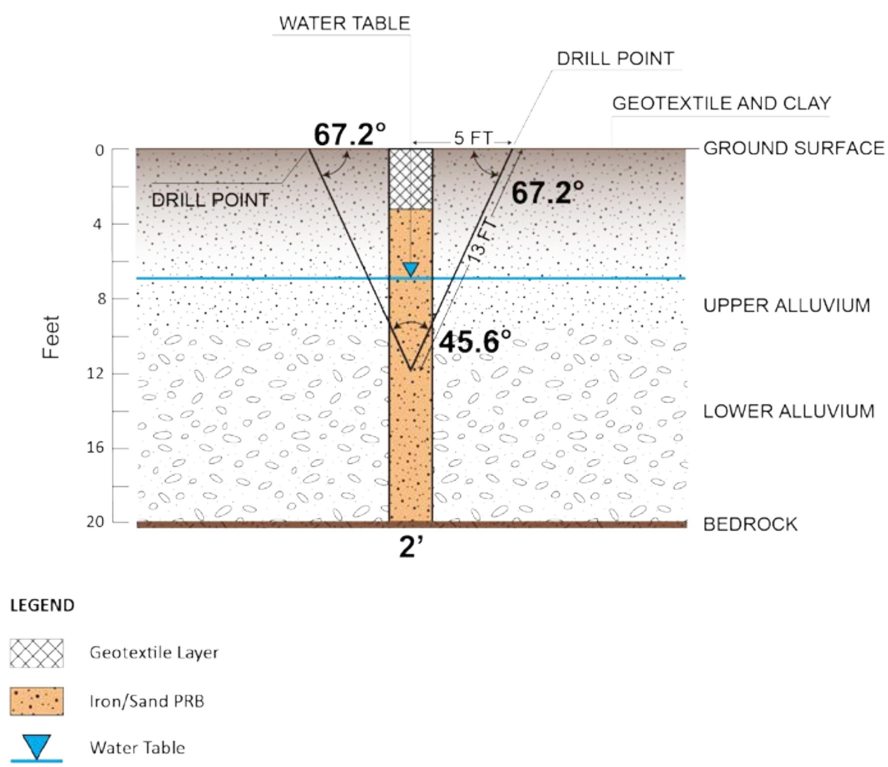

Figure 5-2. Iron Core Drilling Configuration

Table 5-1. Iron Core Depths

Core ID	Depth on Diagonal at which Iron Was Encountered (ft)	Description – Notes
DP001	11	Native soil is reddish brown silt, some gravel and sand. ZVI staining of native soil 0.4 feet from actual ZVI material.
DP001-EPA	13.5*	
DP001-OHSU	13.5*	
DP002	14	Native soil is light brown saturated, sandy silt
DP002-EPA	14*	
DP002-OHSU	14*	
DP003	12	Native soil is brown silty clay
DP003-EPA	12*	
DP003-OHSU	10*	
DP004	12	Native soil is reddish brown sandy silt
DP004-EPA	13*	
DP004-OHSU	13*	

Notes:

*Observation based on soil visible through unopened acetate liner

OHSU = Oregon Health and Science University

ZVI = zero-valent iron

The 4-foot-long acetate cores collected for laboratory analysis were cut into 2-foot-long sections for ease of shipping. Sleeve sections were capped on both ends. Ends were labeled to indicate placement within the wall and depth. In most cases, two cores per location were necessary to capture the wall interface and the wall centerline. Once collected, the samples were frozen immediately on dry ice. One set of samples was shipped overnight on dry ice to USEPA's National Risk Management Research Laboratory for mineralogical analysis as described in **Section 5.3.10**. The duplicate set of cores was sent to the Oregon Health and Science University (OHSU) for reactivity testing. A manufacturer-provided reference sample of ZVI from the same iron source was also sent to each of the laboratories for mineralogical baseline comparison purposes.

5.3.2 ZVI Sampling – Former St. Louis Ordnance Plant OU1

DPT soil/ZVI cores were also collected within the ZVI soil mixing area at the former St. Louis Ordnance Plant in locations shown on **Figure 5-3**. Soils were collected from acetate sleeves and were visually inspected to evaluate lithology. Field notes are included in **Appendix B**. Boring logs are included in **Appendix C**. Cores for laboratory analysis were collected from 16 to 20 feet bgs, consistent with the depth of the middle to lower portion of the mixing zone (which extends from the water table at approximately 5 feet bgs to 25 feet bgs). Cores were collected at one upgradient, one downgradient, and two soil mixing locations. Duplicates were collected within

2 feet of the primary samples within the ZVI mixing area only. One set of samples was shipped overnight on dry ice to OHSU for reactivity testing (**Section 5.1.10**). The duplicate set of mixing area cores was sent to USEPA's National Risk Management Research Laboratory for mineralogical analysis (**Section 5.3.10**). An iron reference sample from the ZVI supplier was also sent to each lab.

5.3.3 Well Installation – ABL Site 5

Two transects of groundwater monitoring wells were installed perpendicular to the PRB (**Figure 5-4)**, with one upgradient well and two downgradient wells in each transect. Wells were installed in alignment with existing groundwater monitoring wells 5GW18 and 5GW25. The new upgradient wells were placed approximately 5 feet away from the PRB. The new downgradient wells were placed approximately 5 feet and 10 feet away from the PRB. Two wells were also installed cross-gradient of the PRB to the east and west of the PRB to evaluate the potential for flow around the PRB.

Well installation was completed using rotosonic drilling. Drill rods with a core barrel and a minimum 6-inch inside diameter were used to drill monitoring well boreholes. Continuous core samples (4-inch outside diameter) were collected for lithologic classification. Boring logs are included in **Appendix C**. Monitoring wells were constructed inside the override casing(s) once the borehole was advanced to the desired depth (bottom of alluvial aquifer at ABL). The wells were constructed of 2-inch-diameter polyvinyl chloride (PVC) casing and 0.010-inch slotted PVC. The screen length for all wells was 10 feet with the exception of 5GW32. Because bedrock was encountered at 11 feet bgs at the location of 5GW32, a 5-foot screen was installed for this well location. A primary sand pack was placed around the screen to a depth of 2 feet above the top of the screen. A bentonite seal was placed above the sand pack. Following setting the well screen, riser, filter pack, and bentonite seal, each well was grouted to the surface with a cement-bentonite grout. The wells were completed at the surface with steel protective covers and locks. Following installation, and at least 24 hours after grouting, wells were developed using pump and surge development methods. Well construction diagrams are included in **Appendix D**. Well construction details are summarized in **Table 5-2**. Existing wells discussed in this study are also included in this table for the purpose of completeness.

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Figure 5-3. Sample Locations, Former St. Louis Ordnance Plant OU1 Site

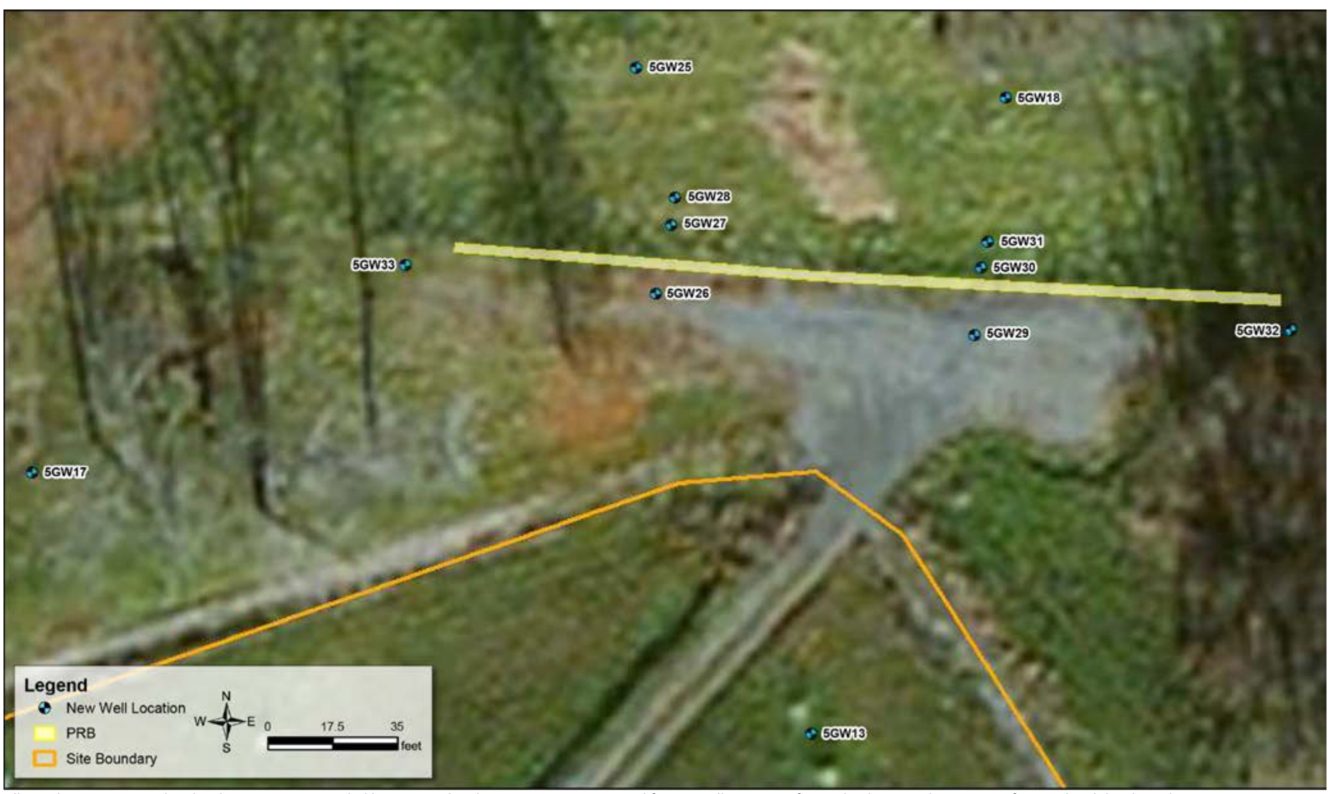

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Figure 5-4. Well Locations, ABL Site 5

Table 5-2. Well Construction Details

Monitoring Well	Installation Date	Ground Elevation (ft amsl)	Top of PVC Casing Elevation (ft amsl)	Total Well Depth (ft bgs)	Length of Screen (ft)	Elevation of Top of Screen (ft amsl)	Elevation of Bottom of Screen (ft amsl)
Allegany Ballistics Lab Site 5							
5GW13*	11/18/1994	686.60	688.82	24	10	672.60	662.60
5GW17*	1/17/1996	674.44	676.39	24	15	665.44	650.44
5GW18*	10/15/1997	672.12	674.75	25	15	662.12	647.12
5GW25*	8/4/2006	672.61	674.86	25	15	672.61	672.61
5GW26	1/19/2017	673.29	675.74	22	10	661.29	651.29
5GW27	1/17/2017	671.97	674.82	22	10	659.97	649.97
5GW28	1/17/2017	671.95	674.63	20	10	661.95	651.95
5GW29	1/19/2017	674.82	677.32	21.5	10	663.32	653.32
5GW30	1/18/2017	672.40	674.98	19	10	663.40	653.40
5GW31	1/18/2017	672.29	674.82	19	10	663.29	653.29
5GW32	1/18/2017	673.86	676.49	10	5	668.86	663.86
5GW33	1/19/2017	673.22	676.07	21.5	10	661.72	651.72
Former St. Louis Ordnance Plant OU1							
MW-119*	5/9/2012	542.15	541.63	30	20	532.15	512.15
DP-001	1/11/2017	540.59	543.81	30	10	520.59	510.59
DP-002	1/11/2017	543.81	546.70	26	10	527.81	517.81
DP-003	1/9/2017	543.13	546.09	25	10	528.13	518.13
DP-004	1/11/2017	537.69	540.63	25	10	522.69	512.69
DP-005	1/9/2017	542.52	545.87	25	10	527.52	517.52
DP-006	1/10/2017	540.99	543.81	28.3	10	522.69	512.69

Notes:

* Historical well included for completeness

ft bgs = feet below ground surface

ft amsl = feet above mean sea level

5.3.4 Well Installation – Former St. Louis Ordnance Plant OU1

Six new monitoring wells were installed following collection of ZVI and soil cores at former St. Louis Ordnance Plant OU1. Wells were installed in the locations of the ZVI cores (one upgradient of the mixing area, one downgradient of the mixing area, and two within the mixing area) as well as in two locations cross-gradient of flow along the east and west sides of the mixing area as shown on **Figure 5-3**. Wells were installed using hollow-stem auger drilling methodology. Where not already available from ZVI and soil coring, cores were collected in acetate sleeves for lithologic characterization. Soil boring logs are included in **Appendix C**. Wells were drilled to the depth of the soil mixing or top of shale. Wells were constructed of 2-inch-diameter PVC casing and 0.010-inch slotted PVC. The screen length for each well was 10 feet. A primary sand pack was placed around the screen to a depth of 2 feet above the top of the screen. A bentonite seal was placed above the sand pack. The wells were installed as temporary wells and no surface completions were installed. Following installation, at least 24 hours after grouting, wells were developed using pump and surge development methods. Well construction diagrams are included in **Appendix D**. Well construction details are summarized in **Table 5-2**. Existing wells discussed in this study are also included in this table for the purpose of completeness.

5.3.5 Groundwater Sampling – ABL Site 5 and Former St. Louis Ordnance Plant OU1

Following completion of well installation and development at each site, new wells and select existing wells were sampled using low-flow sampling methodology. Wells 5GW13, 5GW17, 5GW18, and 5GW25 at the ABL site were sampled in addition to the new wells (**Figure 5-4**). At the former St. Louis Ordnance Plant, existing well MW-119 was sampled in addition to the new wells (**Figure 5-3**). Wells were purged prior to sample collection using a peristaltic pump. During purging, DO, ORP, temperature, conductivity, turbidity, salinity, and pH were monitored using a field meter and flow-through cell. Once parameters were stabilized to within 10 percent and at least one well volume was purged, samples were collected into laboratory-prepared bottles. Samples were then shipped overnight on ice to Microbac Laboratory in Boulder, Colorado for analysis of VOCs, total and dissolved metals, silica, strontium, sulfide, nitrate, nitrite, ammonia, total organic carbon (TOC), hardness, alkalinity, methane, ethane, ethene, acetylene, and the following anions: sulfide, chloride, phosphate, and fluoride. Additionally, one round of microbial samples was collected by pumping water through laboratory-provided biofilters and sending the filters and volume pumped to Microbial Insights of Knoxville, Tennessee for next generation sequencing (NGS) and QuantArray-Chlor analysis.

Quality assurance/quality control samples were collected for VOC and metals analyses only and included trip blanks (for VOCs only), field duplicates, and temperature blanks. Field duplicates were collected at a frequency of ten percent.

5.3.6 Water Level Survey – ABL Site 5 and Former St. Louis Ordnance Plant OU1

Three water level surveys were completed at each site to evaluate flow in the vicinity of the treatment areas. Water levels were collected using an electronic water level indicator and measured to the nearest 0.01 foot. Results of the water level surveys are included in **Section 5.4.5**.

5.3.7 Slug Testing – Former St. Louis Ordnance Plant OU1

At the former St. Louis Ordnance Plant Site, slug tests were completed beginning on January 30th and ending on February 1st for wells within and outside of the mixing area to determine whether hydraulic conductivity changes have occurred as the result of treatment. Most tests were completed as falling head tests in accordance with the Demonstration Plan (NAVFAC EXWC and CH2M, 2016). The test at DP006 was completed as a rising head test.

Before each test, a digital data-logger (Level Troll 700) was installed in the well to a depth of several feet below the static water level. Prior to insertion of the data logger, the static water level was measured using an electronic water level indicator. The data logger was securely fastened in the well and programmed to logarithmically record the depth of water above the sensor at a maximum of 15-second intervals. A displacement slug was lowered into the well and held steady as the water level stabilized. For the well at which a rising head test was completed, data were recorded as the water level stabilized. For all other wells, once the water level stabilized to within 90 percent of the original static water level, the slug was removed to conduct the rising head test, monitoring the return of the water to its original static level. Recovery at the site was very slow, with tests running at least a half hour each, with one test running over 8 hours (DP004). The slug tests data sets were analyzed by AQTESOLV using the Bouwer-Rice solution method.

5.3.8 Decontamination

Override casings, core barrel, DPT equipment, and other downhole drilling tools were decontaminated prior to the installation of wells and soil borings, between each location, and before demobilization from each site. Equipment was decontaminated by steam cleaning at a designated area in accordance with the Demonstration Plan.

5.3.9 IDW Management

Investigation-derived waste (IDW) consisting of soil from well installation, purge water (from well development and groundwater sampling), and decontamination fluids was generated and managed in accordance with the Demonstration Plan. IDW disposal paperwork is provided as **Appendix E** of this document.

5.3.10 Laboratory Testing

This section summarizes laboratory testing to meet the project objectives.

5.3.10.1 Chemical and Microbial Analysis

Geochemical, VOC, metals, and microbial analyses were completed using the analytical methods specified below:

- VOCs – SW846 8260B/PAT01/MSV01
- Metals (total and dissolved) – SW846 3005A/6010C/6020A/ME401/ME600E/ME600G/ ME700A
- Nitrogen and ammonia – USEPA 350.1/SM 4500-NH3 B,G-1997 (2011 Editorial Revision)
- Phosphate – USEPA 365.2/SM 4500-P E-1997 (2011 Editorial Revision)
- TOC – USEPA 415.1/SW 846 9060A/SM5310C-2000 (2011 Editorial Revision)
- Anions – USEPA 9056/IC01
- Alkalinity – USEPA 310.1/SM2320B -1997 (2011 Editorial Revision)
- Sulfide – USEPA 376.1/ SM4500-S-F-2000(2011 Editorial Revision)/K3761
- Hardness – USEPA 130.2, Standard Method 2340C-1997 (2011 Editorial Revision)

- Methane, ethane, ethene, and acetylene – RSK-175
- Microbial analysis – QuantArray-Chlor and Next Generation Sequencing by Microbial Insights

5.3.10.2 Mineralogical Analysis

Upon arrival to USEPA's Risk Management Research Laboratory, frozen cores were transferred from a walk-in freezer to a Coy Laboratories anaerobic glove box containing an atmosphere of nitrogen gas and <4 percent hydrogen gas. The cores were opened, partitioned into ~6-inch segments, and the aquifer solids were allowed to dry anaerobically. Materials from each core segment were homogenized and disaggregated using an agate mortar and pestle. Subsamples were obtained for analyses of inorganic carbon concentrations, acid-volatile sulfur (AVS), and mineralogy/composition using x-ray diffraction, scanning electron and optical microscopy, and x-ray absorption spectroscopy.

Solid-phase inorganic carbon concentrations were determined using acid digestion and carbon dioxide (CO_2) detection with a carbon coulometer (UIC Model CM5014; Paul et al., 2003). Each sample was analyzed in duplicate or triplicate. Solid-phase concentrations of AVS were determined using acid digestion (Wilkin and Bischoff, 2006).

X-ray diffraction (XRD) analyses were conducted using a Rigaku Miniflex diffractometer using manganese-filtered FeKα radiation (λ = 0.1937 nanometers). Diffraction data were collected from 5° to 90° 2θ with 0.01° 2θ step increments at a scan rate of 6 seconds per step. National Institute of Standards and Technology 640b standard reference material (silicon powder) was used as a quality control check of d-spacing accuracy. XRD scans were imported into the Jade (Materials Data, Inc.) software package for analysis and matched to the Powder Diffraction File Data Base (PDF, International Centre for Diffraction Data). Samples were prepared by sonicating anaerobically dried materials in methanol and collecting the dispersed fine fraction. The fine-grained solid fraction was dried in a vacuum desiccator prior to XRD analysis.

Particle morphology and composition was studied using an optical microscope (Olympus BX60) in reflected-light mode and using scanning electron microscopy (SEM) (TESCAN Vega3 microscope) coupled with Energy-Dispersive X-ray Spectroscopy (EDS) (EDAX Element EDS System). An accelerating voltage of 30,000 electron-volts (eV) was used and images were obtained with secondary and backscattered electron detectors. Polished sections were prepared by Spectrum Petrographics. The polished samples were coated with gold to prevent sample charging.

For samples from St. Louis only, X-ray absorption near edge structure (XANES) measurements were made on the bending magnet located at Materials Research Collaborative Access Team Sector 10 (beamline 10-BM) at the Advanced Photon Source (Argonne National Laboratory). The fluorescent x-ray signal was monitored using a four-element Vortex energy dispersive detector. Sample pellets were pressed between layers of Kapton tape. Three scans each of five samples were collected and each scan was energy-corrected using an iron reference foil (7,112 eV). The raw data were background corrected, summed, and step-height normalized using the Athena software package (Ravel and Newville, 2005).

Results of the mineralogy testing are discussed in **Section 5.4.1**.

5.3.10.3 Reactivity Analysis

Upon arrival at OHSU, frozen cores for the St. Louis site only were processed into 1-inch-thick slices in an anaerobic glove box. Slices were collected every half foot from 16.5 to 19.5 feet for both upgradient and downgradient reference samples (DP003 and DP004) and mixing area samples (DP001 and DP002). ZVI content analysis via acidification and hydrogen generation analysis was completed for each sample. Magnetic and gravimetric analysis was then performed to determine the magnetically separable fraction of material. Finally, reactivity was assessed using the chemical reactive dye, resazurin. An ultraviolet–visible spectrophotometer was utilized to assess the presence of resazurin, and its reduced form, resorufin, in a select subset of samples (DP001 and DP003). All analyses were completed in accordance with the standard operating procedure (SOP) in **Appendix F** (note that this SOP was not included in the Demonstration Plan). Due to resource restrictions, ABL cores were not analyzed.

5.4 STUDY RESULTS

5.4.1 Field Parameter and Geochemistry Results

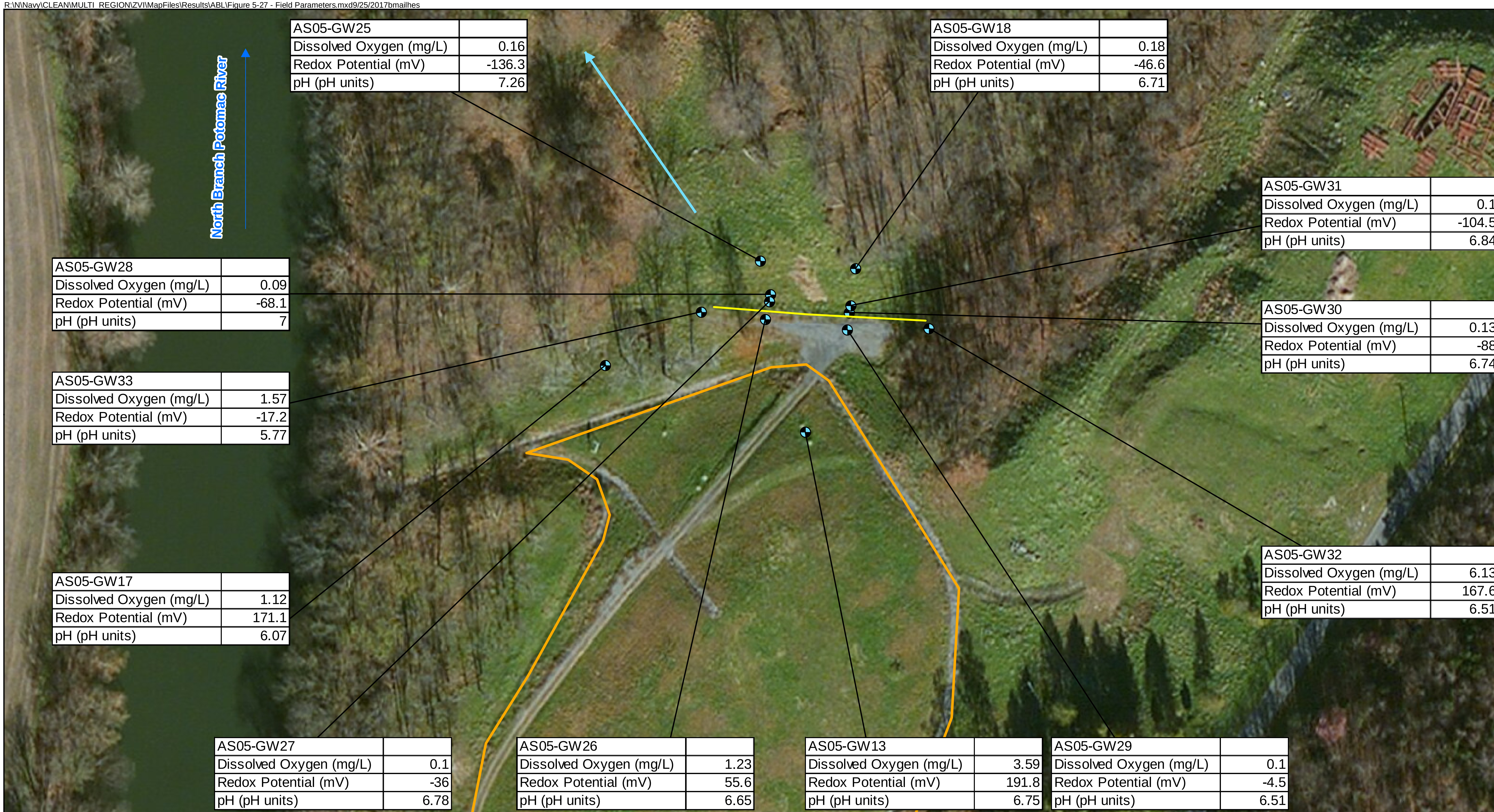
5.4.1.1 ABL Site 5 Field Parameters, Geochemical Results, Metals, and VOC Results

Graphical illustrations of field and laboratory analytical results on ABL Site 5 maps are included as **Figures 5-5 through 5-9.** All laboratory analytical results are provided as **Appendix G.** Field analytical results for ABL are presented in **Table 5-3.** A summary of laboratory analytical detections is provided as **Table 5-4.** Graphs showing changes in select parameters across the PRB and cross-gradient are provided as **Appendix H.**

Increases in pH were observed from the close upgradient location to the downgradient locations in both PRB transects (**Figure 5-5**). Decreases in ORP were also observed across the wall. The immediate downgradient wells, 5GW27 (western transect) and 5GW30 (eastern transect), indicate ORP values of -36 mV and -88 mV, respectively. The second-tier downgradient wells, 5GW28 (western transect) and 5GW31 (eastern transect) indicated ORP values of -68 mV and -104.5 mV, respectively. DO concentrations downgradient of the wall were consistently less than 0.2 mg/L, indicating anoxic to anaerobic conditions. Cross-gradient locations and all but one upgradient location (GW29, close upgradient to the wall) had DO concentration of greater than 1 mg/L, indicating aerobic conditions on the upgradient side.

TOC concentrations decreased from the close upgradient (6.83 mg/L to 7.81 mg/L) to the immediate and second tier downgradient (2.74 mg/L to 5.39 mg/L) close downgradient sample locations in both transects. Alkalinity and hardness decreased across both transects (**Figure 5-6 and Appendix H-1A**). Sulfate also decreased across the PRB, as expected due to reduction to sulfide. However, no sulfide was detected, presumably due to precipitation of iron sulfide minerals. No increase in chloride was noted across the PRB, but because VOC concentrations are very low at this site, no notable increase was anticipated. Detections of nitrate were sporadic across the site and nitrite was not detected. No notable change in ammonia concentrations was observed across either transect, but the concentration of ammonia was higher in the entire eastern transect in comparison to the western transect and cross-gradient, possibly due to a source in the landfill in this area. Methane, ethane, and ethene concentrations increased downgradient of the wall in comparison to close upgradient locations and cross-gradient locations (**Appendix H-1B**).

R:\N\Navy\CLEAN\MULTI_REGION\ZVI\MapFiles\Results\ABL\Figure 5-27 - Field Parameters.mxd9/25/2017bmailhes



Legend

- Well Location
- PRB
- Estimated Groundwater Flow Direction
- Site Boundary

Notes:
mV - millivolts
mg/L - milligrams per Liter

N

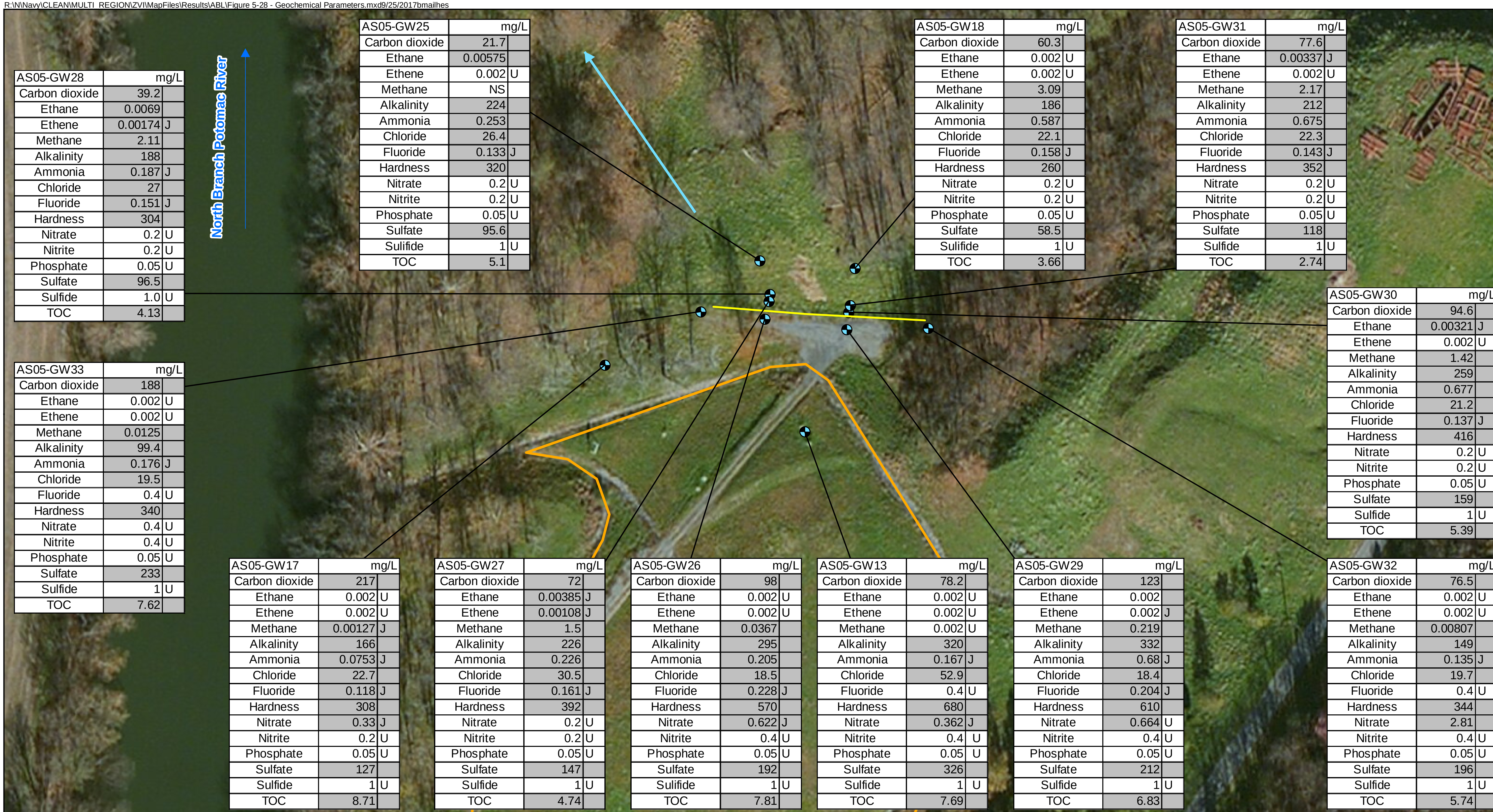
0 50 100 Feet

1 inch = 100 feet

Figure 5-5
Select Field Parameter Results - January 2017
Allegany Ballistics Laboratory Site 5
Rocket Center, WV

ch2m.

All aerial maps contained in this document are provided by Esri; road and terrain maps are sourced from installation-specific geodatabases and are cross referenced with local GIS data.



AS05-GW28	mg/L	
Carbon dioxide	39.2	
Ethane	0.0069	
Ethene	0.00174	J
Methane	2.11	
Alkalinity	188	
Ammonia	0.187	J
Chloride	27	
Fluoride	0.151	J
Hardness	304	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	96.5	
Sulfide	1.0	U
TOC	4.13	

AS05-GW25	mg/L	
Carbon dioxide	21.7	
Ethane	0.00575	
Ethene	0.002	U
Methane	NS	
Alkalinity	224	
Ammonia	0.253	
Chloride	26.4	
Fluoride	0.133	J
Hardness	320	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	95.6	
Sulifide	1	U
TOC	5.1	

AS05-GW18	mg/L	
Carbon dioxide	60.3	
Ethane	0.002	U
Ethene	0.002	U
Methane	3.09	
Alkalinity	186	
Ammonia	0.587	
Chloride	22.1	
Fluoride	0.158	J
Hardness	260	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	58.5	
Sulifide	1	U
TOC	3.66	

AS05-GW31	mg/L	
Carbon dioxide	77.6	
Ethane	0.00337	J
Ethene	0.002	U
Methane	2.17	
Alkalinity	212	
Ammonia	0.675	
Chloride	22.3	
Fluoride	0.143	J
Hardness	352	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	118	
Sulifide	1	U
TOC	2.74	

AS05-GW30	mg/L	
Carbon dioxide	94.6	
Ethane	0.00321	J
Ethene	0.002	U
Methane	1.42	
Alkalinity	259	
Ammonia	0.677	
Chloride	21.2	
Fluoride	0.137	J
Hardness	416	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	159	
Sulfide	1	U
TOC	5.39	

AS05-GW33	mg/L	
Carbon dioxide	188	
Ethane	0.002	U
Ethene	0.002	U
Methane	0.0125	
Alkalinity	99.4	
Ammonia	0.176	J
Chloride	19.5	
Fluoride	0.4	U
Hardness	340	
Nitrate	0.4	U
Nitrite	0.4	U
Phosphate	0.05	U
Sulfate	233	
Sulfide	1	U
TOC	7.62	

AS05-GW17	mg/L	
Carbon dioxide	217	
Ethane	0.002	U
Ethene	0.002	U
Methane	0.00127	J
Alkalinity	166	
Ammonia	0.0753	J
Chloride	22.7	
Fluoride	0.118	J
Hardness	308	
Nitrate	0.33	J
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	127	
Sulfide	1	U
TOC	8.71	

AS05-GW27	mg/L	
Carbon dioxide	72	
Ethane	0.00385	J
Ethene	0.00108	J
Methane	1.5	
Alkalinity	226	
Ammonia	0.226	
Chloride	30.5	
Fluoride	0.161	J
Hardness	392	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	147	
Sulfide	1	U
TOC	4.74	

AS05-GW26	mg/L	
Carbon dioxide	98	
Ethane	0.002	U
Ethene	0.002	U
Methane	0.0367	
Alkalinity	295	
Ammonia	0.205	
Chloride	18.5	
Fluoride	0.228	J
Hardness	570	
Nitrate	0.622	J
Nitrite	0.4	U
Phosphate	0.05	U
Sulfate	192	
Sulfide	1	U
TOC	7.81	

AS05-GW13	mg/L	
Carbon dioxide	78.2	
Ethane	0.002	U
Ethene	0.002	U
Methane	0.002	U
Alkalinity	320	
Ammonia	0.167	J
Chloride	52.9	
Fluoride	0.4	U
Hardness	680	
Nitrate	0.362	J
Nitrite	0.4	U
Phosphate	0.05	U
Sulfate	326	
Sulfide	1	U
TOC	7.69	

AS05-GW29	mg/L	
Carbon dioxide	123	
Ethane	0.002	
Ethene	0.002	J
Methane	0.219	
Alkalinity	332	
Ammonia	0.68	J
Chloride	18.4	
Fluoride	0.204	J
Hardness	610	
Nitrate	0.664	U
Nitrite	0.4	U
Phosphate	0.05	U
Sulfate	212	
Sulfide	1	U
TOC	6.83	

AS05-GW32	mg/L	
Carbon dioxide	76.5	
Ethane	0.002	U
Ethene	0.002	U
Methane	0.00807	
Alkalinity	149	
Ammonia	0.135	J
Chloride	19.7	
Fluoride	0.4	U
Hardness	344	
Nitrate	2.81	
Nitrite	0.4	U
Phosphate	0.05	U
Sulfate	196	
Sulfide	1	U
TOC	5.74	

Legend

- Well Location
- PRB
- Estimated Groundwater Flow Direction
- Site Boundary

Notes:
U - The material was analyzed for, but not detected
mg/L - milligrams per Liter
Shaded cell indicates detection
Acetylene was not detected in any samples; therefore, results are not included on this figure.

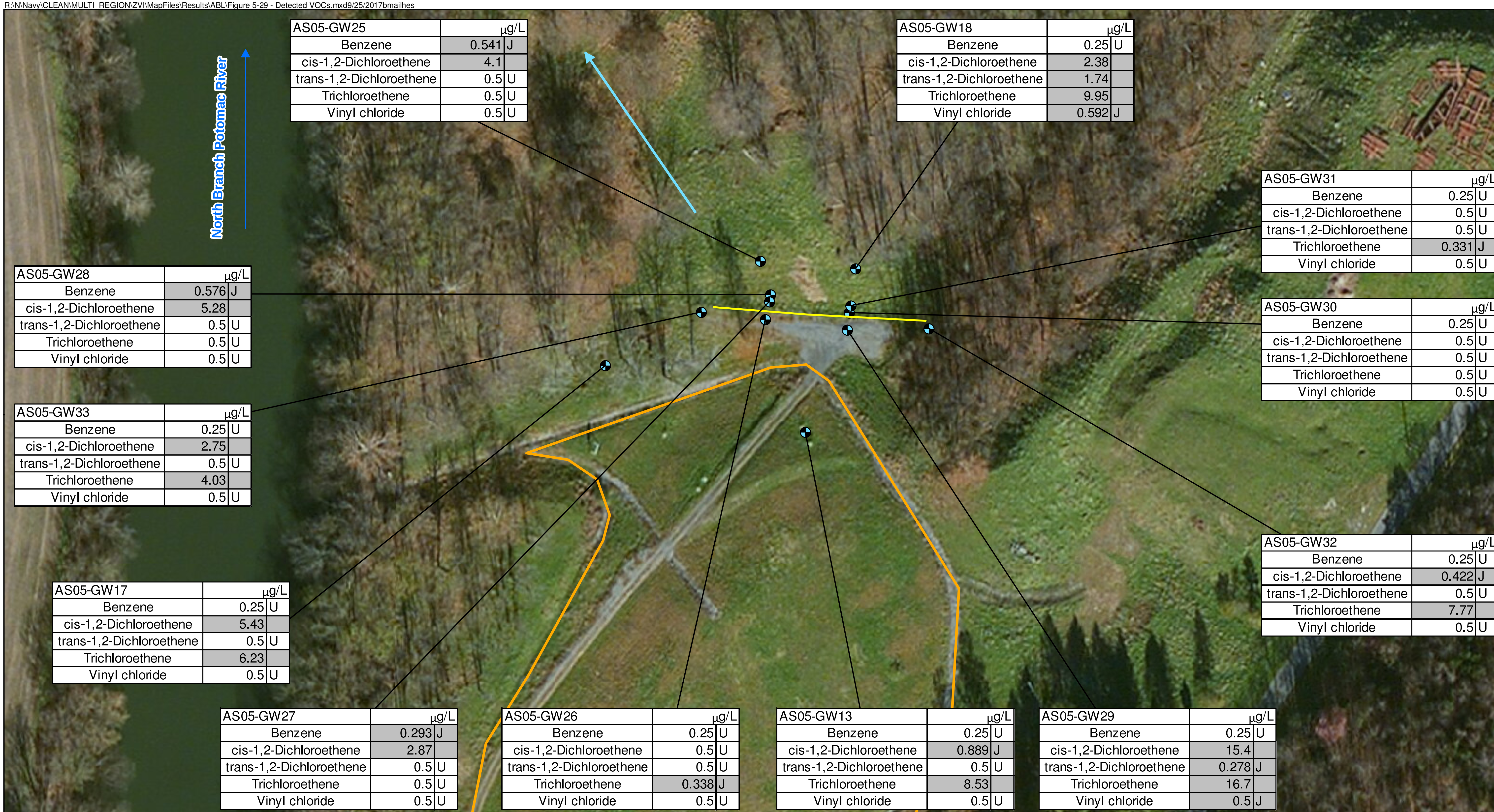
N

0 50 100 Feet

1 inch = 100 feet

Figure 5-6
Geochemical Parameters - January 2017
Allegany Ballistics Laboratory Site 5
Rocket Center, WV

ch2m



AS05-GW25	µg/L	
Benzene	0.541	J
cis-1,2-Dichloroethene	4.1	
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	0.5	U
Vinyl chloride	0.5	U

AS05-GW18	µg/L	
Benzene	0.25	U
cis-1,2-Dichloroethene	2.38	
trans-1,2-Dichloroethene	1.74	
Trichloroethene	9.95	
Vinyl chloride	0.592	J

AS05-GW31	µg/L	
Benzene	0.25	U
cis-1,2-Dichloroethene	0.5	U
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	0.331	J
Vinyl chloride	0.5	U

AS05-GW28	µg/L	
Benzene	0.576	J
cis-1,2-Dichloroethene	5.28	
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	0.5	U
Vinyl chloride	0.5	U

AS05-GW30	µg/L	
Benzene	0.25	U
cis-1,2-Dichloroethene	0.5	U
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	0.5	U
Vinyl chloride	0.5	U

AS05-GW33	µg/L	
Benzene	0.25	U
cis-1,2-Dichloroethene	2.75	
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	4.03	
Vinyl chloride	0.5	U

AS05-GW32	µg/L	
Benzene	0.25	U
cis-1,2-Dichloroethene	0.422	J
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	7.77	
Vinyl chloride	0.5	U

AS05-GW17	µg/L	
Benzene	0.25	U
cis-1,2-Dichloroethene	5.43	
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	6.23	
Vinyl chloride	0.5	U

AS05-GW27	µg/L	
Benzene	0.293	J
cis-1,2-Dichloroethene	2.87	
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	0.5	U
Vinyl chloride	0.5	U

AS05-GW26	µg/L	
Benzene	0.25	U
cis-1,2-Dichloroethene	0.5	U
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	0.338	J
Vinyl chloride	0.5	U

AS05-GW13	µg/L	
Benzene	0.25	U
cis-1,2-Dichloroethene	0.889	J
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	8.53	
Vinyl chloride	0.5	U

AS05-GW29	µg/L	
Benzene	0.25	U
cis-1,2-Dichloroethene	15.4	
trans-1,2-Dichloroethene	0.278	J
Trichloroethene	16.7	
Vinyl chloride	0.5	J

Legend
- Well Location
- PRB
- Estimated Groundwater Flow Direction
- Site Boundary

Notes:
J - The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outisde the quantitation range).
U - The material was analyzed for, but not detected
µg/L - micrograms per Liter
Shaded cell indicates detection

N

0 50 100 Feet

1 inch = 100 feet

Figure 5-7
Detected VOCs - January 2017
Allegany Ballistics Laboratory Site 5
Rocket Center, WV

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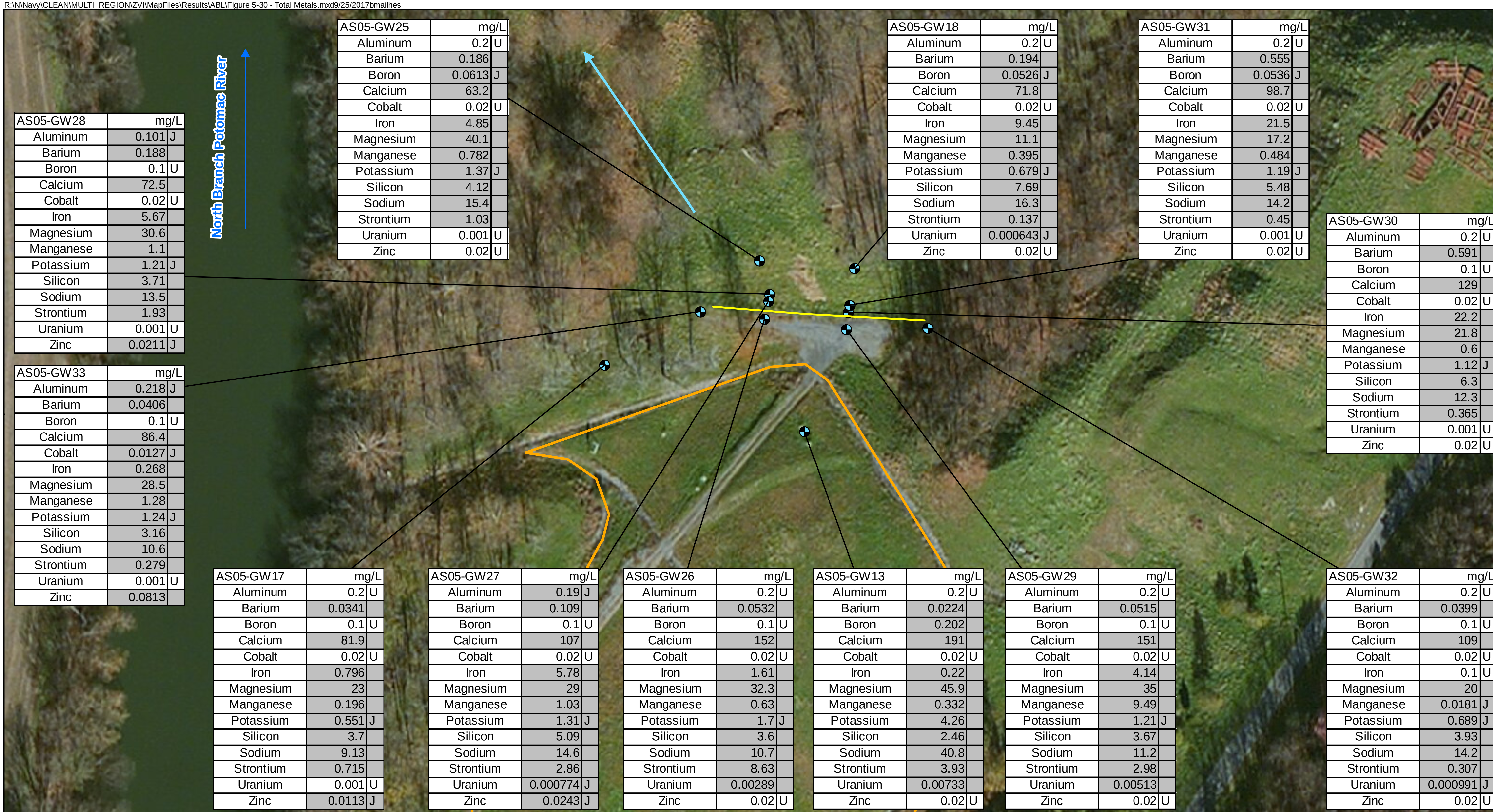


AS05-GW28	mg/L	
Aluminum	0.101	J
Barium	0.188	
Boron	0.1	U
Calcium	72.5	
Cobalt	0.02	U
Iron	5.67	
Magnesium	30.6	
Manganese	1.1	
Potassium	1.21	J
Silicon	3.71	
Sodium	13.5	
Strontium	1.93	
Uranium	0.001	U
Zinc	0.0211	J

AS05-GW33	mg/L	
Aluminum	0.218	J
Barium	0.0406	
Boron	0.1	U
Calcium	86.4	
Cobalt	0.0127	J
Iron	0.268	
Magnesium	28.5	
Manganese	1.28	
Potassium	1.24	J
Silicon	3.16	
Sodium	10.6	
Strontium	0.279	
Uranium	0.001	U
Zinc	0.0813	

AS05-GW25	mg/L	
Aluminum	0.2	U
Barium	0.186	
Boron	0.0613	J
Calcium	63.2	
Cobalt	0.02	U
Iron	4.85	
Magnesium	40.1	
Manganese	0.782	
Potassium	1.37	J
Silicon	4.12	
Sodium	15.4	
Strontium	1.03	
Uranium	0.001	U
Zinc	0.02	U

AS05-GW18	mg/L	
Aluminum	0.2	U
Barium	0.194	
Boron	0.0526	J
Calcium	71.8	
Cobalt	0.02	U
Iron	9.45	
Magnesium	11.1	
Manganese	0.395	
Potassium	0.679	J
Silicon	7.69	
Sodium	16.3	
Strontium	0.137	
Uranium	0.000643	J
Zinc	0.02	U

AS05-GW31	mg/L	
Aluminum	0.2	U
Barium	0.555	
Boron	0.0536	J
Calcium	98.7	
Cobalt	0.02	U
Iron	21.5	
Magnesium	17.2	
Manganese	0.484	
Potassium	1.19	J
Silicon	5.48	
Sodium	14.2	
Strontium	0.45	
Uranium	0.001	U
Zinc	0.02	U

AS05-GW30	mg/L	
Aluminum	0.2	U
Barium	0.591	
Boron	0.1	U
Calcium	129	
Cobalt	0.02	U
Iron	22.2	
Magnesium	21.8	
Manganese	0.6	
Potassium	1.12	J
Silicon	6.3	
Sodium	12.3	
Strontium	0.365	
Uranium	0.001	U
Zinc	0.02	U

AS05-GW17	mg/L	
Aluminum	0.2	U
Barium	0.0341	
Boron	0.1	U
Calcium	81.9	
Cobalt	0.02	U
Iron	0.796	
Magnesium	23	
Manganese	0.196	
Potassium	0.551	J
Silicon	3.7	
Sodium	9.13	
Strontium	0.715	
Uranium	0.001	U
Zinc	0.0113	J

AS05-GW27	mg/L	
Aluminum	0.19	J
Barium	0.109	
Boron	0.1	U
Calcium	107	
Cobalt	0.02	U
Iron	5.78	
Magnesium	29	
Manganese	1.03	
Potassium	1.31	J
Silicon	5.09	
Sodium	14.6	
Strontium	2.86	
Uranium	0.000774	J
Zinc	0.0243	J

AS05-GW26	mg/L	
Aluminum	0.2	U
Barium	0.0532	
Boron	0.1	U
Calcium	152	
Cobalt	0.02	U
Iron	1.61	
Magnesium	32.3	
Manganese	0.63	
Potassium	1.7	J
Silicon	3.6	
Sodium	10.7	
Strontium	8.63	
Uranium	0.00289	
Zinc	0.02	U

AS05-GW13	mg/L	
Aluminum	0.2	U
Barium	0.0224	
Boron	0.202	
Calcium	191	
Cobalt	0.02	U
Iron	0.22	
Magnesium	45.9	
Manganese	0.332	
Potassium	4.26	
Silicon	2.46	
Sodium	40.8	
Strontium	3.93	
Uranium	0.00733	
Zinc	0.02	U

AS05-GW29	mg/L	
Aluminum	0.2	U
Barium	0.0515	
Boron	0.1	U
Calcium	151	
Cobalt	0.02	U
Iron	4.14	
Magnesium	35	
Manganese	9.49	
Potassium	1.21	J
Silicon	3.67	
Sodium	11.2	
Strontium	2.98	
Uranium	0.00513	
Zinc	0.02	U

AS05-GW32	mg/L	
Aluminum	0.2	U
Barium	0.0399	
Boron	0.1	U
Calcium	109	
Cobalt	0.02	U
Iron	0.1	U
Magnesium	20	
Manganese	0.0181	J
Potassium	0.689	J
Silicon	3.93	
Sodium	14.2	
Strontium	0.307	
Uranium	0.000991	J
Zinc	0.02	U

Legend

- Well Location
- PRB
- Estimated Groundwater Flow Direction
- Site Boundary

Notes:
J - The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outisde the quantitation range).
U - The material was analyzed for, but not detected
mg/L - milligrams per Liter
Shaded cell indicates detection

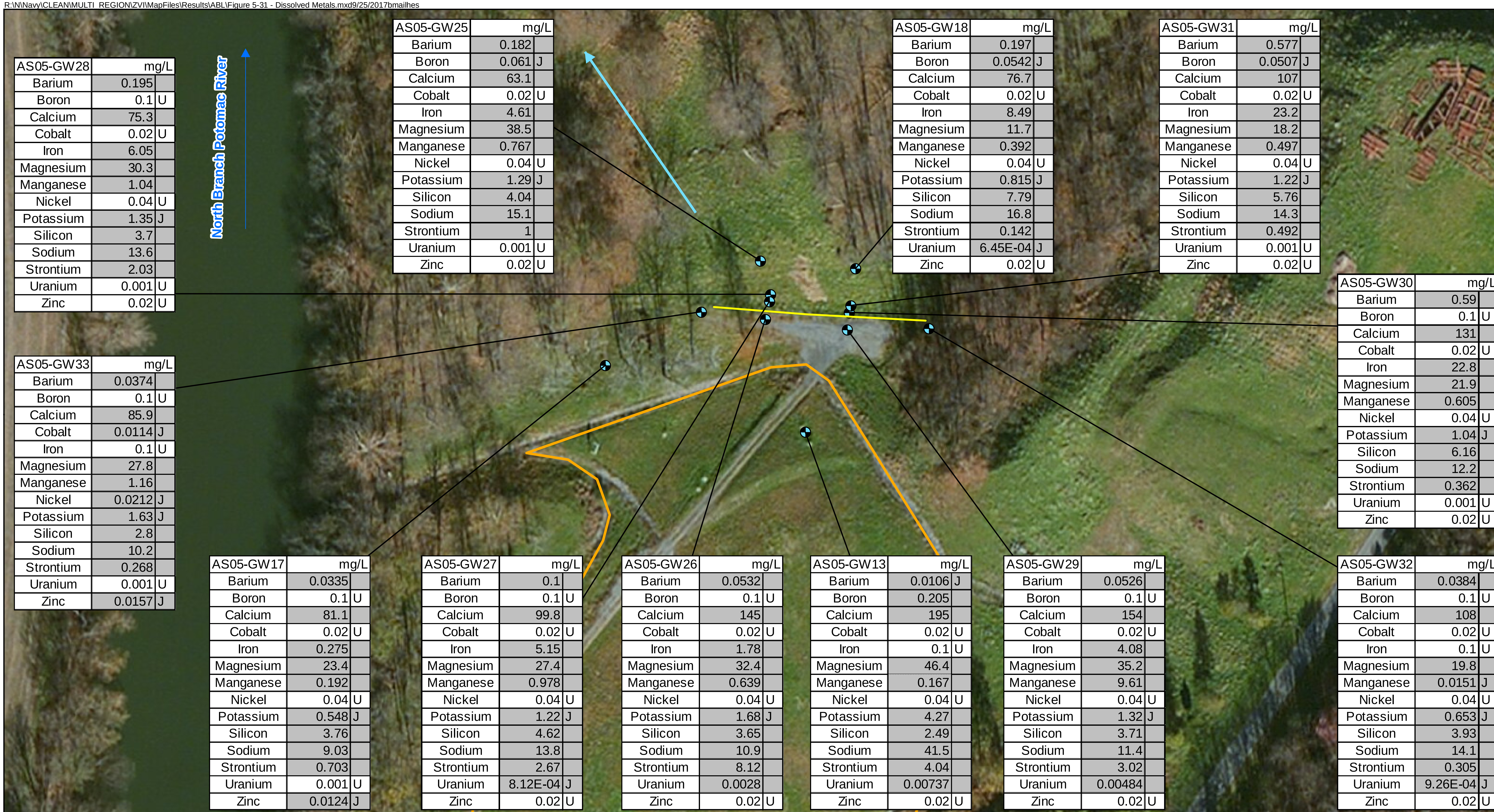
N

0 50 100 Feet

1 inch = 100 feet

Figure 5-8
Total Metals - January 2017
Allegany Ballistics Laboratory Site 5
Rocket Center, WV

ch2m



AS05-GW28	mg/L	
Barium	0.195	
Boron	0.1	U
Calcium	75.3	
Cobalt	0.02	U
Iron	6.05	
Magnesium	30.3	
Manganese	1.04	
Nickel	0.04	U
Potassium	1.35	J
Silicon	3.7	
Sodium	13.6	
Strontium	2.03	
Uranium	0.001	U
Zinc	0.02	U

AS05-GW25	mg/L	
Barium	0.182	
Boron	0.061	J
Calcium	63.1	
Cobalt	0.02	U
Iron	4.61	
Magnesium	38.5	
Manganese	0.767	
Nickel	0.04	U
Potassium	1.29	J
Silicon	4.04	
Sodium	15.1	
Strontium	1	
Uranium	0.001	U
Zinc	0.02	U

AS05-GW18	mg/L	
Barium	0.197	
Boron	0.0542	J
Calcium	76.7	
Cobalt	0.02	U
Iron	8.49	
Magnesium	11.7	
Manganese	0.392	
Nickel	0.04	U
Potassium	0.815	J
Silicon	7.79	
Sodium	16.8	
Strontium	0.142	
Uranium	6.45E-04	J
Zinc	0.02	U

AS05-GW31	mg/L	
Barium	0.577	
Boron	0.0507	J
Calcium	107	
Cobalt	0.02	U
Iron	23.2	
Magnesium	18.2	
Manganese	0.497	
Nickel	0.04	U
Potassium	1.22	J
Silicon	5.76	
Sodium	14.3	
Strontium	0.492	
Uranium	0.001	U
Zinc	0.02	U

AS05-GW30	mg/L	
Barium	0.59	
Boron	0.1	U
Calcium	131	
Cobalt	0.02	U
Iron	22.8	
Magnesium	21.9	
Manganese	0.605	
Nickel	0.04	U
Potassium	1.04	J
Silicon	6.16	
Sodium	12.2	
Strontium	0.362	
Uranium	0.001	U
Zinc	0.02	U

AS05-GW33	mg/L	
Barium	0.0374	
Boron	0.1	U
Calcium	85.9	
Cobalt	0.0114	J
Iron	0.1	U
Magnesium	27.8	
Manganese	1.16	
Nickel	0.0212	J
Potassium	1.63	J
Silicon	2.8	
Sodium	10.2	
Strontium	0.268	
Uranium	0.001	U
Zinc	0.0157	J

AS05-GW17	mg/L	
Barium	0.0335	
Boron	0.1	U
Calcium	81.1	
Cobalt	0.02	U
Iron	0.275	
Magnesium	23.4	
Manganese	0.192	
Nickel	0.04	U
Potassium	0.548	J
Silicon	3.76	
Sodium	9.03	
Strontium	0.703	
Uranium	0.001	U
Zinc	0.0124	J

AS05-GW27	mg/L	
Barium	0.1	
Boron	0.1	U
Calcium	99.8	
Cobalt	0.02	U
Iron	5.15	
Magnesium	27.4	
Manganese	0.978	
Nickel	0.04	U
Potassium	1.22	J
Silicon	4.62	
Sodium	13.8	
Strontium	2.67	
Uranium	8.12E-04	J
Zinc	0.02	U

AS05-GW26	mg/L	
Barium	0.0532	
Boron	0.1	U
Calcium	145	
Cobalt	0.02	U
Iron	1.78	
Magnesium	32.4	
Manganese	0.639	
Nickel	0.04	U
Potassium	1.68	J
Silicon	3.65	
Sodium	10.9	
Strontium	8.12	
Uranium	0.0028	
Zinc	0.02	U

AS05-GW13	mg/L	
Barium	0.0106	J
Boron	0.205	
Calcium	195	
Cobalt	0.02	U
Iron	0.1	U
Magnesium	46.4	
Manganese	0.167	
Nickel	0.04	U
Potassium	4.27	
Silicon	2.49	
Sodium	41.5	
Strontium	4.04	
Uranium	0.00737	
Zinc	0.02	U

AS05-GW29	mg/L	
Barium	0.0526	
Boron	0.1	U
Calcium	154	
Cobalt	0.02	U
Iron	4.08	
Magnesium	35.2	
Manganese	9.61	
Nickel	0.04	U
Potassium	1.32	J
Silicon	3.71	
Sodium	11.4	
Strontium	3.02	
Uranium	0.00484	
Zinc	0.02	U

AS05-GW32	mg/L	
Barium	0.0384	
Boron	0.1	U
Calcium	108	
Cobalt	0.02	U
Iron	0.1	U
Magnesium	19.8	
Manganese	0.0151	J
Nickel	0.04	U
Potassium	0.653	J
Silicon	3.93	
Sodium	14.1	
Strontium	0.305	
Uranium	9.26E-04	J
Zinc	0.02	U

Legend
- Well Location
- PRB
- Estimated Groundwater Flow Direction
- Site Boundary

Notes:
J - The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outisde the quantitation range).
U - The material was analyzed for, but not detected
mg/L - milligrams per Liter
Shaded cell indicates detection

Figure 5-9
Dissolved Metals - January 2017
Allegany Ballistics Laboratory Site 5
Rocket Center, WV

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Table 5-3. Water Quality Parameters, ABL Site 5

Sample ID:	AS05-GW13-012017	AS05-GW17-012017	AS05-GW18-012017	AS05-GW25-012017	AS05-GW26-012017	AS05-GW27-012017
Sample Date:	**1/26/17**	**1/26/17**	**1/25/17**	**1/26/17**	**1/24/17**	**1/24/17**
Water Quality Parameters						
Dissolved Oxygen (mg/L)	3.59	1.12	0.18	0.16	1.23	0.1
Depth to Water (ft)	13.63	4.93	3.27	3.3	3.46	2.63
ORP (mV)	191.8	171.1	-46.6	-136.3	55.6	-36
pH (pH units)	6.75	6.07	6.71	7.26	6.65	6.78
Specific Conductivity (mS/cm)	2.683	1.336	1.072	1.392	0.981	0.854
Temperature (°C)	11.49	11.01	12.3	11.4	10.38	11.33
Turbidity (NTU)	0	1.8	6.9	0	0	1
Sample ID:	**AS05-GW28-012017**	**AS05-GW29-012017**	**AS05-GW30-012017**	**AS05-GW31-012017**	**AS05-GW32-012017**	**AS05-GW33-012017**
Sample Date:	**1/24/17**	**1/25/17**	**1/25/17**	**1/25/17**	**1/24/17**	**1/23/17**
Water Quality Parameters						
Dissolved Oxygen (mg/L)	0.09	0.1	0.13	0.1	6.13	1.57
Depth to Water (ft)	2.46	4.29	2.55	2.56	1.52	5.49
ORP (mV)	-68.1	-4.5	-88	-104.5	167.6	-17.2
pH (pH units)	7	6.51	6.74	6.84	6.51	5.77
Specific Conductivity (mS/cm)	0.701	1.991	1.758	1.438	0.802	0.715
Temperature (°C)	11.37	10.63	11.34	12.38	9.4	10.7
Turbidity (NTU)	2.9	6.6	0	0	0	1.4

Notes:

°C = degrees CelsiusmS/cm = milliSiemens per centimeter

NTU = nephelometric turbidity units

Table 5-4. Laboratory Analytical Detections, ABL Site 5

			Sample ID:	GW13	GW13P	GW26	GW27	GW28	GW25	GW25P	GW29	GW30	GW31	GW18	GW17	GW32	GW33
			Sample Date:	1/26/17	1/6/17	1/24/17	1/24/17	1/24/17	1/26/17	1/26/17	1/25/17	1/25/17	1/25/17	1/25/17	1/26/17	1/24/17	1/23/17
Chemical Name	Frequency	Max Value	Max Location														
Volatile Organic Compounds (µg/L)																	
Benzene	4 / 14	0.576 J	AS05-GW28-012017	0.25 U	0.25 U	0.25 U	0.293 J	0.576 J	0.532 J	0.541 J	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
Carbon dioxide	12 / 12	217,000	AS05-GW17-012017	78,200	NS	98,000	72,000	39,200	21,700	NS	123,000	94,600	77,600	60,300	217,000	76,500	188,000
cis-1,2-Dichloroethene	11 / 14	15.4	AS05-GW29-012017	0.889 J	0.697 J	0.5 U	2.87	5.28	4.1	4.07	15.4	0.5 U	0.5 U	2.38	5.43	0.422 J	2.75
Ethane	5 / 12	6.90	AS05-GW28-012017	ND U	NS	ND U	3.85 J	6.9	5.75	NS	ND U	3.21 J	3.37 J	ND U	ND U	ND U	ND U
Ethene	2 / 12	1.74 J	AS05-GW28-012017	ND U	NS	ND U	1.08 J	1.74 J	ND U	NS	ND U	ND U	ND U	ND U	ND U	ND U	ND U
Methane	10 / 11	3,090	AS05-GW18-012017	ND U	NS	36.7	1,500	2,110	NS	NS	219	1,420	2,170	3,090	1.27 J	8.07	12.5
trans-1,2-Dichloroethene	2 / 14	1.74	AS05-GW18-012017	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.278 J	0.5 U	0.5 U	1.74	0.5 U	0.5 U	0.5 U
Trichloroethene	9 / 14	16.7	AS05-GW29-012017	6.54	8.53	0.338 J	0.5 U	0.5 U	0.5 U	0.5 U	16.7	0.5 U	0.331 J	9.95	6.23	7.77	4.03
Vinyl chloride	2 / 14	0.592 J	AS05-GW18-012017	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 J	0.5 U	0.5 U	0.592 J	0.5 U	0.5 U	0.5 U
Total Metals (mg/L)																	
Aluminum	3 / 14	0.218 J	AS05-GW33-012317	ND U	ND U	ND U	0.19 J	0.101 J	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	0.218 J
Barium	14 / 14	0.591	AS05-GW30-012017	0.0224	0.0122 J	0.0532	0.109	0.188	0.186	0.182	0.0515	0.591	0.555	0.194	0.0341	0.0399	0.0406
Boron	6 / 14	0.202	AS05-GW13-012017	0.202	0.2	ND U	ND U	ND U	0.0613 J	0.0587 J	ND U	ND U	0.0536 J	0.0526 J	ND U	ND U	ND U
Calcium	14 / 14	191.0	AS05-GW13P-010617	184	191	152	107	72.5	63.1	63.2	151	129	98.7	71.8	81.9	109	86.4
Cobalt	1 / 14	0.0127 J	AS05-GW33-012317	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	0.0127 J
Iron	12 / 14	22.2	AS05-GW30-012017	0.22	ND U	1.61	5.78	5.67	4.85	4.6	4.14	22.2	21.5	9.45	0.796	ND U	0.268
Magnesium	14 / 14	45.9	AS05-GW13P-010617	44	45.9	32.3	29	30.6	39	40.1	35	21.8	17.2	11.1	23	20	28.5
Manganese	14 / 14	9.49	AS05-GW29-012017	0.332	0.199	0.63	1.03	1.1	0.782	0.773	9.49	0.6	0.484	0.395	0.196	0.0181 J	1.28
Potassium	14 / 14	4.26	AS05-GW13-012017	4.26	3.23	1.7 J	1.31 J	1.21 J	1.37 J	1.22 J	1.21 J	1.12 J	1.19 J	0.679 J	0.551 J	0.689 J	1.24 J
Silicon	14 / 14	7.69	AS05-GW18-012017	2.46	2.23	3.6	5.09	3.71	4.12	4.02	3.67	6.3	5.48	7.69	3.7	3.93	3.16
Sodium	14 / 14	40.8	AS05-GW13-012017	40.8	40.5	10.7	14.6	13.5	15.4	15.2	11.2	12.3	14.2	16.3	9.13	14.2	10.6
Strontium	14 / 14	8.63	AS05-GW26-012017	3.65	3.93	8.63	2.86	1.93	1.03	1.01	2.98	0.365	0.45	0.137	0.715	0.307	0.279
Uranium	7 / 14	0.00733	AS05-GW13P-010617	0.00717	0.00733	0.00289	0.000774 J	ND U	ND U	ND U	0.00513	ND U	ND U	0.000643 J	ND U	0.000991 J	ND U
Zinc	4 / 14	0.0813	AS05-GW33-012317	ND U	ND U	ND U	0.0243 J	0.0211 J	ND U	ND U	ND U	ND U	ND U	ND U	0.0113 J	ND U	0.0813
Dissolved Metals (mg/L)																	
Barium	14 / 14	0.590	AS05-GW30-012017	0.00883 J	0.0106 J	0.0532	0.1	0.195	0.182	0.176	0.0526	0.59	0.577	0.197	0.0335	0.0384	0.0374
Boron	6 / 14	0.205	AS05-GW13-012017	0.205	0.199 J	ND U	ND U	ND U	0.0556 J	0.061 J	ND U	ND U	0.0507 J	0.0542 J	ND U	ND U	ND U
Calcium	14 / 14	195.0	AS05-GW13P-010617	181	195	145	99.8	75.3	62.7	63.1	154	131	107	76.7	81.1	108	85.9
Cobalt	1 / 14	0.0114 J	AS05-GW33-012317	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	0.0114 J
Iron	10 / 14	23.2	AS05-GW31-012017	ND U	ND U	1.78	5.15	6.05	4.55	4.61	4.08	22.8	23.2	8.49	0.275	ND U	ND U
Magnesium	14 / 14	46.4	AS05-GW13P-010617	43.9	46.4	32.4	27.4	30.3	38.5	38.5	35.2	21.9	18.2	11.7	23.4	19.8	27.8
Manganese	14 / 14	9.61	AS05-GW29-012017	0.0343	0.167	0.639	0.978	1.04	0.767	0.775	9.61	0.605	0.497	0.392	0.192	0.0151 J	1.16
Nickel	1 / 14	0.0212 J	AS05-GW33-012317	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	0.0212 J

Table 5-4. Laboratory Analytical Detections, ABL Site 5

Sample ID:				GW13	GW13P	GW26	GW27	GW28	GW25	GW25P	GW29	GW30	GW31	GW18	GW17	GW32	GW33
Sample Date:				1/26/17	1/6/17	1/24/17	1/24/17	1/24/17	1/26/17	1/26/17	1/25/17	1/25/17	1/25/17	1/25/17	1/26/17	1/24/17	1/23/17
Chemical Name	Frequency	Max Value	Max Location														
Potassium	14 / 14	4.27	AS05-GW13-012017	4.27	2.97	1.68 J	1.22 J	1.35 J	1.29 J	1.15 J	1.32 J	1.04 J	1.22 J	0.815 J	0.548 J	0.653 J	1.63 J
Silicon	14 / 14	7.79	AS05-GW18-012017	2.49	2.19	3.65	4.62	3.7	3.98	4.04	3.71	6.16	5.76	7.79	3.76	3.93	2.8
Sodium	14 / 14	41.5	AS05-GW13-012017	41.5	40	10.9	13.8	13.6	15.1	15	11.4	12.2	14.3	16.8	9.03	14.1	10.2
Strontium	14 / 14	8.12	AS05-GW26-012017	3.59	4.04	8.12	2.67	2.03	1	0.989	3.02	0.362	0.492	0.142	0.703	0.305	0.268
Uranium	7 / 14	0.00737	AS05-GW13-012017	0.00737	0.00704	0.0028	8.12E-04 J	ND U	ND U	ND U	0.00484	ND U	ND U	6.45E-04 J	ND U	9.26E-04 J	ND U
Zinc	2 / 14	0.0157 J	AS05-GW33-012317	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	ND U	0.0124 J	ND U	0.0157 J
Wet Chemistry (mg/L)																	
Alkalinity	12 / 12	332.0	AS05-GW29-012017	320	NS	295	226	188	224	NS	332	259	212	186	166	149	99.4
Ammonia	12 / 12	0.680	AS05-GW29-012017	0.167 J	NS	0.205	0.226	0.187 J	0.253	NS	0.68	0.677	0.675	0.587	0.0753 J	0.135 J	0.176 J
Chloride	12 / 12	52.9	AS05-GW13-012017	52.9	NS	18.5	30.5	27	26.4	NS	18.4	21.2	22.3	22.1	22.7	19.7	19.5
Fluoride	9 / 12	0.228 J	AS05-GW26-012017	ND U	NS	0.228 J	0.161 J	0.151 J	0.133 J	NS	0.204 J	0.137 J	0.143 J	0.158 J	0.118 J	ND U	ND U
Hardness	12 / 12	680.0	AS05-GW13-012017	680	NS	570	392	304	320	NS	610	416	352	260	308	344	340
Nitrate	5 / 12	2.81	AS05-GW32-012017	0.362 J	NS	0.622 J	ND U	ND U	ND U	NS	0.664 J	ND U	ND U	ND U	0.33 J	2.81	ND U
Sulfate	12 / 12	326.0	AS05-GW13-012017	326	NS	192	147	96.5	95.6	NS	212	159	118	58.5	127	196	233
Total organic carbon (TOC)	12 / 12	8.71	AS05-GW17-012017	7.69	NS	7.81	4.74	4.13	5.1	NS	6.83	5.39	2.74	3.66	8.71	5.74	7.62

Notes:
J = The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outside the quantitation range).
Q = One or more quality control criteria failed (e.g., laboratory control sample recovery, surrogate spike recovery, or continuing calibration verification recovery).
U = The material was analyzed for, but not detected.
Shading indicates detection
ND = not detected
NS = not sampled

- Far Upgradient (purple)
- Close Upgradient (5 feet upgradient) (blue)
- Immediately Downgradient (5 feet downgradient) (yellow)
- Close Downgradient (10 feet downgradient) (orange)
- Far Downgradient (50-60 feet downgradient) (red)
- Cross-Gradient (green)

While VOC concentrations were very low in close upgradient samples 5GW26 and 5GW29 (**Figure 5-7**), a clean front (non-detect results in closest downgradient location) was observed in the eastern transect and the only chlorinated VOC detected in the immediately downgradient western location was cis-1,2-DCE at a concentration of 2.87 µg/L.

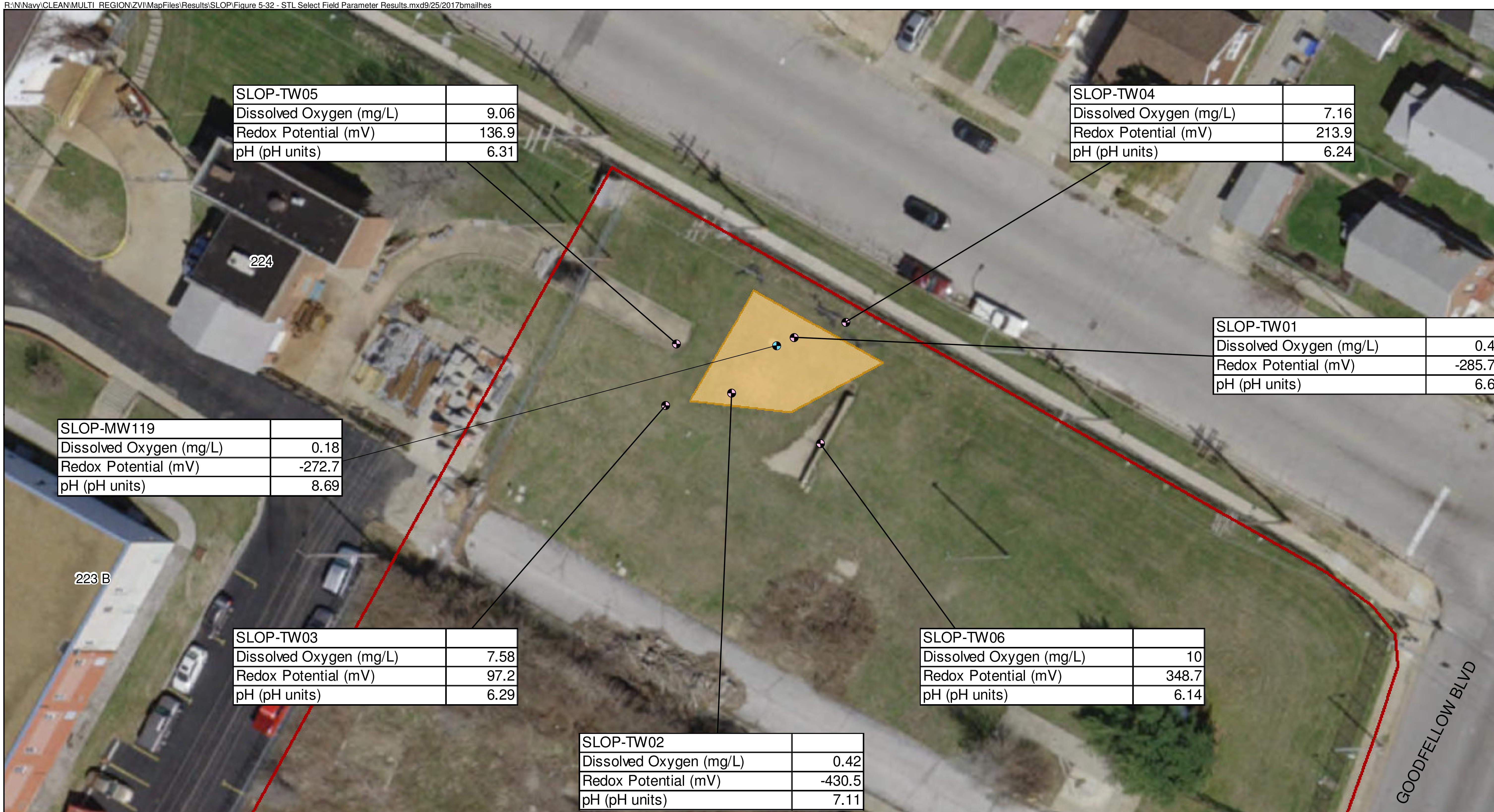
Metals data indicate that precipitation of a number of metals is likely occurring within the wall. Notable decreases in total and dissolved calcium, magnesium, and strontium were observed in both the western and eastern transects (**Figures 5-8 and 5-9 and Appendix H-2),** though for the western transect, magnesium concentrations increased between the immediately downgradient and close downgradient samples. A notable decrease in manganese was also observed in the eastern transect without a similar decrease in the western transect; however, the upgradient concentration of manganese in the eastern transect was an order of magnitude higher than in the western transect **(Appendix H-2).** Decreases in these metals were expected as the iron wall can serve as a long-term sink for these constituents. Iron, barium, sodium, and silicon concentrations increased across the PRB in both transects, although silicon and sodium decreased between the immediate downgradient samples and the close downgradient samples. There were no notable trends in other metals concentrations.

5.4.1.2 Former St. Louis Ordnance Plant OU1 Field Parameters, Geochemical Results, Metals, and VOC Results

Graphical illustrations of field and laboratory analytical results on ABL Site 5 maps are included as **Figures 5-10 through 5-14.** All laboratory analytical results are provided as **Appendix G.** Field analytical results are shown in **Table 5-5.** Graphs showing changes in select parameters across site are provided as **Appendix I.** A summary of detections is provided as **Table 5-6.**

Increases in pH were observed in all mixing area wells in comparison to wells outside of the mixing area, with the highest pH observed in existing well, MW-119 (**Figure 5-10**). Decreases in ORP were also observed, with the lowest ORP (-430.5 mV) observed in the most upgradient of the mixing area samples (TW02). DO concentrations within the mixing area were also significantly lower than the background concentrations. The lowest mixing area concentration was 0.18 mg/L at MW-119 compared to the upgradient (TW03) concentration of 7.58 mg/L. These data are indicative of highly reducing conditions typically associated with reactive ZVI.

TOC concentrations were highest within the mixing area (**Figure 5-11 and Appendix I-1A**). Alkalinity and hardness were similar within and outside of the treatment area. Sulfate concentrations were considerably lower within the treatment area in comparison to outside. Sulfide was not detected. Chloride concentrations were highest in TW02, in the upgradient portion of the mixing area. Fluoride concentrations increased in the mixing area and subsequently decreased on the downgradient side of the mixing area. Nitrate was only detected in the sample from TW02 and no nitrite was detected at the site, indicating nitrate reduction may not be a significant biodegradation process at this site. Ammonia concentrations were not notably different inside vs. outside of the treatment area. Methane, ethane, and ethene concentrations were all higher in the mixing area than outside, as expected. In fact, these constituents were generally not detected outside of the mixing area, but were consistently detected within the mixing area (**Appendix I-1B**).



SLOP-TW05	
Dissolved Oxygen (mg/L)	9.06
Redox Potential (mV)	136.9
pH (pH units)	6.31

SLOP-TW04	
Dissolved Oxygen (mg/L)	7.16
Redox Potential (mV)	213.9
pH (pH units)	6.24

SLOP-TW01	
Dissolved Oxygen (mg/L)	0.4
Redox Potential (mV)	-285.7
pH (pH units)	6.6

SLOP-MW119	
Dissolved Oxygen (mg/L)	0.18
Redox Potential (mV)	-272.7
pH (pH units)	8.69

SLOP-TW03	
Dissolved Oxygen (mg/L)	7.58
Redox Potential (mV)	97.2
pH (pH units)	6.29

SLOP-TW06	
Dissolved Oxygen (mg/L)	10
Redox Potential (mV)	348.7
pH (pH units)	6.14

SLOP-TW02	
Dissolved Oxygen (mg/L)	0.42
Redox Potential (mV)	-430.5
pH (pH units)	7.11

Legend

ZVI Monitoring Well

- Treatment Area
- Temporary Well Location
- Soil Mixing Treatment Areas
- Installation Boundary

Notes:
mV - millivolts
mg/L - milligrams per Liter

N

0 20 40 Feet

1 inch = 40 feet

Imagery Source: ©2017, Esri

Figure 5-10
Select Field Parameter Results - January 2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m.

All aerial maps contained in this document are provided by Esri; road and terrain maps are sourced from installation-specific geodatabases and are cross referenced with local GIS data.

R:\N\Navy\CLEAN\MULTI_REGION\ZVI\MapFiles\Results\SLOP\Figure 5-33 - STL Geochemical Parameters.mxd9/25/2017bmailhes

SLOP-TW05	Concentration (mg/L)	
Alkalinity	233	
Ammonia	0.0951	J
Chloride	25.8	
Fluoride	0.257	J
Hardness	260	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	84.8	
Sulfide	1	U
TOC	6.84	
Methane	0.002	U
Ethane	0.002	U
Ethene	0.002	U

SLOP-TW04	Concentration (mg/L)	
Alkalinity	154	
Ammonia	0.0913	J
Chloride	43	
Fluoride	0.204	J
Hardness	224	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	107	
Sulfide	1	U
TOC	7.35	
Methane	0.013	
Ethane	0.0084	
Ethene	0.002	U

SLOP-MW119	Concentration (mg/L)	
Alkalinity	221	
Ammonia	0.18	J
Chloride	31.4	
Fluoride	1.8	
Hardness	130	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.142	
Sulfate	1.7	J
Sulfide	1	U
TOC	11.4	
Methane	14.0	
Ethane	0.14	
Ethene	0.0041	J

SLOP-TW01	Concentration (mg/L)	
Alkalinity	232	
Ammonia	0.164	J
Chloride	22.6	
Fluoride	0.477	
Hardness	252	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	25.4	
Sulfide	1	U
TOC	17.8	
Methane	0.120	
Ethane	0.022	
Ethene	0.011	

SLOP-TW03	Concentration (mg/L)	
Alkalinity	175	
Ammonia	0.163	J
Chloride	60.4	
Fluoride	0.281	J
Hardness	110	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	84.7	
Sulfide	1	U
TOC	5.24	
Methane	0.002	U
Ethane	0.002	U
Ethene	0.002	U

SLOP-TW02	Concentration (mg/L)	
Alkalinity	96.4	
Ammonia	0.0867	J
Chloride	228	
Fluoride	0.422	J
Hardness	328	
Nitrate	0.922	J
Nitrite	0.4	U
Phosphate	0.05	U
Sulfate	44	
Sulfide	1	U
TOC	27.6	
Methane	3.2	
Ethane	0.27	
Ethene	0.0045	J

SLOP-TW06	Concentration (mg/L)	
Alkalinity	128	
Ammonia	0.0708	J
Chloride	38.9	
Fluoride	0.211	J
Hardness	188	
Nitrate	0.2	U
Nitrite	0.2	U
Phosphate	0.05	U
Sulfate	84.4	
Sulfide	1	U
TOC	4.25	
Methane	0.002	U
Ethane	0.002	U
Ethene	0.002	U

Legend

ZVI Monitoring Well
- Treatment Area
- Temporary Well Location
- Soil Mixing Treatment Areas
- Installation Boundary

Notes:
TOC - Total organic carbon
J - The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outside the quantitation range).
U - The material was analyzed for, but not detected
mg/L - milligrams per Liter
Acetylene was not detected in any samples; therefore, results are not included on this figure.

N

0 20 40 Feet

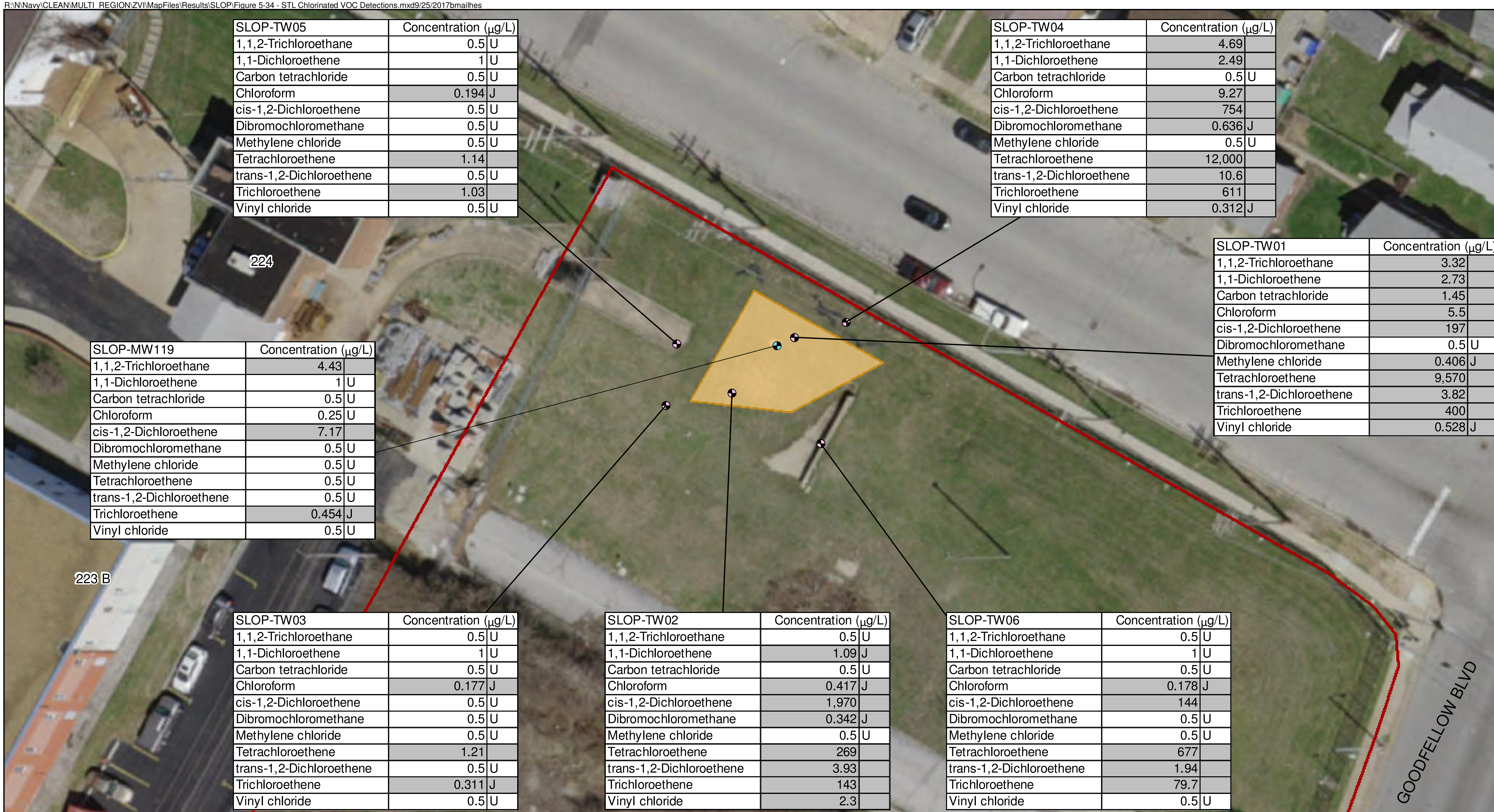
1 inch = 40 feet

Imagery Source: ©2017, Esri

Figure 5-11
Geochemical Parameters - January 2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m:

All aerial maps contained in this document are provided by Esri; road and terrain maps are sourced from installation-specific geodatabases and are cross referenced with local GIS data.



SLOP-TW05	Concentration (μg/L)	
1,1,2-Trichloroethane	0.5	U
1,1-Dichloroethene	1	U
Carbon tetrachloride	0.5	U
Chloroform	0.194	J
cis-1,2-Dichloroethene	0.5	U
Dibromochloromethane	0.5	U
Methylene chloride	0.5	U
Tetrachloroethene	1.14	
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	1.03	
Vinyl chloride	0.5	U

SLOP-TW04	Concentration (μg/L)	
1,1,2-Trichloroethane	4.69	
1,1-Dichloroethene	2.49	
Carbon tetrachloride	0.5	U
Chloroform	9.27	
cis-1,2-Dichloroethene	754	
Dibromochloromethane	0.636	J
Methylene chloride	0.5	U
Tetrachloroethene	12,000	
trans-1,2-Dichloroethene	10.6	
Trichloroethene	611	
Vinyl chloride	0.312	J

SLOP-TW01	Concentration (μg/L)	
1,1,2-Trichloroethane	3.32	
1,1-Dichloroethene	2.73	
Carbon tetrachloride	1.45	
Chloroform	5.5	
cis-1,2-Dichloroethene	197	
Dibromochloromethane	0.5	U
Methylene chloride	0.406	J
Tetrachloroethene	9,570	
trans-1,2-Dichloroethene	3.82	
Trichloroethene	400	
Vinyl chloride	0.528	J

SLOP-MW119	Concentration (μg/L)	
1,1,2-Trichloroethane	4.43	
1,1-Dichloroethene	1	U
Carbon tetrachloride	0.5	U
Chloroform	0.25	U
cis-1,2-Dichloroethene	7.17	
Dibromochloromethane	0.5	U
Methylene chloride	0.5	U
Tetrachloroethene	0.5	U
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	0.454	J
Vinyl chloride	0.5	U

SLOP-TW03	Concentration (μg/L)	
1,1,2-Trichloroethane	0.5	U
1,1-Dichloroethene	1	U
Carbon tetrachloride	0.5	U
Chloroform	0.177	J
cis-1,2-Dichloroethene	0.5	U
Dibromochloromethane	0.5	U
Methylene chloride	0.5	U
Tetrachloroethene	1.21	
trans-1,2-Dichloroethene	0.5	U
Trichloroethene	0.311	J
Vinyl chloride	0.5	U

SLOP-TW02	Concentration (μg/L)	
1,1,2-Trichloroethane	0.5	U
1,1-Dichloroethene	1.09	J
Carbon tetrachloride	0.5	U
Chloroform	0.417	J
cis-1,2-Dichloroethene	1,970	
Dibromochloromethane	0.342	J
Methylene chloride	0.5	U
Tetrachloroethene	269	
trans-1,2-Dichloroethene	3.93	
Trichloroethene	143	
Vinyl chloride	2.3	

SLOP-TW06	Concentration (μg/L)	
1,1,2-Trichloroethane	0.5	U
1,1-Dichloroethene	1	U
Carbon tetrachloride	0.5	U
Chloroform	0.178	J
cis-1,2-Dichloroethene	144	
Dibromochloromethane	0.5	U
Methylene chloride	0.5	U
Tetrachloroethene	677	
trans-1,2-Dichloroethene	1.94	
Trichloroethene	79.7	
Vinyl chloride	0.5	U

Legend

ZVI Monitoring Well
- Treatment Area
- Temporary Well Location
- Soil Mixing Treatment Areas
- Installation Boundary

Notes:
J - The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outside the quantitation range).
U - The material was analyzed for, but not detected
μg/L - milligrams per Liter

N

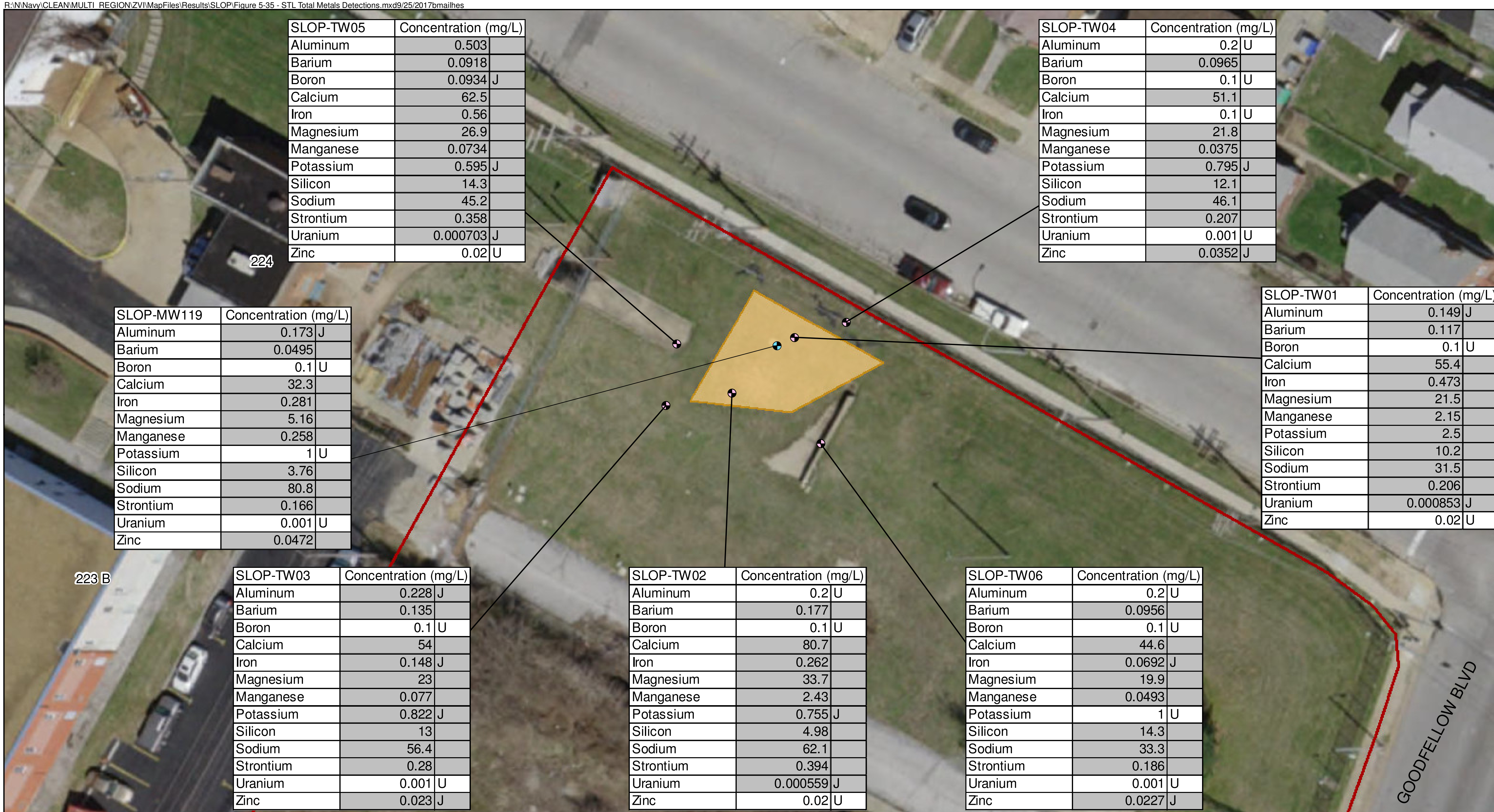
0 20 40 Feet

1 inch = 40 feet

Imagery Source: ©2017, Esri

Figure 5-12
Chlorinated VOC Detections - January 2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m:



SLOP-TW05	Concentration (mg/L)	
Aluminum	0.503	
Barium	0.0918	
Boron	0.0934	J
Calcium	62.5	
Iron	0.56	
Magnesium	26.9	
Manganese	0.0734	
Potassium	0.595	J
Silicon	14.3	
Sodium	45.2	
Strontium	0.358	
Uranium	0.000703	J
Zinc	0.02	U

SLOP-TW04	Concentration (mg/L)	
Aluminum	0.2	U
Barium	0.0965	
Boron	0.1	U
Calcium	51.1	
Iron	0.1	U
Magnesium	21.8	
Manganese	0.0375	
Potassium	0.795	J
Silicon	12.1	
Sodium	46.1	
Strontium	0.207	
Uranium	0.001	U
Zinc	0.0352	J

SLOP-TW01	Concentration (mg/L)	
Aluminum	0.149	J
Barium	0.117	
Boron	0.1	U
Calcium	55.4	
Iron	0.473	
Magnesium	21.5	
Manganese	2.15	
Potassium	2.5	
Silicon	10.2	
Sodium	31.5	
Strontium	0.206	
Uranium	0.000853	J
Zinc	0.02	U

SLOP-MW119	Concentration (mg/L)	
Aluminum	0.173	J
Barium	0.0495	
Boron	0.1	U
Calcium	32.3	
Iron	0.281	
Magnesium	5.16	
Manganese	0.258	
Potassium	1	U
Silicon	3.76	
Sodium	80.8	
Strontium	0.166	
Uranium	0.001	U
Zinc	0.0472	

SLOP-TW03	Concentration (mg/L)	
Aluminum	0.228	J
Barium	0.135	
Boron	0.1	U
Calcium	54	
Iron	0.148	J
Magnesium	23	
Manganese	0.077	
Potassium	0.822	J
Silicon	13	
Sodium	56.4	
Strontium	0.28	
Uranium	0.001	U
Zinc	0.023	J

SLOP-TW02	Concentration (mg/L)	
Aluminum	0.2	U
Barium	0.177	
Boron	0.1	U
Calcium	80.7	
Iron	0.262	
Magnesium	33.7	
Manganese	2.43	
Potassium	0.755	J
Silicon	4.98	
Sodium	62.1	
Strontium	0.394	
Uranium	0.000559	J
Zinc	0.02	U

SLOP-TW06	Concentration (mg/L)	
Aluminum	0.2	U
Barium	0.0956	
Boron	0.1	U
Calcium	44.6	
Iron	0.0692	J
Magnesium	19.9	
Manganese	0.0493	
Potassium	1	U
Silicon	14.3	
Sodium	33.3	
Strontium	0.186	
Uranium	0.001	U
Zinc	0.0227	J

Legend

ZVI Monitoring Well

- Treatment Area
- Temporary Well Location
- Soil Mixing Treatment Areas
- Installation Boundary

Notes:

J - The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outside the quantitation range).

U - The material was analyzed for, but not detected

mg/L - milligrams per Liter

N

0 20 40 Feet

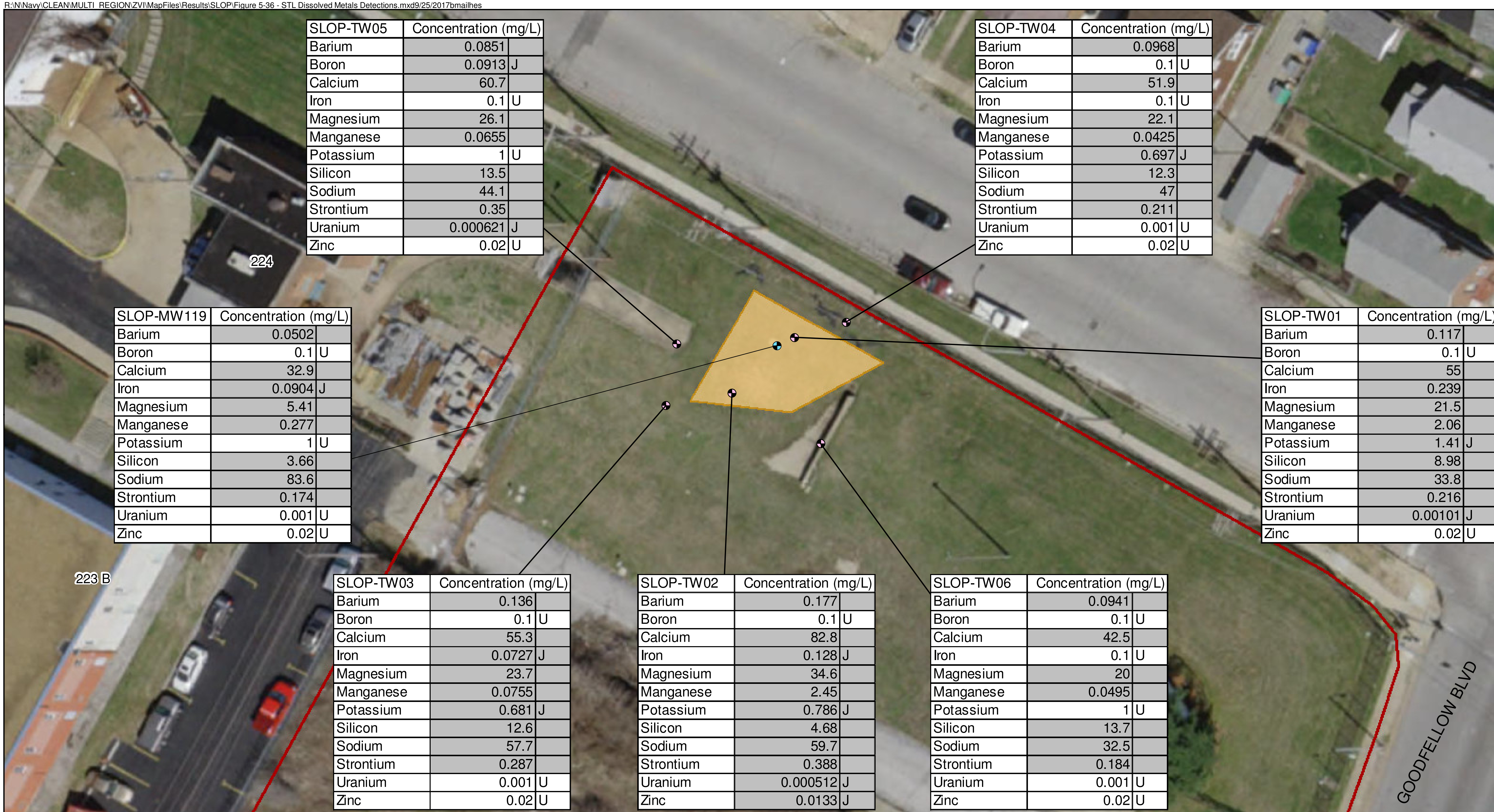
1 inch = 40 feet

Imagery Source: ©2017, Esri

Figure 5-13
Total Metals Detections - January 2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m.

R:\N\Navy\CLEAN\MULTI_REGION\ZVI\MapFiles\Results\SLOP\Figure 5-36 - STL Dissolved Metals Detections.mxd9/25/2017bmailhes



SLOP-TW05	Concentration (mg/L)	
Barium	0.0851	
Boron	0.0913	J
Calcium	60.7	
Iron	0.1	U
Magnesium	26.1	
Manganese	0.0655	
Potassium	1	U
Silicon	13.5	
Sodium	44.1	
Strontium	0.35	
Uranium	0.000621	J
Zinc	0.02	U

SLOP-TW04	Concentration (mg/L)	
Barium	0.0968	
Boron	0.1	U
Calcium	51.9	
Iron	0.1	U
Magnesium	22.1	
Manganese	0.0425	
Potassium	0.697	J
Silicon	12.3	
Sodium	47	
Strontium	0.211	
Uranium	0.001	U
Zinc	0.02	U

SLOP-MW119	Concentration (mg/L)	
Barium	0.0502	
Boron	0.1	U
Calcium	32.9	
Iron	0.0904	J
Magnesium	5.41	
Manganese	0.277	
Potassium	1	U
Silicon	3.66	
Sodium	83.6	
Strontium	0.174	
Uranium	0.001	U
Zinc	0.02	U

SLOP-TW01	Concentration (mg/L)	
Barium	0.117	
Boron	0.1	U
Calcium	55	
Iron	0.239	
Magnesium	21.5	
Manganese	2.06	
Potassium	1.41	J
Silicon	8.98	
Sodium	33.8	
Strontium	0.216	
Uranium	0.00101	J
Zinc	0.02	U

SLOP-TW03	Concentration (mg/L)	
Barium	0.136	
Boron	0.1	U
Calcium	55.3	
Iron	0.0727	J
Magnesium	23.7	
Manganese	0.0755	
Potassium	0.681	J
Silicon	12.6	
Sodium	57.7	
Strontium	0.287	
Uranium	0.001	U
Zinc	0.02	U

SLOP-TW02	Concentration (mg/L)	
Barium	0.177	
Boron	0.1	U
Calcium	82.8	
Iron	0.128	J
Magnesium	34.6	
Manganese	2.45	
Potassium	0.786	J
Silicon	4.68	
Sodium	59.7	
Strontium	0.388	
Uranium	0.000512	J
Zinc	0.0133	J

SLOP-TW06	Concentration (mg/L)	
Barium	0.0941	
Boron	0.1	U
Calcium	42.5	
Iron	0.1	U
Magnesium	20	
Manganese	0.0495	
Potassium	1	U
Silicon	13.7	
Sodium	32.5	
Strontium	0.184	
Uranium	0.001	U
Zinc	0.02	U

Legend

ZVI Monitoring Well

- Treatment Area
- Temporary Well Location
- Soil Mixing Treatment Areas
- Installation Boundary

Notes:
J - The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outside the quantitation range).
U - The material was analyzed for, but not detected
mg/L - milligrams per Liter

N

0 20 40 Feet

1 inch = 40 feet

Imagery Source: ©2017, Esri

Figure 5-14
Dissolved Metals Detections - January 2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m.

Table 5-5. Water Quality Parameters, Former St. Louis Ordnance Plant OU1

Sample ID:	SLOP-MW119-012017	SLOP-TW01-012017	SLOP-TW02-012017	SLOP-TW03-012017	SLOP-TW04-012017	SLOP-TW05-012017	SLOP-TW06-012017
Sample Date:	**1/23/17**	**1/25/17**	**1/24/17**	**1/23/17**	**1/25/17**	**1/24/17**	**1/24/17**
Water Quality Parameters							
Dissolved Oxygen (mg/L)	0.18	0.4	0.42	7.58	7.16	9.06	10
ORP (mV)	-272.7	-285.7	-430.5	97.2	213.9	136.9	348.7
pH (pH units)	8.69	6.6	7.11	6.29	6.24	6.31	6.14
Specific Conductivity (mS/cm)	0.526	0.823	1.031	0.687	0.935	0.667	0.535
Temperature (°C)	12.94	12.2	15.23	11.25	12.81	12.03	13.29
Turbidity (NTU)	6.9	29.7	7.76	7.75	4.22	21.3	5.27

Table 5-6. Laboratory Analytical Detections, Former St. Louis Ordnance Plant OU1

			Sample ID:	TW03	TW03P	MW119	TW01	TW02	TW04	TW05	TW06
			Sample Date:	1/23/17	1/23/17	1/23/17	1/25/17	1/24/17	1/25/17	1/24/17	1/24/17
Chemical Name	Frequency	Max Value	Max Location								
Volatile Organic Compounds (µg/L)											
1,1,2-Trichloroethane	3 / 8	4.69	SLOP-TW04-012017	0.5 U	0.5 U	4.43	3.32	0.5 U	4.69	0.5 U	0.5 U
1,1-Dichloroethene	3 / 8	2.73	SLOP-TW01-012017	1 U	1 U	1 U	2.73	1.09 J	2.49	1 U	1 U
2-Butanone	3 / 8	21.6	SLOP-TW02-012017	5 U	5 U	4.02 J	3.72 J	21.6	5 U	5 U	5 U
Acetone	4 / 8	36.1 Q	SLOP-TW02-012017	5 U	5 U	6.89 J	9.87 Q	36.1 Q	3.26 Q	5 UQ	5 UQ
Benzene	4 / 8	7.92	SLOP-TW02-012017	0.25 U	0.25 U	3.13	0.794 J	7.92	0.441 J	0.25 U	0.25 U
Carbon tetrachloride	1 / 8	1.45	SLOP-TW01-012017	0.5 U	0.5 U	0.5 U	1.45	0.5 U	0.5 U	0.5 U	0.5 U
Chloroform	7 / 8	9.27	SLOP-TW04-012017	0.161 J	0.177 J	0.25 U	5.5	0.417 J	9.27	0.194 J	0.178 J
cis-1,2-Dichloroethene	5 / 8	1,970	SLOP-TW02-012017	0.5 U	0.5 U	7.17	197	1,970	754	0.5 U	144
Dibromochloromethane	2 / 8	0.636 J	SLOP-TW04-012017	0.5 U	0.5 U	0.5 U	0.5 U	0.342 J	0.636 J	0.5 U	0.5 U
Ethane	4 / 7	270.0	SLOP-TW02-012017	2 U	NS	140	22	270	8.4	2 U	2 U
Ethene	3 / 7	11.0	SLOP-TW01-012017	2 U	NS	4.1 J	11	4.5 J	2 U	2 U	2 U
Ethylbenzene	3 / 8	9.57	SLOP-TW02-012017	0.5 U	0.5 U	1.52	0.291 J	9.57	0.5 U	0.5 U	0.5 U
Isopropylbenzene	1 / 8	0.256 J	SLOP-TW02-012017	0.5 U	0.5 U	0.5 U	0.5 U	0.256 J	0.5 U	0.5 U	0.5 U
m- and p-Xylene	2 / 8	18.1	SLOP-TW02-012017	1 U	1 U	1.2 J	1 U	18.1	1 U	1 U	1 U
Methane	4 / 7	14,000	SLOP-MW119-012017	2 U	NS	14,000	120	3,200	13	2 U	2 U
Methylene chloride	1 / 8	0.406 J	SLOP-TW01-012017	0.5 U	0.5 U	0.5 U	0.406 J	0.5 U	0.5 U	0.5 U	0.5 U
o-Xylene	3 / 8	2.86	SLOP-TW02-012017	0.5 U	0.5 U	0.763 J	0.277 J	2.86	0.5 U	0.5 U	0.5 U
Tetrachloroethene	7 / 8	12,000	SLOP-TW04-012017	1.21	1.13	0.5 U	9,570	269	12,000	1.14	677
Toluene	6 / 8	6.73	SLOP-TW02-012017	0.258 J	0.278 J	4.14	1.3	6.73	0.504 J	0.5 U	0.5 U
trans-1,2-Dichloroethene	4 / 8	10.6	SLOP-TW04-012017	0.5 U	0.5 U	0.5 U	3.82	3.93	10.6	0.5 U	1.94
Trichloroethene	8 / 8	611.0	SLOP-TW04-012017	0.298 J	0.311 J	0.454 J	400	143	611	1.03	79.7
Vinyl chloride	3 / 8	2.30	SLOP-TW02-012017	0.5 U	0.5 U	0.5 U	0.528 J	2.3	0.312 J	0.5 U	0.5 U
Total Metals (mg/L)											
Aluminum	5 / 8	0.503	SLOP-TW05-012017	0.162 J	0.228 J	0.173 J	0.149 J	ND U	ND U	0.503	ND U
Barium	8 / 8	0.177	SLOP-TW02-012017	0.133	0.135	0.0495	0.117	0.177	0.0965	0.0918	0.0956
Boron	1 / 8	0.0934 J	SLOP-TW05-012017	ND U	ND U	ND U	ND U	ND U	ND U	0.0934 J	ND U
Calcium	8 / 8	80.7	SLOP-TW02-012017	53.7	54	32.3	55.4	80.7	51.1	62.5	44.6
Iron	7 / 8	0.560	SLOP-TW05-012017	0.136 J	0.148 J	0.281	0.473	0.262	ND U	0.56	0.0692 J
Magnesium	8 / 8	33.7	SLOP-TW02-012017	22.8	23	5.16	21.5	33.7	21.8	26.9	19.9
Manganese	8 / 8	2.43	SLOP-TW02-012017	0.0773	0.077	0.258	2.15	2.43	0.0375	0.0734	0.0493
Potassium	6 / 8	2.50	SLOP-TW01-012017	0.822 J	0.661 J	ND U	2.5	0.755 J	0.795 J	0.595 J	ND U
Silicon	8 / 8	14.3	SLOP-TW05-012017	12.4	13	3.76	10.2	4.98	12.1	14.3	14.3
Sodium	8 / 8	80.8	SLOP-MW119-012017	56.2	56.4	80.8	31.5	62.1	46.1	45.2	33.3
Strontium	8 / 8	0.394	SLOP-TW02-012017	0.278	0.28	0.166	0.206	0.394	0.207	0.358	0.186

Table 5-6. Laboratory Analytical Detections, Former St. Louis Ordnance Plant OU1

			Sample ID:	TW03	TW03P	MW119	TW01	TW02	TW04	TW05	TW06
			Sample Date:	1/23/17	1/23/17	1/23/17	1/25/17	1/24/17	1/25/17	1/24/17	1/24/17
Chemical Name	Frequency	Max Value	Max Location								
Uranium	3 / 8	0.000853 J	SLOP-TW01-012017	ND U	ND U	ND U	0.000853 J	0.000559 J	ND U	0.000703 J	0.001 U
Zinc	4 / 8	0.0472	SLOP-MW119-012017	0.023 J	ND U	0.0472	ND U	ND U	0.0352 J	ND U	0.0227 J
Dissolved Metals (mg/L)											
Barium	8 / 8	0.177	SLOP-TW02-012017	0.136	0.133	0.0502	0.117	0.177	0.0968	0.0851	0.0941
Boron	1 / 8	0.0913 J	SLOP-TW05-012017	ND U	ND U	ND U	ND U	ND U	ND U	0.0913 J	ND U
Calcium	8 / 8	82.8	SLOP-TW02-012017	55.3	55.2	32.9	55	82.8	51.9	60.7	42.5
Iron	4 / 8	0.239	SLOP-TW01-012017	0.0727 J	ND U	0.0904 J	0.239	0.128 J	ND U	ND U	ND U
Magnesium	8 / 8	34.6	SLOP-TW02-012017	23.7	23	5.41	21.5	34.6	22.1	26.1	20
Manganese	8 / 8	2.45	SLOP-TW02-012017	0.0755	0.0742	0.277	2.06	2.45	0.0425	0.0655	0.0495
Potassium	5 / 8	1.41 J	SLOP-TW01-012017	0.681 J	0.821 J	ND U	1.41 J	0.786 J	0.697 J	ND U	ND U
Silicon	8 / 8	13.7	SLOP-TW06-012017	12.6	12.4	3.66	8.98	4.68	12.3	13.5	13.7
Sodium	8 / 8	83.6	SLOP-MW119-012017	57.7	56.5	83.6	33.8	59.7	47	44.1	32.5
Strontium	8 / 8	0.388	SLOP-TW02-012017	0.287	0.281	0.174	0.216	0.388	0.211	0.35	0.184
Uranium	3 / 8	0.00101 J	SLOP-TW01-012017	ND U	ND U	ND U	0.00101 J	0.000512 J	ND U	0.000621 J	ND U
Zinc	1 / 8	0.0133 J	SLOP-TW02-012017	ND U	ND U	ND U	ND U	0.0133 J	ND U	ND U	ND U
Wet Chemistry (mg/L)											
Alkalinity	7 / 7	233.0	SLOP-TW05-012017	175	NS	221	232	96.4	154	233	128
Ammonia	7 / 7	0.180 J	SLOP-MW119-012017	0.163 J	NS	0.18 J	0.164 J	0.0867 J	0.0913 J	0.0951 J	0.0708 J
Chloride	7 / 7	228.0	SLOP-TW02-012017	60.4	NS	31.4	22.6	228	43	25.8	38.9
Fluoride	7 / 7	1.80	SLOP-MW119-012017	0.281 J	NS	1.8	0.477	0.422 J	0.204 J	0.257 J	0.211 J
Hardness	7 / 7	328.0	SLOP-TW02-012017	110	NS	130	252	328	224	260	188
Nitrate	1 / 7	0.922 J	SLOP-TW02-012017	ND U	NS	ND U	ND U	0.922 J	ND U	ND U	ND U
Phosphate	1 / 7	0.142	SLOP-MW119-012017	ND U	NS	0.142	ND U	ND U	ND U	ND U	ND U
Sulfate	7 / 7	107.0	SLOP-TW04-012017	84.7	NS	1.7 J	25.4	44	107	84.8	84.4
Total organic carbon (TOC)	7 / 7	27.6	SLOP-TW02-012017	5.24	NS	11.4	17.8	27.6	7.35	6.84	4.25

Notes:

J = The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outside the quantitation range).

Q = One or more quality control criteria failed (e.g., laboratory control sample recovery, surrogate spike recovery, or continuing calibration verification recovery).

U = The material was analyzed for, but not detected

UQ = The material was analyzed for, but not detected. One or more quality control criteria failed.

Shading indicates detection

Treatment Area (yellow)

Upgradient (blue)

Downgradient (orange)

Cross-gradient (green)

VOC concentrations in existing well MW-119 were consistent with historical data (**Appendix A**). No constituents in samples from this well exceeded corresponding MCLs (**Figure 5-12**). However, MCL exceedances were observed in temporary mixing area wells TW01 and TW02, with a maximum PCE concentration of 9,570 µg/L observed in downgradient mixing area well TW01. The concentration of PCE in TW04, which is outside of and downgradient of the mixing area, was 12,000 µg/L. Concentrations of PCE, TCE, and cis-1,2-DCE were 677 µg/L, 79.7 µg/L, and 144 µg/L, respectively, in the sample from cross-gradient well TW06. While these concentrations are less than the clean-up goal established for this site (21,000 µg/L), they are above MCLs and represent significant remaining contaminant mass. Concentrations in the sample from cross-gradient well TW05 were less than MCLs.

Metals data indicate a number of differences between the mixing zone and untreated area at the former St. Louis Ordnance Plant OU1. Concentrations of total and dissolved calcium, magnesium, manganese, barium, and strontium were highest in the sample from TW02, the most upgradient location in the mixing area (**Figures 5-13 and 5-14 and Appendix I-2)**. While dissolved iron concentrations were higher in the mixing area and total iron concentrations were generally higher, iron concentrations overall were very low at this site, with the maximum concentration of both total and dissolved iron at less than 1 mg/L. Silicon concentrations were lowest within the treatment area and sodium concentrations were highest in MW-119, in the middle of the treatment area, with downgradient concentrations less than those observed in the upgradient reference well. There were no notable trends in other metals concentrations.

5.4.2 Mineralogical Testing Results

5.4.2.1 ABL Site 5 Mineralogical Testing Results

Average concentration values for inorganic carbon and solid phase AVS results are provided in **Table 5-7**.

Table 5-7. Concentrations of Inorganic Carbon and Acid-Volatile Sulfur in Cores from the ABL Site 5 PRB

Core	Segment [a]	Distance Along Core (ft)	Inorganic Carbon (µg/g)	Acid-Volatile Sulfur (µg/g)
WV DP001	L, top	0 – 0.335	41	12
WV DP001	K	0.335 – 0.669	19	15
WV DP001	J, interface	0.669 – 1.003	2124	28
WV DP001	I, interface	1.003 – 1.339	5251	240
WV DP001	H	1.339 – 1.673	615	372
WV DP001	G	1.673 – 2.008	288	183
WV DP001	F	2.008 – 2.343	175	121
WV DP001	E	2.343 – 2.677	250	224
WV DP001	D	2.677 – 3.012	306	65
WV DP001	C	3.012 – 3.346	284	117
WV DP001	B	3.346 – 3.681	203	105
WV DP001	A, bottom	3.681 – 4.016	209	173

Table 5-7. Concentrations of Inorganic Carbon and Acid-Volatile Sulfur in Cores from the ABL Site 5 PRB

Core	Segment [a]	Distance Along Core (ft)	Inorganic Carbon (µg/g)	Acid-Volatile Sulfur (µg/g)
WV DP003	G, top	0 – 0.335	27	39
WV DP003	F	0.335 – 0.669	64	41
WV DP003	E	0.669 – 1.003	11	44
WV DP003	D, interface	1.003 – 1.339	77	45
WV DP003	C, interface	1.339 – 1.673	622	202
WV DP003	B	1.673 – 2.008	473	229
WV DP003	A, bottom	2.008 – 2.343	378	789

Note:

[a] The letters in this column are the designations assigned to the various segments in the laboratory. The distances along the core these represent are defined in the Distance Along Core column.

The interface region between the upgradient aquifer and the ZVI medium is marked by an abrupt increase in inorganic carbon concentrations (**Figures 5-15 and 5-16**; **Table 5-7)**. In core DP001, the concentration of inorganic carbon increased from levels of <50 micrograms per gram (µg/g) to >2,000 µg/g over an interval of ~0.3 feet. This upward shift in solid-phase inorganic carbon is due to precipitation of aragonite (a form of calcium carbonate), driven by alkaline pH in the ZVI porewater. Similarly, concentrations of AVS also increased within the reactive medium. AVS concentrations as high as 789 µg/g were determined in the core samples. AVS is derived from the dissolution of iron sulfide that forms within the reactive medium as a consequence of sulfate reduction/sulfide production. The iron sulfide is thought to provide secondary reactivity to the PRB zone and capacity to degrade chlorinated ethenes; whereas the aragonite does not provide secondary reactivity. These results indicate passivation may be more substantial at the upgradient interface, but continued reactivity is likely further into the wall.

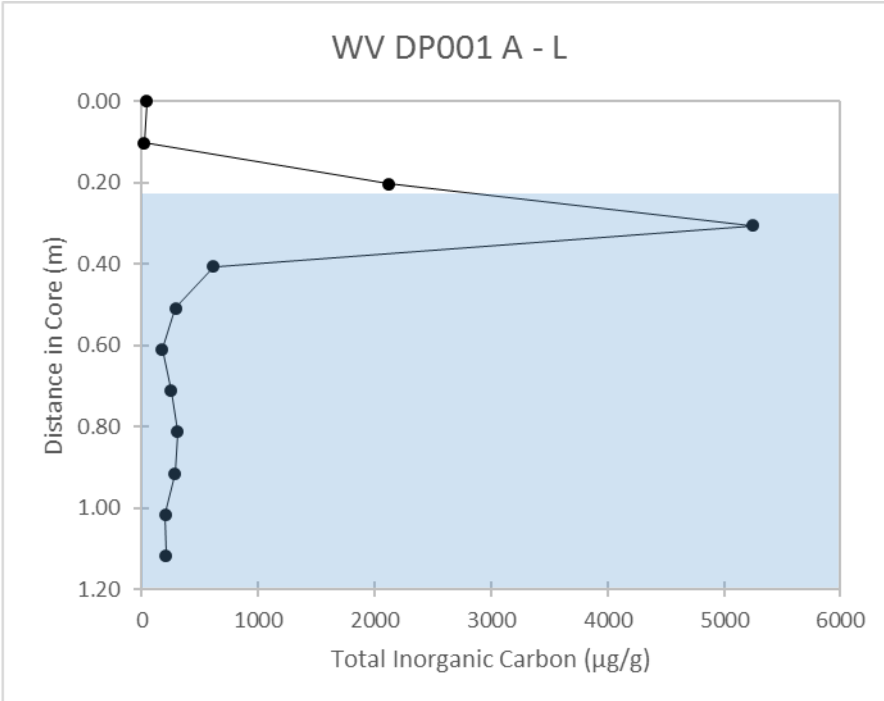


Figure 5-15. Inorganic Carbon Concentrations in ABL Site 5 Core DP001
The interface region shows an abrupt increase in the concentration of solid-phase carbonate; the blue-shaded region represents core material dominated by granular iron.

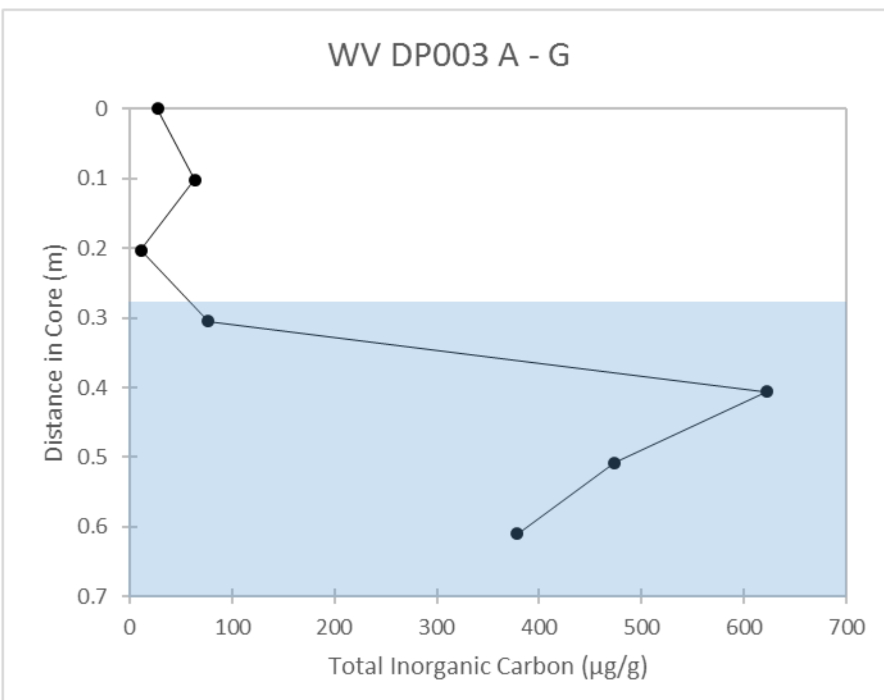


Figure 5-16. Inorganic Carbon Concentrations in ABL Site 5 Core DP003
The blue-shaded region represents core material dominated by granular iron.

XRD patterns for samples from ABL samples DP001 and DP003 are plotted in **Figures 5-17 and 5-18**. The identified minerals were quartz, clays (illite and kaolinite), iron oxides (magnetite, hematite), and aragonite. Some minerals that are common in other ZVI PRBs, such as iron sulfide, green rust, siderite, and ferrous hydroxy carbonate, were not identified. The data generally indicate the iron remaining is significantly weathered. As noted above, the presence of AVS is consistent with the presence of iron sulfide; however, the maximum concentration of AVS, and its likely poor crystallinity, did not allow for identification using powder x-ray techniques.

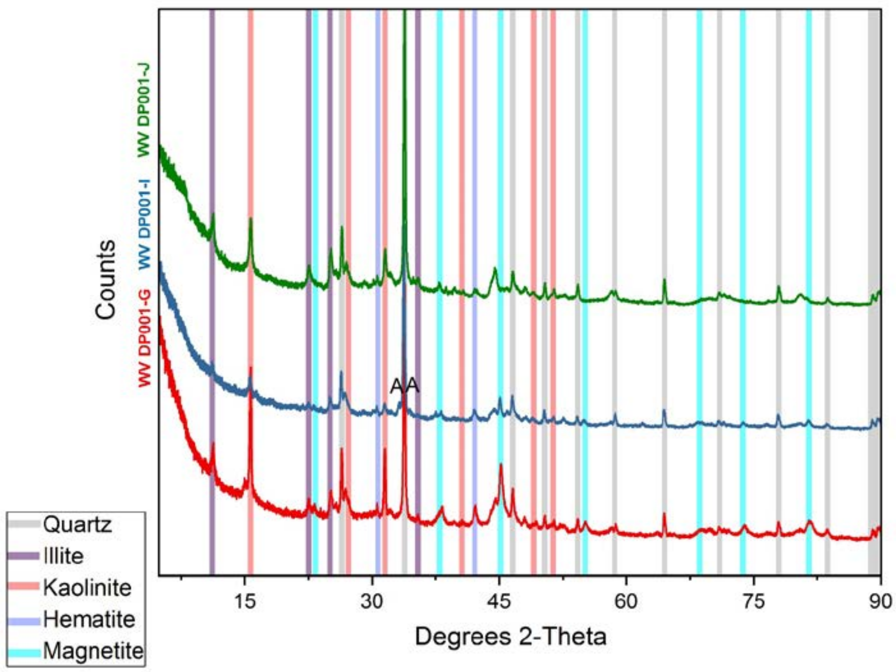


Figure 5-17. X-ray Diffraction Results for ABL Site 5 Core DP001

The analyzed sections of the core were section J (interface region), section I (mid-core), and section G (interior). The primary minerals identified were quartz, clays (illite and kaolinite), and iron oxides (magnetite and hematite). Calcium carbonate (aragonite; marked as A) was identified in sample sections I and J, collected near the PRB/aquifer upgradient interface.

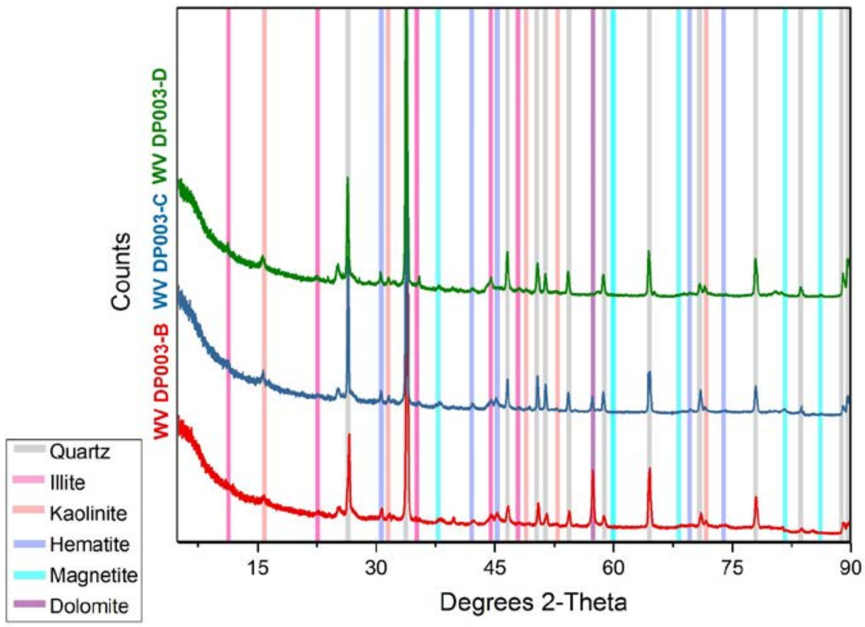


Figure 5-18. X-ray Diffraction Results for ABL Site 5 Core DP003

The analyzed sections of the core were section D (interface region), section C (interface), and section B (interior). The primary minerals identified were quartz, clays (illite and kaolinite), and iron oxides (magnetite and hematite). No major differences were noted between this core and core DP001, except a lower abundance of clay minerals was apparent in DP003.

SEM micrographs and EDS element mapping images for samples from ABL core DP001 are shown in **Figures 5-19 and 5-20**. Key findings from the microscopy study are: 1) near the ZVI/aquifer interface, iron particles show a mottled texture indicative of corrosion; 2) native quartz grains are often cemented together by iron oxide and calcium carbonate; 3) calcium carbonate and iron oxides occur as coatings on the ZVI grains; and 4) at deeper levels in the core, inward from the ZVI/aquifer interface, the thickness of coatings diminishes and the iron grains show fewer corrosion features. The maximum thickness of coatings on the iron grains occurred in samples from section DP001-H, near the ZVI/aquifer interface. The cementation of quartz and iron grains observed at the micro-level was also witnessed at the macro-level as welded concretions that were observed during the anaerobic drying. Overall results of the SEM and EDS element maps indicate significant weathering of the iron and some cementation of wall particles, but likely not enough to cause diminished hydraulic conductivity throught the wall.

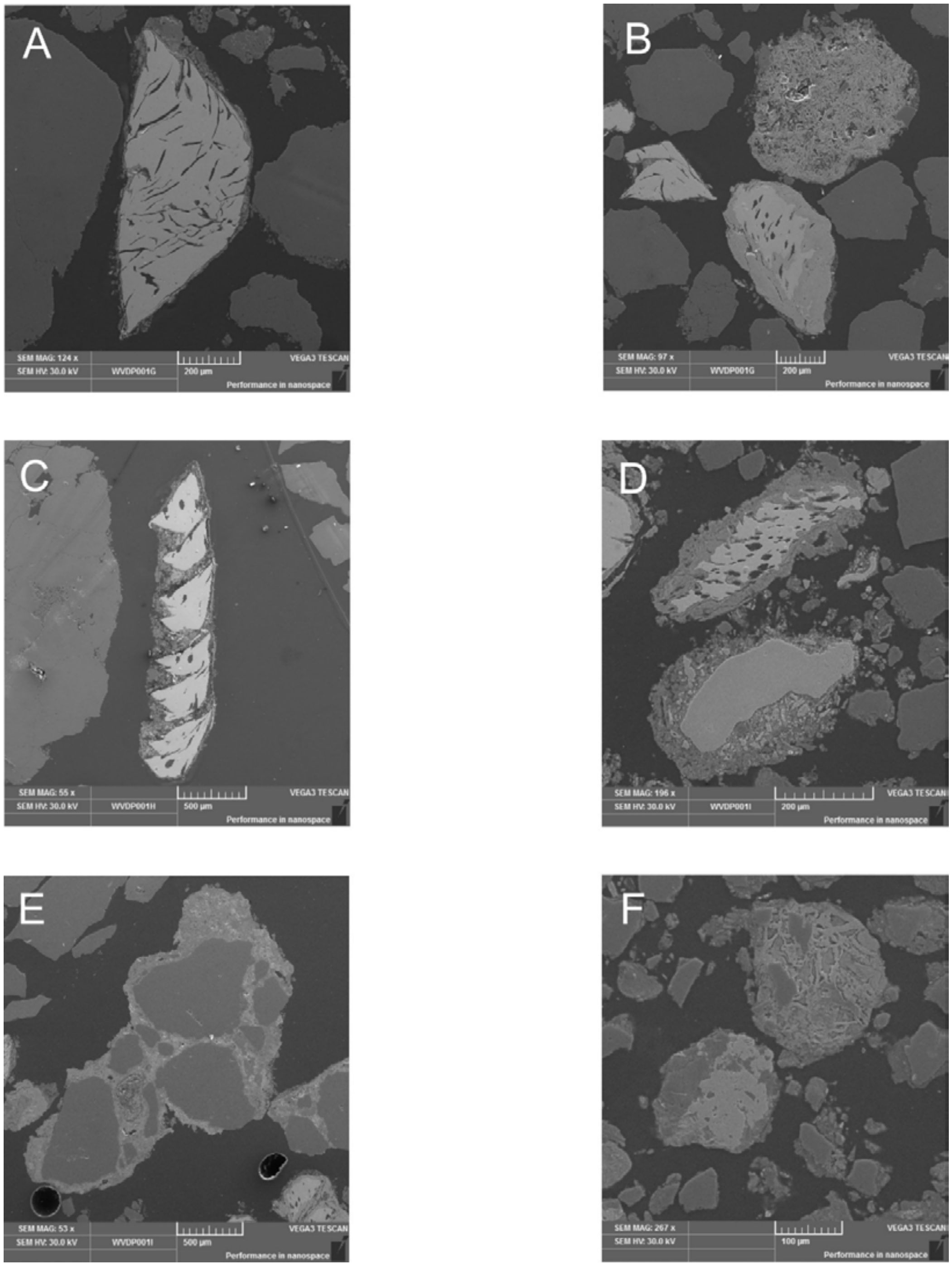


Figure 5-19. Scanning Electron Microscopy Images from ABL Site 5 Core DP001

Image A is from the lowest level within the core and Image F is from the highest level.

A) A typical iron (Fe) grain in the lower part of the core, from DP001-G, note the thin oxide layer.

B) A corroded Fe grain in the top right, and a zoned grain with an Fe center and a ferrous oxide (FeO) outer layer, from DP001-G.

C) Fe grain with FeO coating, from DP001-H.

D) Fe grains within a calcium-rich coating from the ZVI/aquifer interface, from DP001-I.

E) Silicon dioxide (SiO_2) grains cemented together by an Fe-rich coating from the ZVI interface, from DP001-I.

F) Amalgamations of SiO_2 grains with Fe-rich coating just above the ZVI/aquifer interface, from DP001-J.

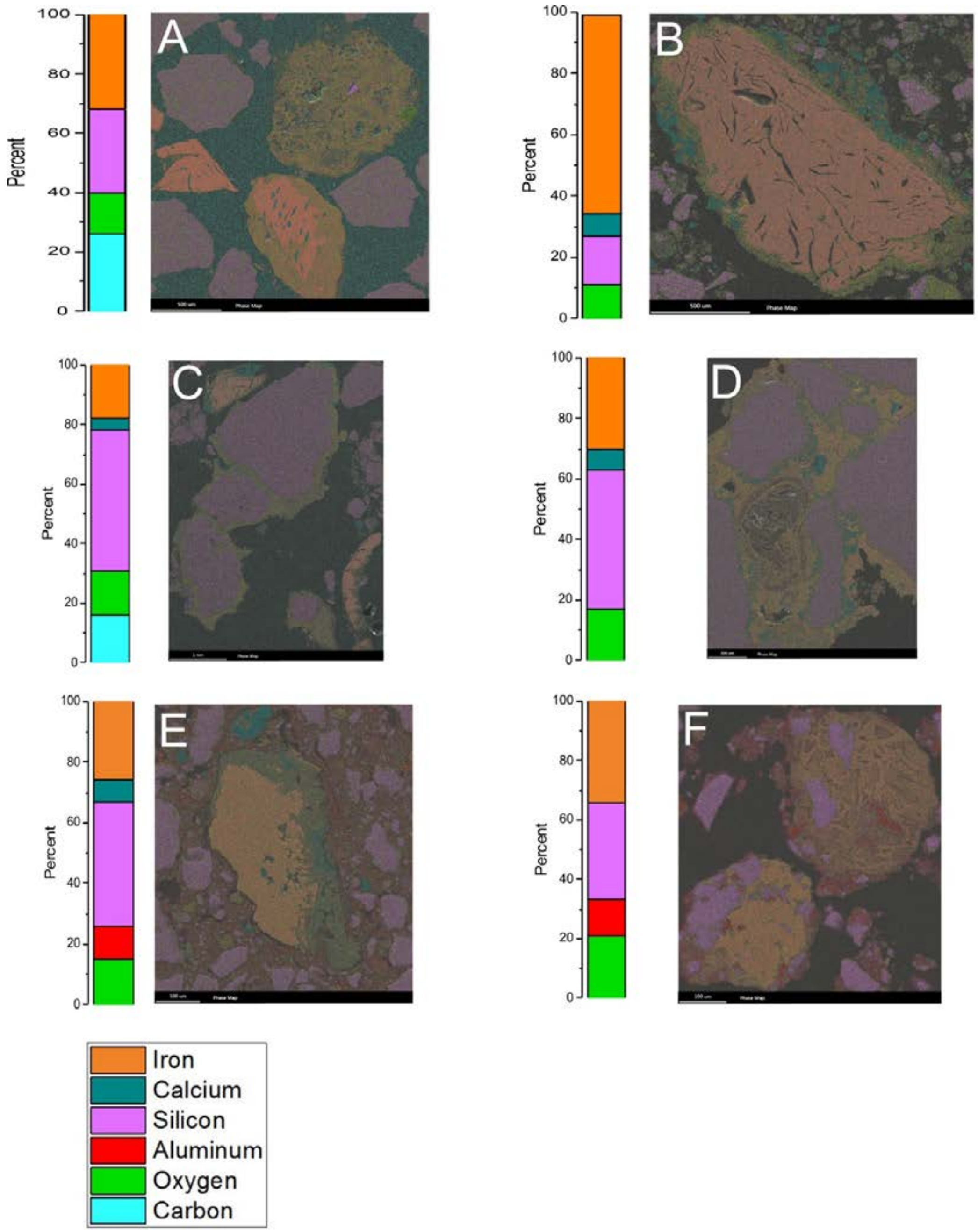


Figure 5-20. Energy-Dispersive X-ray Spectroscopy Element Maps from ABL Site 5 Core DP001

Image A is from the lowest level within the core and Image F is from the highest level.

A) Fe grain with FeO zoning and a corroded FeO grain in the top right, from the lower core, DP001-I

B) Fe grain with calcium (Ca)-rich FeO coating, from ZVI core interface, DP001-I

C) Quartz (SiO_2) grains cemented together by FeO coating, from DP001-I

D) Closeup of FeO cementing SiO_2 grains together, from DP001-I

E) Fe grain with Ca-rich FeO coating and aluminum (Al)-rich background, just above the ZVI/aquifer interface from DP001-J

F) SiO_2 grains caught up in FeO cementation with Al-rich background, from DP001-J.

As part of the SEM analysis, coating thicknesses of mineralized iron grains were measured on a population of grains within each sample. The average thickness of the coatings was determined by measuring rim thickness at 3 to 5 points depending on the size of the grain; the mean coating thickness is plotted on **Figure 5-21**. As described above, the thickness was greatest at the upgradient interface.

Analysis of samples from ABL core DP003 was also conducted and SEM micrographs and EDS x-ray element maps are shown in **Figures 5-22 and 5-23**. This core showed similar features to those documented in core DP001.

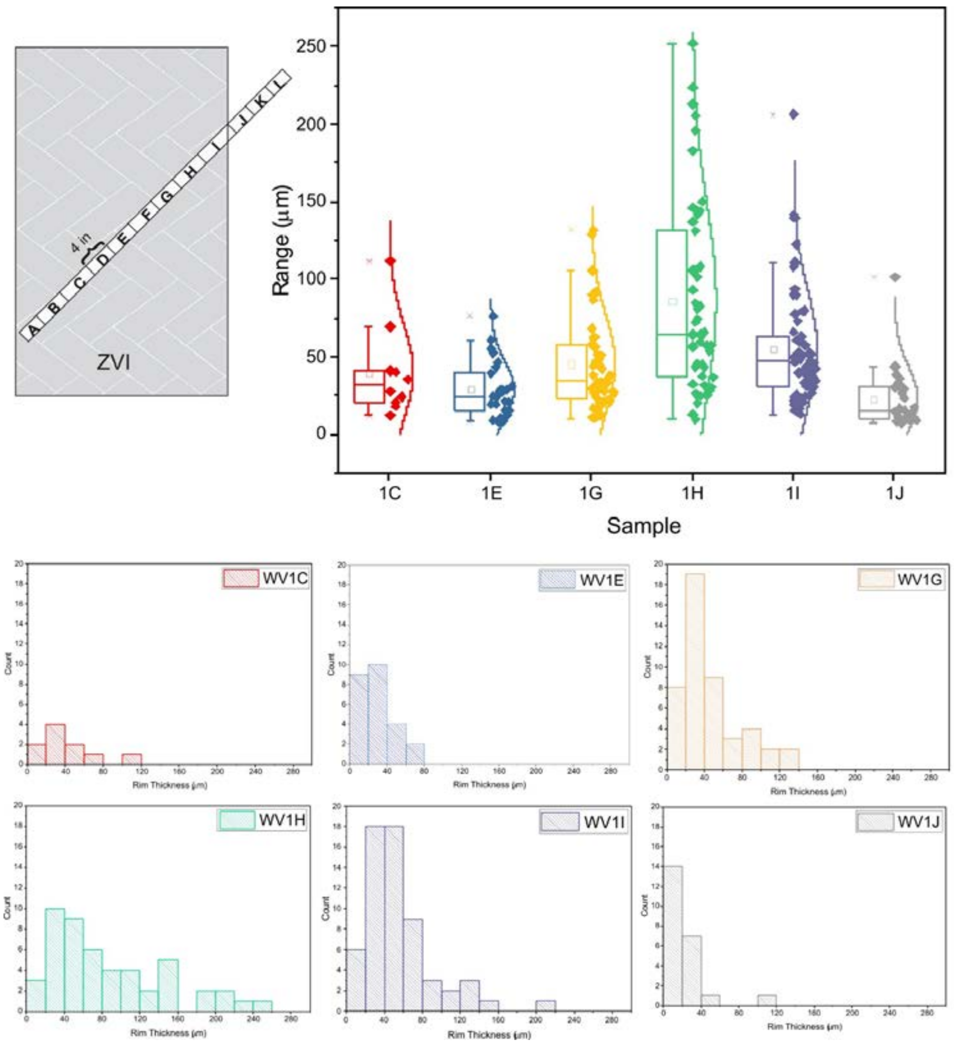


Figure 5-21. Diagram of ABL Site 5 Core DP001 Showing the Locations of the Individual Core Segments Relative to the ZVI/Aquifer Interface

The interface was noted in sample DP001-I. Samples DP001-C, 1-E, 1-G, 1-H, 1-I, and 1-J were analyzed by scanning electron microscopy. Box charts at top right of figure show measured coating thicknesses on iron grains contained in the samples. The diamond symbols represent the actual data points; the stars are the minimum and maximum data points; the top of the box is the 75th percentile, the midline is the median; the bottom of the box is the 25th percentile; the inside box is the mean thickness; the line below the box is the 5th percentile; and the line above the box is the 95th percentile.

The six histograms at the bottom of the figure indicate the thicknesses of coatings on iron grains measured from each sample.

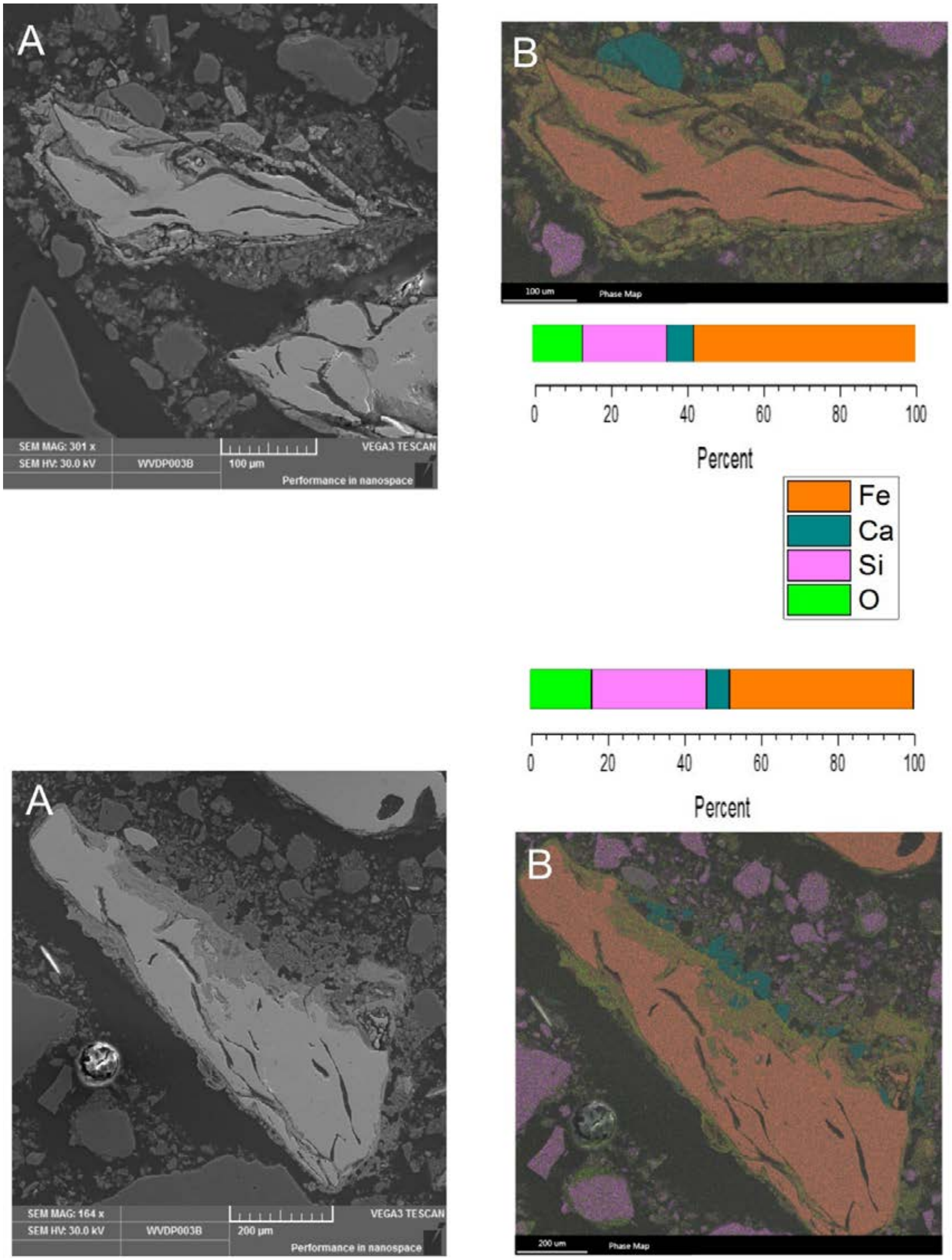


Figure 5-22. SEM Photographs and EDS Maps from ABL Site 5 Core DP003

Top: A) *SEM photo and energy-dispersive x-ray spectroscopy (EDS) map of an iron grain with a FeO rim that is surrounded by SiO_2 and calcium carbonate from DP003-B.*

Bottom: A) *SEM photo and B) EDS map of an iron grain with a FeO rim that is surrounded by SiO_2 and calcium carbonate from DP003-B.*

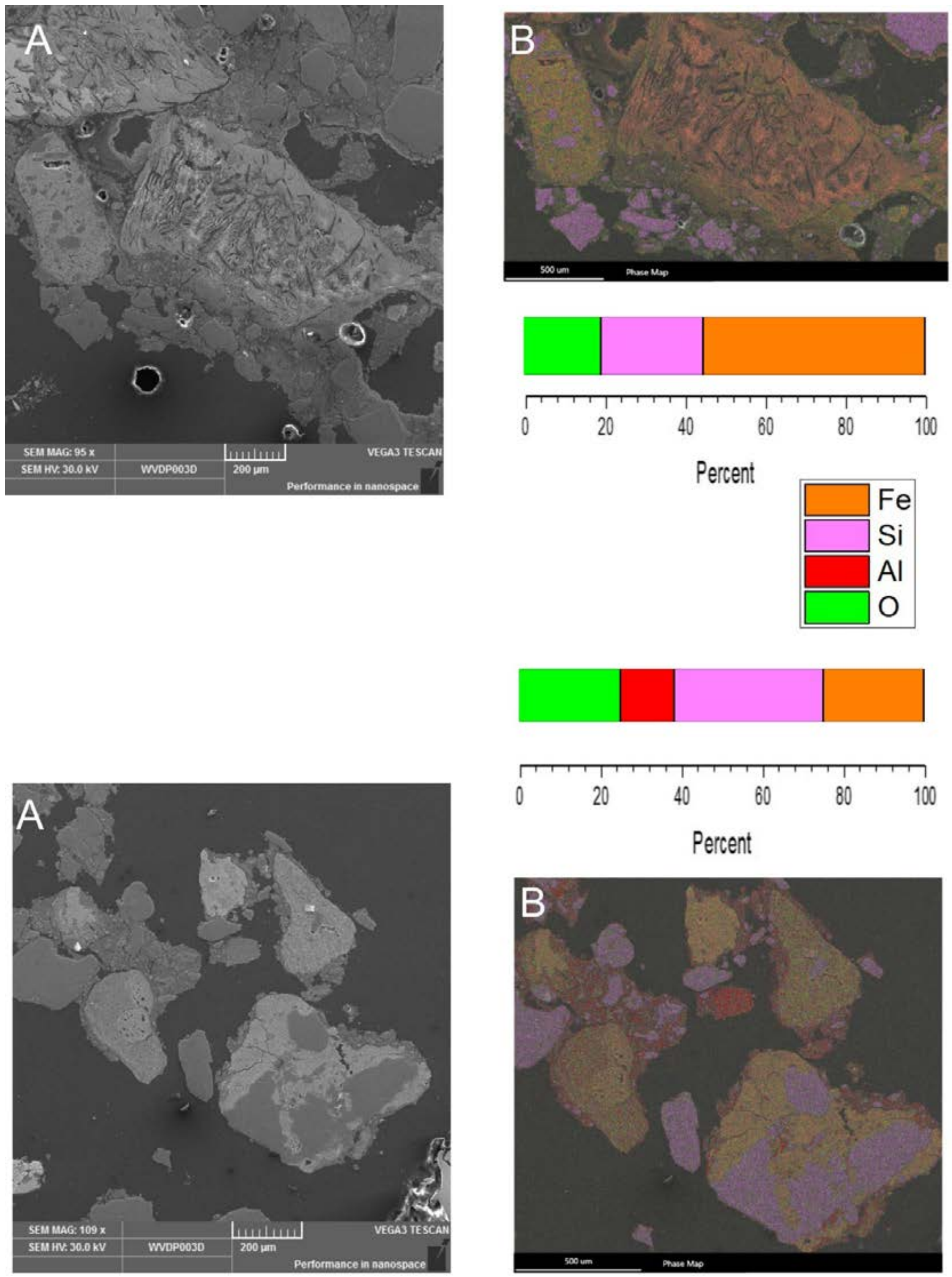


Figure 5-23. Additional SEM Photographs and EDS Maps from ABL Site 5 Core DP003

Top: A) *SEM photo and B) EDS map of a corroded iron grain (right) with a (FeO rim, and an FeO grain with SiO_2 fragments within, from DP003-D, which contains the ZVI/aquifer interface.*

Bottom: A) *SEM photo and B) EDS map of SiO_2 grains (bottom right) cemented by FeO and coated with aluminum silicate and FeO.*

Solid-phase inorganic carbon concentrations were determined using acid digestion and CO_2 detection with a carbon coulometer (UIC Model CM5014; Paul et al., 2003). Each sample was analyzed in duplicate or triplicate. Average concentration values for solid-phase inorganic carbon are provided in **Table 5-8** for the former St. Louis Ordnance Plant OU1. One core was enriched in inorganic carbon (DP002-A; 16-18 feet bgs) and showed a decreasing concentration trend with depth from 16 to 18 feet bgs (**Figure 5-24**). Solid-phase concentrations of AVS were determined using acid digestion (Wilkin and Bischoff, 2006). AVS was not detected in the samples from this site. This indicates the St. Louis iron cores sent for analysis indicated dominance of non-reactive iron carbonate minerals.

Table 5-8. Concentrations of Inorganic Carbon and Acid-Volatile Sulfur in Cores from Former St. Louis Ordnance Plant OU1

Core	Segment	Depth (ft)	Inorganic Carbon (μg/g)	Acid-volatile Sulfur (μg/g)
DP001/TW01	C4	16.75	22	<10
DP001/TW01	C3	17.25	30	<10
DP001/TW01	C2	17.75	19	<10
DP001/TW01	D4	18.40	24	<10
DP001/TW01	D3	18.75	26	<10
DP001/TW01	D2	19.25	20	<10
DP001/TW01	D1	19.75	18	<10
DP002/TW02	A4	16.25	1,470	<10
DP002/TW02	A3	16.75	1,162	<10
DP002/TW02	A2	17.25	800	<10
DP002/TW02	A1	17.75	498	<10
DP002/TW02	B4	16.25	19	<10
DP002/TW02	B3	16.75	15	<10
DP002/TW02	B2	17.25	15	<10
DP002/TW02	B1	17.75	17	<10

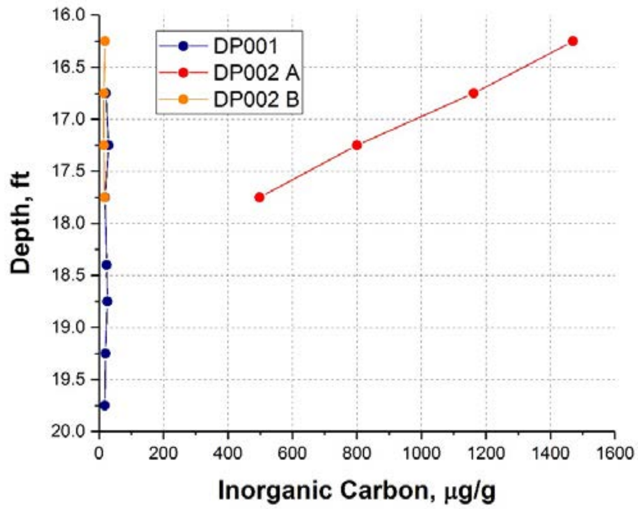


Figure 5-24. Inorganic Carbon vs. Depth in Former St. Louis Ordnance Plant OU1 in ZVI Core Samples

XRD patterns for samples from core DP002/TW02 are plotted in **Figure 5-25** and an XRD pattern for the original ZVI material obtained from GMA Industries, known as ZVI-M, is shown in **Figure 5-26**. The dominant mineral components in each of the samples were quartz, potassium feldspar, sodium feldspar, and kaolinite. Magnetite (PDF 079-0419) was also detected in each of the core segments; iron metal was not indicated in the XRD scans as a minor component. Possible detection of ZVI in sample DP002 B3 is indicated. Results indicate significant weathering of the original ZVI to magnetite.

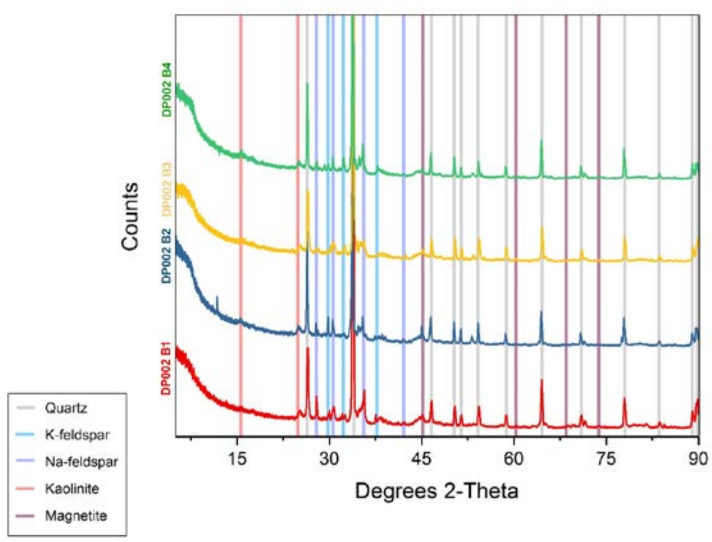


Figure 5-25. Stacked X-Ray Diffraction Patterns for Former St. Louis Ordnance Plant OU1 Core DP002.

The dominant mineral components in each of the samples were quartz, K-feldspar, Na-feldspar, and kaolinite. Magnetite (PDF 079-0419) was also detected in each of the core segments; iron metal was not indicated in the XRD scans as a minor component. Possible detection of ZVI in sample DP002 B3 is indicated.

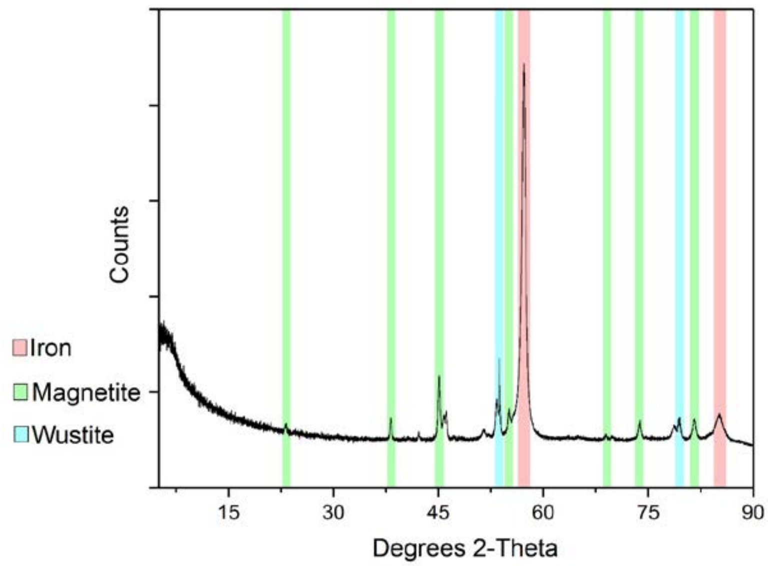


Figure 5-26. X-Ray Diffraction Pattern of the Original ZVI-M Granular Iron used at Former St. Louis Ordnance Plant OU1

ZVI-M is the original ZVI material obtained from GMA Industries. Pattern analysis indicates the presence of iron metal (PDF 087-0721), magnetite (PDF 079-0419), and wüstite (PDF 086-2316).

SEM micrographs for samples from St. Louis core DP002/TW02 and the original ZVI are shown in **Figure 5-27**. There was no apparent accumulation of precipitates observed on the surfaces of the iron particles. A histogram and cumulative frequency diagram of particle diameters from the original ZVI and iron oxide grains from six samples are provided as **Figure 5-28**, indicating considerable reduction in average grain size compared to the original ZVI product.

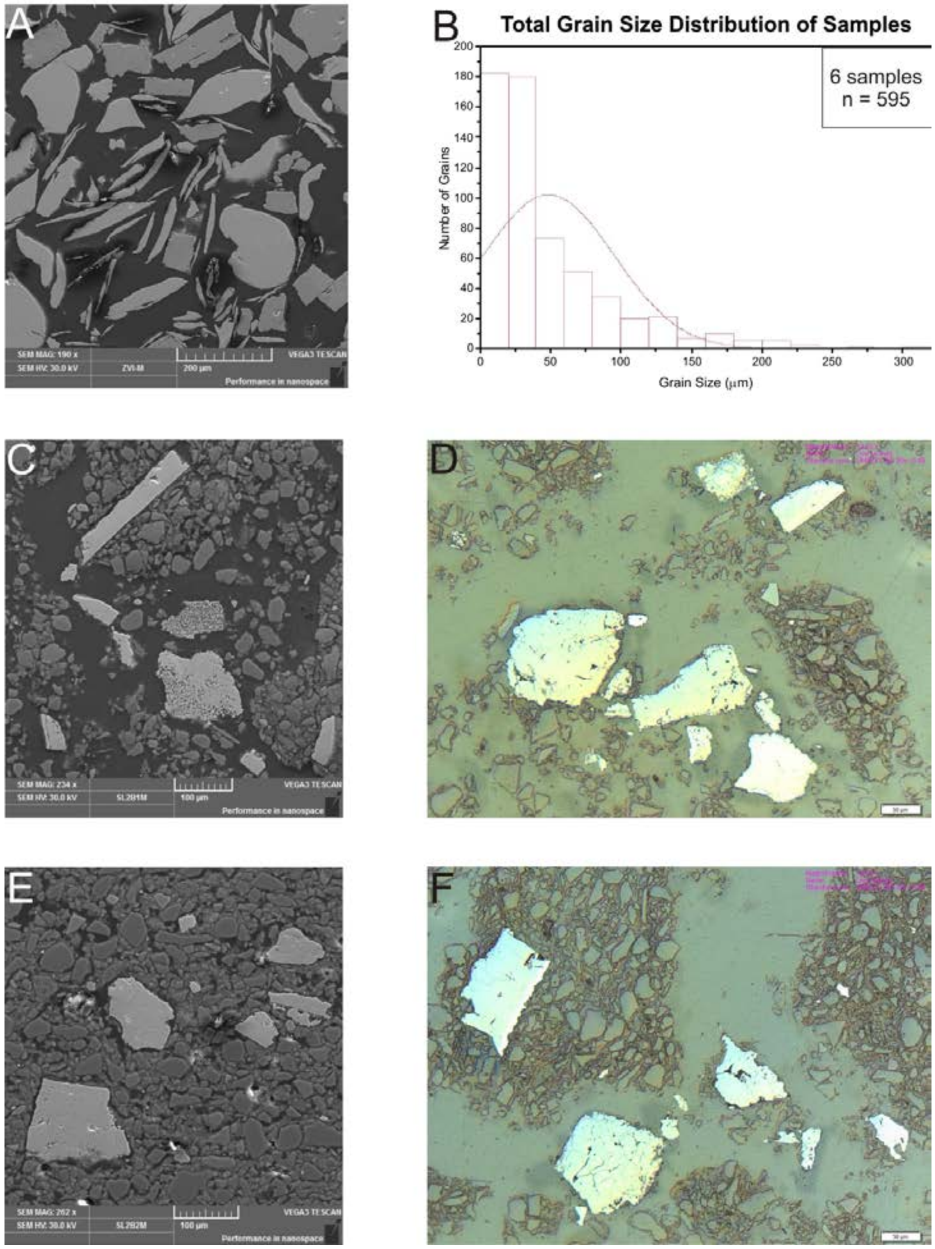


Figure 5-27. SEM Micrographs for Samples from St. Louis Core DP002/TW02 and the Original ZVI-M Material

A) SEM photomicrograph of the original ZVI-M material.

B) Grain size distribution of iron oxide particles from six samples.

C & D) Paired SEM and reflected-light images of representative iron oxide grains from sample DP002 B1.

E & F) Paired SEM and reflected-light images of representative iron oxide grains from sample DP002 B2. Note there is no apparent accumulation of precipitates at the surfaces of the iron particles.

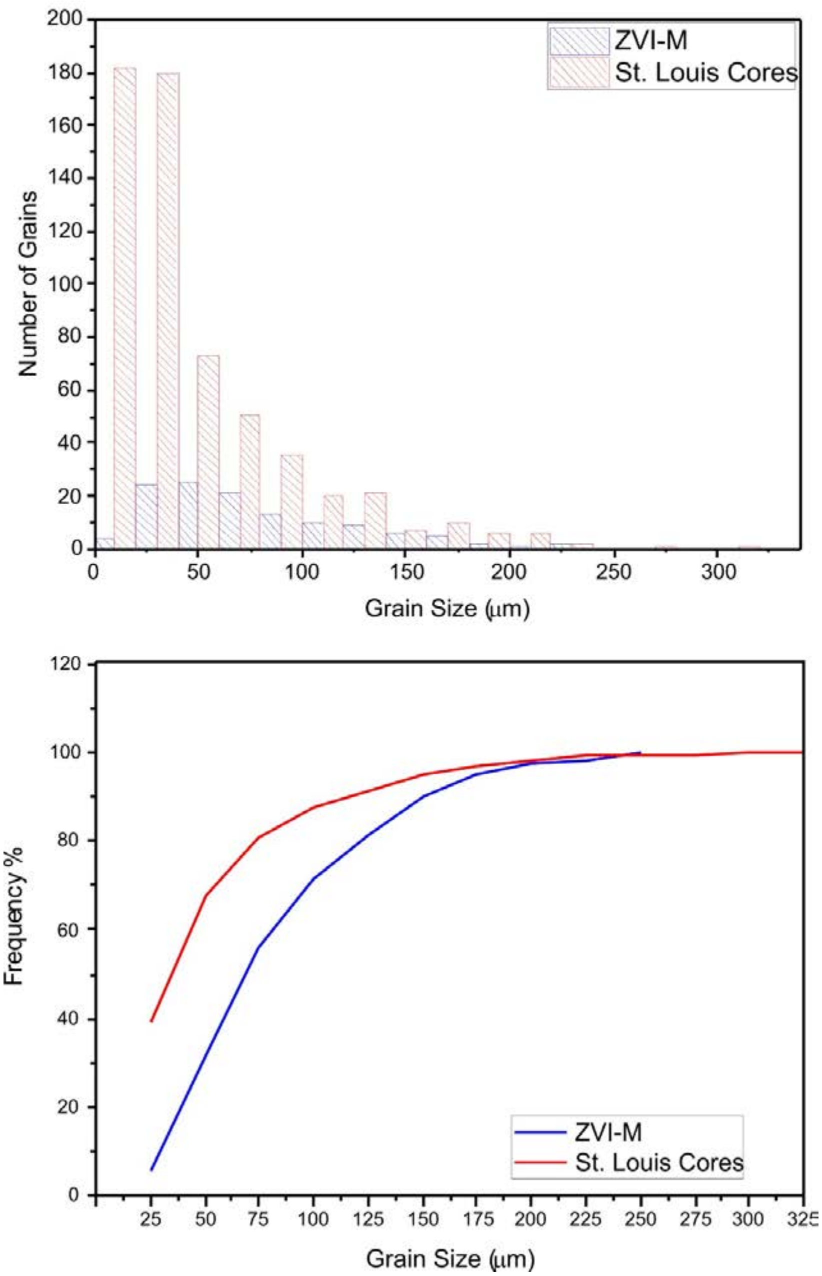


Figure 5-28. Histograms and Cumulative Frequency Diagram of Particle Diameters from the Original ZVI-M Zero-valent Iron and Iron Oxide Grains from Six St. Louis Samples
ZVI-M is the original ZVI material obtained from GMA Industries. Note reduced grain size of the site samples in comparison to the original ZVI material.

X-ray absorption near edge structure (XANES) spectrographic analyses were completed for five aquifer samples (**Figure 5-29**). The aquifer solids demonstrated no spectral components consistent with ZVI. Linear combination fitting analysis indicates a mixture of magnetite and goethite-type spectra. These findings are consistent with weathering of the original ZVI material to magnetite and goethite.

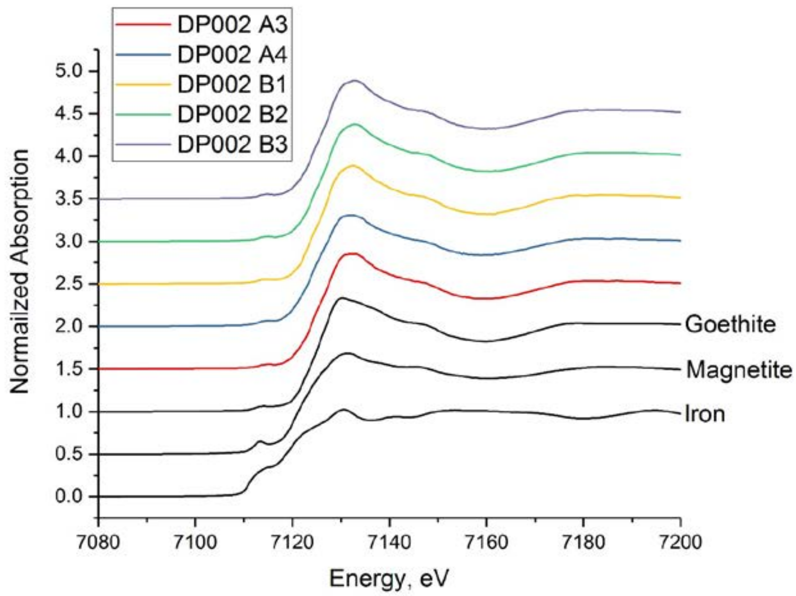


Figure 5-29. XANES Analysis of Five St. Louis Aquifer Samples

Normalized (edge jump = 1) X-ray absorption near edge structure (XANES) analysis of five aquifer samples and reference patterns for iron metal, magnetite, and goethite. The aquifer solids show no spectral component of ZVI. Linear combination fitting analysis indicates a mixture of magnetite and goethite-type spectra.

Energy dispersive line scans were completed for the original ZVI and for three grains from the mixing area cores (**Figure 5-30 and 5-31**, respectively). The original ZVI showed no detected oxygen, consistent with the ZVI product. Two of the site grains demonstrated consistent iron/oxygen ratios that were independent of the depths from the grain surface. The third grain showed more pronounced zonation and compositional shifts (decreasing iron/oxygen) from the core to the rim.

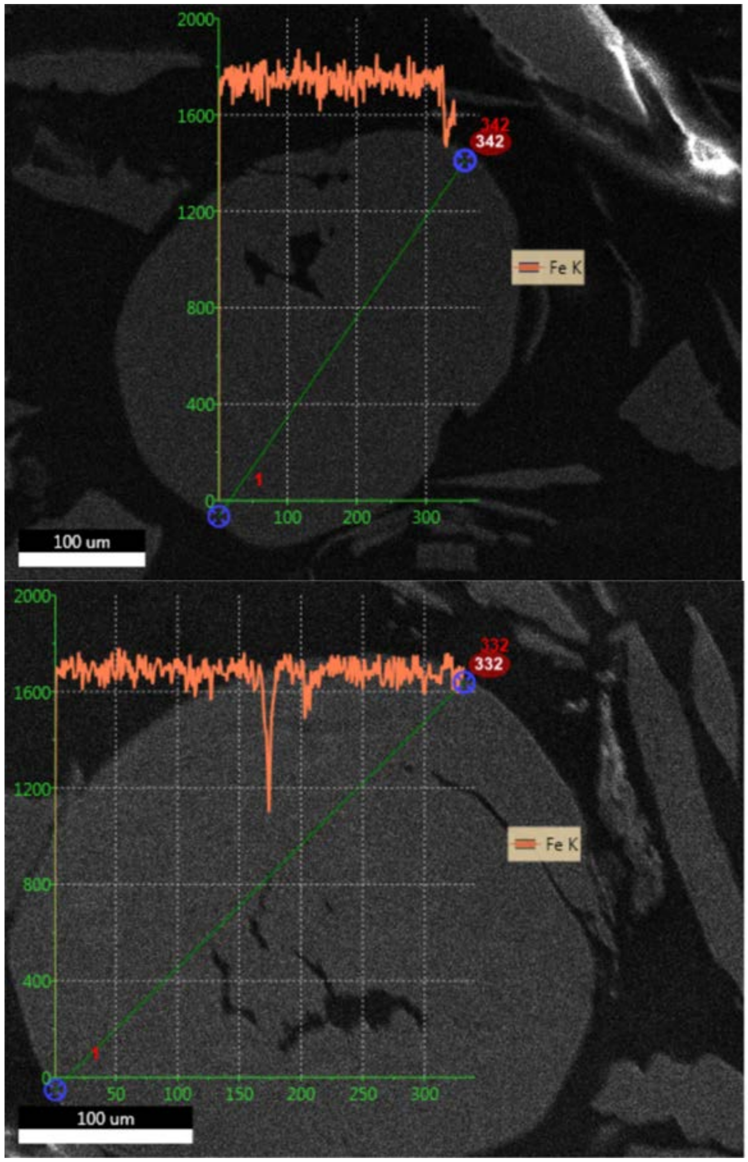


Figure 5-30. Energy Dispersive Line Scans across Two ZVI-M Grains

ZVI-M is the original ZVI material obtained from GMA Industries. These figures depict Energy dispersive line scans across two ZVI-M grains. Both of the grains analyzed showed no detected O, consistent with Fe metal.

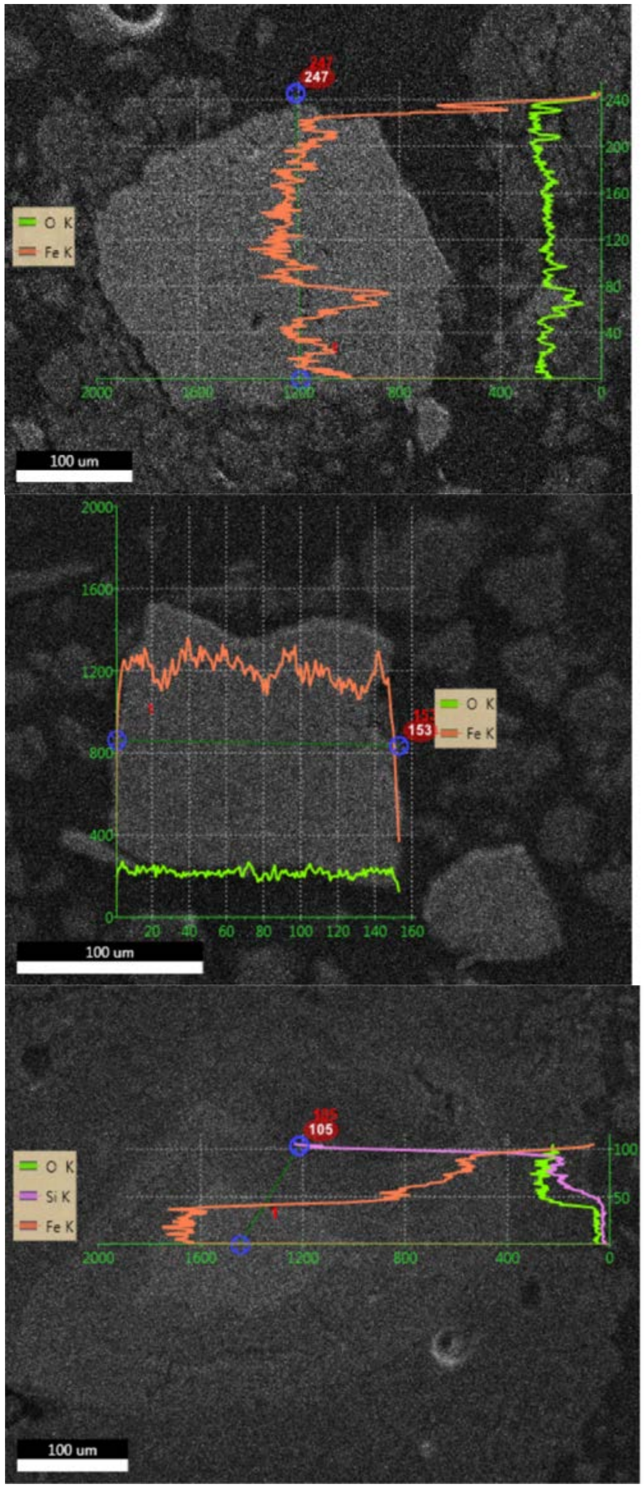


Figure 5-31. Energy Dispersive Line Scans Across Three Grains Observed in the St. Louis Cores

These figures depict energy dispersive line scans across three grains observed in the St. Louis cores. The top two grains show consistent Fe/O ratios that are independent of depth in the grains. The bottom grain shows more pronounced zonation and compositional shifts (decreasing Fe/O) from core to rim.

5.4.3 Reactivity Testing Results

5.4.3.1 ABL Site 5 Reactivity Testing Results

Due to laboratory availability and time and materials constraints, reactivity testing for the PRB at Site 5 was not performed.

5.4.3.2 Former St. Louis Ordnance Plant OU1 Reactivity Testing Results

Results of ZVI content of each sample for the St. Louis site based on acidification and hydrogen generation analysis are shown on **Figure 5-32**. ZVI content was higher in mixing area samples (DP001 and DP002) than was observed in the background reference samples (DP003 and DP004). The maximum percentage of ZVI observed was less than 0.04 percent, which is considerably less than the ZVI dose used (1 percent). Magnetic and gravimetric analysis (**Figure 5-33**) indicated approximately an order of magnitude higher quantity of magnetic material in the mixing area core (DP001) than in background reference core (DP003), and the total magnetic fraction of the mixing area cores (**Figure 5-34**) was between 0.2 percent and 0.7 percent. This range is within the range observed in the confirmation samples collected during ZVI mixing activities (CH2M, 2012). These data in combination indicate, at least for these two samples, that while some ZVI remains in the mixing area, much of the remaining iron may be in the form of magnetite (CH2M, 2012). Reactivity using resazurin indicated higher potential for reduction in ZVI mixing area core DP001 in comparison to the background sample (DP003) (**Figure 5-35**), supporting the continued reactivity of any remaining ZVI and magnetite.

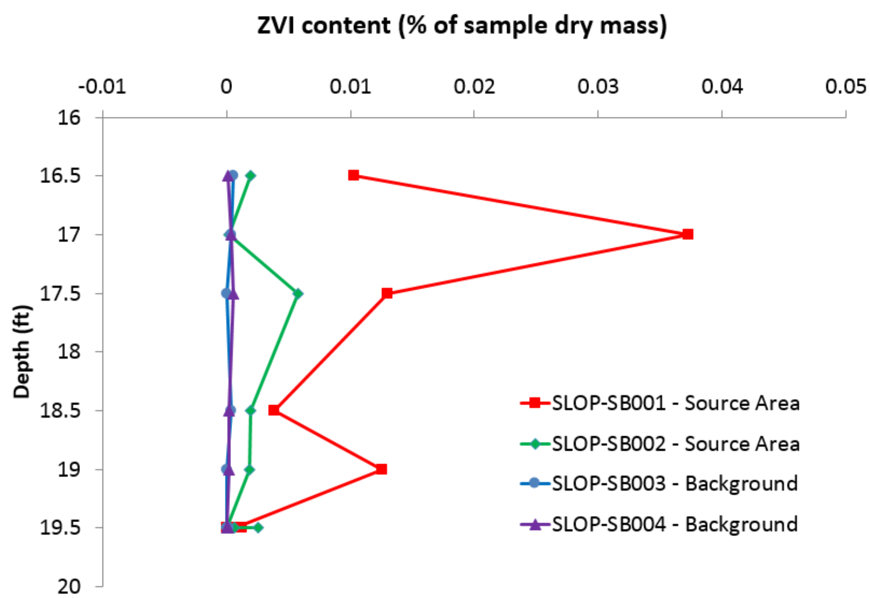


Figure 5-32. ZVI Content of St. Louis Samples (Percent of Sample Dry Mass) Based on Acidification and Hydrogen Generation Testing

Mixing area samples (SLOP-SB001 and SLOP-SB002) samples showed higher ZVI content than up- and downgradient samples, with maximum percentage of ZVI observed at approximately 0.04%.

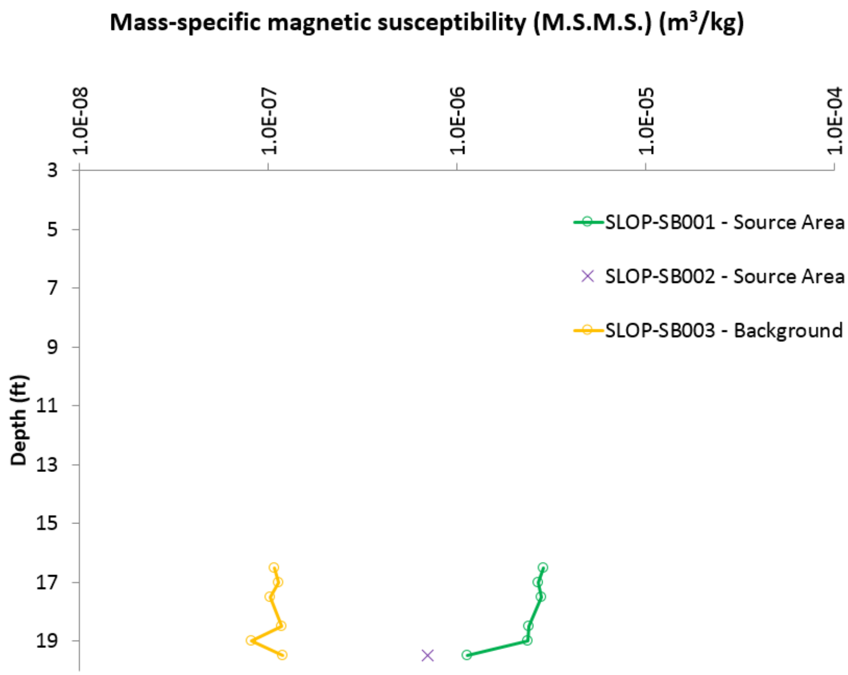


Figure 5-33. Magnetic Fraction in St. Louis Samples DP001 and DP003

Magnetic and gravimetric analysis indicated approximately an order of magnitude higher quantity of magnetic material in the mixing area core (DP001/SB001) than in background reference core (DP003/SB003)

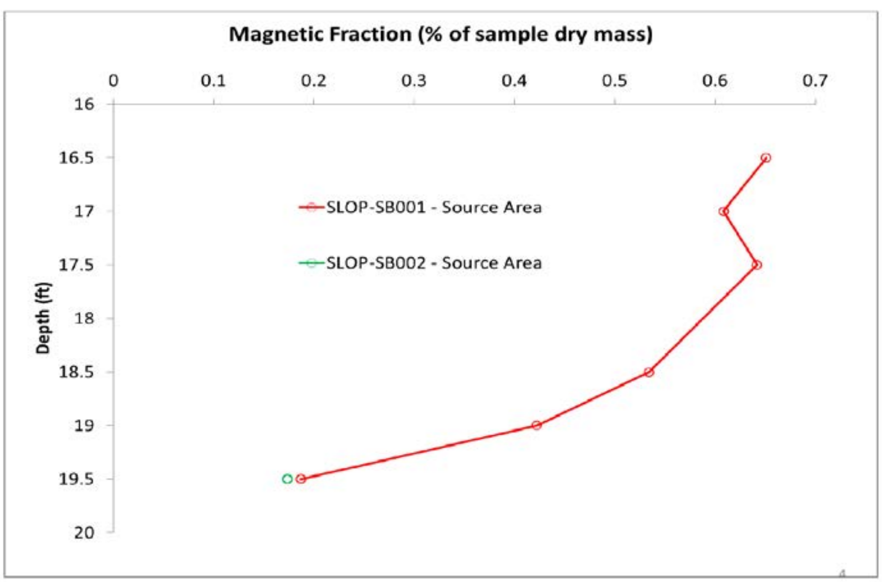


Figure 5-34. Magnetic Fraction in St. Louis Samples DP001 and DP002

Magnetic Fraction in mixing area samples indicate between 0.2 and 0.7 percent magnetic material

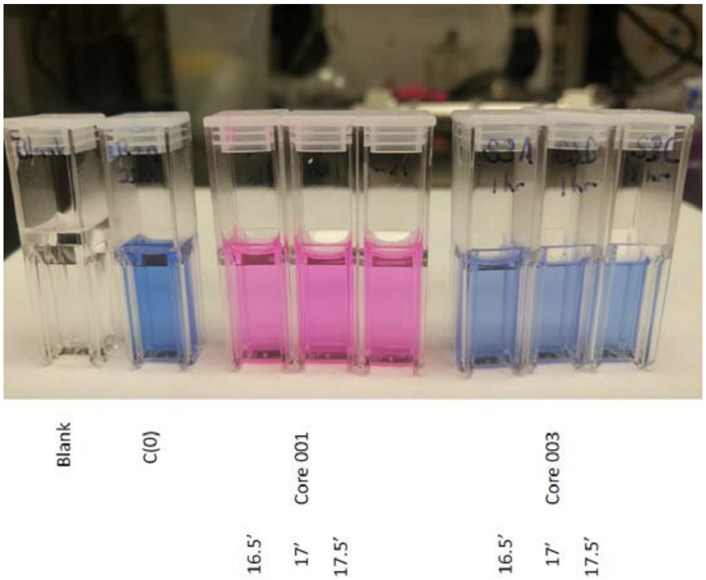


Figure 5-35. 1-hour Mixing Area (DP001) Reaction with Resazurin (in Pink) in Comparison with Upgradient Reference Sample (DP003), St. Louis Site
Following one hour of addition of resazurin to mixing area (DP001) and an upgradient reference sample (DP003), conversion to resorufin is evident in the mixing area sample, but not in the upgradient reference sample.

5.4.4 Microbial Results

5.4.4.1 ABL Site 5 Microbial Results

Select ABL samples were analyzed using a combination of Quantarray-Chlor analysis to assess populations of common dechlorinating microbes/functional genes and NGS, which provides Phylum and genus data for microbes present in the water at the site. Results for the Quantarray-Chlor analysis are presented as **Table 5-9**. Complete NGS data reports along with all other site analytical data are provided in **Appendix G**.

Quantarray-Chlor analyzes numbers of multiple microbes/functional genes involved in biodegradation of chlorinated solvents, including anaerobic reductive dechlorinators and associated functional genes, genes involved in direct metabolism of vinyl chloride (present in some ethenotrophic bacteria), and genes involved in cometabolism of VOCs (present in ethenotrophic and methanotrophic bacteria).Populations of methanogens and sulfate reducers are also provided to assist in assessment of the ecological microbial habitat.

At ABL Site 5, a number of anaerobic reductive dechlorinators were detected including *Dehalobacter*, *Dehalococcoides*, *Dehalogenimonas*, *Desulfitobacterium*, *Desulfuromonas*, and *Dehalobium*. In most cases, if concentrations of these organisms were present upgradient of the wall in the close upgradient samples (GW26 and GW29), there were decreases in concentrations in the samples from the immediate downgradient side of the wall (5GW27 and 5GW30). For example, *Dehalogenimonas* was not detected in the samples immediately downgradient of the wall, despite being detected upgradient.

Table 5-9. Quantarray-Chlor Microbial Analysis Results, ABL Site 5

	In Landfill	West Transect				East Transect			
	Upgradient	5' Upgradient	5' Downgradient	10' Downgradient	50' Downgradient	5' Upgradient	5' Downgradient	10' Downgradient	60' Downgradient
Sample ID	**GW13**	**GW26**	**GW27**	**GW28**	**GW25**	**GW29**	**GW30**	**GW31**	**GW18**
Sample Date	**1/6/17**	**1/20/17**	**1/20/17**	**1/20/17**	**1/20/17**	**1/20/17**	**1/20/17**	**1/20/17**	**1/20/17**
Analyte (cells/mL)									
Total Bacteria	7.99E+04	3.07E+05	9.04E+04	6.53E+05	1.34E+06	3.12E+05	1.91E+05	4.84E+04	3.09E+05
BAV1 R-Dase	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
CFR	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01
DCA	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01
DCAR	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01
DCM	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01
DCMA	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01
Dehalobium chlorocercia (DECO)	4.28E+01	4.41E+01	6.00E-01	4.40E+01	1.08E+02	1.70E+02	6.36E+01	0.00E+00	4.45E+01
Dehalobacter (DHB)	1.68E+01	8.19E+01	9.40E+00	5.44E+02	2.63E+02	0.00E+00	1.70E+02	9.60E+00	2.36E+02
Dehalococcoides (DHC)	0.00E+00	1.01E+01	0.00E+00	7.80E+00	4.68E+01	2.94E+02	3.34E+01	9.00E+00	3.40E+02
Dehalogenimonas (DHG)	7.53E+01	3.25E+02	0.00E+00	0.00E+00	3.88E+02	8.33E+02	0.00E+00	0.00E+00	0.00E+00
Desulfitobacterium (DSB)	0.00E+00	0.00E+00	0.00E+00	3.34E+02	4.20E+01	1.61E+02	1.07E+02	0.00E+00	0.00E+00
Desulfuromonas (DSM)	0.00E+00	0.00E+00	0.00E+00	1.64E+04	9.75E+03	1.34E+04	2.59E+03	1.46E+03	1.38E+03
TCE R-Dase	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-01	0.00E+00	0.00E+00	7.00E-01
VC R-Dase	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.20E+00	0.00E+00	0.00E+00	2.00E-01
Phenol Hydrozylase (PHE)	6.70E+00	6.65E+02	8.83E+01	2.58E+02	7.30E+01	1.82E+02	2.88E+02	9.80E+00	7.30E+00
Particulate Methane Monooxygenase (PMMO)	3.15E+01	2.07E+02	8.46E+02	4.64E+01	1.20E+02	6.86E+01	2.63E+01	9.10E+00	2.60E+02
Toluene Dioxygenase (TOD)	7.00E+00	2.83E+01	7.40E+00	1.76E+01	2.14E+01	1.93E+01	1.51E+01	2.00E+00	1.05E+01
Toluene Monooyzgenase 2 (RDEG)	0.00E+00	7.12E+02	0.00E+00	3.80E+02	0.00E+00	3.20E+00	9.74E+01	0.00E+00	2.96E+01
Toluene Monooyzgenase (RMO)	0.00E+00	0.00E+00	2.72E+01	0.00E+00	0.00E+00	0.00E+00	5.07E+01	0.00E+00	0.00E+00
Soluable Methane Monoozygenase (SMMO)	4.87E+02	5.93E+02	5.51E+01	2.14E+02	1.12E+03	2.89E+02	1.66E+02	4.56E+01	2.21E+03
TCBO	1.00E+01	1.00E+01	1.00E+01	1.40E+00	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01
EtnC	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01	1.00E+01
Expozyalkane transferase (EtnE)	0.00E+00	1.00E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E+02
Sulfate Reducing Bacteria (APS)	1.29E+04	7.29E+04	2.46E+04	1.10E+05	7.64E+05	1.06E+05	7.22E+04	1.58E+04	2.13E+05
Methanogens (MGN)	3.30E+00	1.81E+01	8.30E+00	1.41E+03	4.62E+02	1.01E+02	9.08E+01	1.72E+01	2.08E+02

Notes:
Shading indicates detection
cells/mL – cells per milliliter

A similar pattern was noted for *Dehalococcoides*, which was detected in the close upgradient sample for the west transect, but was not detected immediately downgradient and for which there was a one order of magnitude decrease in concentration between upgradient and immediately downgradient in the eastern transect. One exception is *Dehalobacter*, for which concentrations increased slightly between the upgradient and immediately downgradient samples in both transects. Generally, the populations of anaerobic dechlorinators at Site 5 were relatively sparse, and functional genes involved in complete dechlorination of TCE to ethene were detected at very low levels in the upgradient and far downgradient samples in the eastern transect only (VC reductase was detected in the sample from GW29 at 3.2 cells per milliliter (mL) and in GW18 at 0.2 cells/mL; TCE reductase was detected in the sample from GW18 at 0.7 cells/mL; BAV1 was not detected). There is no indication, based on the data, that the PRB is facilitating reductive dechlorination downgradient of the wall.

Expoxyalkane transferase (EtnE) and alkene monooxygenase (EtnC) are measures of functional genes associated with ethenotrophic organisms capable of direct metabolism of vinyl chloride and cometabolism of cis-1,2-DCE. At ABL Site 5, EtnE and EtnC were not detected with the exception of the far downgradient sample, GW18, which had an EtnE concentration of 1.1×10^2 cells/mL. These data support that there is no impact from the PRB on these ethenotrophs.

Several other genes associated with aerobic cometabolism of chlorinated VOCs were detected at ABL Site 5, comprising phenol hydrozylase (PHE), particulate methane monooxygenase (PMMO), toluene dioxygenase (TOD), toluene monooxygenase 2 (RDEG), toluene monooxygenase (RMO), and soluble methane monooxygenase (SMMO). Concentrations of these genes, which are associated with primarily aerobic microorganisms, were similar or increased across the wall transects from upgradient to downgradient, indicating little to no impact on populations of organisms carrying these genes from reducing conditions generated by the wall.

Sulfate reducers and methanogens were detected consistently across the site, with no notable change in concentrations due to the presence of the PRB.

NGS data provide information on phylum and genus of microbes found in a sample. Because microbes from the same phylum can often live under widely different conditions, the genus data are more useful in assessing environmental conditions present at a site. At ABL Site 5, *Proteobacteria* was the primary phylum for all samples analyzed at the site, followed by *Firmicutes*. *Proteobacteria* are gram-negative bacteria with an outer membrane consisting largely of lipopolysaccharides. Members of this phylum are anaerobic, facultative anaerobes, or obligate aerobes. *Firmicutes* are typically gram-positive bacteria with round cells, called cocci (singular, coccus) or with rod-like forms (bacillus). *Firmicutes* are anaerobic or are obligate or facultative aerobes and are known acetylenotrophs, which may help explain why acetylene was not detected at the site. Genus data for Site 5 indicate that areas 5-10 ft downgradient of the PRB area dominated by *Sulfurimonas* (**Table 5-10**). The genus *Sulfurimonas* combines a group of sulfur-oxidizing bacteria (Inagaki et al., 2003). Many kinds of reduced sulfur compounds, such as sulfide, elemental sulfur, thiosulfate and sulfite, can serve as an electron donor for the growth of *Sulfurimonas*. The higher population of these bacteria downgradient of the PRB could potentially be due to the release of reduced sulfur species to groundwater from the PRB. Genera upgradient and far downgradient of the PRB are more diverse, without a single Genera dominant in these samples. The most common genera for each sample are presented in **Table 5-10**.

Table 5-10. Summary of Next Generation Sequencing Results, ABL Site 5

Location		Well ID	Top Four Genera Detected In Sample
Upgradient in Landfill		GW13	33.7% Unclassified at Genus Level
			6.5% Crenothrix, a a filamentous methane oxidizer
			3.3% Thermodesulfovibrio, thermophilic anaerobic sulfate reducers
			2.8% Legionella, a gram-negative, non-spore-forming, aerobic bacterium
West Transect	Close Upgradient	GW26	35% Sulfuricurvum, a motile, anaerobic, sulfur-oxidizing bacterium
			13.6% Rhodoferax, which can be aerobic or anaerobic and is found in stagnant aquatic systems
			10.3% Janthinobacterium, a diverse group of bacteria capable of tolerating a variety of environmental stressors
			9.6% Pseudomonas, a gram-negative, chemoorganotrophic, and aerobic bacterium. Biofilms produced by Pseudomonas are involved in the rapid corrosion of metals.
	Immediately Downgradient	GW27	38.2% Sulfurimonas, sulfur- and thiosulfate-oxidizing bacteria
			12.9% Sulfuricurvum, a motile, anaerobic, sulfur-oxidizing bacterium
			6.3% Pseudomonas, , a gram-negative, chemoorganotrophic, and aerobic bacterium. Biofilms produced by Pseudomonas are involved in the rapid corrosion of metals.
			6% Desulfurispora, thermophilic sulfate reducers
			6% Janthinobacterium, a diverse group of bacteria capable of tolerating a variety of environmental stressors
	Close Downgradient	GW28	40.5% Sulfurimonas, sulfur- and thiosulfate-oxidizing bacteria
			9.8% Sulfuricurvum, a motile, anaerobic, sulfur-oxidizing bacterium
			9.5% Thermodesulfovibrio, thermophilic anaerobic sulfate reducers
			7.1% Unclassified at genus level
	Far Downgradient	GW25	19.6% Thermodesulfovibrio, thermophilic anaerobic sulfate reducers
			17.1% Unclassified at genus level
			10.4% Sulfurimonas, sulfur- and thiosulfate-oxidizing bacteria
			9.3% Desulfococcus, a strictly anaerobic, sulfate-reducing bacteria
East Transect	Close Upgradient	GW29	17.9% Unclassified at genus level
			11.1% Janthinobacterium, a diverse group of bacteria capable of tolerating a variety of environmental stressors
			7.2% Pseudomonas, , a gram-negative, chemoorganotrophic, and aerobic bacterium. Biofilms produced by Pseudomonas are involved in the rapid corrosion of metals.
			7.0% Rhodoferax, which can be aerobic or anaerobic and is found in stagnant aquatic systems
	Immediately Downgradient	GW30	41% Sulfurimonas, sulfur- and thiosulfate-oxidizing bacteria
			9.3% Unclassified at genus level
			7% Pseudomonas, , a gram-negative, chemoorganotrophic, and aerobic bacterium. Biofilms produced by Pseudomonas are involved in the rapid
			5.8% Sulfuricurvum, a motile, anaerobic, sulfur-oxidizing bacterium
	Close Downgradient	GW31	40.4% Sulfurimonas, sulfur- and thiosulfate-oxidizing bacteria
			10.9% Unclassified at genus level
			4.3% Thermodesulfovibrio, thermophilic anaerobic sulfate reducers
			4.2% Sulfuricurvum, a motile, anaerobic, sulfur-oxidizing bacterium
	Far Downgradient	GW18	32.7% Crenothrix, a a filamentous methane oxidizer
			16.4% Gallionella, iron-oxidizing, chemolithotrophic bacteria that have been found in a variety of different aquatic habitats
			13.5% Thermodesulfovibrio, thermophilic anaerobic sulfate reducers
			11.1% Unclassified at genus level

5.4.4.2 Former St. Louis Ordnance Plant OU1 Microbial Results

Samples from new temporary wells (TW01 through TW06) and MW119 were analyzed using a combination of Quantarray-Chlor analysis and NGS. Results for the Quantarray-Chlor analysis are presented as **Table 5-11**. A summary of the NGS requests is presented as **Table 5-12**. Complete NGS data reports along with all other site analytical data are provided in **Appendix G**.

Table 5-11. Quantarray-Chlor Microbial Analysis Results, Former St. Louis Ordnance Plant, OU1

Sample ID	SLOP-MW119-012017	SLOP-TW01-012017	SLOP-TW02-012017	SLOP-TW03-012017	SLOP-TW04-012017	SLOP-TW05-012017	SLOP-TW06-012017
Sample Date	**1/23/17**	**1/25/17**	**1/24/17**	**1/23/17**	**1/25/17**	**1/24/17**	**1/24/17**
APS	6.95E+05	2.28E+02	2.31E+01	2.70E+00 J	2.70E+00 J	2.00E+01 U	3.14E+01
DECO	1.15E+03	2.00E+01 U	4.40E+00 J	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
Dehalobacter	7.07E+02	2.51E+03	1.95E+03	1.00E+01 U	4.18E+01	2.00E+01 U	4.70E+00 J
Dehalococcoides	2.42E+01	5.11E+01	2.00E+00 U	1.00E+00 U	2.03E+01	2.00E+00 U	1.70E+00 U
DHG	9.69E+03	2.00E+01 U	4.19E+02	1.00E+01 U	1.78E+02	2.00E+01 U	1.67E+01 U
Desulfitobacterium	3.93E+02	1.22E+02	1.27E+02	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
Desulfuromonas	1.22E+04	5.17E+03	5.65E+03	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
Total Bacteria	7.25E+06	6.56E+05	7.76E+05	1.19E+04	1.60E+05	3.56E+03	1.46E+04
EtnE	3.89E+02	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.44E+02	2.00E+01 U	1.67E+01 U
Methanogens	4.27E+03	3.70E+01	1.55E+02	1.90E+00 J	4.14E+01	2.00E+01 U	2.90E+00 J
PHE	1.03E+04	3.81E+03	3.71E+03	1.93E+02	1.27E+03	1.00E+00 J	5.30E+02
PMMO	1.32E+04	3.99E+01	3.37E+01	3.60E+00 J	3.26E+02	2.00E+01 U	2.90E+00 J
RDEG	2.79E+03	1.25E+03	1.36E+03	1.01E+03	5.39E+03	2.00E+01 U	7.81E+01
RMO	5.17E+03	9.34E+01	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
SMMO	1.01E+04	4.03E+02	2.28E+02	4.84E+01	2.37E+02	2.00E+01 U	3.15E+02
TCBO	8.33E+01	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
TCE R-Dase	1.30E+00 U	9.00E-01 J	2.00E+00 U	1.00E+00 U	2.00E+00 U	2.00E+00 U	1.70E+00 U
Toluene Dioxygenase	8.66E+01	3.88E+01	3.37E+01	6.80E+00 J	9.74E+02	7.00E-01 J	6.60E+00 J
VC R-Dase	1.30E+00 U	5.00E-01 J	2.00E+00 U	1 U	2.00E+00 U	2.00E+00 U	1.70E+00 U

Notes:

J - The reported result is an estimated value

U - TAnalyzed for, but not detected

UQ - The material was analyzed for, but not detected. One or more quality control criteria failed.

Shading indicates detection

Cells/mL - cells per milliliter

Table 5-12. Summary of Next Generation Sequencing Results, Former St. Louis Ordnance Plant OU1

Location	Well ID	Top Four Genera Detected In Sample
Upgradient	TW03	55.7% Pseudomonas, , a gram-negative, chemoorganotrophic, and aerobic bacterium. Biofilms produced by Pseudomonas are involved in the rapid corrosion of metals.
		8% Flavobacterium, a gram-negative, aerobic or facultatively anaerobic bacteria which degrades biopolymers such as chitin and cellulose
		6.8% Rhodoferax, which can be aerobic or anaerobic and is found in stagnant aquatic systems
		6% Unclassified at genus level
Treatment Area Upgradient Portion	TW02	40.2% Pseudomonas, , a gram-negative, chemoorganotrophic, and aerobic bacterium. Biofilms produced by Pseudomonas are involved in the rapid corrosion of metals.
		27.7% Alkaliphilus, a strictly anaerobic metalliredigen capable of reducing Fe (III)
		4.7% Unclassified at genus level
		4.5% Oxalobacter, a strictly anaerobic chemoorganotroph capable of degrading oxalic acid
		4.5% Dechloromonas, rod shaped bacteria which can anaerobically degrade certain aromatics and can and oxidize iron and hydrogen sulfide
Treatment Area Center	MW-119	51.8% Alkaliphilus, a strictly anaerobic metalliredigen capable of reducing Fe (III)
		8.1% Unclassified at genus level
		4.9% Hydrogenophaga, aerobic bacteria, some of which can degrade methyl-tert-butyl ether and oxidize carbon monoxide
		4.2% Methylomonas, a methanotroph; methane, methanol and formaldehyde are the only known sources of energy and carbon for this organism.
Treatment Area Downgradient Portion	TW01	30.4% Sulfuricurvum, a motile, anaerobic, sulfur-oxidizing bacterium
		9.2% Unclassified at genus level
		9% Pseudomonas, , a gram-negative, chemoorganotrophic, and aerobic bacterium. Biofilms produced by Pseudomonas are involved in the rapid corrosion of metals.
		6.5% Pedobacter, an aerobic facultative psychrophile (prefers temperature less than 20 degrees C)
Downgradient	TW04	73.8% Methylotenera, can utilize methylamine as a single source of energy, carbon, and nitrogen.
		13.9% Pseudomonas, , a gram-negative, chemoorganotrophic, and aerobic bacterium. Biofilms produced by Pseudomonas are involved in the rapid corrosion of metals.
		2.3% Methylobacillus, a methylotrophic genus of obligate methanol- and methylamine-utilizers.
		2% Unclassified at genus level
Crossgradient	TW05	47% Unclassified at genus level
		14.2% Desulfovibrio, a halophilic sulfate-reducer commonly found in sediment of lakes, brackish water and marine environments. Desulfovibrio has been implicated in the corrosion of various metals, including carbon steel, stainless steel, galvanized steel, and copper alloys.
		2% Candidatus Tammella
		1.9% Sphingomonas, an aerobic chemoorganotrophs shown to degrade toluene, naphthalene, and other aromatic compounds
Crossgradient	TW06	25.2% Pseudomonas, , a gram-negative, chemoorganotrophic, and aerobic bacterium. Biofilms produced by Pseudomonas are involved in the rapid corrosion of metals.
		20.8% Janthinobacterium, a diverse group of bacteria capable of tolerating a variety of environmental stressors
		15.6% Acinetobacter, a strictly aerobic microbe which contibutes to mineralization of multiple compounds, including aromatics
		13% Methylotenera, can utilize methylamine as a single source of energy, carbon, and nitrogen.

At the former St. Louis Ordnance Plant OU1, a number of anaerobic reductive dechlorinators were detected. *Dehalobacter* concentrations were elevated in the treatment area in comparison to background, with the highest concentration (2.51 x 10^3 cells/mL) in the sample from TW01, the most downgradient of the mixing area sample locations. *Dehalobacter* was not detected in the upgradient reference sample (TW03). Similarly, *Dehalococcoides* was detected in two treatment area samples (MW-119 and TW01) and in TW04, which is downgradient and outside of the mixing zone, but not in the upgradient or cross-gradient samples. Similar patterns were observed for *Dehalogenimonas*, *Desulfitobacterium*, *Desulfuromonas*, and *Dehalobium,* where detections are limited to the treatment area and/or downgradient area. Functional genes involved in complete dechlorination of TCE to ethene by *Dehalococcoides* were detected at very low levels, and only in the sample from TW01 (TCE reductase at 9x10^{-1} cells/mL and VC reductase at 5 x 10^{-1} cells/mL; BAV1 was not detected). It appears that the treatment may be facilitating reductive dechlorination, but complete dechlorination may be limited by the lack of VC reductase and BAV1 presence, or other factors, such as low TOC. Fieldwork was performed before the identification of the chloroethene reductase (cerA) gene was published (Yang, et. al. 2017). This gene is sometimes present in *Dehalogenimonas* and can also facilitate complete reductive dechlorination of TCE to ethene. However, this gene was not included in the analysis and its presence and potential for complete degradation through this mechanism at the site is unknown.

At the former St. Louis Ordnance Plant OU1, EtnC was not detected, but EtnE was detected in one treatment area sample (MW-119 at 3.89 x 10^2 cells/mL) and the downgradient sample (TW04 at 2.44 x 10^2 cells/mL), indicating direct metabolism of vinyl chloride by ethenotrophs may be possible at the site.

Several genes associated with aerobic cometabolism of chlorinated VOCs were also detected at OU1, comprising PHE, PMMO, TOD, RDEG, RMO, and SMMO. Concentrations of these constituents were generally similar within and outside of the treatment area, with the exception of RMO, which was detected only in the mixing area and not outside. Additionally, with the exception of TOD, these genes were not detected in samples from TW05, a cross-gradient well, which seems very different from the other site samples with respect to the microbial population.

Methanogens were detected consistently across the site except in TW05, with concentrations slightly higher in the treatment area than outside.

At the former St. Louis Ordnance Plant OU1, *Proteobacteria* and *Firmicutes* were the primary phyla for all samples analyzed at the site with the exception of TW05, with numbers of *Firmicutes* higher in the treatment area than outside. *Firmicutes* are acetylenotrophic, possibly explaining the non-detect results for acetylene at the site. For TW05, 39.9% of detected bacteria were unclassified at the phylum level, suggesting this sample location is different than the others, consistent with the findings of the Quantarray analysis. Genus data demonstrated highly variable microbial populations at the site. *Pseudomonas* dominated in the samples from the upgradient background location (TW03) and one cross-gradient location (TW06) (**Table 5-12 and Appendix G**). The dominant genus was different for each of the treatment area samples. *Pseudomonas* was still the most abundant genus in the most upgradient sample within the treatment area (TW02) despite the low ORP in this location and the aerobic nature of this genus. The percentage of the population in this location, was, however, lower than that observed in TW03. In the center portion of the treatment area (MW-119), the most dominant genus was

Alkaliphilus, a strictly anaerobic metalliredigen capable of reducing Fe (III). In the downgradient portion of the treatment area (TW01), the most common genus observed was *Sulfuricurvum*, a motile, anaerobic, sulfur-oxidizing bacterium. *Methylotenera* were abundant just downgradient of the treatment area (TW04) and represented 73.8% of the population in that sample. The bacteria most commonly observed in the sample from TW05 were unclassified at the genus level.

5.4.5 Water Level and Slug Testing Results

Results of the water level surveys at ABL Site 5 and the former St. Louis Ordnance Plant OU1 are shown on **Tables 5-13 and 5-14**, respectively. Maps showing groundwater contours for each of the gauging events at ABL are presented as **Figures 5--36 through 5-38**. Because new wells within the treatment area appeared to have not fully recharged at the former St. Louis Ordnance Plant at the time of the first gauging event, maps are only provided for the last two events. Additionally, because the water levels were significantly different in the two new temporary wells in the treatment area (DP001 and DP002) in comparison to the existing well (MW-119), contours were drawn for three combinations of wells: with all site wells included, with all wells except MW-119 included, and with all wells except DP001 and DP002 included. These figures are presented as **Figures 5-39 through 5-44**.

The groundwater potentiometric surface observed during this study was slightly inconsistent with the historic groundwater potentiometric surface gradient direction (**Figure 4-2**). This variation in flow direction is not believed to impact current remedy effectiveness, as concentrations are very low cross-gradient on the west side of the wall where migration potential around the wall is most likely (see **Section 5.4.3**). There was no mounding observed behind the wall that would indicate plugging due to excessive mineralization of the iron.

Groundwater flow direction interpretation at the St. Louis site was complicated by the screen interval of MW-119, which is slightly deeper than the temporary wells and interacts with the shale unit below the ZVI mixing zone. If these two data points are plotted with the surrounding new temporary wells as well as existing well MW-119, an apparent mound is evident in the vicinity of MW-119 with depressions at DP001/TW01 and DP002/TW02 (**Figures 5-39 and 5-40**), which seems unlikely. The potential for the data point at MW-119 to be anomalous was also considered. Without this data point, the gradient appears relatively consistent across the site, with flow to the north and northeast (**Figures 5-41 and 5-42**). Contours were also drawn eliminating only DP001/TW01 and DP002/TW02. In this configuration, a mound is present across the upgradient portion of the treatment area (**Figures 5-43 and 5-44**).

The graphical AQTESOLV analysis sheets from the slug testing at the St. Louis site are presented in **Appendix J.** Calculated hydraulic conductivity (K) values are included in **Table 5-15**. The results indicate the hydraulic conductivity of the aquifer material is consistent with clay. There are no notable differences in conductivity between the treatment area (DP001/TW01 and DP002/TW02) and the surrounding aquifer materials based on slug test results.

Table 5-13. Groundwater Elevations, ABL Site 5

Well ID	Total Depth (ft btoc)	Ground Surface Elevation (ft amsl)	Riser Elevation (ft amsl)	1/23/17 Groundwater Level (ft btoc)	1/23/17 Groundwater Elevation (ft amsl)	2/15/17 Groundwater Level (ft btoc)	2/15/17 Groundwater Elevation (ft amsl)	3/9/17 Groundwater Level (ft btoc)	3/9/17 Groundwater Elevation (ft amsl)
AS05-GW13	36.06	686.6	688.82	15.16	673.66	14.34	674.48	15.15	673.67
AS05-GW17	25.92	674.44	676.39	5.61	670.78	5.34	671.05	6.14	670.25
AS05-GW18	27.08	672.12	674.75	3.40	671.35	3.01	671.74	3.48	671.27
AS05-GW25	26.98	672.61	674.86	4.09	670.77	3.80	671.06	4.80	670.06
AS05-GW26	24.22	673.29	675.74	4.61	671.13	3.80	671.94	4.51	671.23
AS05-GW27	24.73	671.97	674.82	3.82	671.00	3.55	671.27	4.50	670.32
AS05-GW28	21.15	671.95	674.63	3.64	670.99	3.40	671.23	4.34	670.29
AS05-GW29	24.63	674.82	677.32	4.75	672.57	4.49	672.83	4.97	672.35
AS05-GW30	22.16	672.40	674.98	2.11	672.87	2.35	672.63	3.34	671.64
AS05-GW31	21.97	672.29	674.82	3.82	671.00	2.70	672.12	3.19	671.63
AS05-GW32	13.22	673.86	676.49	3.09	673.40	2.36	674.13	3.34	673.15
AS05-GW33	25.23	673.22	676.07	5.34	670.73	4.50	671.57	5.35	670.72

Table 5-14. Groundwater Elevations, Former St. Louis Ordnance Plant OU1

Well ID	Total Depth (ft bgs)	Ground Surface Elevation (ft amsl)	Riser Elevation (ft amsl)	1/17/17 Groundwater Level (ft btoc)	1/17/17 Groundwater Elevation (ft amsl)	1/23/17 Groundwater Level (ft btoc)	1/23/17 Groundwater Elevation (ft amsl)	1/30/17 Groundwater Level (ft btoc)	1/30/17 Groundwater Elevation (ft amsl)
DP001/TW01	27	540.59	543.81	14.05	529.76	21.80	522.01	16.66	527.15
DP002/TW02	25	543.81	546.70	18.62	528.08	19.20	527.50	13.41	533.29
DP003/TW03	22	543.13	546.09	2.82	543.27	5.96	540.13	6.88	539.21
DP004/TW04	25	537.69	540.63	1.85	538.78	4.91	535.72	5.25	535.38
DP005/TW05	20	542.52	545.87	2.78	543.09	10.10	535.77	7.82	538.05
DP006/TW06	27	540.99	543.81	2.50	541.31	7.01	536.80	6.46	537.35
MW-119	30	542.15	541.63	NR	NR	1.49	540.14	2.46	539.17

Well ID	Total Depth (ft bgs)	Ground Surface Elevation (ft amsl)	Riser Elevation (ft amsl)	2/8/17 Groundwater Level (ft btoc)	2/8/17 Groundwater Elevation (ft amsl)	2/28/17 Groundwater Level (ft btoc)	2/28/17 Groundwater Elevation (ft amsl)	3/8/17 Groundwater Level (ft btoc)	3/8/17 Groundwater Elevation (ft amsl)
DP001/TW01	27	540.59	543.81	12.18	531.63	9.68	534.13	10.01	533.80
DP002/TW02	25	543.81	546.70	10.25	536.45	9.87	536.83	11.59	535.11
DP003/TW03	22	543.13	546.09	7.69	538.40	8.52	537.57	8.51	537.58
DP004/TW04	25	537.69	540.63	5.68	534.95	6.65	533.98	5.47	535.16
DP005/TW05	20	542.52	545.87	8.46	537.41	9.01	536.86	8.78	537.09
DP006/TW06	27	540.99	543.81	7.20	536.61	7.92	535.89	7.39	536.42
MW-119	30	542.15	541.63	3.21	538.42	4.43	537.20	4.40	537.23

Legend
- Well Location
- PRB
- Groundwater Elevation Contour
- Estimated Groundwater Flow Direction
- Site Boundary

N

0 37.5 75 Feet

1 inch = 75 feet

Figure 5-36
Groundwater Contours - January 23, 2017
Allegany Ballistics Laboratory Site 5
Rocket Center, WV

ch2m

Legend
- Well Location
- PRB
- Groundwater Elevation Contour
- Estimated Groundwater Flow Direction
- Site Boundary

N

0 37.5 75 Feet

1 inch = 75 feet

Figure 5-37
Groundwater Contours - February 15, 2017
Allegany Ballistics Laboratory Site 5
Rocket Center, WV

ch2m

\\brookside\GIS_SHARE\ENBG\00_Proj\N\Navy\CLEAN\MULTI_REGION\ZVI\MapFiles\Results\ABL\Figure 5-16 AB-X - GW Contours - Mar2017_Update.mxd8/16/2017AR055181

Legend
- Well Location
- PRB
- Groundwater Elevation Contour
- Estimated Groundwater Flow Direction
- Site Boundary

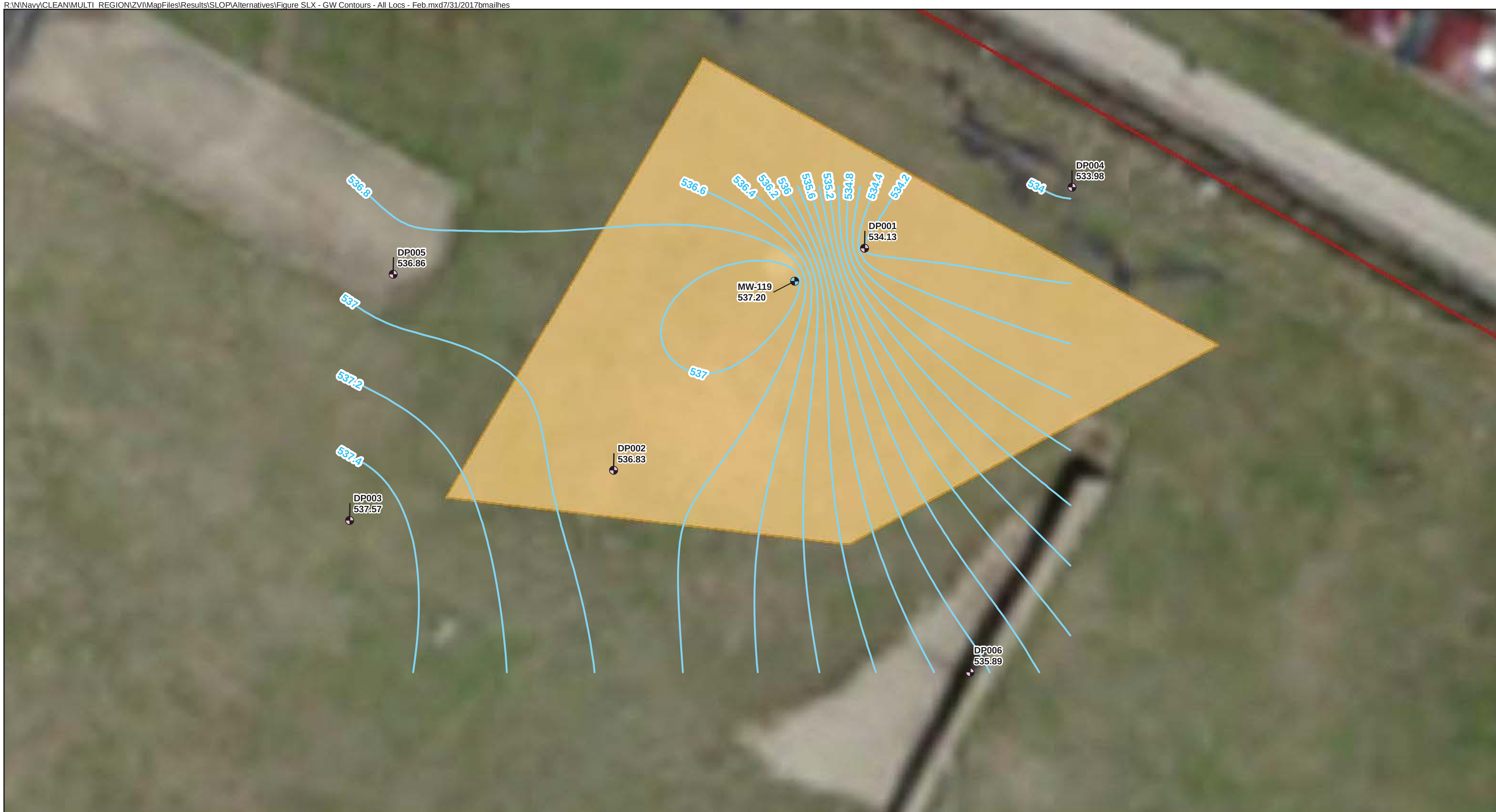
N

0 37.5 75 Feet

1 inch = 75 feet

Figure 5-38
Groundwater Contours - March 9, 2017
Allegany Ballistics Laboratory Site 5
Rocket Center, WV

ch2m.



Legend

ZVI Monitoring Well

- Treatment Area
- Temporary Well Location
- Groundwater Elevation Contour (ft amsl)
- Soil Mixing Treatment Areas
- Installation Boundary

N

0 5 10 Feet

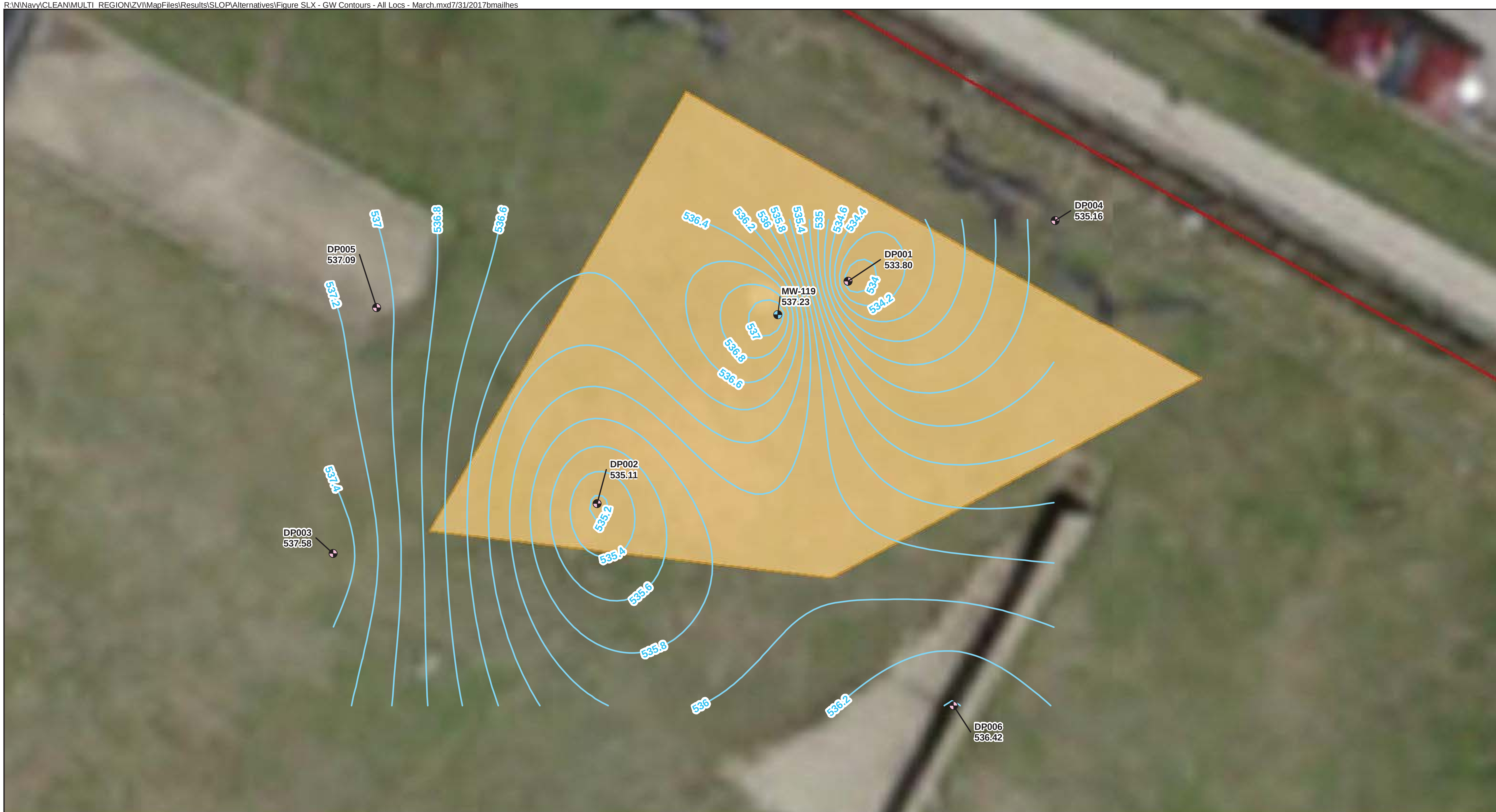
1 inch = 10 feet

Imagery Source: ©2016, Esri

Figure 5-39
Groundwater Contours Using All Locations
02/28/2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m.

R:\N\Navy\CLEAN\MULTI_REGION\ZVI\MapFiles\Results\SLOP\Alternatives\Figure SLX - GW Contours - All Locs - March.mxd7/31/2017bmailhes



Legend

ZVI Monitoring Well

- Treatment Area
- Temporary Well Location
- Groundwater Elevation Contour (ft amsl)
- Soil Mixing Treatment Areas
- Installation Boundary

N

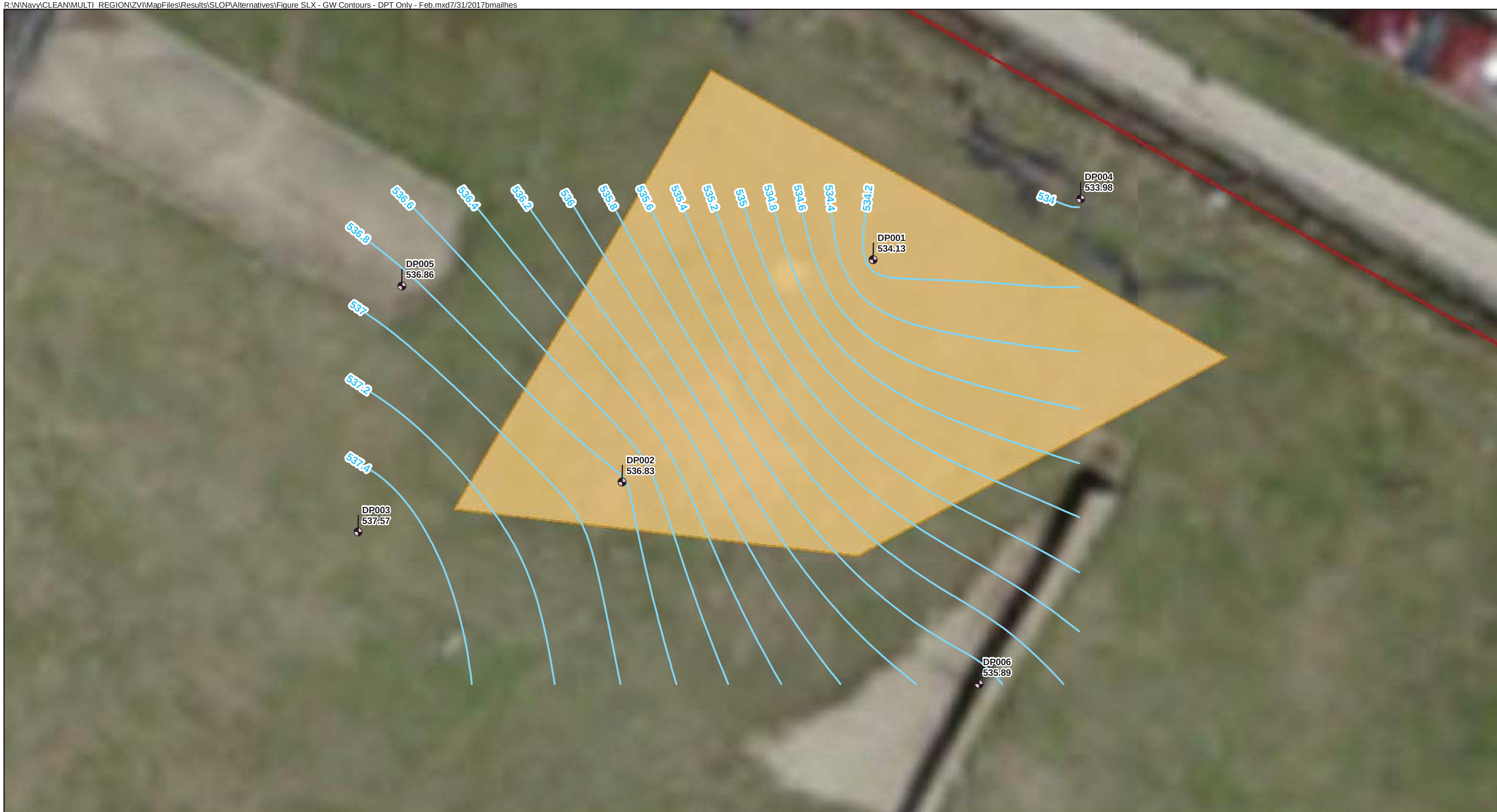
0 5 10 Feet

1 inch = 10 feet

Imagery Source: ©2016, Esri

Figure 5-40
Groundwater Contours Using All Locations
03/08/2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m:



Legend

- Temporary Well Location
- Groundwater Elevation Contour (ft amsl)
- Soil Mixing Treatment Areas
- Installation Boundary

N

0 5 10 Feet

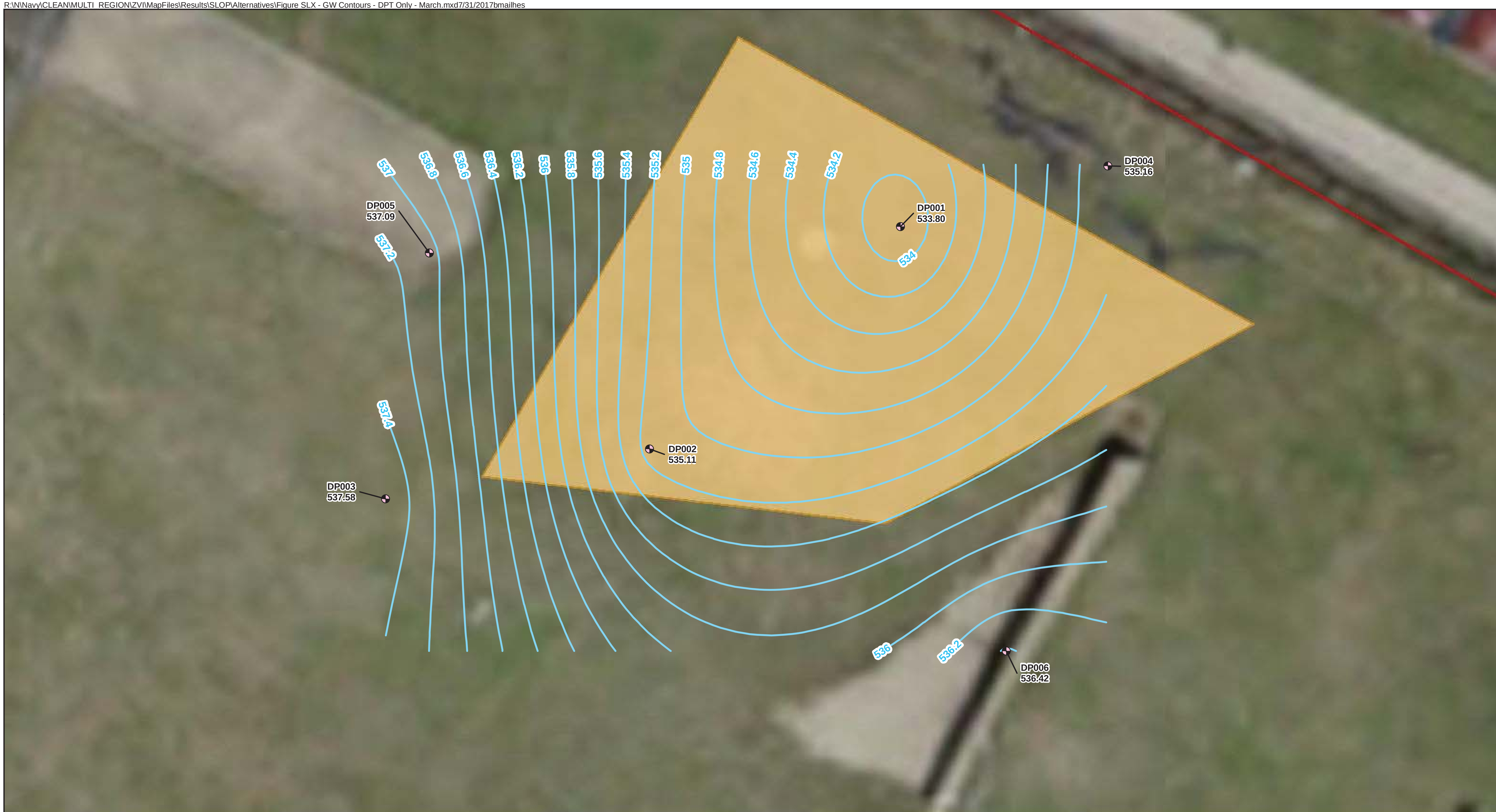
1 inch = 10 feet

Imagery Source: ©2016, Esri

Figure 5-41
Groundwater Contours, MW119 Omitted
02/28/2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m.

R:\N\Navy\CLEAN\MULTI_REGION\ZVI\MapFiles\Results\SLOP\Alternatives\Figure SLX - GW Contours - DPT Only - March.mxd7/31/2017bmailhes



Legend
- Temporary Well Location
- Groundwater Elevation Contour (ft amsl)
- Soil Mixing Treatment Areas
- Installation Boundary

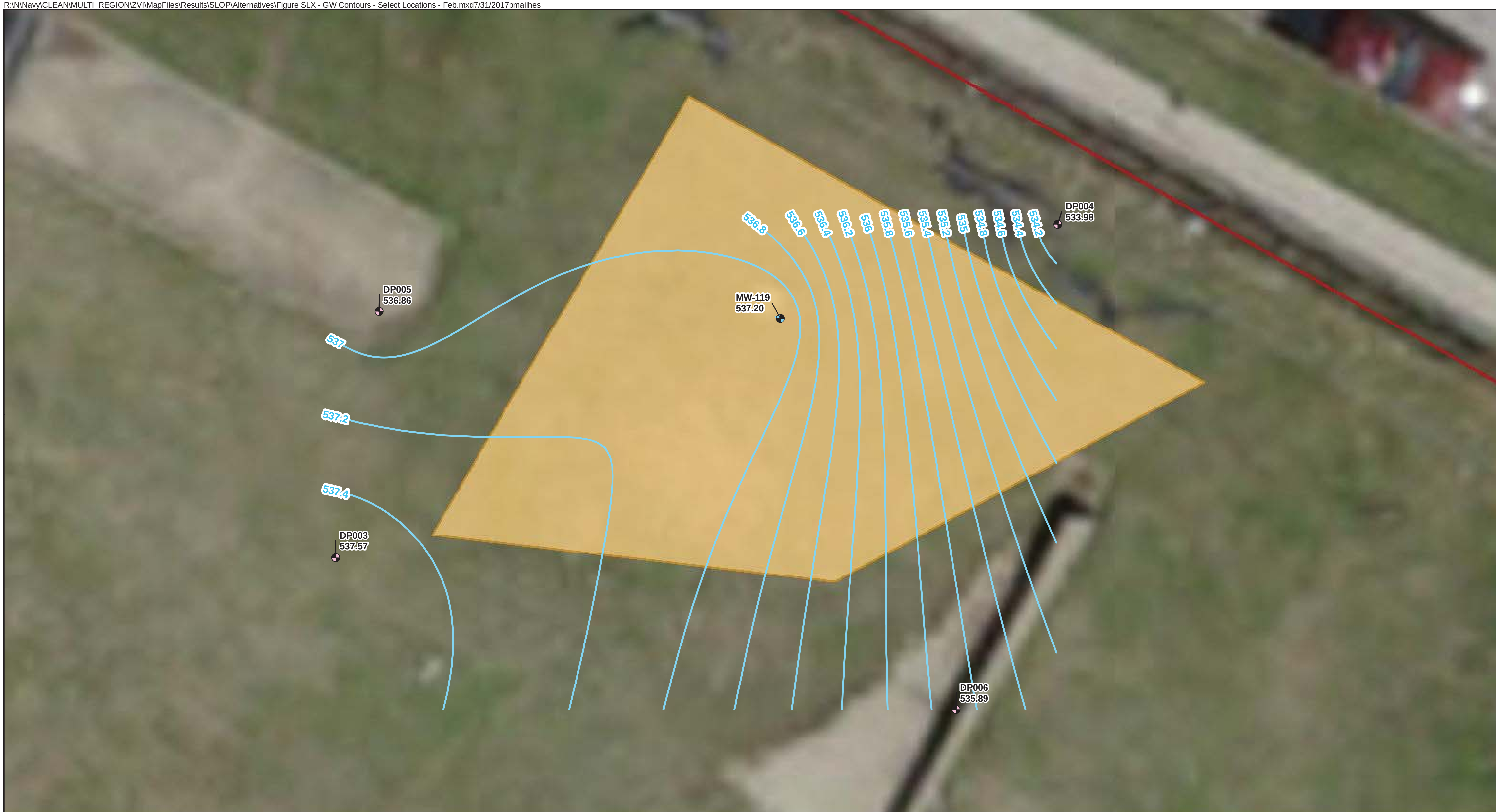
1 inch = 10 feet

Imagery Source: ©2016, Esri

Figure 5-42
Groundwater Contours MW-119 Omitted
03/08/2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m.

R:\N\Navy\CLEAN\MULTI_REGION\ZVI\MapFiles\Results\SLOP\Alternatives\Figure SLX - GW Contours - Select Locations - Feb.mxd7/31/2017bmailhes



Legend

ZVI Monitoring Well

- Treatment Area
- Temporary Well Location
- Groundwater Elevation Contour (ft amsl)
- Soil Mixing Treatment Areas
- Installation Boundary

N

0 5 10 Feet

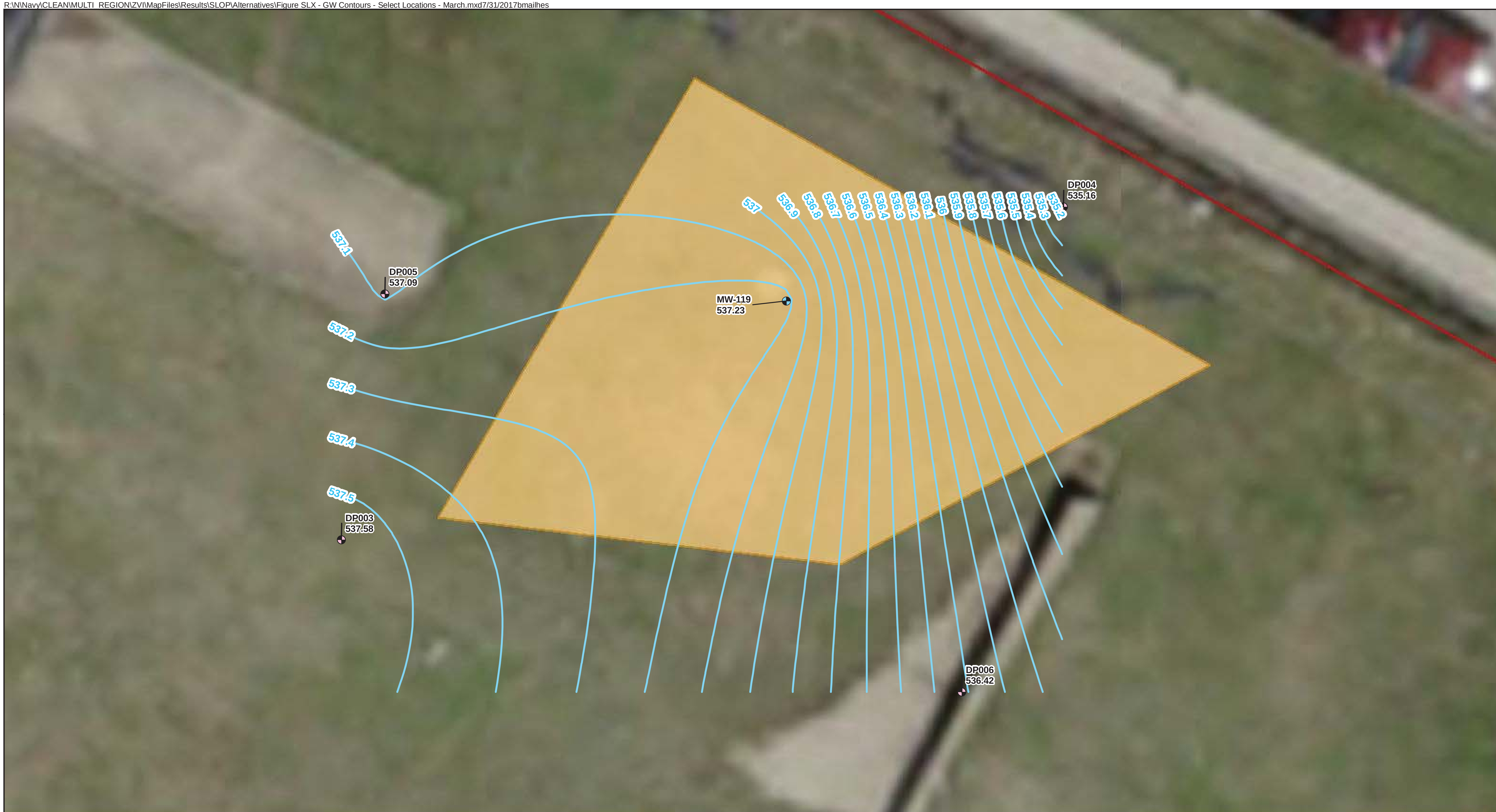
1 inch = 10 feet

Imagery Source: ©2016, Esri

Figure 5-43
Groundwater Contours DP002 and DP002 Omitted
02/28/2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m:

R:\N\Navy\CLEAN\MULTI_REGION\ZVI\MapFiles\Results\SLOP\Alternatives\Figure SLX - GW Contours - Select Locations - March.mxd7/31/2017bmailhes



Legend

ZVI Monitoring Well

- Treatment Area
- Temporary Well Location
- Groundwater Elevation Contour (ft amsl)
- Soil Mixing Treatment Areas
- Installation Boundary

N

0 5 10 Feet

1 inch = 10 feet

Imagery Source: ©2016, Esri

Figure 5-44
Groundwater Contours DP001 and DP002 Omitted
03/08/2017
Former St. Louis Ordnance Plant OU1
St. Louis, Missouri

ch2m

Table 5-15. Slug Testing Results, Former St. Louis Ordnance Plant OU1

Well	Test Date	Test 1 (Falling Head)			Test 2 (Rising Head)			Hydraulic Conductivity Summary	
		Analysis Method[1]	Hydraulic Conductivity		Analysis Method[1]	Hydraulic Conductivity			
			(cm/s)	(ft/d)		(cm/s)	(ft/d)	(cm/s)	(ft/d)
DP001 Run #1	1/30/2017	Bouwer-Rice	5E-06	0.01	--	--	--	5E-06	0.01
DP001 Run #2	1/30/2017	Bouwer-Rice	5E-06	0.01	--	--	--		
DP002 Run #1	1/30/2017	Bouwer-Rice	9E-07	0.003	--	--	--	2E-06	0.005
DP002 Run #2	1/30/2017	Bouwer-Rice	3E-06	0.01	--	--	--		
DP003	2/1/2017	Bouwer-Rice	1E-06	0.003	--	--	--	1E-06	0.003
DP004	2/1/2017	Bouwer-Rice	1E-06	0.003	--	--	--	1E-06	0.003
DP005 Run #1	1/30/2017	Bouwer-Rice	4E-06	0.012	--	--	--	3E-06	0.01
DP005 Run #2	1/30/2017	Bouwer-Rice	3E-06	0.008	--	--	--		
DP006	1/31/2017	--	--		Bouwer-Rice	6E-06	0.02	6E-06	0.02

Notes:

[1] Bouwer-Rice using normalized head ranges to address ambiguity in the recovery curves. This method is recommended to improve the reliability of data analysis where possible.

-- test was not completed

cm/s = centimeters per second; ft/d = feet per day

AQTESOLV Professional version 4.50.002 was used for this evaluation.

6.0 PERFORMANCE ASSESSMENT

This section presents the assessment of the long-term performance of the ZVI remedies evaluated as part of this project, as determined by the results of data collection and assessment against performance criteria established in the Demonstration Plan (NAVFAC EXWC and CH2M, 2016) and outlined in Section 3 of this report. These observations represent conditions observed 11 years following treatment at the ABL site and 5 years following treatment at the former St. Louis Ordnance Plant site.

6.1 GEOCHEMICAL AND CHEMICAL IMPACTS OF ZVI TREATMENT

At ABL Site 5, notable changes in site groundwater chemistry were observed associated with the presence of the ZVI PRB. Increases in pH and decreases in ORP and DO were observed downgradient of the PRB, relative to upgradient groundwater. TOC, alkalinity, hardness, and sulfate decreased across the two monitoring transects. Methane, ethane, and ethene concentrations increased across the transects. Additionally, a "clean front" of non-detected VOC results was observed in one of the two transects sampled. Decreases of calcium, magnesium, and strontium were observed downgradient. Iron, barium, sodium, and silicon concentrations increased from upgradient to downgradient across the transects. Overall, data indicate continued geochemical reactions resulting from the PRB.

At the former St. Louis Ordnance Plant, changes in site groundwater chemistry were also observed associated with the ZVI treatment. DO and ORP were considerably lower within the treatment area than outside of it and pH was considerably higher. ORP levels were still within the optimal range for ZVI treatment (<400 mV) in one treatment area sample. Sulfate concentrations were lower within the treatment area while chloride, methane, ethane, and ethene concentrations were higher. Concentrations of calcium, magnesium, manganese, barium, and strontium were highest in the upgradient portion of the mixing area. Overall, data indicate ongoing geochemical reactions resulting from the treatment and likely, conditions favorable for abiotic reduction of site contaminants.

6.2 MINERALIZATION OF ZVI

At the ABL Site 5 upgradient ZVI/aquifer interface, iron particles were shown through electron micrographs and x-ray mapping to have a mottled appearance indicative of corrosion. Additionally, coatings of calcium carbonate and iron oxides were observed on the iron particles, with the thickness of the coating decreasing inward from the upgradient ZVI/aquifer interface. Native quartz grains also were cemented together by iron oxide and calcium carbonate. None of the coatings of the quartz particles were significant enough to greatly influence hydraulic characteristics of the wall. XRD indicated the presence of iron oxides (magnetite and hematite). AVS data were also consistent with presence of iron sulfide, which is thought to provide secondary reactivity to the PRB. Overall, mineralogical results indicate weathered ZVI with some passivation due to precipitation of coatings (e.g., calcium carbonate) and transformation of ZVI into less reactive minerals, such as iron carbonate, to at least 0.5 foot into the PRB (deepest core sample analyzed). Decreases in calcium and alkalinity as groundwater passes through the PRB provide supporting evidence for formation of these calcium carbonate minerals within the PRB. However, despite the passivation observed, secondary reactivity is likely occurring based on the presence of iron sulfide. Additionally, because cores collected on the downgradient side of the wall were not analyzed, it is also possible that iron closer to the downgradient side was less corroded and had less significant precipitate coating.

At the former St. Louis Ordnance Plant site, XRD, energy dispersive line scans, and XANES of a limited number of samples indicated no identifiable ZVI remaining in cores from the mixing area. Iron identified was primarily magnetite and goethite. SEM micrographs did not indicate the presence of precipitates on the transformed (to magnetite and goethite) iron particles. Particle size indicated remaining particles showed considerable reduction in size relative to the original ZVI product. Overall, results indicate weathering of the ZVI.

6.3 REACTIVITY OF ZVI

Due to limited OHSU resources, reactivity was not assessed for the ABL Site 5 cores.

Magnetic and gravimetric analysis as well as acidification and hydrogen generation results for St. Louis Ordnance Plant OU1 indicated a small amount of remaining ZVI (less than 0.04 percent) in the three cores from two sample locations analyzed from the mixing area at the site. Total magnetic material observed in these samples was between 0.2- and 0.7-percent, consistent with the range of ZVI percentages measured in confirmation samples during the 2012 mixing. Remaining iron observed in the mixing area cores was believed to primarily be in the form of magnetite. Resazurin testing indicated higher reduction potential for the treated source area core material relative to background, supporting that the magnetite is facilitating secondary reactivity in the treatment area. Because of the limited number of analyzed samples, it is unknown if more ZVI might be present in other areas of the mixing zone not sampled. It is possible that the cores somehow did not collect enough ZVI in a heterogeneously distributed application, particularly because these findings do not correspond well with other field findings which are indicative of continued reactivity of the ZVI.

6.4 MICROBIAL COMMUNITY CHANGES

At ABL Site 5, concentrations of anaerobic dechlorinators were generally lower just downgradient of the PRB than they were immediately upgradient, indicating that groundwater downgradient of the PRB has conditions less favorable for proliferation of dechlorinating microbes (such as lower VOC concentrations). Genes involved in aerobic direct metabolism and cometabolism of VC were either not identified or were present in spatial patterns that did not support a significant impact of the PRB on microbes carrying these genes. Sulfate reducers and methanogens were detected consistently across the site, with no notable changes due to the presence of the PRB. NGS data indicate the presence of sulfur-oxidizing bacteria (*Sulfurimonas*) just downgradient of the wall, but not in other portions of the site, which may be a result of the release of reduced sulfur species in groundwater from the PRB. While this, in conjunction with the geochemical data summarized above, supports continued reactivity in the wall and impacts to the surrounding microbial community, overall, data do not support facilitation of significant microbiological dechlorination processes due to reducing conditions created by the PRB.

At former St. Louis Ordnance Plant OU1, concentrations of reductive dechlorinators were one to three orders of magnitude higher within the mixing area and downgradient of the mixing area than they were cross-gradient or upgradient, indicating that the reducing conditions created by the ZVI may be facilitating reductive dechlorination. However, genes involved in complete dechlorination of VC by *Dehalococcoides* were either not detected, or present at very low levels (<1 cell/mL). Genes associated with direct metabolism and/or cometabolism of VC were present throughout the site, indicating a complete dechlorination pathway may be present despite the absence of functional genes involved in reductive dechlorination of VC. NGS data also indicated changes in the microbial population due to the ZVI, particularly in the downgradient portion of the treatment area, with decreasing cell counts of the phylum *Proteobacteria* and genus *Pseudomonas* from the upgradient location moving downgradient into the treatment area in addition to increases in the phylum *Firmicutes* and the genera *Alkaliphilus*, *Sulfuricurvum*, and *Methylotenera*. In conjunction with the geochemical data, which indicate a highly aerobic environment surrounding the mixing area, microbial data from the former St. Louis Ordnance Plant support that the ZVI treatment has created reducing conditions conducive to partial reductive dechlorination in an environment where these processes would otherwise be unlikely. In tandem with the existing/ongoing potential for VC metabolism and cometabolism, this may allow for complete biological destruction of site contaminants of concern. Potential for reductive dechlorination through the recently discovered cerA gene was not evaluated due to the timing of that discovery relative to the schedule for this project.

6.5 GROUNDWATER FLOW CHANGES

At ABL Site 5, there was no mounding observed behind the wall or apparent migration around the wall that would indicate plugging due to excessive mineralization of the iron. The groundwater potentiometric surface was observed to be toward the northwest, which is offset from the contaminant plume direction, to the north. This is likely due to the anisotropy of the alluvial sediments in the area. The landfill and resultant groundwater contaminant plume are located in a former meander bend of the North Branch Potomac River. The depositional environment (i.e., paleochannel) likely has more influence on the contaminant migration then the groundwater potentiometric gradient. Evaluating the depositional geomorphology was beyond the scope of this study.

At the former St. Louis Ordnance Plant OU1, the groundwater flow evaluation was complicated by the slightly different screen interval of existing well MW-119 relative to the new wells. The slug test data from within the mixing area and surrounding area indicate similar hydraulic conductivity values, ranging from 0.003 to 0.01 foot per day indicating minimal impacts to hydraulic conductivity from mixing activities.

The two ZVI application sites studied did not indicate any discernible reduction in groundwater flow through the ZVI application area/barrier.

6.6 BEST PRACTICES

Best practices based on these data are presented in **Table 2-3.**

7.0 COST ASSESSMENT

Because the scope of this project involved evaluation of remedies that have already been implemented, no new information on cost of implementing ZVI remedies was collected as part of this project. However, a thorough review of costs of ZVI remedies is available in the following documents:

- ESTCP. 2010. *Cost and Performance Report Emulsified Zero-valent Iron Nano-scale Iron Treatment of Chlorinated Solvent DNAPL Source Areas (ER-200431)*. September.
- NAVFAC. 2012. *Permeable Reactive Barrier Cost and Performance Report*. March.
- NAVFAC. 2008. *Cost and Performance Report for a Zero Valent Iron Treatability Study at Naval Air Station, North Island*. July.

8.0 IMPLEMENTATION ISSUES

Because the scope of this project involved evaluation of remedies that have already been implemented, no new information on implementability was collected. However, a thorough review of implementation of ZVI remedies is available in the following documents:

- Interstate Technology and Regulatory Council (ITRC). 2005. *Permeable Reactive Barriers: Lessons Learned/New Directions.* February.
- ITRC. 2011. *Permeable Reactive Barrier: Technology Update.* June.
- Powell, R. M., P. D. Powell, and R. W. Puls. 2002. *Economic Analysis of the Implementation of Permeable Reactive Barriers for Remediation of Contaminated Groundwater*. EPA/600/R-02/034. U.S. Environmental Protection Agency.

9.0 RECOMMENDATIONS

9.1 BEST PRACTICE RECOMMENDATIONS

The results of this study were used to develop best practices to be used for ZVI treatment design and performance monitoring. These best practices are provided in **Table 9-1**.

Table 9-1. Recommended Best Practices

Category	Observation	Recommended Best Practice
Pre-Remedy Selection	At sites with high dissolved oxygen (DO) and oxidation/reduction potential (ORP), natural reductant demand may more-rapidly deplete zero-valent iron (ZVI), impacting remedy effectiveness	ORP and DO should be carefully considered prior to selection of ZVI remedies. In cases where DO and ORP are very high, other remedies more compatible with oxidizing conditions may be more effective. Currently, natural oxidant demand testing is common when assessing in situ chemical oxidation remedies, but the natural reductant demand of aquifers is not often assessed prior to implementing chemical reduction remedies.
	At permeable reactive barrier (PRB) sites, contamination is often observed downgradient of the wall following installation. Additionally, flow direction may be seasonably variable resulting in the PRB not remaining perpendicular to groundwater flow at times.	When feasible, PRB design should be completed after installation and sampling of monitoring wells downgradient, upgradient, and cross-gradient of the proposed PRB. This will allow for optimization of wall position.
	At sites where contaminant concentrations were delineated using DPT, groundwater geochemistry and field parameter data were often not available for the period prior to remedy implementation in the treated area.	Collect some baseline geochemistry and field data in the highest concentration areas to assist in the evaluation of treatment effectiveness once iron treatment is employed.
Remedy Implementation, Performance Monitoring, and Optimization	Lack of pre-implementation geochemical data in the immediate downgradient vicinity of an PRB installed within the groundwater contaminant plume limits the assessing the PRB's performance due to effect of desorption/diffusion of contaminants.	Collect two rounds of geochemical data prior (within a year) to installation of ZVI application in the area 5-15 feet downgradient of the planned application. Plan on a site visit by the Remedial Design team 90-95 percent submission to layout ZVI application align/area as closely as possible so that permanent or temporary groundwater monitoring wells can be installed.
	Effectiveness is highly dose-related (ZVI to soil ratio) with mixing areas at which doses were >1% generally achieving the best results	While doses of 0.5% may be sufficient at some sites, designs of >1% are generally effective.

Table 9-1. Recommended Best Practices

Category	Observation	Recommended Best Practice
	While aquifer ORP was often consistent with conditions favorable for dechlorinating microbes, such as Dehalococcoides sp., these microbes were not present in abundant concentrations and/or with ideal functional genes downgradient of or within treatment areas at either field study site, possibly as a result of generally low organic carbon concentrations or sub-optimal native microbial populations.	If a treatment train is desired in which anaerobic conditions created by ZVI are intended to facilitate reductive dechlorination downgradient of the ZVI treatment area, addition of organic carbon or bioaugmentation amendments may be necessary.
	At the St. Louis site, ZVI was found to have converted to magnetite over time in the small number of samples evaluated. At the ABL PRB site, iron was present primarily in the form of magnetite and hematite. Iron particles at the upgradient interface exhibited some mineral precipitates on their surfaces, primarily calcium carbonate and iron oxide. Minimal ZVI was observed in the few samples collected from St. Louis 5 years after treatment, though sample cores were not likely representative of the entire mixing area and the remaining magnetite still facilitated reductive activity based on reactivity analysis. Geochemical and microbial parameters at both sites were supportive of continued activity of the iron over time. While some signs of ZVI depletion were evident based on reactivity testing and mineralology testing of the limited sample set, geochemistry indicated highly reducing conditions, indicating the potential for more ZVI to be present in areas not sampled.	Because magnetite may still facilitate abiotic degradation of chlorinated volatile organic compounds, conversion of ZVI to magnetite is not entirely inconsistent with continued treatment. Additionally, build-up of precipitates which would inhibit reactivity at the ABL site was more common in portions of the wall at the upgradient interface, likely allowing for continued reactivity within the wall. However, monitoring of reactivity using redox indicators, such as resazurin, or batch reactors may be useful in determining the need for enhancements to mature iron remedies. Additionally, if microscopic analysis is completed, a larger sample set may be necessary to adequately assess the presence/absence of remaining ZVI.

9.2 RECOMMENDATIONS FOR FURTHER STUDY

Because of the level of heterogeneity observed between data points, additional collection of iron and analysis for reactivity and mineralogy is recommended to further assess the longevity of ZVI at the Former St, Louis Ordnance Plant and possibly one of the other sites evaluated in the desktop study. The desktop review data indicated only one site, White Oak, Site 13, still had ORP values consistent with abiotic reactions. However, an ORP of less than -400 mV was observed at the St. Louis Site in a new monitoring point added as part of this investigation. This highlights the potential for heterogeneous conditions at ZVI treatment sites and the need for a robust data set to evaluate such conditions.

Because no acetylene was observed at the field test sites, additional collection using passive samplers is recommended. Trend monitoring of acetylenotrophic microbes (such as *Firmicutes*) might also be evaluated as a potential indicator of passivation of ZVI. It was unclear from the data collected as part of this study whether the ethenotrophs and methanotrophs identified in the ZVI mixing zone at the St. Louis Ordnance Plant are active in aerobic microenvironments within the mixing area, dormant, or present and tolerant of the anaerobic conditions. Performance of mRNA transcriptional analysis on site samples would be useful to evaluate this unknown. The presence of biologically-active aerobic microzones in a highly reducing area such as a ZVI mixing zone would support the likely widespread presence of these microzones at other, less reducing sites.

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Appendix A
Analysis of Long-term Performance of Zero-valent Iron Treatment at Nine Sites

Analysis of Long-Term Performance of Zero Valent Iron Treatment at Nine Sites

PREPARED FOR: Environmental Security Technology Certification Program

PREPARED BY: Laura Cook/CH2M HILL, Dean Williamson/CH2M HILL, Kyle Kirchner/NAVFAC EXWC

DATE: June 30, 2016

REVISION NO.: 1

This technical memorandum describes the results of a desk-top evaluation of nine sites at which in-situ groundwater remedies or treatments have been performed with zero valent iron (ZVI) to address chlorinated volatile organic compounds (VOCs). This work has been completed in support Environmental Security Technology Certification Program (ESTCP) Project #ER-201589-PR, Analysis of Long-Term Performance of Zero-valent Iron Applications. Specific objectives of the desktop evaluation are to:

- Evaluate trends in redox potential, dissolved oxygen (DO), and geochemical indicators of oxidation/reductive state from the baseline round of treatment to the most recent data available
- Evaluate changes in inorganic concentrations following treatment where data were available
- Evaluate contaminant concentration trends (parent chemical and daughter products) in consideration of geochemical and redox state to determine longevity of ZVI efficacy and to evaluate the degree to which contaminant degradation/destruction is occurring through reductive β-elimination or through sequential hydrogenolysis
- Compare designs and treatment outcomes of each implemented action and identify any best practices for future treatment
- Review groundwater flow data to determine the potential for preferential flow around treated areas due to reduced hydraulic conductivity and “plugging” from mineral precipitation in the pore spaces of the treatment zones
- Evaluate the presence or absence of a “clean front” on the downgradient side of Permeable Reactive Barrier (PRB) Sites
- Identify two sites (one PRB site and one injection site) to be carried forward into the field portion of the project

Sites included in this analysis are as follows:

- PRB Sites
  - Allegany Ballistics Laboratory (ABL) Site 5, Rocket Center, West Virginia
  - Boeing Michigan Aeronautical Research Center (BOMARC) OT-16, Joint Base McGuire-Dix-Lakehurst, New Hanover Township, New Jersey
- Injection Sites
  - St. Julien’s Creek Annex (SJCA) Site 21, Chesapeake, Virginia
  - Naval Surface Warfare Center (NSWC) White Oak Site 13, White Oak, Maryland

 - Savannah Air National Guard (SANG) Base, Site 8, Garden City, Georgia

- Soil Mixing Sites
  - Arnold Air Force Base (AFB), Solid Waste Management Unit (SWMU) 16, Manchester, Tennessee
  - United States Army Corps of Engineers (USACE) St. Louis Ordnance Plant Operable Unit I, St. Louis, Missouri
  - Marine Corps Base (MCB) Camp Lejeune Site 89, Jacksonville, North Carolina
  - Naval Support Facility (NSF) Indian Head Site 17, Indian Head, Maryland

Evaluation criteria for this analysis are included in **Table 1**. All data or parameters listed in **Table 1** were not collected at all sites. However, data available for review were evaluated in accordance with performance criteria identified in the table.

Table 1. Performance Objectives and Criteria.

Performance Objective	Data Requirements	Performance Criteria
Determine long-term effectiveness of ZVI treatment for achieving site specific remedial objectives	VOCs	Site-specific VOC data indicate the degree of contaminant destruction/degradation across the ZVI treatment areas. Trends in daughter products also allow for a determination of the degree to which parent compound concentration reduction is due to β-elimination vs. reductive dechlorination
Secondary indicators of ZVI performance.	pH	The production of the hydroxyl radical during the corrosion reaction between iron and water results in higher pH across the ZVI treatment area. Higher pH conditions can result in the precipitation of certain carbonate and other compounds within the iron system.
	Oxidation Reduction Potential (ORP) and dissolved oxygen (DO)	Addition of ZVI to an aquifer system results in rapid consumption of oxygen and a resultant decrease in ORP and DO, due to the following reaction: $2Fe^0 + O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4OH^-$ Therefore, decreasing ORP and DO are expected within and downgradient of iron treatment zones
Determine if ZVI application changed groundwater flow and/or permeability	Groundwater potentiometric data Hydraulic conductivity data	Available static water levels over time and comparison of groundwater potentiometric maps. Hydraulic conductivity data from aquifer tests can be used to evaluate changes in permeability due to mineralization within the ZVI treatment zones.

Table 1. Performance Objectives and Criteria.

Performance Objective	Data Requirements	Performance Criteria
Evaluate the extent of the biogeochemically altered zone and potential influence on VOC degradation	Total Organic Carbon (TOC)	Organic carbon compounds may have a wide range of effects on groundwater geochemistry, such as providing electron donors for biological reactions or may act as electron shuttles facilitating redox reactions. Higher TOC levels indicate greater potential for these effects to occur. Depending on PRB construction/ZVI injection methods, TOC concentrations may also provide an indicator of guar residuals used during PRB construction.
	Total and Dissolved Metals	Due to changes in pH, redox potential, iron corrosion, and resultant mineral precipitation, ZVI is a long-term sink for metals such as calcium, manganese, and magnesium. Increases in dissolved iron may be observed downgradient of iron treatment areas, as a result of release of iron from native soils due to decreased redox potential in the regions downgradient of the reactive media. Decreases in arsenic within a PRB can also occur because As(III) and As(V) that are adsorbed onto ZVI surfaces are occluded by layers of corrosion products. Subsequent increases in arsenic in native soils downgradient of the ZVI treatment are also possible due to decreasing ORP and mobilization of As from native soils. Decreases in other metals concentrations may also occur within a ZVI treatment area. These decreases may occur due to hydroxide precipitation (e.g., magnesium), reductive precipitation (e.g. copper, mercury, and silver), sorption processes (e.g. zinc, cadmium, and barium), or through a combination of these processes (e.g. nickel and lead).
	Ferrous iron	Ferrous iron may be an indicator of reduction of zero valent iron, enhanced dissimilatory iron reduction, and of the redox state of the aquifer within, upgradient, and downgradient of the ZVI treatment area.
	Sulfate, Sulfide	Sulfate and sulfide are indicators of sulfate reduction and precipitation of sulfide minerals. Reduction of sulfate to sulfide, and subsequent formation of metal sulfides occurs through the reaction sequence: $2CH_2O_{(s)} + SO_4^{2-} + 2H^+ \rightarrow H_2S_{(aq)} + 2CO_{2(aq)} + 2H_2O$ $Me^{2+} + H_2S_{(aq)} \rightarrow MeS_{(s)} + 2H^+$ where CH_2O represents organic carbon and Me^{2+} represents a divalent metal cation in solution.
	Nitrate, nitrite, and ammonia	Nitrate, nitrite, and ammonia are indicators of reduction of nitrate across the ZVI treatment zone. Reduction of NO_3 by Fe(0) results in production of NO_2 and subsequently ammonium through the following reaction: $4Fe(0) + NO^{3-} + 10H^+ \rightarrow 4Fe^{2+} + NH^{4+} + 3H_2O$

Table 1. Performance Objectives and Criteria.

Performance Objective	Data Requirements	Performance Criteria
	Chloride	May be used to evaluate mass balance during degradation in settings where initial chlorinated VOC concentrations were high.

1 ABL Site 5, Rocket Center, West Virginia Background

1.1 ABL Site 5 Site History

ABL is a government-owned (Navy), contractor-operated (ATK Tactical Systems Company LLC1 [ATK]), research, development, testing, and production facility for solid propellants and motors used for ammunition, rockets, and armaments. The facility is located in Mineral County, in the northeastern part of West Virginia, along the West Virginia and Maryland border (**Figure AB-1**). The facility lies between the North Branch Potomac River, to the north and west, and Knobly Mountain, to the south and east. The land surrounding the ABL facility is primarily rural agricultural and forest. ABL consists of about 1,634 acres of land with about 350 buildings. The facility is divided into two distinct operating plants, Plant 1 and Plant 2. Plant 1 is the government-owned, contractor-operated (GOCO) facility owned by the Navy and leased to ATK, by the Naval Sea Systems Command through a Facilities Use Contract. It occupies about 1,577 acres in area (including a large undeveloped area). Plant 2, owned and operated by ATK, occupies the remaining 57 acres.

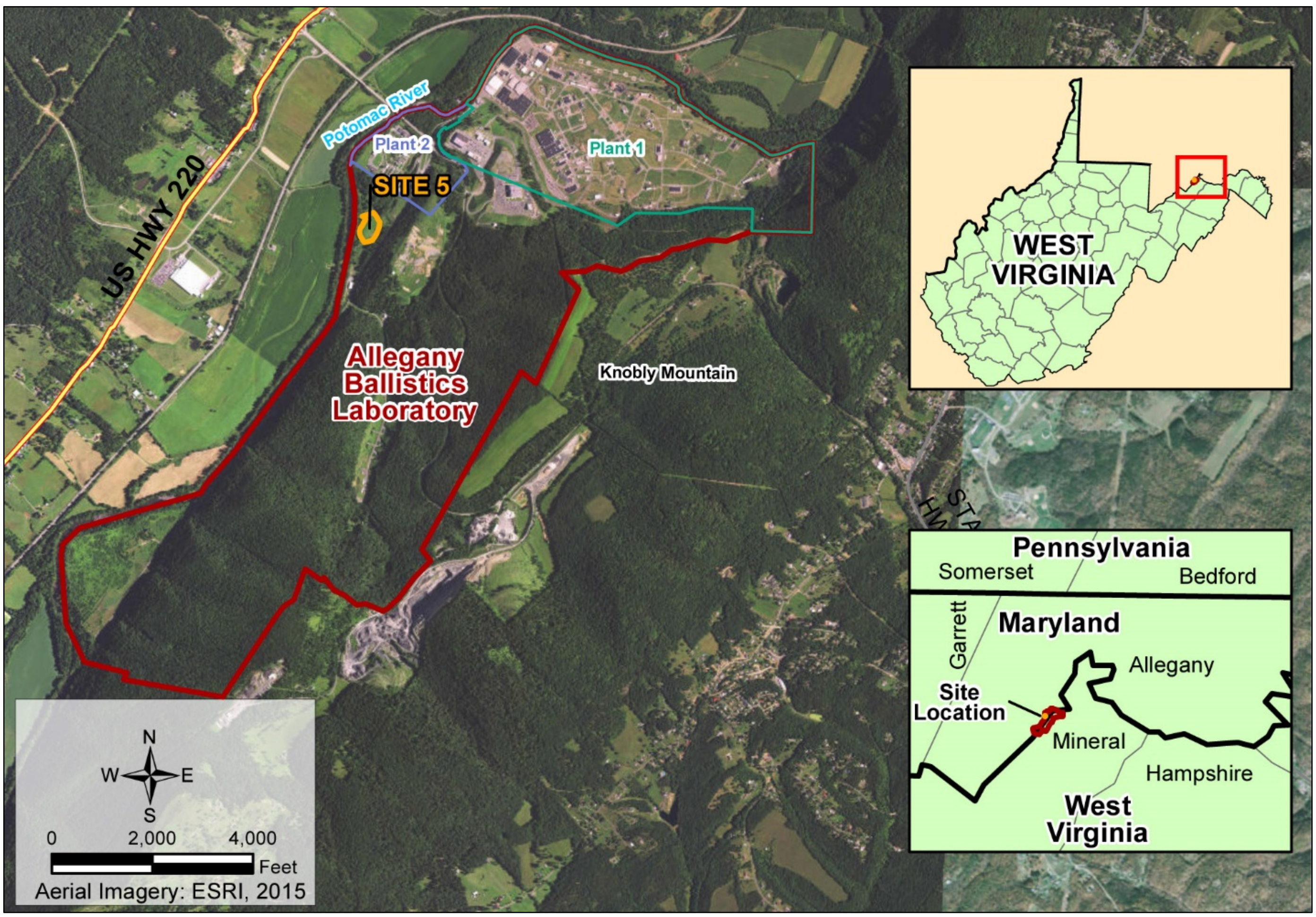


Figure AB-1. ABL Site 5 Location Map

Site 5 is a former landfill on the GOCO portion of the facility. The landfill operated from the early 1960s to 1985, accepting wastes generated by ABL that were deemed to be inert. Inert wastes were defined as wastes not contaminated with explosives nor generated at an area on the facility where explosives were managed. Wastes reported to have been disposed of at Site 5 include drums that previously contained tetrachloroethene (PCE), methylene chloride, and acetone; fluorescent tubes (potential mercury source); unknown laboratory and photographic chemicals; fiberglass and other resin-coated fibers; metal and plastic machining wastes; and construction and demolition debris (CH2M HILL, 2003). The landfill covers 1.3-acres and was capped in 1997.

1.2 ABL Site 5 Physical and Hydrogeologic Setting

Site 5 is located on a terrace above the North Branch Potomac River. The Site 5 topography gently slopes toward the North Branch Potomac River then becomes steeper immediately adjacent to the river. Site 5 is underlain by unconsolidated alluvial deposits of fill, silty clay, and clayey gravel (alluvium) and predominantly shale bedrock. The depth to bedrock at Site 5 is approximately 15 to 20 feet below ground surface (bgs). Cross sections and a conceptual site model are provided in **Appendix A**. Shallow (alluvial) groundwater flows northwestward, sub-parallel to the river, eventually discharging to the river at the northern end of Site 5 (**Figure AB-2**). Alluvial groundwater velocity downgradient of the landfill was estimated to be 0.81 feet per day, or 293 feet per year.

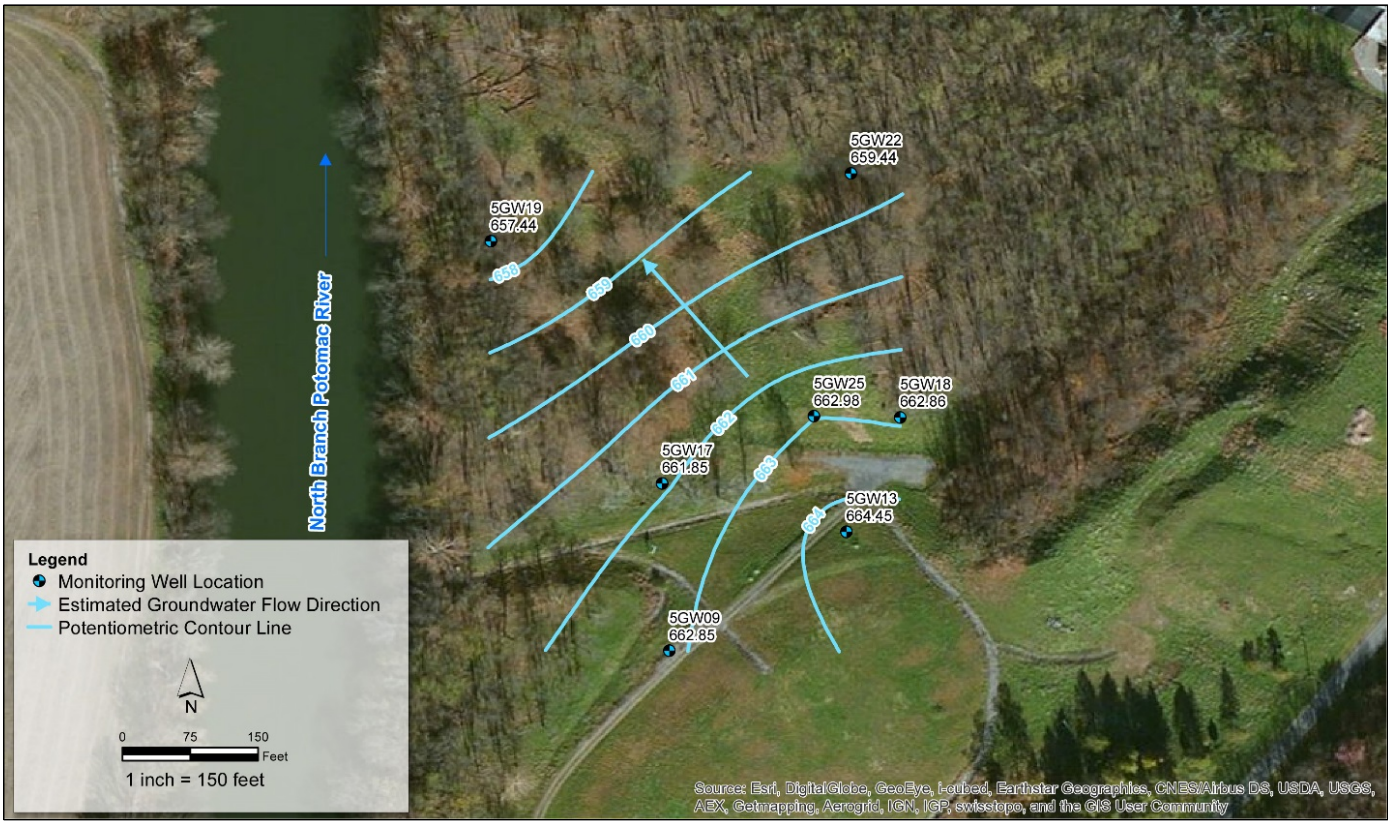


Figure AB-2. ABL Site 5 Groundwater Contour Map (2012)

1.3 ABL Site 5 Contaminant Distribution Prior to Treatment

The highest trichloroethene (TCE) concentrations at ABL Site 5 have been in the 100 to 150 micrograms per liter (µg/L) range, on the downgradient edge of the landfill boundary within the alluvium. The dissolved phase TCE plume in the alluvial aquifer originated within the landfill, and prior to the installation of the PRB, extended over 700 feet downgradient toward the North Branch of the Potomac River (**Figure AB-3**). While TCE has been detected in wells installed in the fractured shale bedrock, detections in these wells have been sporadic and have typically not exceeded the maximum contaminant level (MCL) of 5 µg/L. TCE daughter products (cis-1,2-dichloroethene [cis-1,2-DCE] and vinyl chloride [VC]) have also been detected in groundwater, but have not exceeded their respective MCLs of 70 and 2 µg/L (CH2M HILL, 2013a).

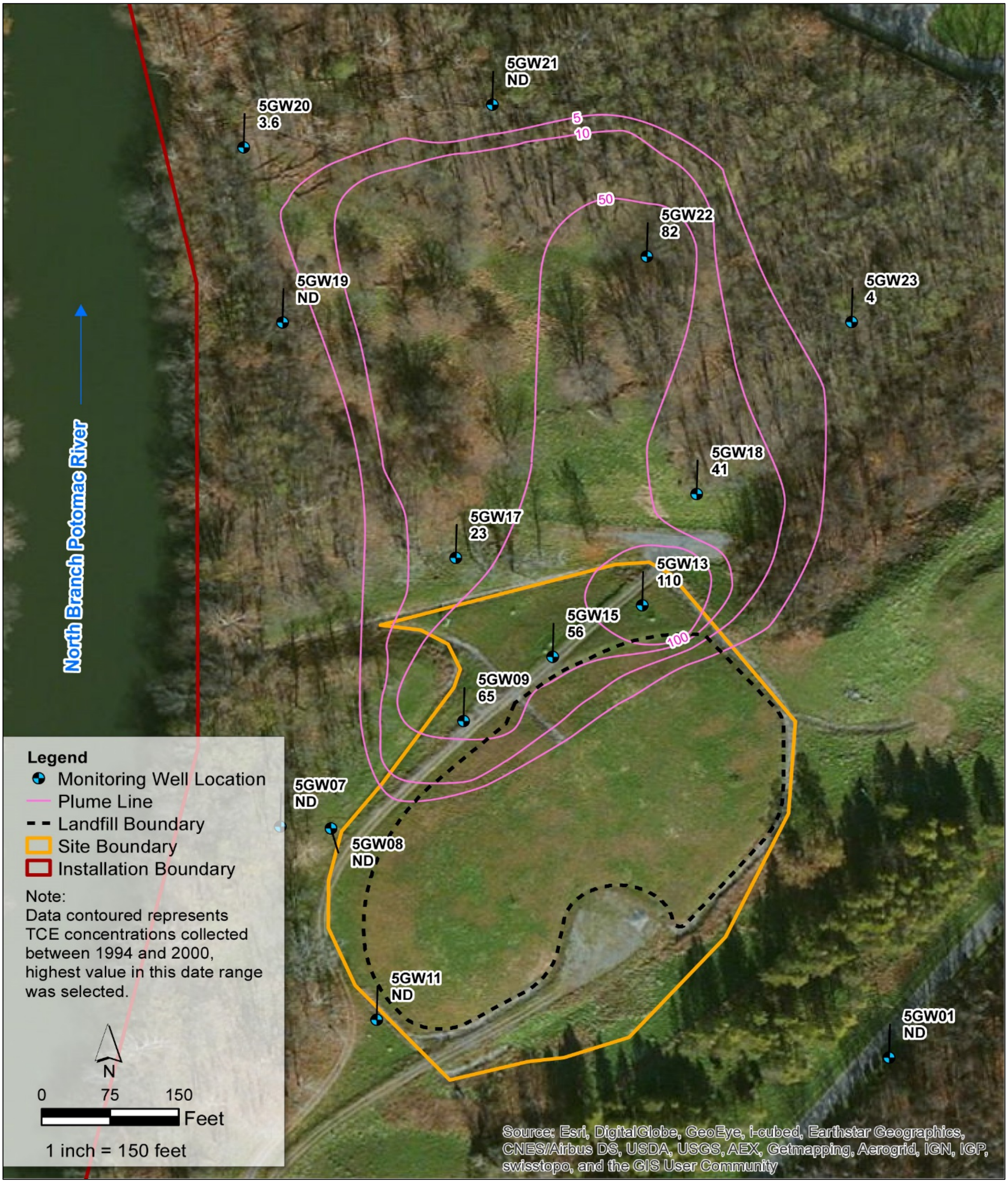


Figure AB-3. ABL Site 5 TCE Plume, Pre-Treatment

1.4 ABL Site 5 Treatment Area and Wells Included in Desktop Evaluation

In June 2006, in order to address the migration of TCE from the landfill towards the Potomac River, a 200-foot long, 2-foot wide, and 17 to 21.5-foot deep PRB was installed through the alluvial aquifer and keyed into the bedrock (**Figure AB-4**) at the downgradient edge of the landfill. A trench was excavated nominally 24 inches wide and up to 21.5 feet deep, depending on the elevation of the bedrock. As the trench was excavated, a biopolymer slurry was added to the trench for side wall support. A total of 357,000 pounds (lb) of ZVI [EnviroMetal Technologies Inc. CC-1004 (-8+50 mesh) manufactured by Connelly GPM, Inc.] were mixed with 536,000 lb of sand that was then added to the excavation for completion. The trench was then covered with a 6-ounce geotextile, and a 3-foot deep clay cap was placed over top of the barrier. While the required residence time for treatment of the ZVI only required a 7-inch thick PRB based on initial calculations (AGVIQ/CH2M HILL, 2006), the wall was constructed to be 2-feet thick due to limitation in trenching. The remedy for TCE in the portion of the plume already downgradient of the PRB at the time of installation was identified as monitored natural attenuation (CH2M HILL, 2013a).

For this study, pre- and post-treatment data from monitoring wells located upgradient, crossgradient, and downgradient of the PRB barrier were evaluated. Wells included in the review are shown on **Figure AB-4** and listed in **Table AB-1**.

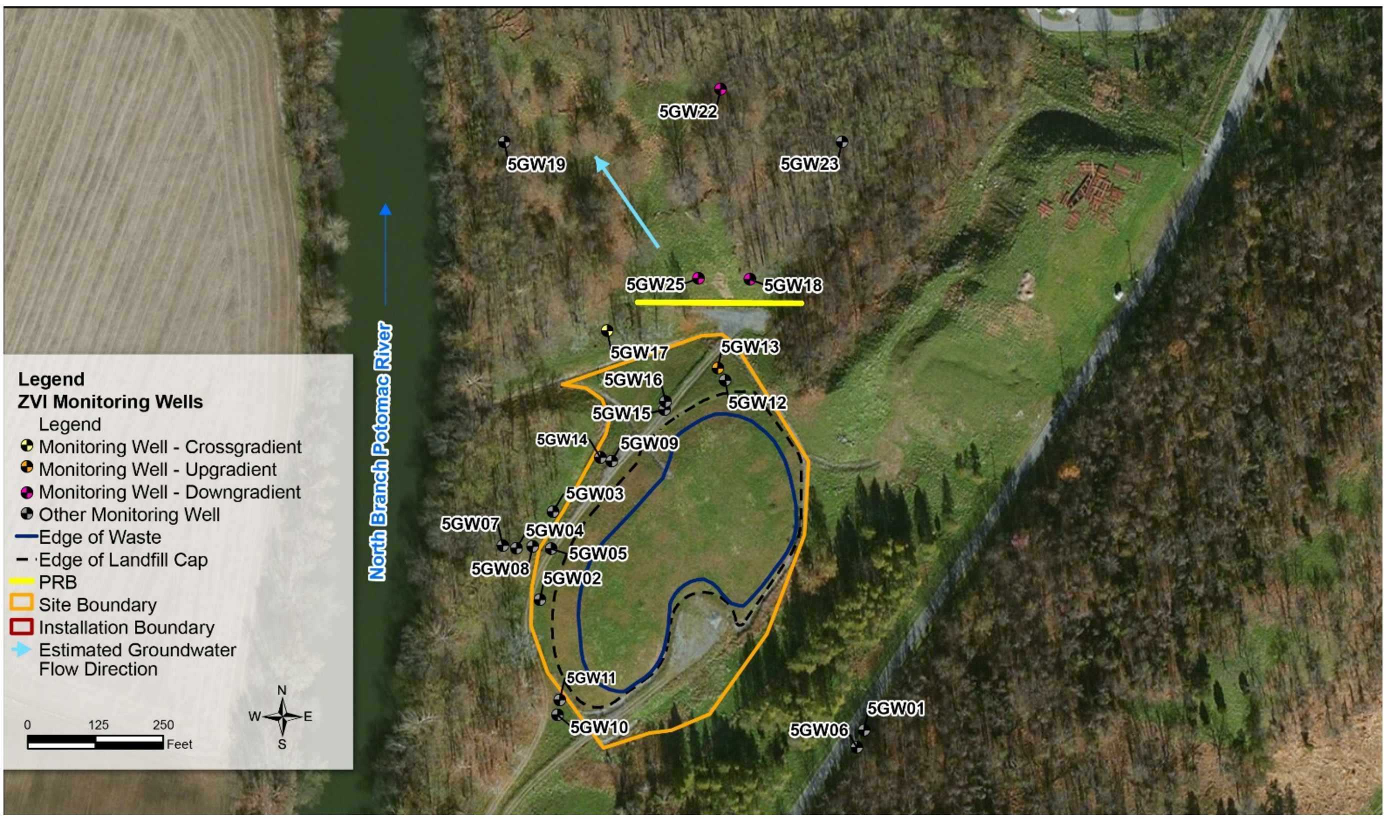


Figure AB-4. ABL Site 5 Treatment Area and Wells Included in Desktop Review

Table AB-1. ABL Site 5 Wells Included in Desktop Review.

Upgradient	5GW13
Crossgradient	5GW17
Downgradient	5GW18, 5GW25, and 5GW22

1.5 ABL Site 5 Desktop Evaluation Results

This section presents an evaluation of the results of ZVI injections with regard to treatment performance (reduction in VOC concentrations) and groundwater geochemistry changes.

1.5.1 ABL Site 5 Baseline Groundwater Conditions

Two wells immediately downgradient of the ABL PRB are currently monitored (5GW18 and 5GW25). However, baseline conditions are only available for one of these wells, as 5GW25 was installed at the time the PRB was installed. A baseline sample was collected from 5GW18 in October 2005.

The results of that sample (**Table AB-1**) indicate the following baseline groundwater geochemical conditions immediately downgradient of the PRB:

- DO was not detected; however, these results are considered inconclusive, as more than half of the results were reported as “0 milligrams per liter (mg/L)” for this monitoring round
- pH was 6.13
- ORP was 128 millivolts (mV)
- Methane was detected at a concentration of 38 J µg/L.
- Sulfate was detected at a concentration of 43 mg/L.
- TOC was not detected (less than the detection limit of 1.6 B mg/L)
- Alkalinity (as $CaCO_3$) was detected at a concentration of 180 mg/L
- Dissolved iron and manganese concentrations were 1,715 µg/L and 394 µg/L, respectively (these data are from 2001 because dissolved metals were not analyzed in 2005)
- Ammonia was not detected (0.1 U mg/L)
- Bicarbonate was detected at a concentration of 180 mg/L
- Chloride was detected at a concentration of 16 mg/L
- Nitrate was detected at a concentration of 0.28 mg/L
- Nitrite was not detected (0.02 U µg/L)
- TCE was detected at a concentration of 80 µg/L
- Cis-1,2-DCE was detected at a concentration of 12 J µg/L
- VC was not detected

Based on these values, baseline groundwater at the site appears oxic to slightly reducing, with some evidence of iron and manganese reduction occurring. Significant reductive dechlorination was not occurring as evidenced by the low concentrations of daughter projects. Strongly reducing conditions do not appear to have been present to a significant degree for baseline conditions in wells downgradient of the PRB location.

One well immediately upgradient of the PRB (5GW13) was sampled during the October 2005 baseline monitoring event. One crossgradient well near-by the PRB (5GW17) was also evaluated. Results of those samples indicate the following baseline conditions.

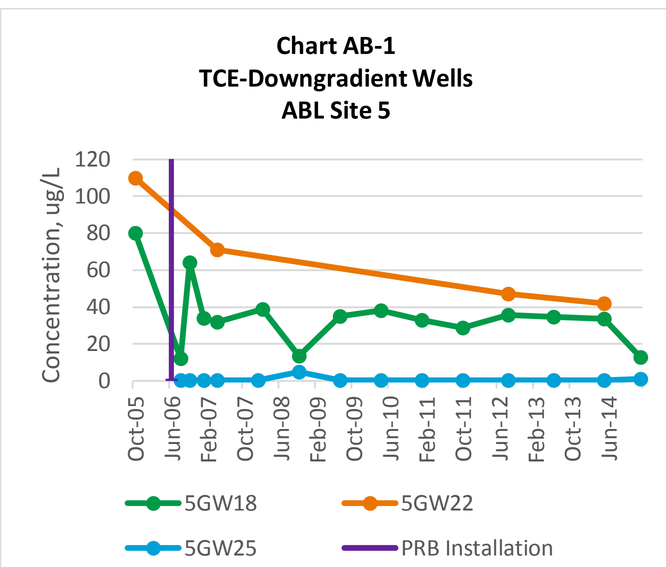
- Dissolved oxygen was not detected, however, these result appear suspect, as all results were the same for this monitoring round (0 mg/L)
- pH ranged from 5.69 to 6.08
- ORP ranged from -199.6 mV to -182.6 mV

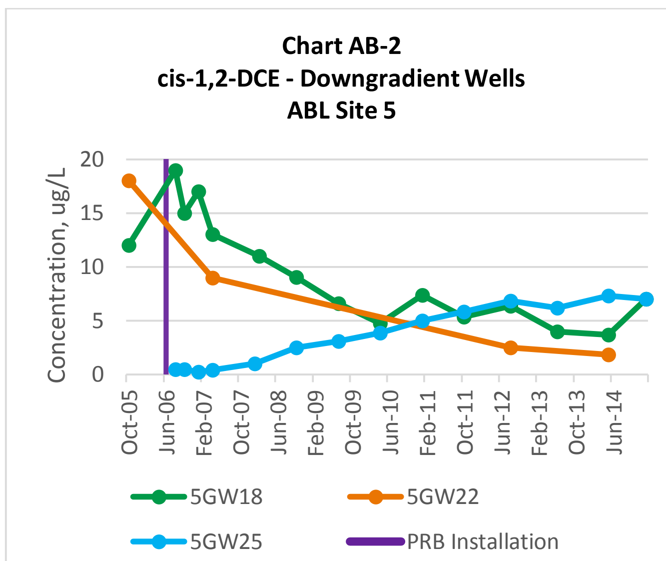
- Methane ranged from 34 mg/L to 180 J µg/L.
- Sulfate ranged from 200 mg/L to 280 mg/L.
- Total organic carbon ranged from not detected (1.4 B mg/L) to 2.1 mg/L
- Alkalinity (as $CaCO_3$) ranged from 71 mg/L to 77 mg/L
- Ranges of dissolved iron and manganese were 46.2 J-1,130 µg/L and 502-8,030 µg/L, respectively
- Ammonia ranged from not detected (0.1 U mg/L) to 0.24 mg/L
- Bicarbonate ranged from 71 mg/L to 77 mg/L
- Chloride ranged from 20 to 30 mg/L
- Nitrate and nitrite were not detected
- While TCE concentrations were as high as 110 µg/L in 5GW17 in 1994, maximum 2005 concentrations of TCE and cis-1,2-DCE in 5GW13 and 5GW17 were 15 µg/L and 6.4 µg/L, respectively
- VC was not detected

Based on these indicators, upgradient and crossgradient conditions are slightly anaerobic, with some degree of iron and manganese reduction likely occurring. Strongly reducing conditions do not appear to have been present to a significant degree in upgradient/crossgradient wells for baseline conditions.

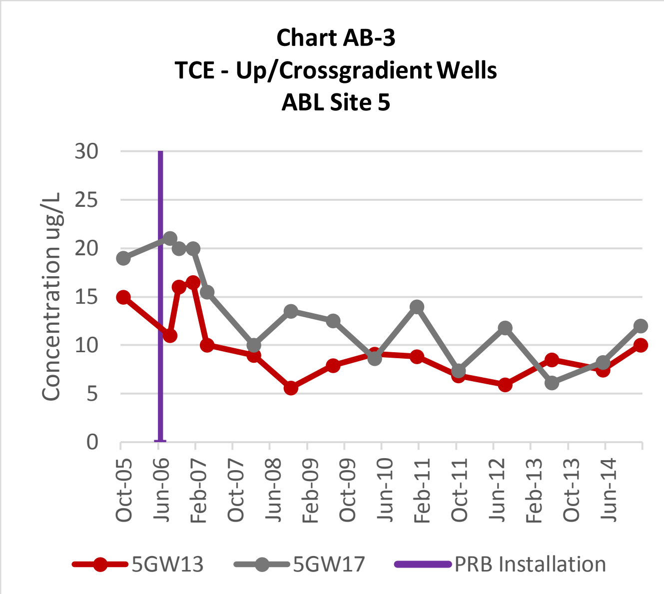
1.5.2 ABL Site 5 Evaluation of Effectiveness of PRB

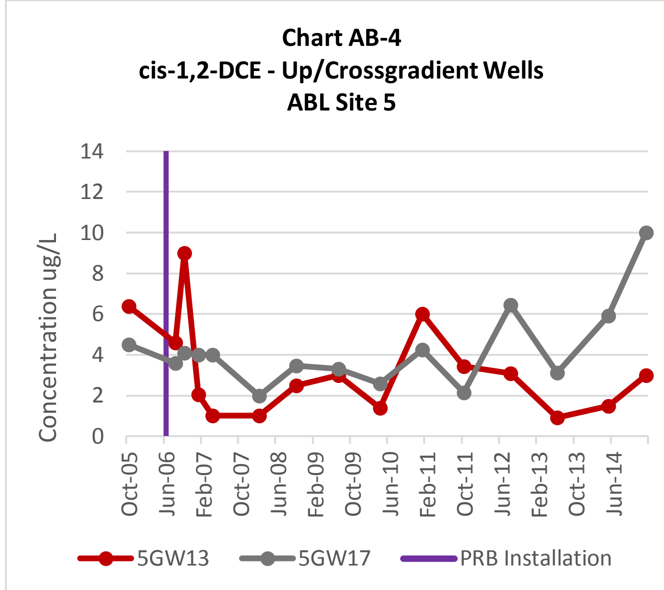
With low concentrations upgradient of the PRB at installation, evaluating performance of the PRB is challenging. However, decreasing trends for TCE downgradient of the PRB have been observed at Site 5 (**Chart AB-1**). An increase in cis-1,2-DCE was also observed in well 5GW25 (**Chart AB-2**) , most likely due to contaminant migration, since TCE concentrations have typically been less than reporting limits in this well. Daughter products, such as cis-1,2-DCE and VC were not detected in other wells. Data from wells downgradient of 5GW22 (5GW20 and 5GW21) were also reviewed and concentrations in these wells remained less than the MCL during through 2012, at which time they were removed from the long-term monitoring (LTM) network. VC concentrations were not graphed because concentrations were at or near the detection level.





Decreases in TCE concentrations were also observed in the upgradient and crossgradient wells, adding uncertainty to the mechanism of the decreases in contaminant trends downgradient of the PRB. Cis-1,2-DCE concentrations in upgradient and crossgradient wells have remaining stable or increased slightly. **Charts AB-3** and **AB-4** show upgradient/crossgradient TCE and cis-1,2-DCE trends.

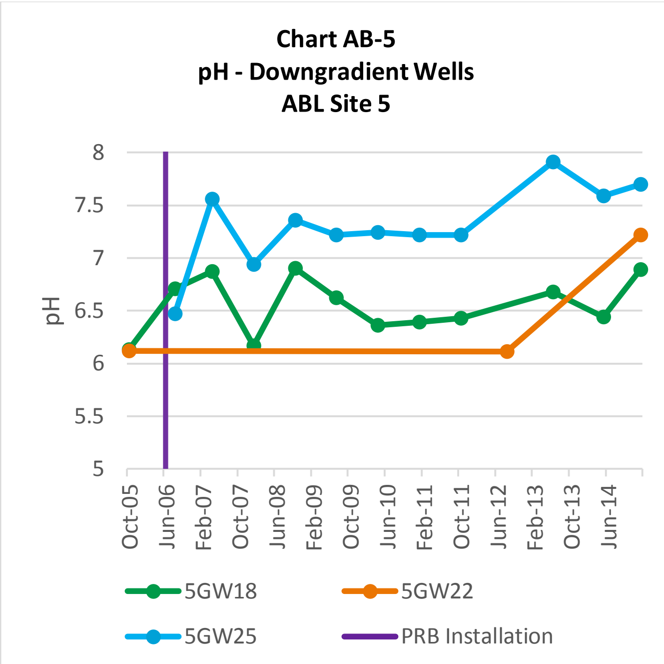


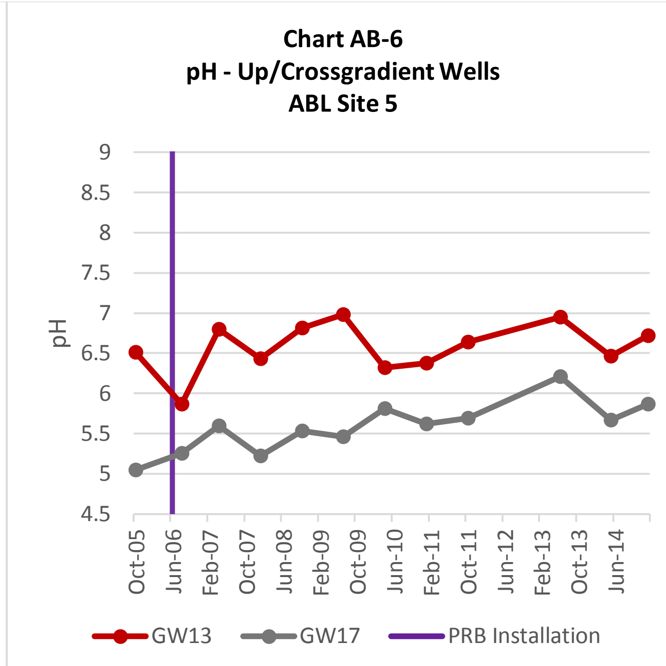


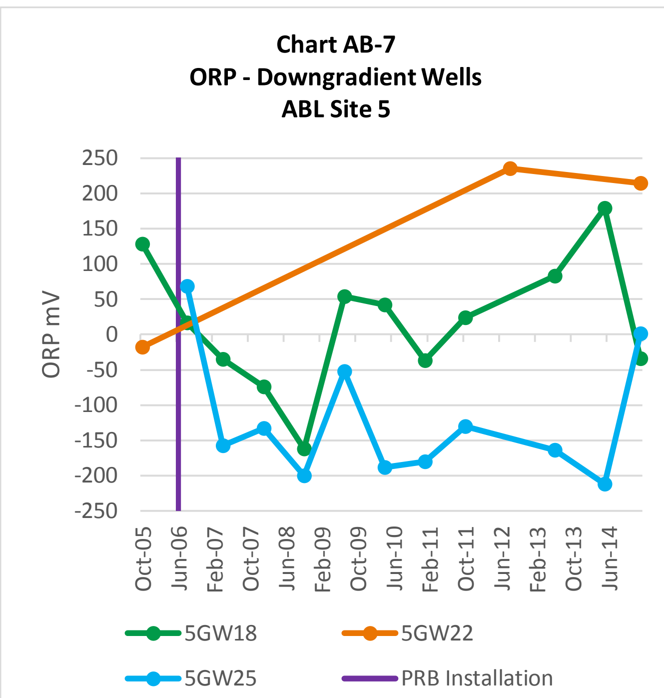
Limited geochemistry data were collected at ABL Site 5 post-installation of the PRB. Field parameters (ORP, DO, pH) and total and dissolved iron and manganese were collected during most rounds. One post-treatment round of monitoring (2014) included methane, sulfate, and alkalinity. While nitrate/nitrite data were also collected in 2014, concentrations of nitrate/nitrite were mostly non-detect, both before and after treatment. Sulfide data was also collected during the 2014 post-treatment round and results were mostly not detected. Additionally baseline sulfide data were not collected. Due to the limited usefulness of the data, further evaluation of nitrate/nitrite, and sulfide was not completed. Time series plots for downgradient and upgradient/crossgradient wells for pH, ORP, dissolved iron, dissolved manganese, alkalinity, methane, and sulfate are shown in **Charts AB-5** through **AB-16**, respectively. DO charts are not included because most values were either 0 or were high (>3 mg/L), creating uncertainty regarding the data. The following conclusions are noted from the field and geochemical data results:

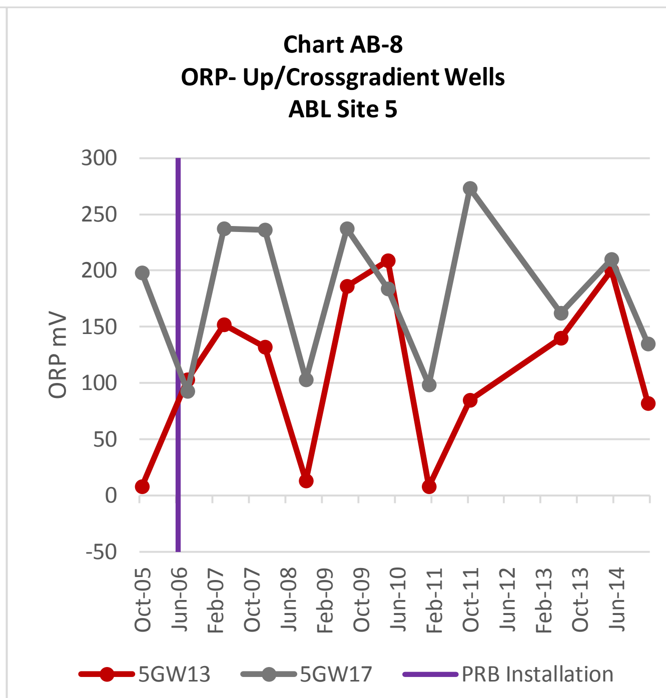
- pH generally increased in downgradient wells, as expected, based on generation of the hydroxyl radical during iron corrosion. Slight increases were also observed in upgradient/crossgradient wells.
- In wells most closely downgradient of the PRB (5GW18 and 5GW25), ORP decreased significantly in the three years immediately following PRB installation, but then returned towards baseline levels. A similar trend was not observed in upgradient/crossgradient wells.
- The dissolved iron concentration increased considerably in 5GW18 in the round immediately following PRB installation, but then subsequently decreased. No other notable trends in iron concentrations were observed.
- Dissolved manganese concentrations have decreased considerably in some of the wells both up- and downgradient of the PRB following installation.
- Alkalinity as $CaCO_3$ increased from baseline in the wells immediately downgradient of the PRB, consistent with generation of OH^- during iron corrosion.
- No meaningful trends in sulfate concentrations were observed.

- Methane concentrations have decreased in upgradient, crossgradient, and downgradient wells since installation of the PRB. However, concentrations were quite variable for this parameter during monitoring completed prior to installation, and it is likely that the shift was not related to the ZVI.









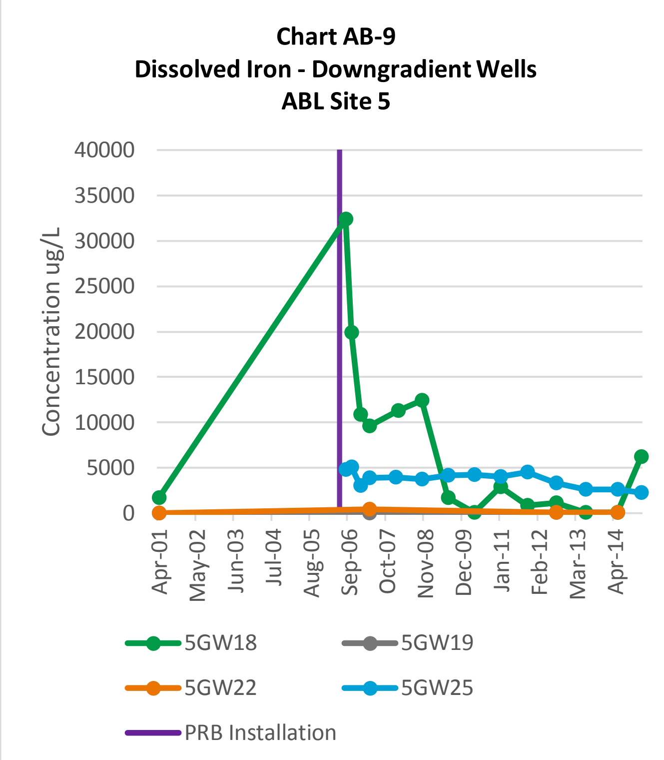


Chart AB-9
Dissolved Iron - Downgradient Wells
ABL Site 5
Concentration ug/L
40000
35000
30000
25000
20000
15000
10000
5000
0
Apr-01
May-02
Jun-03
Jul-04
Aug-05
Sep-06
Oct-07
Nov-08
Dec-09
Jan-11
Feb-12
Mar-13
Apr-14
5GW18
5GW19
5GW22
5GW25
PRB Installation

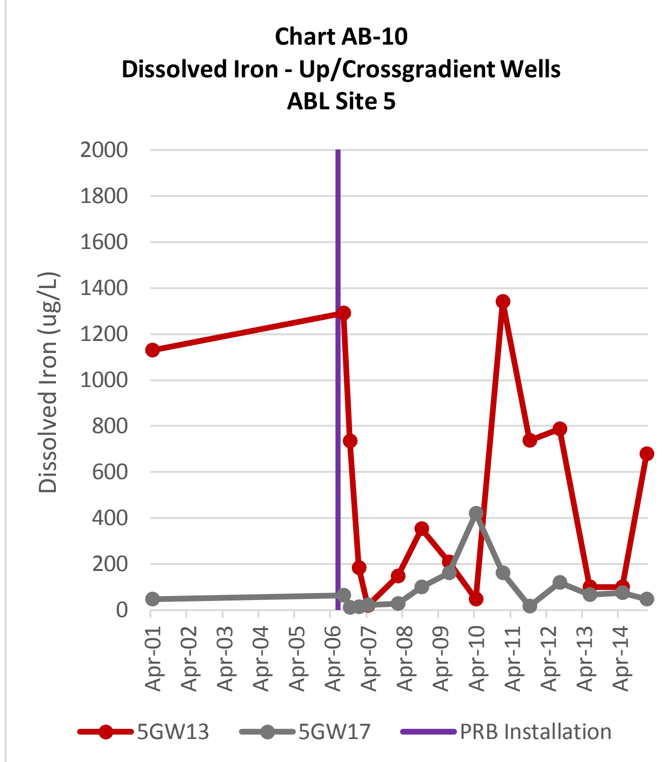


Chart AB-10
Dissolved Iron - Up/Crossgradient Wells
ABL Site 5
Dissolved Iron (ug/L)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Apr-01
Apr-02
Apr-03
Apr-04
Apr-05
Apr-06
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
5GW13
5GW17
PRB Installation

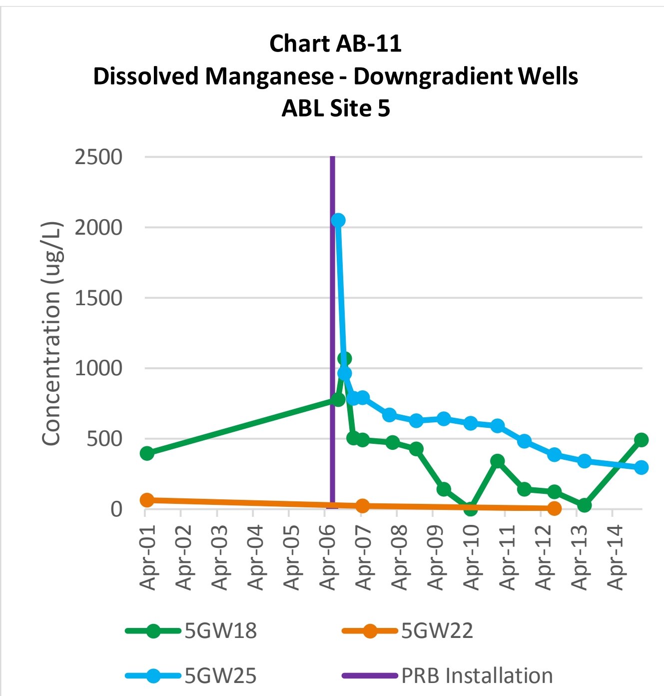


Chart AB-11
Dissolved Manganese - Downgradient Wells
ABL Site 5
Concentration (ug/L)
2500
2000
1500
1000
500
0
Apr-01
Apr-02
Apr-03
Apr-04
Apr-05
Apr-06
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
5GW18
5GW22
5GW25
PRB Installation

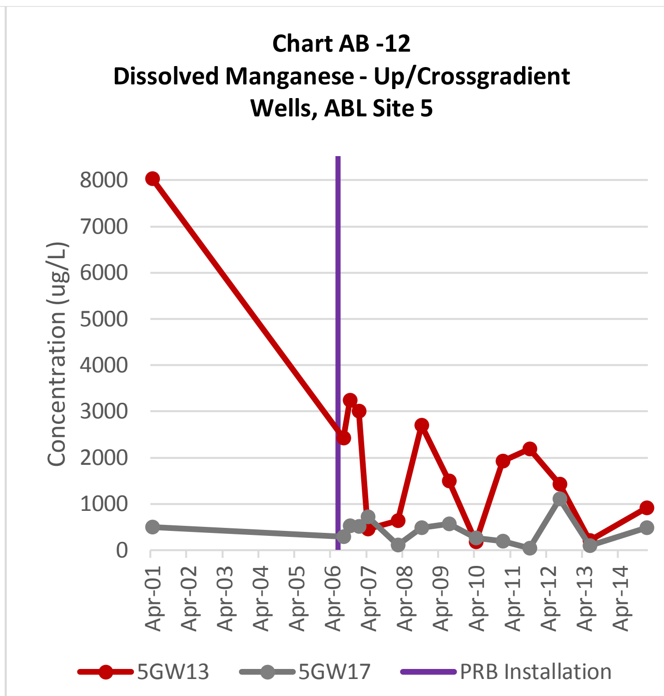


Chart AB -12
Dissolved Manganese - Up/Crossgradient
Wells, ABL Site 5
Concentration (ug/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
Apr-01
Apr-02
Apr-03
Apr-04
Apr-05
Apr-06
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
Apr-12
Apr-13
Apr-14
5GW13
5GW17
PRB Installation

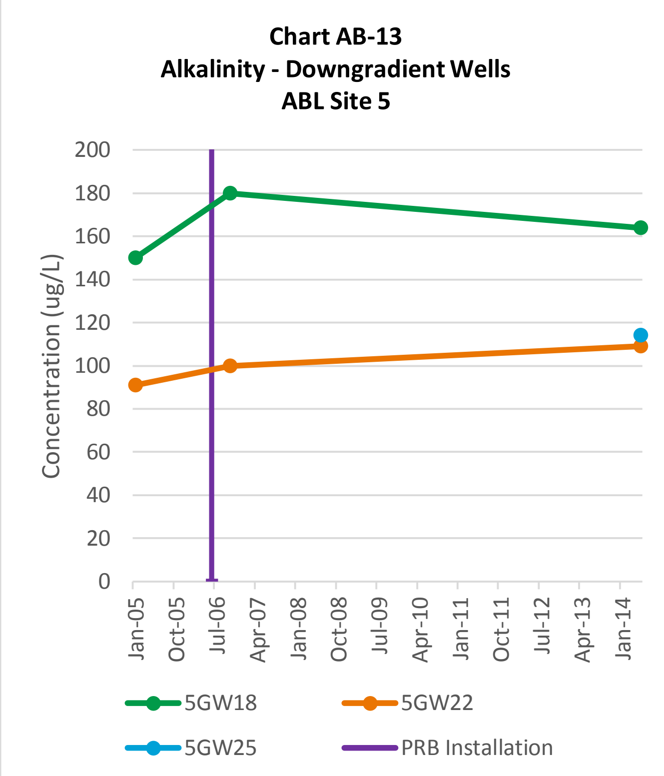


Chart AB-13
Alkalinity - Downgradient Wells
ABL Site 5
Concentration (ug/L)
200
180
160
140
120
100
80
60
40
20
0
Jan-05
Oct-05
Jul-06
Apr-07
Jan-08
Oct-08
Jul-09
Apr-10
Jan-11
Oct-11
Jul-12
Apr-13
Jan-14
5GW18
5GW22
5GW25
PRB Installation

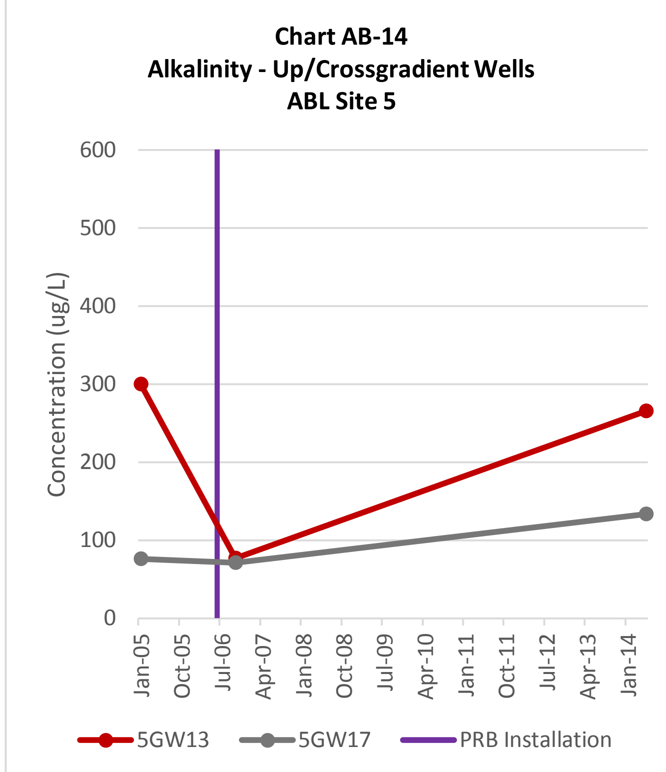


Chart AB-14
Alkalinity - Up/Crossgradient Wells
ABL Site 5
Concentration (ug/L)
600
500
400
300
200
100
0
Jan-05
Oct-05
Jul-06
Apr-07
Jan-08
Oct-08
Jul-09
Apr-10
Jan-11
Oct-11
Jul-12
Apr-13
Jan-14
5GW13
5GW17
PRB Installation

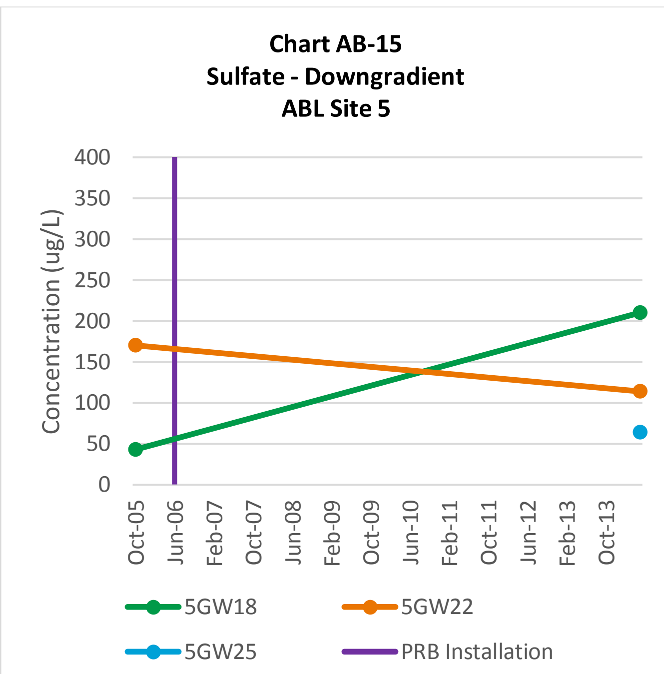


Chart AB-15
Sulfate - Downgradient
ABL Site 5
Concentration (ug/L)
400
350
300
250
200
150
100
50
0
Oct-05
Jun-06
Feb-07
Oct-07
Jun-08
Feb-09
Oct-09
Jun-10
Feb-11
Oct-11
Jun-12
Feb-13
Oct-13
5GW18
5GW22
5GW25
PRB Installation

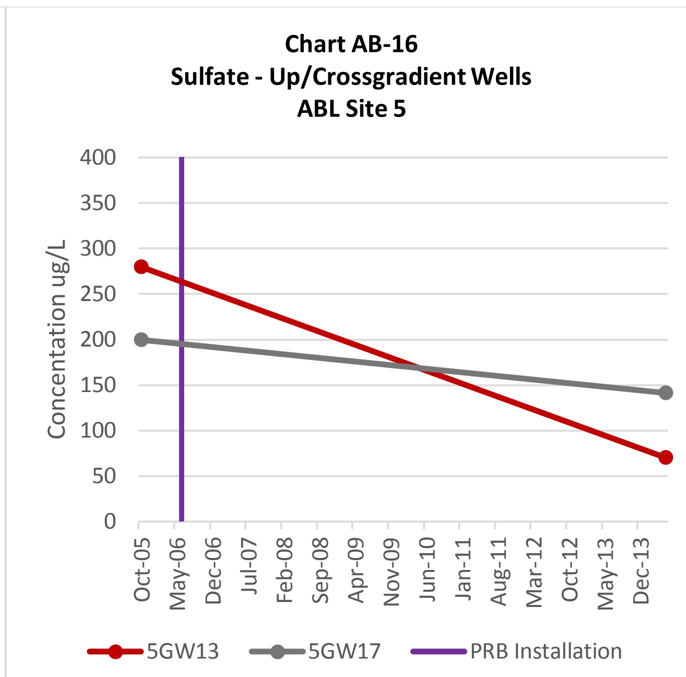
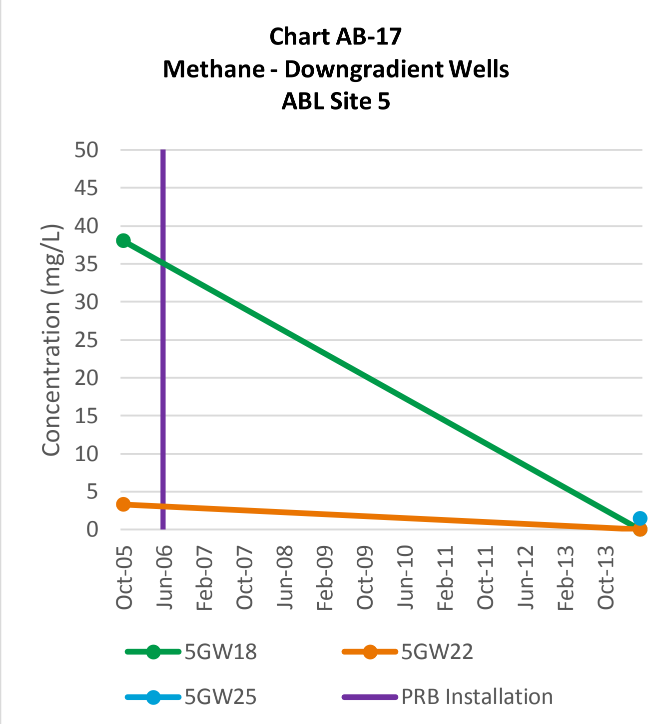
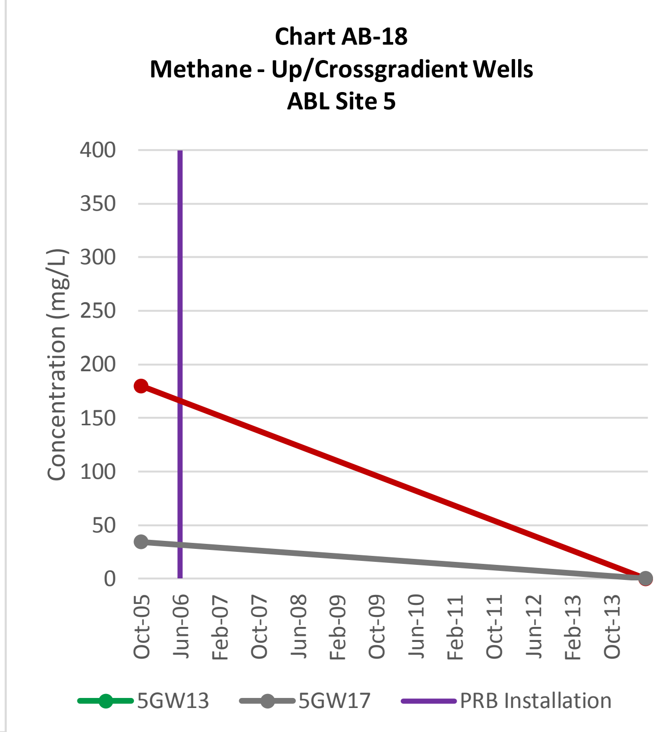


Chart AB-16
Sulfate - Up/Crossgradient Wells
ABL Site 5
Concentation ug/L
400
350
300
250
200
150
100
50
0
Oct-05
May-06
Dec-06
Jul-07
Feb-08
Sep-08
Apr-09
Nov-09
Jun-10
Jan-11
Aug-11
Mar-12
Oct-12
May-13
Dec-13
5GW13
5GW17
PRB Installation





1.6 ABL Site 5 Changes in Groundwater Flow

Groundwater flow maps from June 2006 (just after PRB installation) and August 2012 are included in **Appendix B**. Based on these maps, no notable change in groundwater flow is noted due to installation of the PRB. However, because the well network is very limited, confidence in this conclusion is limited. Additionally, both sets of maps show the flow as not perpendicular to the PRB, which may impact effectiveness.

2 BOMARC OT-16 Joint Base McGuire-Dix-Lakehurst, New Hanover Township, New Jersey Background

2.1 BOMARC OT-16 Site History

BOMARC OT-16 TCE Groundwater Plume (referred to as OT-16) is located in South-Central New Jersey on 218 acres of rural land. The site is located in the Pinelands National Reserve, approximately 11 miles east of the McGuire portion of Joint Base McGuire-Dix-Lakehurst in Plumstead Township, Ocean County (**Figure OT-1**). The BOMARC missile facility was established in 1958 and housed 84 surface-to-air missiles (56 liquid-fueled and 28 solid-fueled), each equipped with a nuclear warhead. The facility was closed in 1972. During investigation of contamination associated with a fire at the site, TCE was identified in groundwater. There is no known documentation of either the usage nor the disposal of TCE at the BOMARC facility. However, TCE was widely used as a degreasing agent during the period of facility operation (USAF, 2012).

2.2 BOMARC OT-16 Physical and Hydrogeologic Setting

The BOMARC facility is located within the Pine Barrens of New Jersey. The topography at the site is approximately 170 feet above mean sea level (amsl) within the fence line and slopes downward to a relatively flat area to approximately 125 feet amsl within the Colliers Mills Wildlife Management Area. Success Branch, an annual stream, originates approximately 2,400 feet east of the BOMARC facility and generally parallels the eastern boundary of the facility, flowing north (**Figure OT-2**). The Elisha Branch and an unnamed tributary of Success Branch originate near the southeast and northeast corners of the BOMARC facility, respectively, and flow east, ultimately discharging into Success Branch; these streams are intermittent. Wetlands surround the streams (Shaw, 2013).

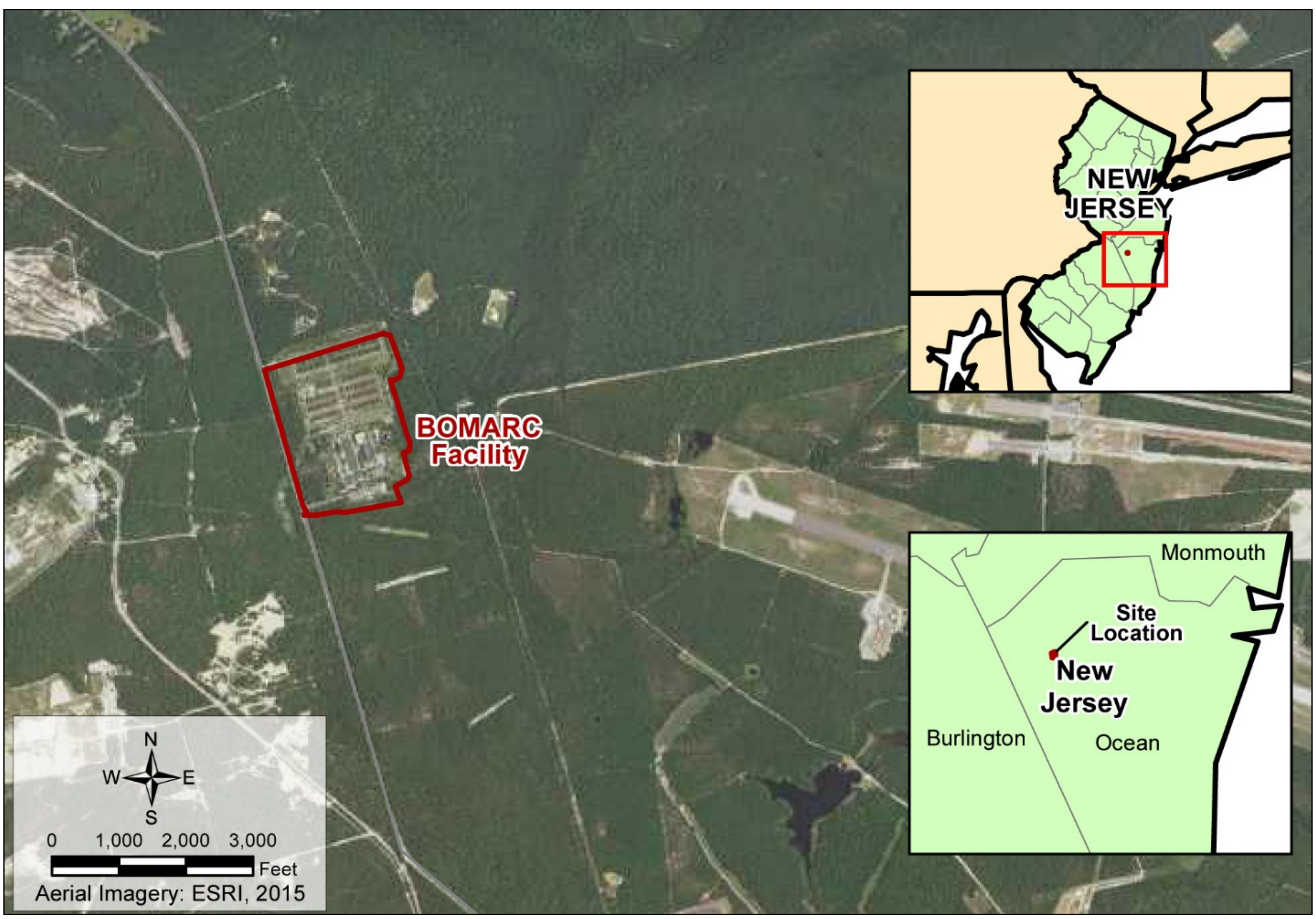


Figure OT-1. McGuire OT-16 Location Map

The surficial geology of the BOMARC facility is comprised of fine to coarse sands, referred to as the Cohansey Sand formation. The thickness of the Cohansey Sand at the site ranges from approximately 90 feet near the fence line to 60 feet near Success Branch (**Appendix A**). Discontinuous peat layers with thicknesses ranging from 2 feet to 4 feet have been identified in borings at the BOMARC site within the Cohansey Sand. The Cohansey Sand is underlain by the Kirkwood formation. Hydraulically, the Cohansey and Kirkwood formations are interconnected and form the Kirkwood-Cohansey aquifer (USGS, 1996). Cohansey-Kirkwood groundwater flows to the northeast and discharges to the wetlands and surface water of Success Branch and its tributaries (**Figure OT-2**). Aquifer tests conducted by the USGS indicate an average hydraulic conductivity of 75 feet per day for the Cohansey Formation at the site (USGS and AFRL, 2003). Groundwater elevation contour maps indicate a hydraulic gradient of 0.002 feet per foot (URS, 2003). On the basis of the gradient and hydraulic conductivity, groundwater velocity at the site is estimated to be 376 feet per year or about one foot per day (USGS, 2003).

Figure OT-2. McGuire OT-16 Groundwater Contour Map

2.3 BOMARC OT-16 Contaminant Distribution Prior to Treatment

The BOMARC TCE plume originates near a storm drain by the eastern fence line of the BOMARC facility (**Figure OT-3**). While the storm drain is thought to be the original source of the contamination (USAF, 2012), migration of TCE into the organic peat downgradient of the storm drain has resulted in numerous secondary sources of TCE due to back-diffusion from the peat material. TCE concentrations as high as 3.5 milligrams per kilogram (mg/kg) have been detected in the peat layers. Additionally, a plume originating near two other BOMARC sites (Site WP-05 and Site ST-15) merge with the OT-16 plume. The width of the TCE plume ranges from approximately 1,000 feet to 1,250 feet with a saturated thickness of approximately 45 feet (USAF, 2012). Approximately one-third of the plume is within the wetland area adjacent to Success Branch. TCE was shown in previous investigations to discharge to an approximately 375-foot stretch of Success Branch (USAF, 2012). Groundwater concentrations of TCE in the storm drain source area as well as the source area near site WP-03 have historically exceeded 1,000 µg/L. The groundwater TCE plume prior to implementation of the Remedial Action (RA) is shown on **Figure OT-3**. Concentrations of TCE discharging to surface water (CM-13) were greater than 1 µg/L, the New Jersey Department of Environmental Protection Surface Water Quality Standard (N.J.A.C. 7:9B; 2011a), which is the rationale for the RA at the site.

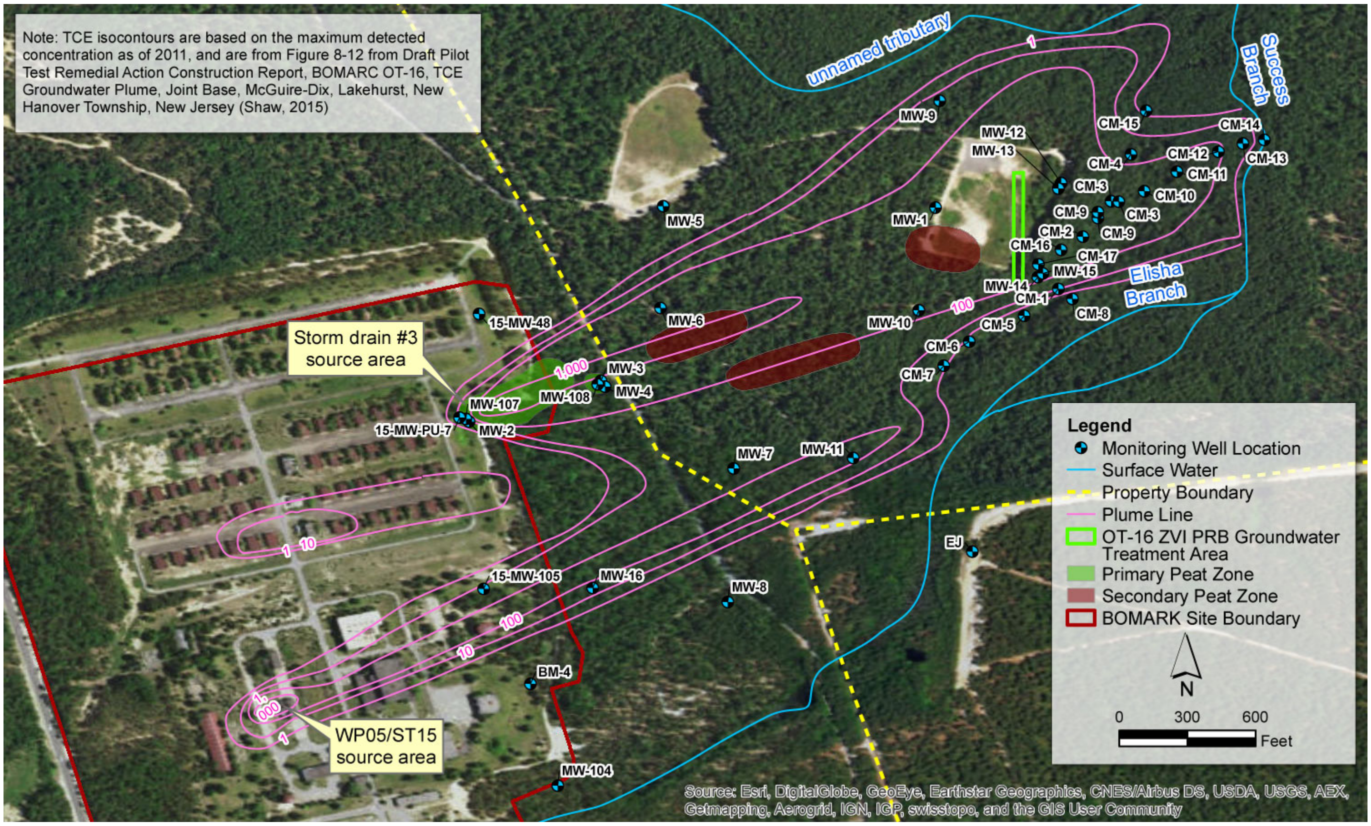


Figure OT-3. McGuire OT-16 TCE Plume

2.4 BOMARC OT-16 Treatment Area and Wells Included in Desktop Evaluation

In order to address the discharge of contamination to the wetland area, a 500-foot long, 35-foot wide PRB was installed, oriented north-south, with a minimum vertical thickness of 40 feet and a maximum thickness of 55 feet. The PRB was installed using high-pressure injection of micro-scale ZVI through 101 direct-push technology (DPT) injection points in April through October 2013. The DPT injection points had a designed radius of influence of 7.5 feet. Based on a ZVI dosage of 0.5 percent (lbs of ZVI per lb of soil), 409,209 lb of ZVI were injected into the subsurface. Injections were completed top down in 3-foot injection intervals with 264 lbs injected in each 3-ft interval. Injection pressures were continually observed throughout injections. If the injection pressure was less than 200 pounds per square inch (psi), the Ferox process involving the addition of nitrogen gas into the slurry at the injection point to atomize the slurry was utilized. Not all intervals were able to be atomized. If pressures exceeded 300 psi, adding more pressure to the formation could cause fracturing of the formation or damage to the tooling. For the shallow intervals typically less than 20 feet bgs, atomization was not used because of the close proximity to ground surface. In total, 1,112 of 1,581 intervals, or approximately 70%, were atomized. The completed PRB occupies 802,800 cubic feet (CB&I, 2015). The wall location is shown on **Figure OT-4**.

Data from 11 well couples and one deep well were evaluated in the desktop review (**Figure OT-4. Table OT-1**). Each of the well couples consists of a shallow and intermediate well (**Appendix C**). Well couples were installed upgradient of the PRB, within the PRB, downgradient of the PRB, and north and south of the PRB.

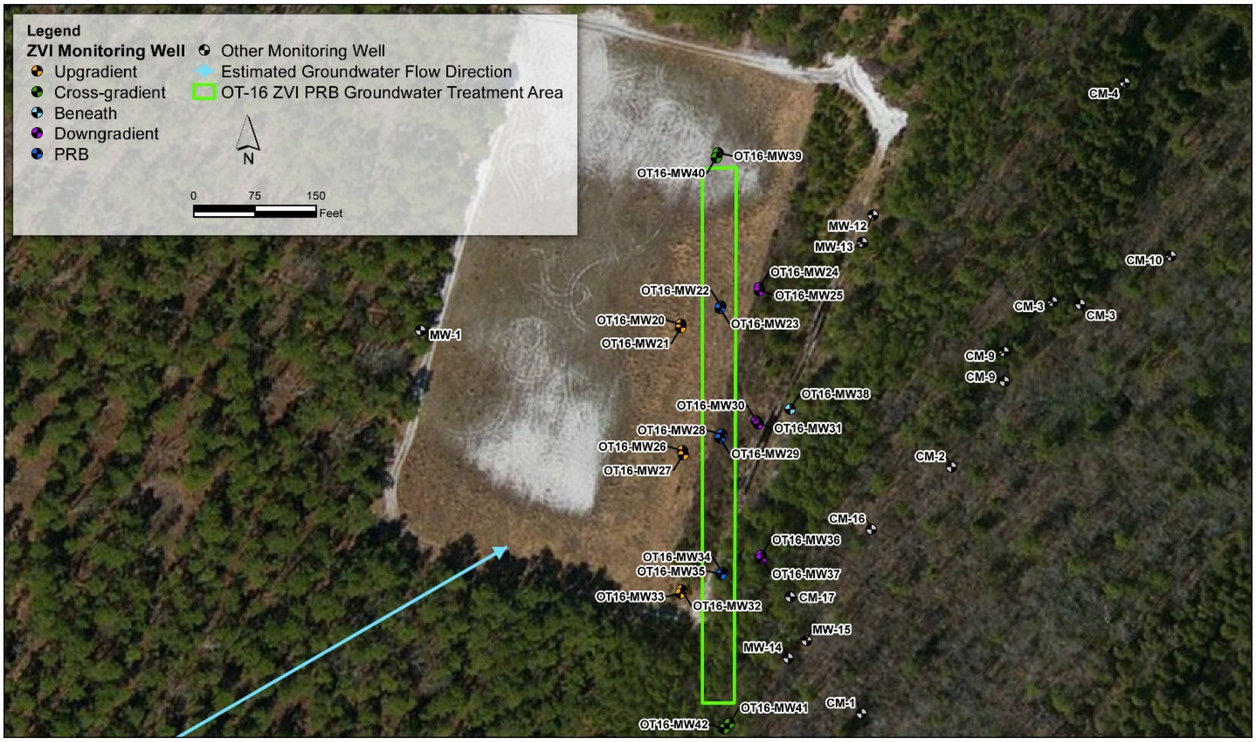


Figure OT-4. McGuire OT-16 Treatment Area and Wells to be Included in Evaluation

Table OT-1. BOMARC OT-16 Wells Included in Desktop Review

Upgradient	MW20, MW21, MW26, MW27, MW32, and MW33
PRB	MW22, MW23, MW28, MW29, MW34, and MW35
Downgradient	MW24, MW25, MW30, MW31, MW36, and MW37
Cross-gradient	MW39 and MW40 (north of PRB) and MW41, and MW42 (south of PRB)
Beneath	MW38

2.5 BOMARC OT-16 Desktop Evaluation Results

This section presents an evaluation of the performance of the ZVI PRB with regard to treatment performance (reduction in VOC concentrations) and groundwater geochemistry changes.

2.5.1 BOMARC OT-16 Baseline Groundwater Conditions

Pre-injection groundwater geochemistry data were collected in March and April 2012. An additional round of monitoring referred to as "baseline" in in *Final Pilot Test Remedial Action Construction Report, BOMARC OT-16, Trichloroethene Groundwater Plume, Joint Base McGuire For-Dix, Lakehurst, New Hanover Township, New Jersey* (CB&I, 2015) was completed in December 2013 just after completion of the PRB in October 2013. Periodic monitoring continued through February 2015. While data for a number of geochemical parameters and anions were collected after PRB installation, no data are available for these parameters before PRB installation began for wells in the vicinity of the PRB. Additionally, the baseline data for most wells was limited to field parameters. As such, this discussion focuses on available chlorinated VOC data as well as DO, pH, and ORP, which were collected during the April 2012 round of monitoring and some of the data collected during or immediately following installation of the PRB (December 2013). A summary of key field and laboratory analytical parameters is presented in **Table OT-2**.

The results indicate the following pre-treatment groundwater conditions [or conditions referred to as "pre-baseline in *Final Pilot Test Remedial Action Construction Report, BOMARC OT-16, Trichloroethene Groundwater Plume, Joint Base McGuire For-Dix, Lakehurst, New Hanover Township, New Jersey* (CB&I, 2015)]:

- Average DO concentration in the area of the PRB was 4.64 mg/L.
- Average pH within the PRB was 5.31.
- Average ORP within the PRB was 19.92 mV.

Based on these results, pre-treatment geochemical conditions in the ZVI treatment area appear to be oxic. Baseline pH at the site was acidic.

Concentrations of TCE prior to installation of the PRB ranged from 1.6 µg/L in the deep well intended to monitor potential migration under the PRB (OT16-MW38) to 120 µg/L in the well just downgradient of the PRB (OT16-MW30). However, in the May 2013 event, which occurred after the PRB installation was initiated, the highest concentration of TCE was 190 µg/L in a well crossgradient and to the south of the PRB (OT16-MW41). Just after completing installation of the PRB, the highest concentration was 400 µg/L, in OT16-MW36, which is located downgradient of the PRB. OT16-MW36 and OT16-MW41 were not sampled prior to installation of the PRB. Concentrations of cis-1,2-DCE in April 2012 ranged from not detected to 5.9 µg/L (OT16-MW30, downgradient of the planned PRB location). The highest concentration of cis-1,2-DCE in December 2013, just after the PRB was installed was 7.8 µg/L in the sample from OT16-MW34, which is located within the PRB. VC was not detected in any baseline samples. Based on the relatively low concentrations of daughter products, significant reductive dechlorination was not occurring at the site at the time the PRB was installed or in the first couple of months following PRB installation (between October 2013 when the PRB was completed and December 2013 when the "baseline" round of sampling was complete).

2.5.2 BOMARC OT-16 Evaluation of Effectiveness of PRB

The most recent post-treatment VOC data and key field parameter results are presented in **Table OT-2**. Time series plots of TCE and cis-1,2-DCE following treatment within and downgradient of the PRB are shown in **Charts OT-1 through OT-4**. Pre-treatment data is plotted where available. While one well showed a notable decrease in concentrations within the PRB (OT16-MW34) and a smaller decrease was observed in the corresponding downgradient well, OT16-MW36, no significant change in VOC concentrations was observed in other wells. There were no decreases in concentrations in crossgradient wells or the well that was intended to monitor migration beneath the PRB. No significant generation of daughter products was noted in any wells (VC remained non-detect following treatment).

Chart OT-1
TCE Concentrations - Wells Within PRB, McGuire AFB, OT-16

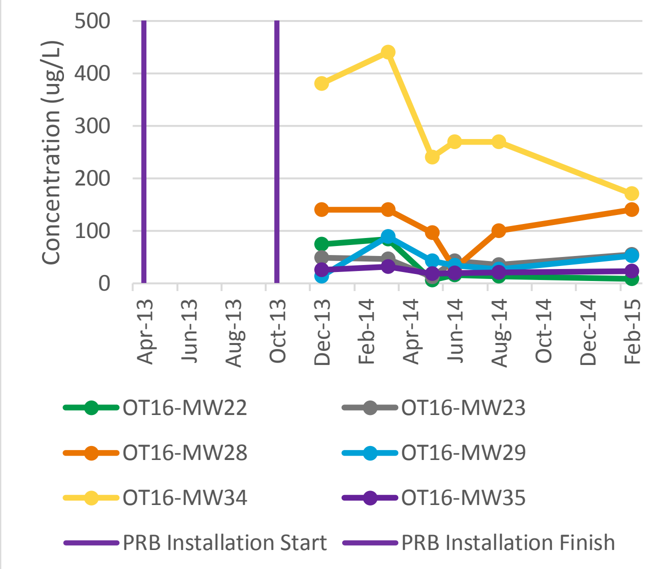


Chart OT-2
TCE Concentrations Downgradient Wells, McGuire AFB OT-16

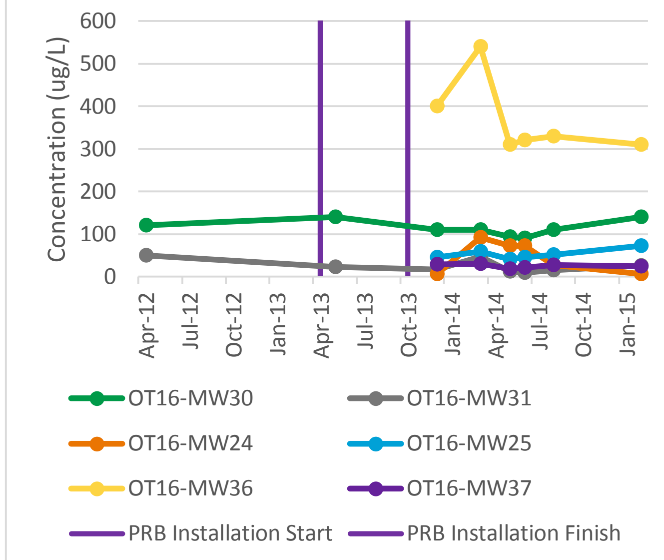


Chart OT-3
cis-1,2-DCE Concentrations - Wells Within PRB McGuire AFB, OT-16

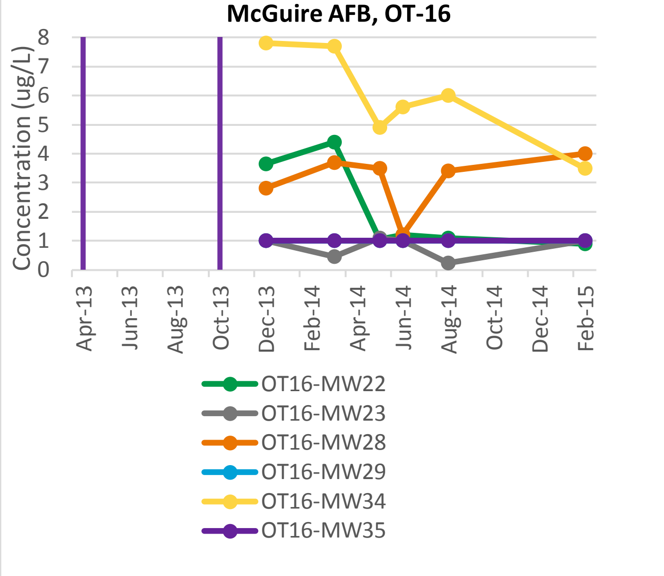
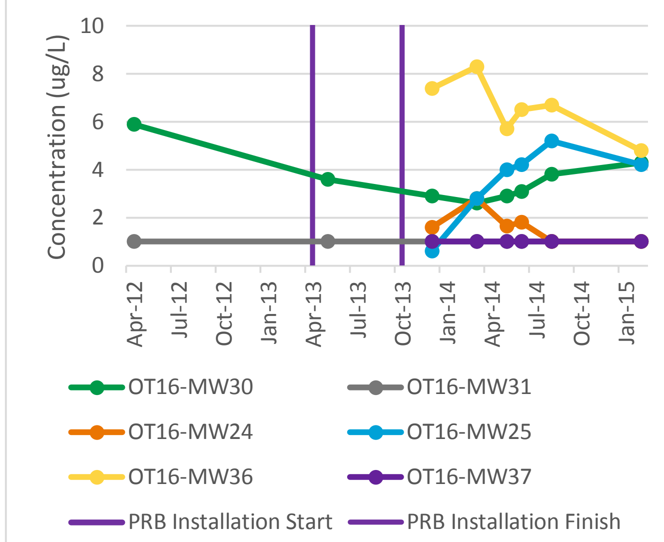


Chart OT-4
cis-1,2-DCE Concentrations Downgradient Wells



Data presented in **Table OT-2** indicates that the ZVI treatment caused minimal changes in monitored field parameters in groundwater within the PRB and downgradient, cross-gradient, and beneath it. Time series plots for pH, ORP, DO, and chloride are shown in **Charts OT-5 through OT-10.** The following conclusions are noted from the field data results.

- pH increased over the monitoring period in only two of the PRB monitoring wells (OT16-MW23 and OT16-MW35), but increased slightly in most downgradient wells. However, pH in all of the PRB wells and downgradient wells with the exception of OT16-MW35 was still acidic based on results of the most recent round of monitoring. This is inconsistent with expectations, as corrosion of ZVI generates the OH^- anion.
- In most PRB wells, ORP decreased to levels of less than -100 mV between the December 2013 (baseline) and March 2014 round of monitoring, but increased back to baseline levels by May 2014.

- DO concentrations were less than 1 mg/L in half of the wells within the PRB and decreased in many wells downgradient following installation, but conditions continued to remain aerobic in most wells following installation.

Overall, the Remedial Action Construction Report (CB&I, 2015) concluded that the PRB was unable to overcome the highly aerobic conditions at the site, resulting in limited efficacy.

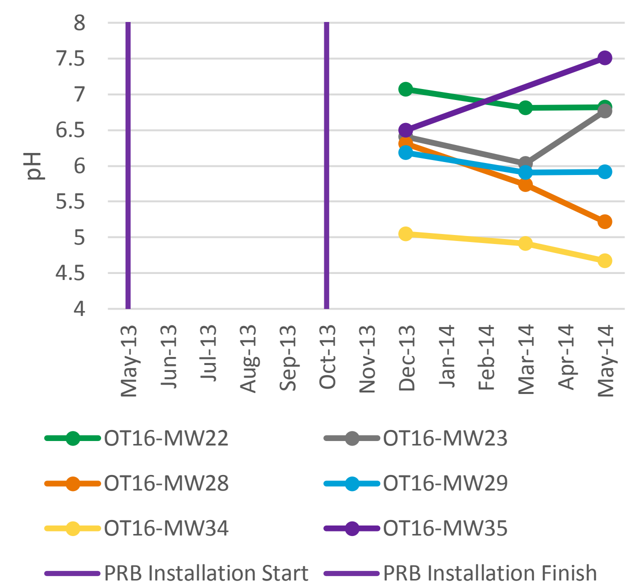


Chart OT-5
pH - Wells within PRB
McGuire AFB OT-16

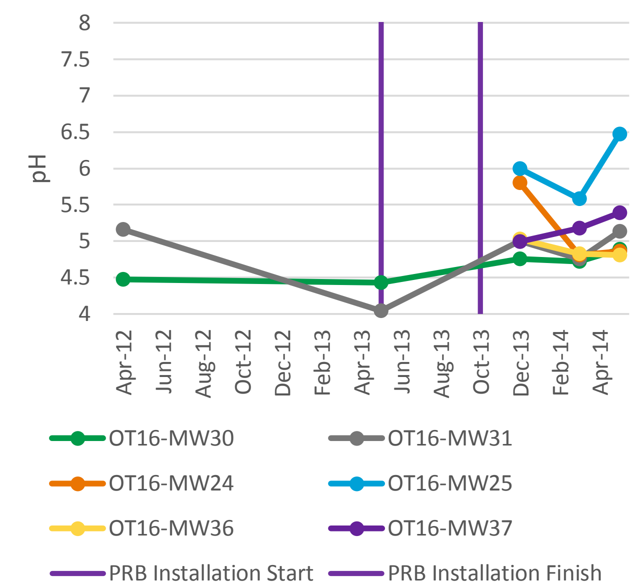


Chart OT-6
pH - Downgradient Wells
McGuire AFB OT-16

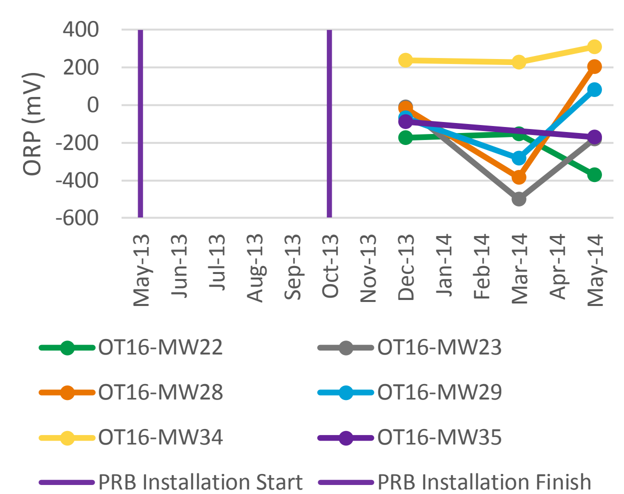


Chart OT-7
ORP - PRB Wells
McGuire AFB, OT-16

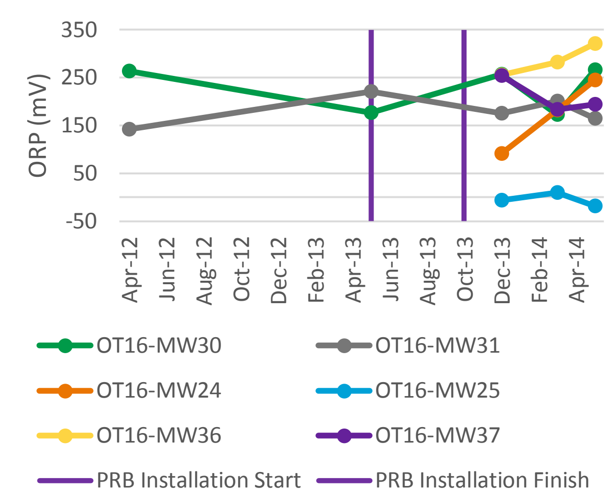
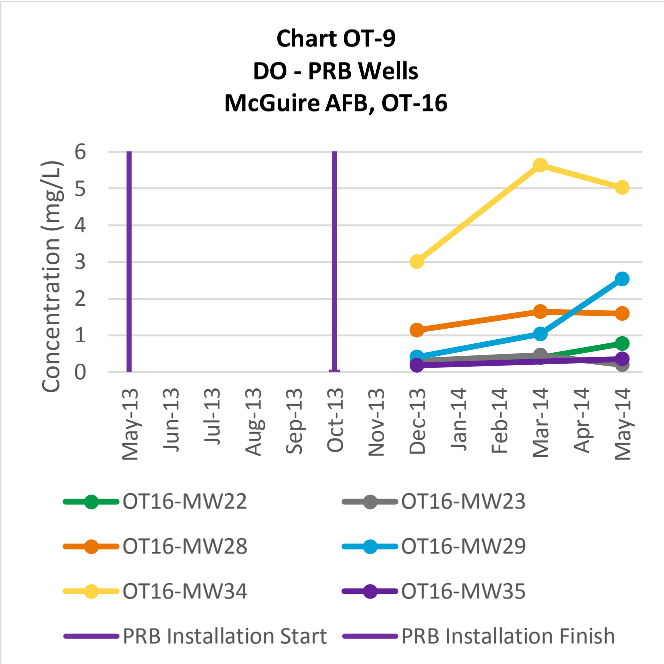
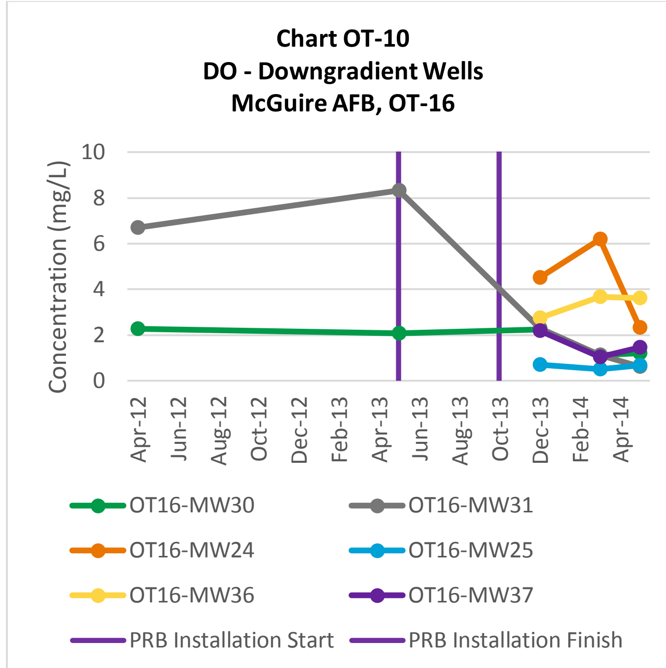


Chart OT-8
ORP - Downgradient Wells
McGuire AFB, OT-16





2.6 BOMARC OT-16 Changes in Groundwater flow

Aquifer testing was completed pre- and post-installation of the PRB and minimal changes in hydraulic conductivity were observed, with average values dropping slightly from 7.7 feet per day to 5.0 feet per day. Additionally, the gradient across the PRB was similar pre- and post-treatment. The difference in groundwater elevation across the PRB (upgradient to downgradient) remained consistently less than 0.5 feet both prior to injection and after injection with no changes indicating localized mounding (CB&I, 2015). Evaluation of water levels and gradients in cross-gradient wells indicated low potential for contaminants from the upgradient side of the wall to be migrating around the wall, with the gradient perpendicular to the wall two orders of magnitude greater than the groundwater gradient parallel to the wall. However, contamination was already present crossgradient of the wall under baseline conditions (OT16-MW41 concentration of 190 µg/L for TCE). Groundwater contour maps before and after treatment do not show changes in flow patterns in the vicinity of the PRB and are presented in **Appendix B**.

3 St. Julien's Creek Annex Site 21, Chesapeake, Virginia Background

3.1 St. Julien's Creek Annex Site 21 History

SJCA is situated at the confluence of St. Juliens Creek and the Southern Branch of the Elizabeth River in the City of Chesapeake, in southeastern Virginia (**Figure SJ-1**). The installation began operations as a naval ammunition facility in 1849 and ordnance operation were discontinued in 1977. The SJCA facility has also been involved in non-ordnance services, including degreasing; operation of paint shops, machine shops, vehicle and locomotive maintenance shops, pest control shops, battery shops, printing shops, electrical shops, boiler plants, wash racks, and potable water and salt water fire-protection systems; fire-fighter training; and storage of oil and chemicals. The current primary mission of SJCA is to provide a radar-testing range and various administrative and warehousing facilities and light industrial shops for nearby Norfolk Naval Shipyard and other local naval activities.

Site 21 is located in an industrial area in the south-central portion of SJCA (**Figure SJ-1**). Historically, the buildings at Site 21 were used as machine, vehicle, and locomotive maintenance shops, electrical shops, and munitions loading facilities. The outdoor areas were used for equipment and chemical storage. Currently, the existing buildings and the Site 21 area are used for storage and maintenance activities. Building 1556, constructed in 1992, is currently used as the Mid-Atlantic Regional Maintenance Center warehouse (CH2M HILL, 2008a).

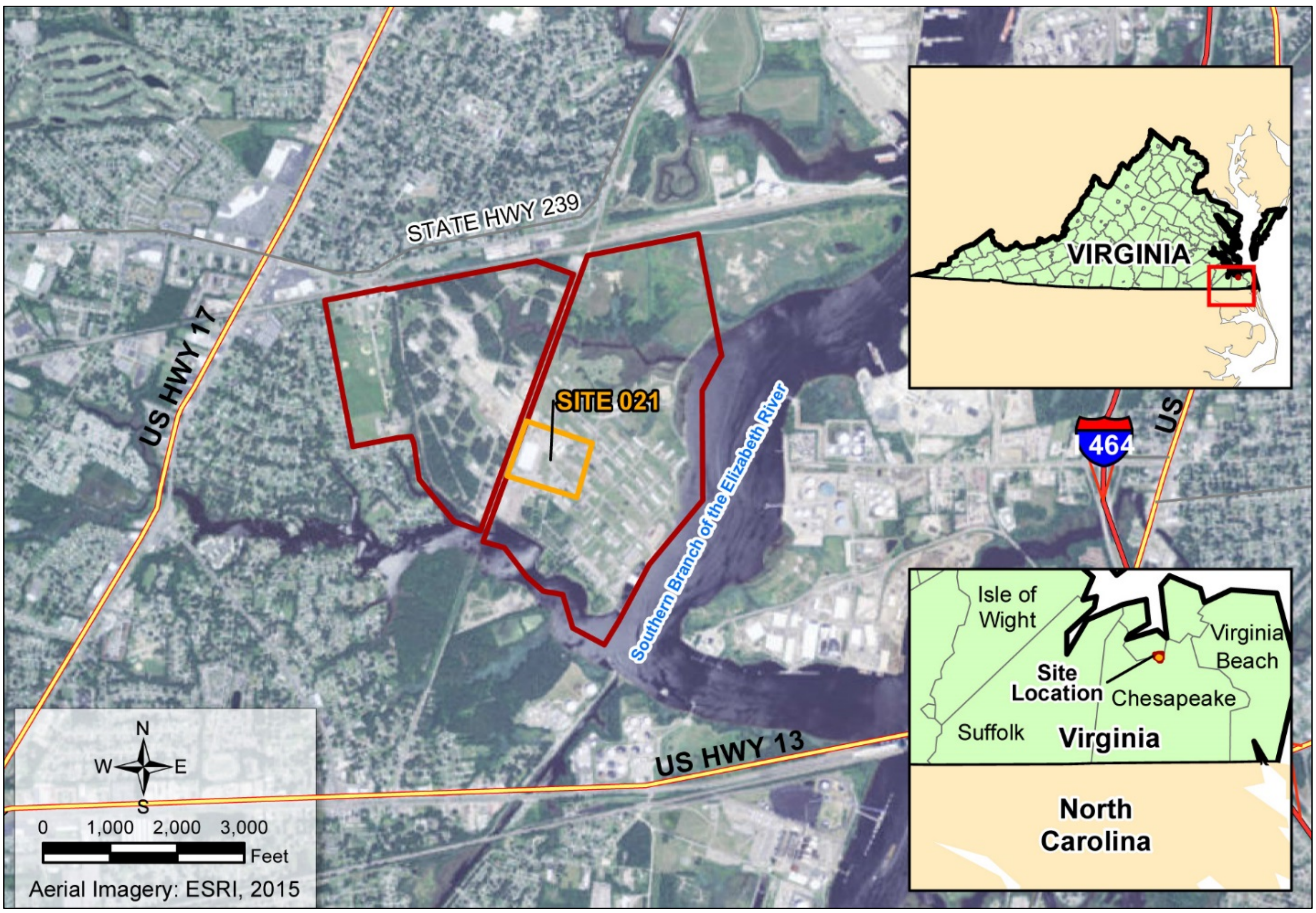


Figure SJ-1. St. Julien's Creek Site 21 Location Map

3.2 St. Julien's Creek Annex Site 21 Physical and Hydrogeologic Setting

The majority of the Site 21 ground surface is covered with asphalt, with the exception of a few small, unconnected grassy areas. Topography is relatively flat, with ground surface elevations ranging from 7 to 9 feet amsl.

The subsurface geology at Site 21 consists of the fine to coarse silty and clayey sands of the Columbia aquifer, underlain by the clay of the Yorktown confining unit. The Columbia aquifer extends to a depth of 13.5 to 20 feet bgs with the average depth to the confining unit being approximately 17 feet. The Yorktown confining unit ranges between 17 and 38 feet thick at the site and overlies the Yorktown aquifer. Cross sections are provided in **Appendix A**.

A storm sewer system passes through Site 21 and discharges to the tidal wetland south of the site. The majority of precipitation on Site 21 runs off into the storm sewer system. A separate storm sewer system serves the eastern quarter of Site 21 acreage and discharges to the Elizabeth River. The small amount of precipitation not captured by the storm sewer system infiltrates to the groundwater, flows as runoff toward Site 2, evaporates, or transpires.

Shallow groundwater at Site 21 is generally encountered from 2 to 7 feet bgs. In general, shallow groundwater flows southwest in the eastern portion of the site and southeast in the western portion of the site, toward the storm sewer system east of Building 1556 (**Figure SJ-2**). Much of the storm sewer system is located beneath the water table and pipe bedding material creates a preferential pathway that controls the flow of groundwater. A video survey did not reveal leaks in the sewer line itself that could be responsible for this hydraulic control.

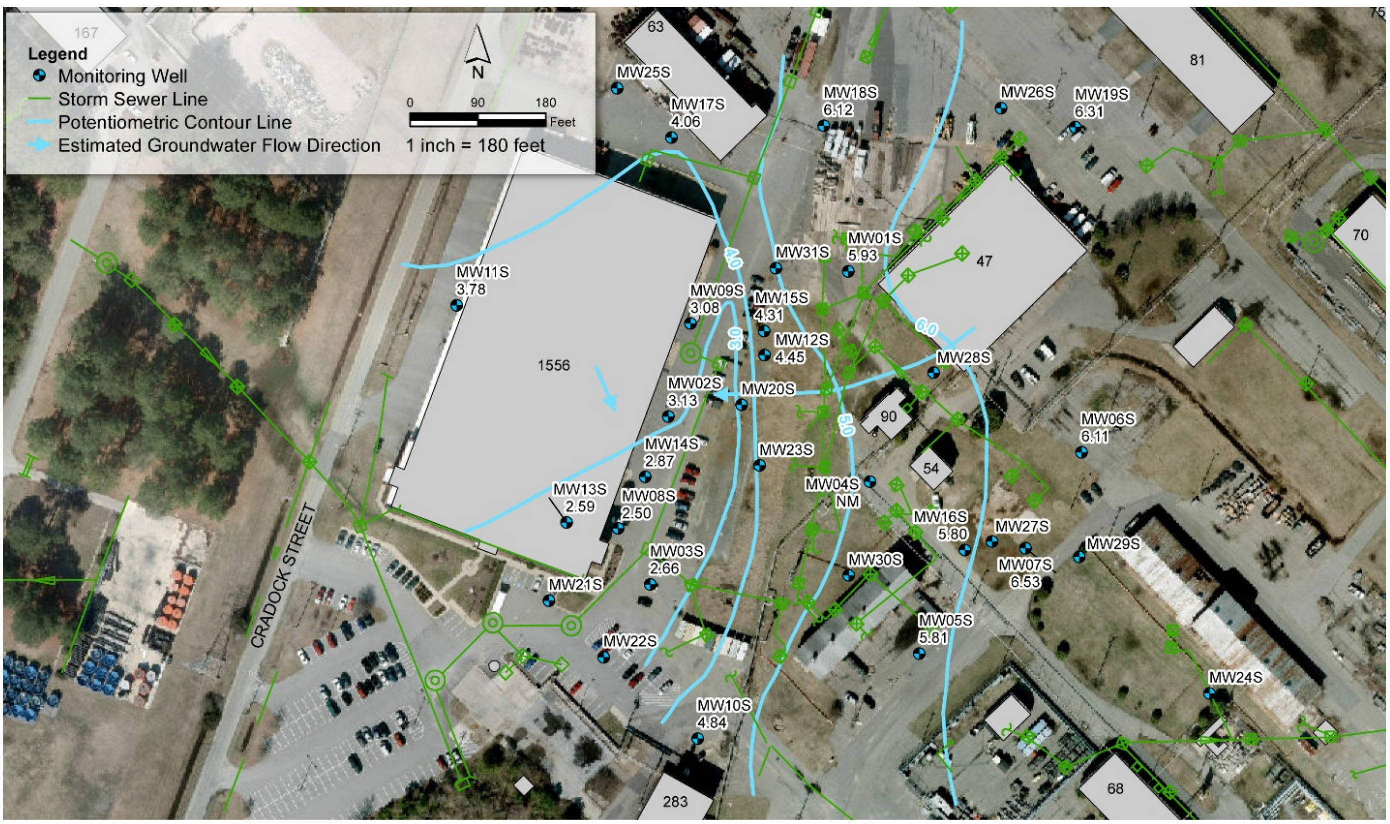


Figure SJ-2. St. Julien's Creek Site 21 Groundwater Contour Map

Aquifer tests conducted at Site 21 indicate that the average hydraulic conductivity in the Columbia aquifer is approximately 7 feet per day. Groundwater flow velocity was calculated at 0.196 feet per day (72 feet per year) using an average hydraulic gradient of 0.007 feet per foot and an estimated effective porosity of 0.25 (typical for silty sand). Since flow at Site 21 is heavily influenced by the position of the storm sewer system, it is likely that the actual velocity in areas close to the sewer lines is higher than calculated (CH2M HILL, 2008a).

3.3 St. Julien's Creek Annex Site 21 Contaminant Distribution Prior to Treatment

Prior to implementation of the RA at Site 21, TCE and cis-1,2-DCE were the most frequently detected contaminants in the shallow aquifer and the plume of these contaminants extended across over 8 acres of the site. The deeper, Yorktown aquifer has not been impacted by the historical contaminant releases. The maximum concentration of TCE detected in shallow groundwater at Site 21 during the baseline monitoring event for the RA was 12,500 µg/L at SJS21-MW15S as shown on **Figure SJ-3** (Shaw, 2011). Depth-specific groundwater samples collected at the bottom of the Columbia aquifer identified chlorinated VOC concentrations 2 to 7 times higher than in groundwater samples collected over the entire screened interval as described in the Remedial Investigation (RI) (CH2M HILL, 2008a). This in addition to the magnitude of the concentration supports the potential for dense non-aqueous phase liquid (DNAPL) to have been present at the site, although no visible evidence of DNAPL was ever observed in the field.

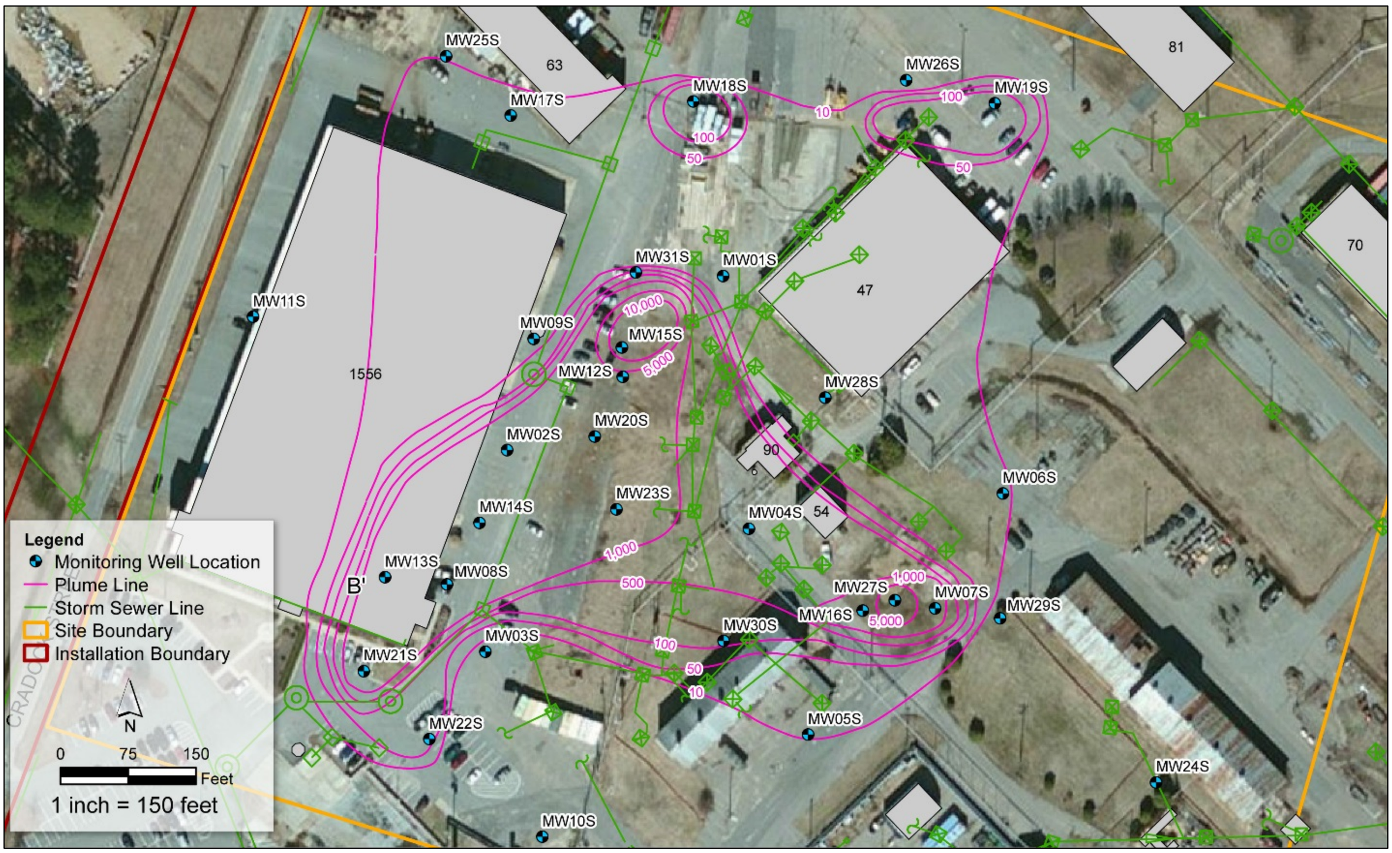


Figure SJ-3. St. Julien's Creek Site 21 TCE Plume (2008)

3.4 St. Julien's Creek Annex Site 21 Treatment Area and Wells Reviewed in Desktop Evaluation

ZVI injections began on December 1, 2010 and were completed on February 2, 2011. Because of the depth stratification of the contamination at Site 21, ZVI was injected into the bottom 5 feet of the shallow (Columbia) aquifer in two areas of the site with concentrations greater than 1000 µg/L for any of the site COCs (TCE, cis-1,2-DCE, and VC). The total areal extent of the two ZVI treatment areas was 18,500 square feet. The soil mass within the target treatment zone was estimated to be 5,365 tons (dry weight basis), assuming a soil bulk density of 116 lb/cubic foot. Based on a target ZVI dosage of 0.8 percent (lbs of ZVI per lb of soil), approximately 85,800 lbs of ZVI were determined to be needed for the site. DPT injection points were placed on 9.4-foot centers. This geometry was developed to provide complete coverage of the treated area using an assumed radius of influence (ROI) of 5.4 feet and a 13 percent overlap of treatment areas. Injection locations were placed at least 10 feet from buildings and known utility locations to avoid damage to structures and short-circuiting through preferential flow paths. Two-hundred and two temporary DPT ZVI injection points were completed, as shown in **Figure SJ-4**. The

DPT injection points extended to the Yorktown confining unit at approximately 17 feet bgs. Approximately 425 lbs of ZVI were injected per injection point. ZVI was mixed with water to create a ZVI/water slurry to facilitate injection. The ZVI slurry for injection contained approximately 3 lbs of ZVI per gallon of water. This corresponds to 142 gallons of slurry per injection point. The ZVI/water slurry was delivered using a high pressure injection process (Shaw, 2011a). Because of the potential for daylighting at the site, much of the ZVI was preferentially injected in the bottom five feet of the Columbia aquifer, just above the Yorktown confining unit, where contamination was noted to be at highest concentrations during investigations. Areas of the plume not treated with ZVI were treated with emulsified vegetable oil (EVO) to stimulate reductive dechlorination.

Figure SJ-4. St. Julien's Creek Site 21 Treatment Area and Wells Included in Desktop Review

For this study, pre- and post-treatment data from monitoring wells located within the ZVI treatment areas were evaluated. Wells included in the review are shown on **Figure SJ-4** and listed in **Table SJ-1**. Upgradient and downgradient well results are not discussed at length for this site because they were within areas treated with EVO, making it difficult to differentiate between VOC and geochemical changes due to biological versus abiotic (ZVI) processes.

Table SJ-1 St. Julien's Creek Annex Site 21 Wells Included in Desktop Review

East Area	
Source Area	MW27SR and MW16S
West Area	
Source Area	MW15S, MW12S, MW20SR, MW02S, and MW14S

3.5 St. Julien's Creek Annex Site 21 Desktop Evaluation Results

This section presents an evaluation of the results of ZVI injections with regard to treatment performance (reduction in VOC concentrations) and groundwater geochemistry changes created by the ZVI injections.

3.5.1 St. Julien's Creek Annex Site 21 Baseline Groundwater Conditions

Baseline (pre-injection) groundwater geochemistry data for the wells listed in **Table SJ-1** were collected in November 2010. Periodic monitoring of these wells has continued throughout the post-injection period. A summary of key geochemical parameters is presented in **Table SJ-2** for the baseline sampling as well as the November 2015 monitoring period.

For the eastern ZVI treatment zone, the results indicate the following baseline groundwater conditions:

- DO concentrations ranged from 0.6 mg/L to 2 mg/L
- pH ranged from 5.36 to 6.92
- ORP ranged from -2.8 mV to 128.5 mV
- Dissolved iron concentrations ranged from 0.756 mg/L to 12 mg/L
- Sulfate concentrations ranged from 7.1 mg/L to 99.1 mg/L
- Sulfide was not detected (less than approximately 0.6 mg/L)
- Methane concentrations ranged from 24.8 µg/L to 68.4 µg/L (0.0248 mg/L to 0.0684 mg/L)

Based on these values, baseline geochemical conditions in the eastern ZVI treatment zone appear to be generally oxic to slightly anaerobic, with aerobic respiration and iron reduction likely key terminal electron accepting processes (TEAPs) occurring in the aquifer. Strongly reducing conditions do not appear to have been present to a significant degree for baseline conditions.

Small amounts of VC, ethene, and methane were detected in some wells during the baseline sampling. Reductive dechlorination of TCE to VC and ethene and production of methane occur only under strongly reducing conditions. Thus, these detections suggest that more reducing conditions (such as sulfate reducing and methanogenesis) were present to some degree in microzones within the aquifer. The limited amount of VC and other compounds indicative of highly reducing conditions that were detected indicates that highly reducing conditions were not widely present in the eastern ZVI treatment zone under baseline conditions.

For the western ZVI treatment zone, the results indicate the following baseline groundwater conditions:

- DO concentrations ranged from 0.4 mg/L to 2mg/L
- Dissolved iron concentrations ranged from 0.758 mg/L to 5.78 mg/L
- Sulfate concentrations ranged from 2.3 mg/L to 99.1 mg/L
- Sulfide concentrations ranged from less than detectable (< 0.6 mg/L) to an estimated value of 0.67 mg/L.
- Methane concentrations ranged from 133 to 582 µg/L (0.133 to 0.582 mg/L)
- pH ranged from 4.99 to 6.46
- ORP ranged from -77 to 186.9 mV

Based on these values, baseline geochemical conditions in the western ZVI treatment zone appear generally similar to those in the eastern ZVI treatment zone, oxic to slightly anaerobic, with aerobic respiration and iron reduction likely the predominant TEAPs occurring in the aquifer. Strongly reducing conditions do not appear to have been present to a significant degree under baseline conditions in the western treatment area.

Methane and VC were detected at greater concentrations during the baseline sampling than in eastern ZVI treatment zone, indicating that microzones with more reducing conditions (such as sulfate reducing and methanogenesis) were also present and possibly to a greater extent than in the eastern ZVI treatment zone. However, highly reducing conditions do not appear to have been widely present in the western ZVI treatment zone prior to ZVI injections.

3.5.2 St. Julien's Creek Annex Site 21 Evaluation of Effectiveness of ZVI Injections

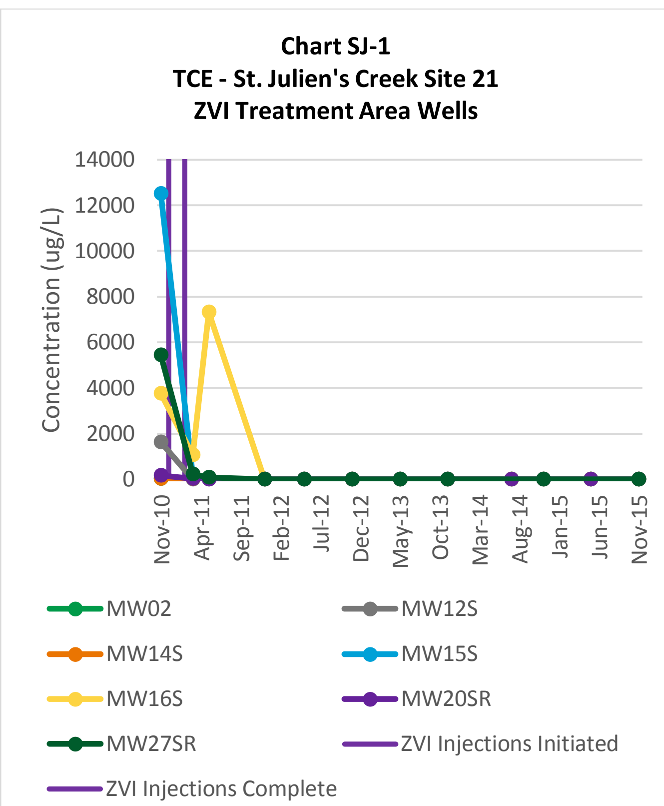
Baseline and the most recent post-injection VOC data for both ZVI treatment areas are presented in **Table SJ-2**. These data indicate that the ZVI injections were effective in both source zones for treating target VOCs.

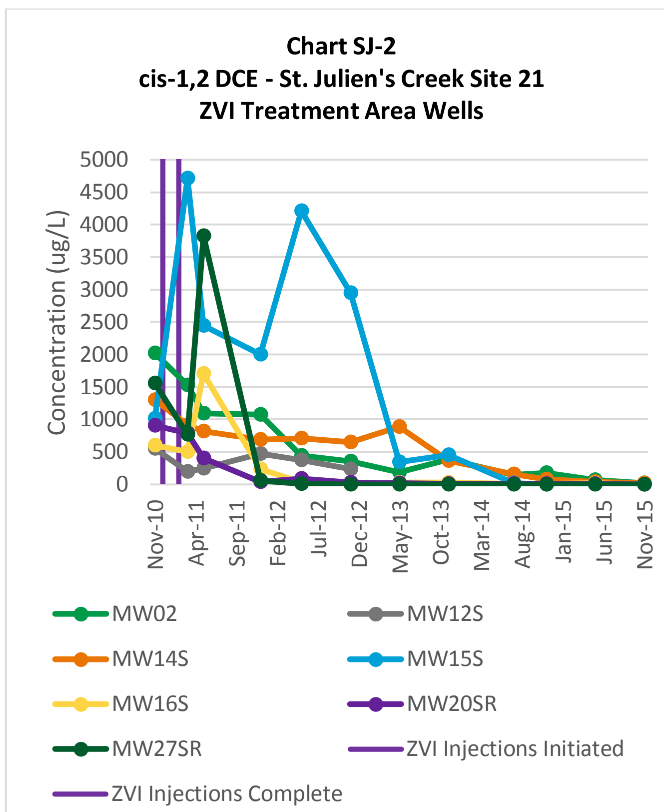
TCE concentrations in well MW27SR (eastern source area) declined from a baseline value of 5440 µg/L to less than detectable (< 0.5 µg/L). Baseline concentrations of cis-1,2-DCE, 1,1-DCE, and VC at 1560, 23, and 22 µg/L, respectively, were also reduced to < 0.5 µg/L each in this well. Similar performance was measured in well MW16S, with a baseline TCE concentration of 3770 µg/L reduced to 2 µg/L. Baseline concentrations of cis-1,2-DCE, 1,1-DCE, and VC at 598, 29.6, and 33.8 µg/L, respectively, were also reduced to <0.5, <0.5, and 0.59 (J), respectively.

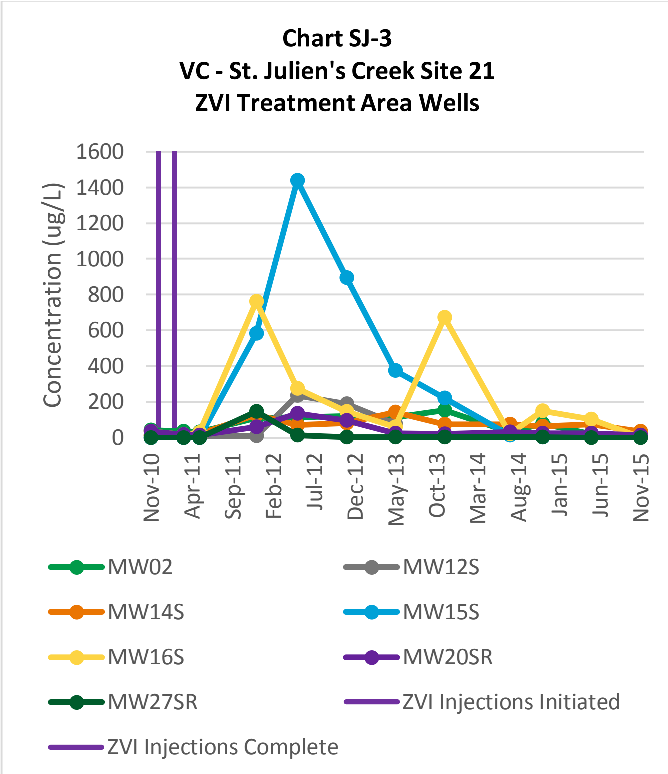
Significant and, in a few wells, nearly complete treatment of VOCs was also observed in source area wells within the western ZVI treatment zone. In well MW15S, TCE concentrations declined from a baseline value of 12,500 µg/L to less than detectable (< 0.5 µg/L). Baseline concentrations of cis-1,2-DCE, 1,1-DCE, and VC at 1010, 58, and 55 µg/L, respectively, were also reduced to 0.76 (J), < 0.5, and 3 µg/L, respectively.

Time series plots of TCE, DCE, and VC during the post-injection monitoring period for wells located within both ZVI treatment zones are presented in **Charts SJ-1 through SJ-3**. It can be seen in **Chart SJ-1** that TCE concentrations declined relatively quickly in all wells after ZVI injections were completed in February 2011.

Charts SJ-2 and SJ-3 show time series plots for cis-1,2-DCE and VC during the post-injection monitoring period. If reaction of TCE and the injected ZVI were proceeding primarily via β-elimination, more limited generation of cis-1,2-DCE and VC than shown in these charts would be expected. These charts suggest that while some degree of β-elimination may be occurring, other processes, such as reductive dechlorination also appear to have occurred. Well MW15S in particular showed the greatest concentrations of reductive dechlorination daughter products. Dechlorination reactions continued over the 5 year post-injection monitoring period.







Data presented in **Table SJ-2** indicates that the ZVI injections caused changes in several geochemical parameters in groundwater within the ZVI treatment zones. Time series plots for pH, ORP, dissolved iron, alkalinity, sulfide, sulfate, dissolved arsenic, TOC, ethene, ethane, and, methane are shown in **Charts SJ-4 through SJ-14**. Geochemical changes observed in these charts include the following:

- pH generally increased during the post-treatment monitoring period. This increase is not unexpected given that the reaction of ZVI and water generates OH^- anion
- ORP generally decreased shortly after injection, then increased throughout the post-injection monitoring period.
- Dissolved iron increased significantly during the post-injection monitoring period
- Alkalinity increased during the post-injection monitoring period, consistent with the generation of OH^- anion
- TOC increased during the post-injection period. An increase in TOC was unexpected given that the ZVI injectate did not include TOC-containing material and the ZVI injection zones were generally not located downgradient of locations where EVO was injected.
- Sulfide was detected during the first two years after ZVI injection.
- Sulfate generally declined during the post-injection monitoring period but was not completely consumed.
- Arsenic increased in most wells during the post-injection monitoring period
- Ethene production began shortly after ZVI injections and continued to be produced generally concurrently with VC production
- Similar to ethene, ethane production began shortly after ZVI injections and continued to be produced generally concurrently with VC production
- Methane production began shortly after ZVI injections and continued throughout the post-injection monitoring

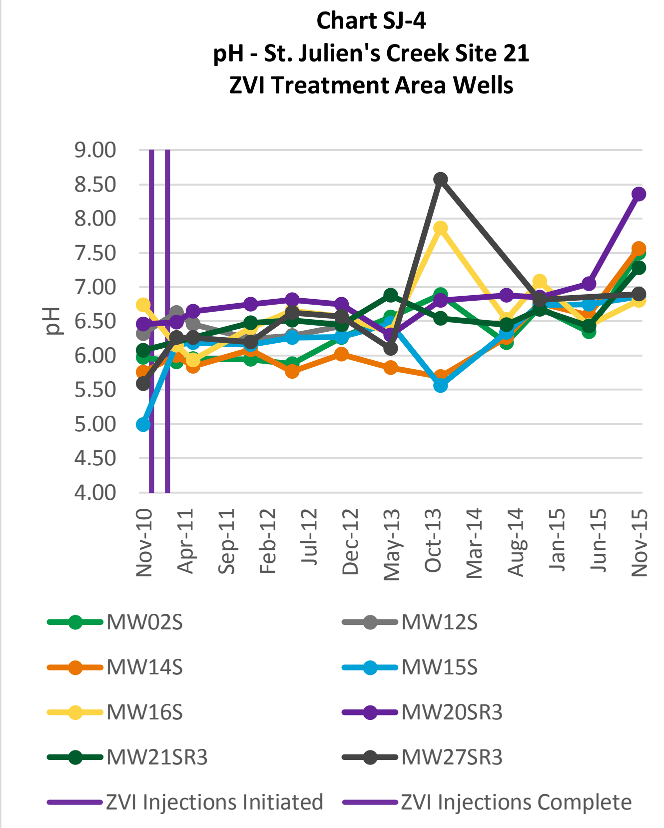


Chart SJ-4
pH - St. Julien's Creek Site 21
ZVI Treatment Area Wells
9.00
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
pH
Nov-10
Apr-11
Sep-11
Feb-12
Jul-12
Dec-12
May-13
Oct-13
Mar-14
Aug-14
Jan-15
Jun-15
Nov-15
MW02S
MW12S
MW14S
MW15S
MW16S
MW20SR3
MW21SR3
MW27SR3
ZVI Injections Initiated
ZVI Injections Complete

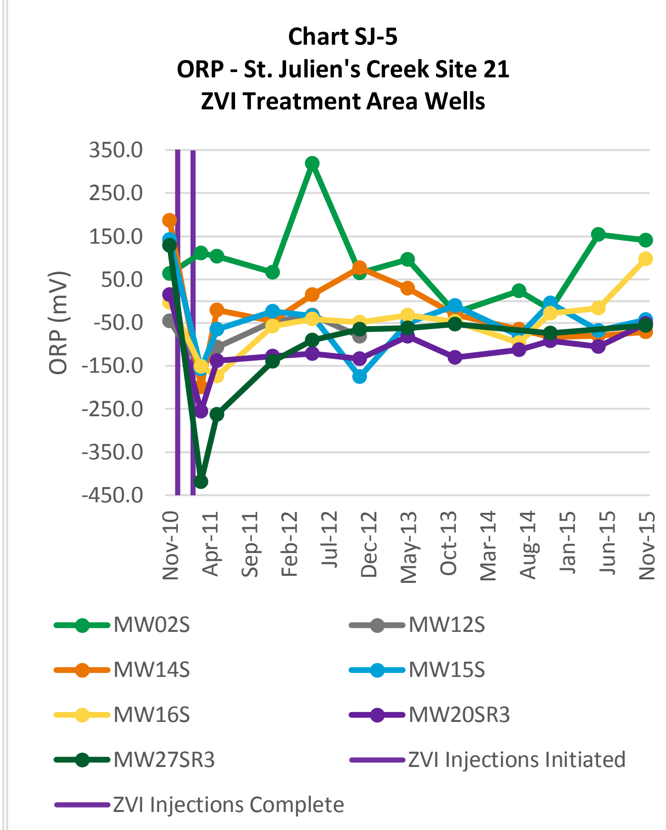


Chart SJ-5
ORP - St. Julien's Creek Site 21
ZVI Treatment Area Wells
350.0
250.0
150.0
50.0
-50.0
-150.0
-250.0
-350.0
-450.0
ORP (mV)
Nov-10
Apr-11
Sep-11
Feb-12
Jul-12
Dec-12
May-13
Oct-13
Mar-14
Aug-14
Jan-15
Jun-15
Nov-15
MW02S
MW12S
MW14S
MW15S
MW16S
MW20SR3
MW27SR3
ZVI Injections Initiated
ZVI Injections Complete

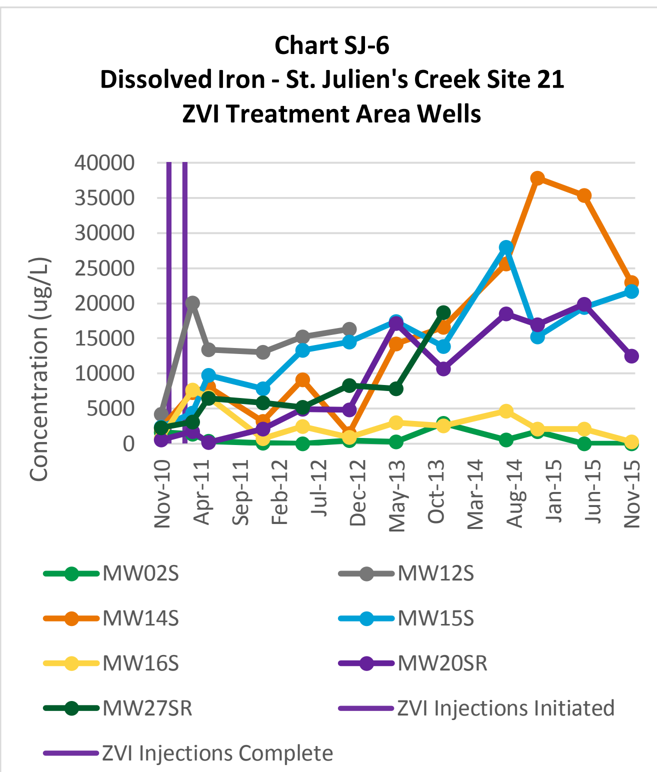


Chart SJ-6
Dissolved Iron - St. Julien's Creek Site 21
ZVI Treatment Area Wells
40000
35000
30000
25000
20000
15000
10000
5000
0
Concentration (ug/L)
Nov-10
Apr-11
Sep-11
Feb-12
Jul-12
Dec-12
May-13
Oct-13
Mar-14
Aug-14
Jan-15
Jun-15
Nov-15
MW02S
MW12S
MW14S
MW15S
MW16S
MW20SR
MW27SR
ZVI Injections Initiated
ZVI Injections Complete

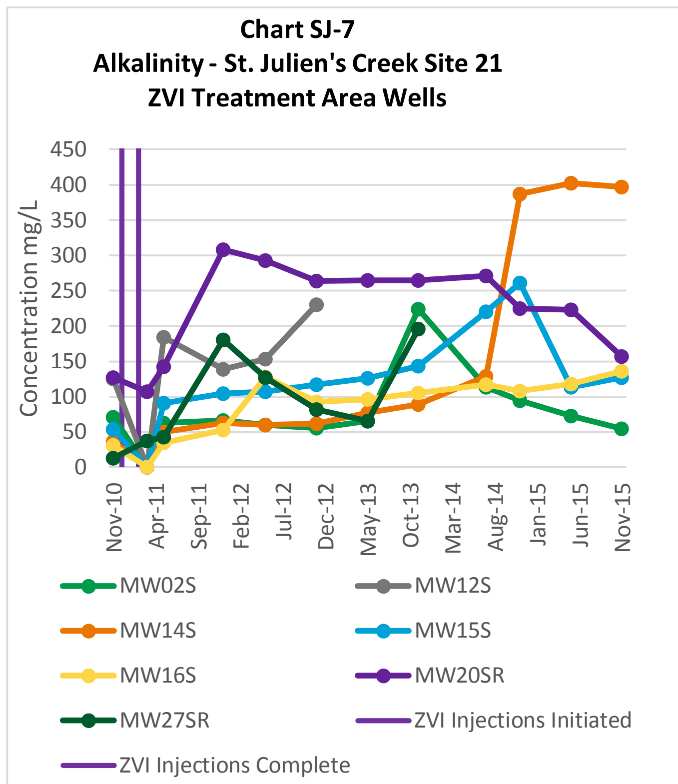


Chart SJ-7
Alkalinity - St. Julien's Creek Site 21
ZVI Treatment Area Wells
450
400
350
300
250
200
150
100
50
0
Concentration mg/L
Nov-10
Apr-11
Sep-11
Feb-12
Jul-12
Dec-12
May-13
Oct-13
Mar-14
Aug-14
Jan-15
Jun-15
Nov-15
MW02S
MW12S
MW14S
MW15S
MW16S
MW20SR
MW27SR
ZVI Injections Initiated
ZVI Injections Complete

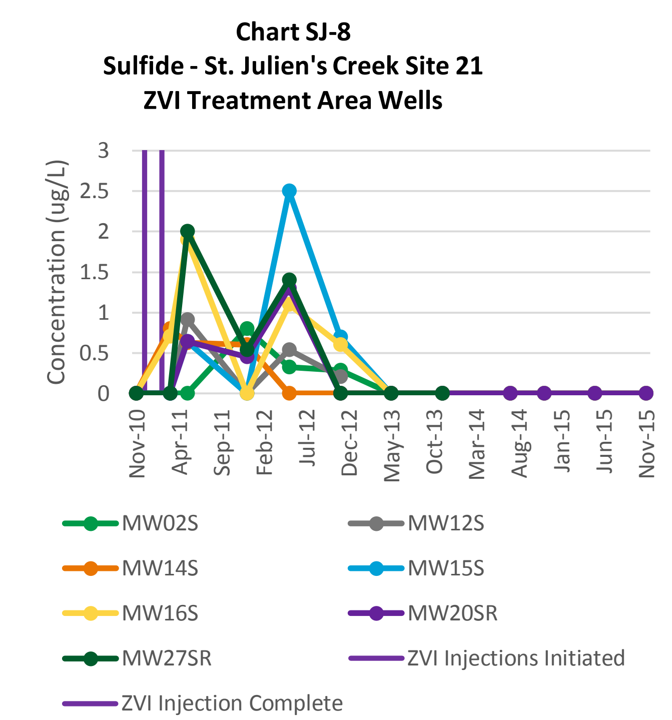


Chart SJ-8
Sulfide - St. Julien's Creek Site 21
ZVI Treatment Area Wells
Concentration (ug/L)
3
2.5
2
1.5
1
0.5
0
Nov-10
Apr-11
Sep-11
Feb-12
Jul-12
Dec-12
May-13
Oct-13
Mar-14
Aug-14
Jan-15
Jun-15
Nov-15
MW02S
MW12S
MW14S
MW15S
MW16S
MW20SR
MW27SR
ZVI Injections Initiated
ZVI Injection Complete

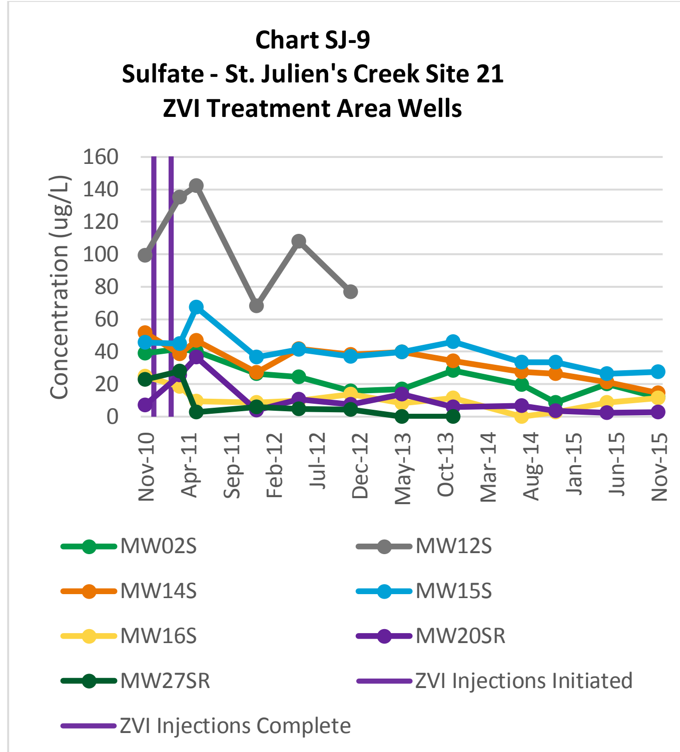


Chart SJ-9
Sulfate - St. Julien's Creek Site 21
ZVI Treatment Area Wells
Concentration (ug/L)
160
140
120
100
80
60
40
20
0
Nov-10
Apr-11
Sep-11
Feb-12
Jul-12
Dec-12
May-13
Oct-13
Mar-14
Aug-14
Jan-15
Jun-15
Nov-15
MW02S
MW12S
MW14S
MW15S
MW16S
MW20SR
MW27SR
ZVI Injections Initiated
ZVI Injections Complete

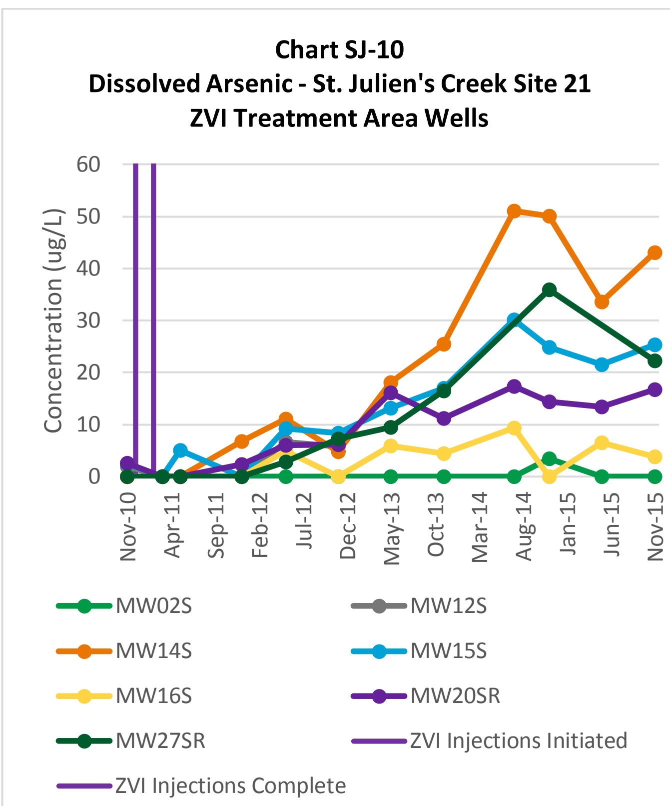


Chart SJ-10
Dissolved Arsenic - St. Julien's Creek Site 21
ZVI Treatment Area Wells
Concentration (ug/L)
60
50
40
30
20
10
0
Nov-10
Apr-11
Sep-11
Feb-12
Jul-12
Dec-12
May-13
Oct-13
Mar-14
Aug-14
Jan-15
Jun-15
Nov-15
MW02S
MW12S
MW14S
MW15S
MW16S
MW20SR
MW27SR
ZVI Injections Initiated
ZVI Injections Complete

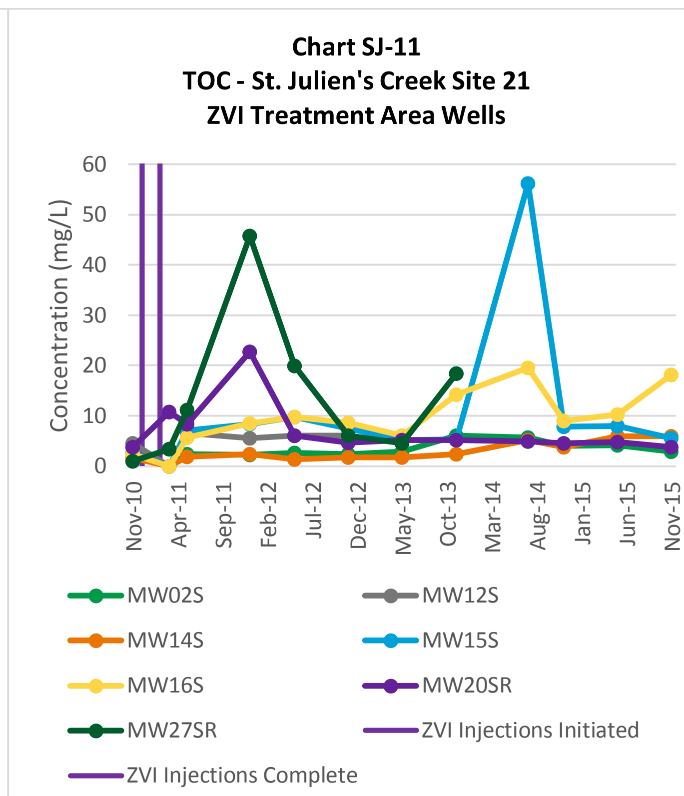
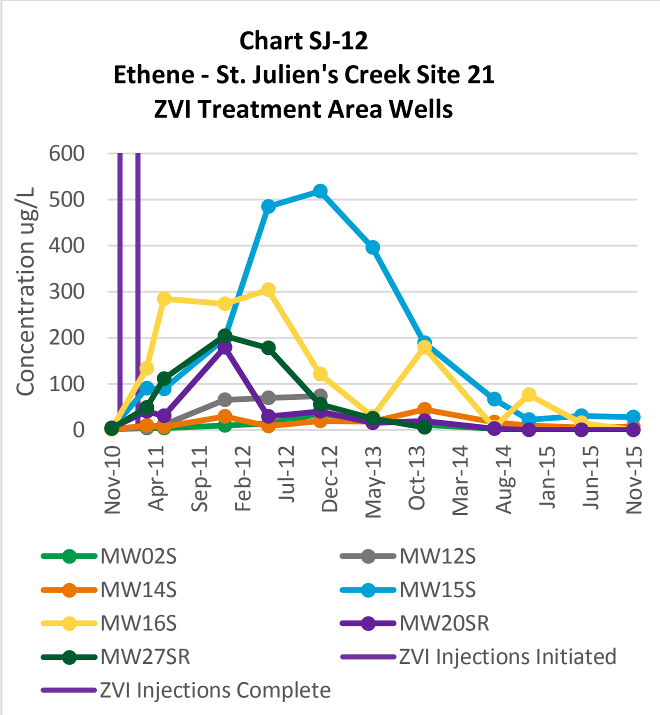
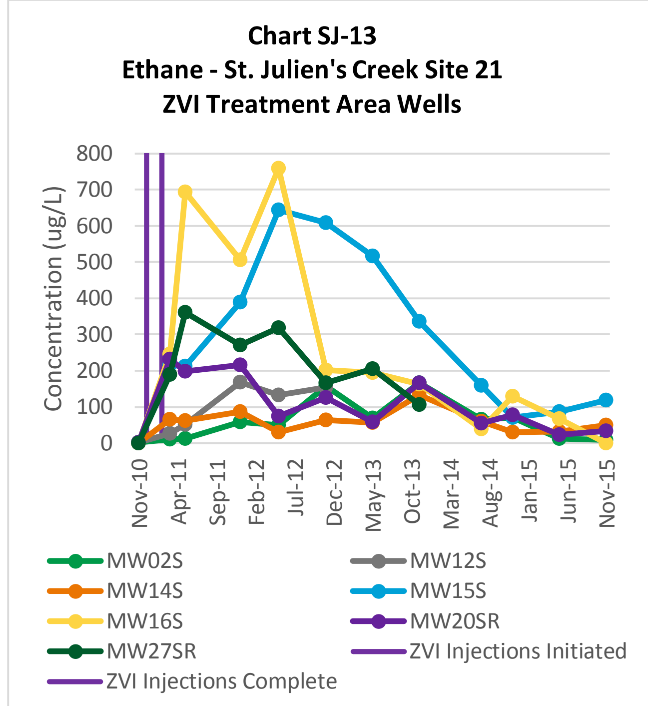
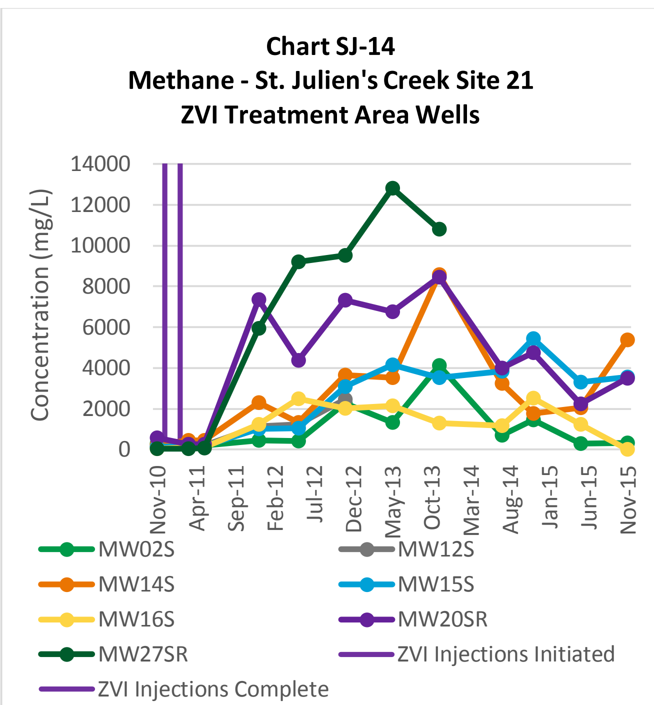


Chart SJ-11
TOC - St. Julien's Creek Site 21
ZVI Treatment Area Wells
Concentration (mg/L)
60
50
40
30
20
10
0
Nov-10
Apr-11
Sep-11
Feb-12
Jul-12
Dec-12
May-13
Oct-13
Mar-14
Aug-14
Jan-15
Jun-15
Nov-15
MW02S
MW12S
MW14S
MW15S
MW16S
MW20SR
MW27SR
ZVI Injections Initiated
ZVI Injections Complete







3.6 St. Julien's Creek Annex Site 21 Changes in Groundwater Flow

Groundwater flow maps from 2010 and 2016 are included in **Appendix B**. Based on these maps, no notable change in groundwater flow is noted due to ZVI Injection. No additional data were collected to evaluate hydraulic conductivity post-treatment.

4 NSWC White Oak Site 13, White Oak, Maryland Background

4.1 White Oak Site 13 History

Former NSWC White Oak is located in Silver Spring, Maryland, approximately 4 miles northwest of Washington, D.C. (**Figure WO-1**). The facility encompasses approximately 710 acres and is located in both Prince George and Montgomery counties. Approximately 635 acres of the property is undeveloped. The facility was established in 1946 as the Naval Ordnance Laboratory. The laboratory conducted research, development, and evaluations for surface warfare weapon systems, ordnance technologies, underwater weapons, and strategic systems. Former NSWC White Oak was closed in 1997 under the Base Realignment and Closure Act. Approximately 662 acres were transferred to the General Services Administration (GSA) and the remaining 48 acres were transferred to the Army.

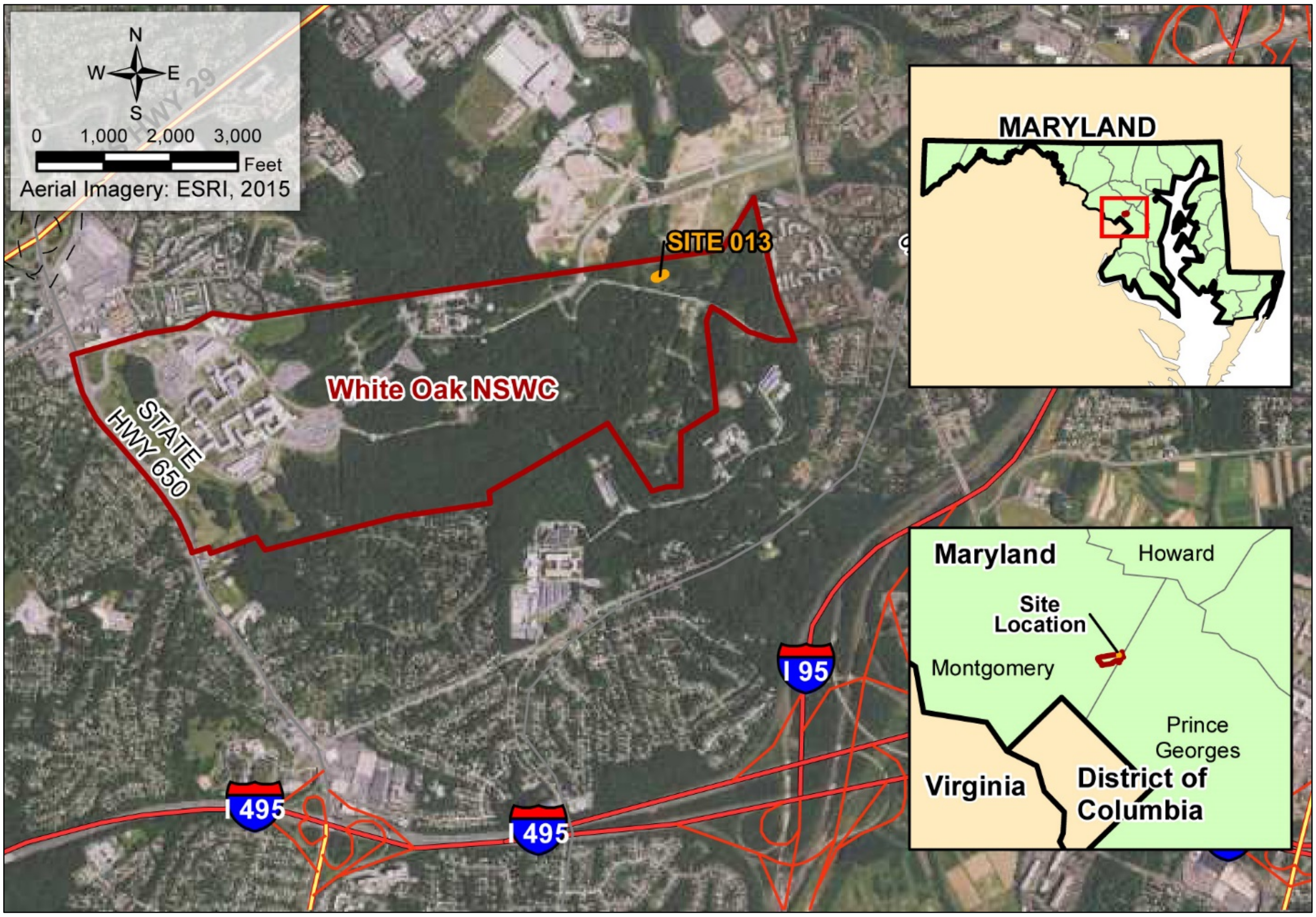


Figure WO-1. White Oak Site 13 Location Map

Site 13 is located in the northeast portion of NSWC White Oak, along the northern property line (**Figure WO-1**). Anecdotal accounts state that between 1970 and 1978, approximately 6,000 to 10,000 gallons of oily sludge from storage tanks containing No. 6 fuel oil were spread over the surface of Site 13; however, the location and history of Site 13 is not well documented and very little petroleum contamination has been found in the soil and groundwater in the area that is currently considered Site 13 (AGVIQ/CH2M HILL, 2010b).

4.2 White Oak Site 13 Physical and Hydrogeologic Setting

The surface of Site 13 gently slopes to the west with a maximum elevation relief across the site of approximately 5 feet. The topography immediately adjacent to Site 13 to the northwest, west and southwest drops steeply at a grade of approximately 33 percent into the valley formed by West Farm Branch.

Site 13 geology, as depicted on the cross-sections included in **Appendix A** consists of a layer of silty sand and gravel (Coastal Plain deposits) ranging in thickness from 0 to 10 feet. The Coastal Plain deposits are underlain by a 10 to 20-foot layer of decomposed rock (saprolite). This grades from a micaceous silt or silty sand with varying amounts of clay and schist fragments to a severely weathered schist with relief texture. Fractured rock underlies the saprolite; the competent bedrock is primarily a garnet schist.

The depth to the water table is approximately 10 to 12 feet. The water table at Site 13 is present in the low-permeability saprolite and the saturated thickness above the bedrock in this area is approximately 20 to 25 feet. Groundwater flow beneath Site 13 is primarily to the west and northwest, toward and into West Farm Branch (**Figure WO-2**). Groundwater velocity was estimated at 0.096 feet per day or 35 feet per year (CH2M HILL, 2008b).

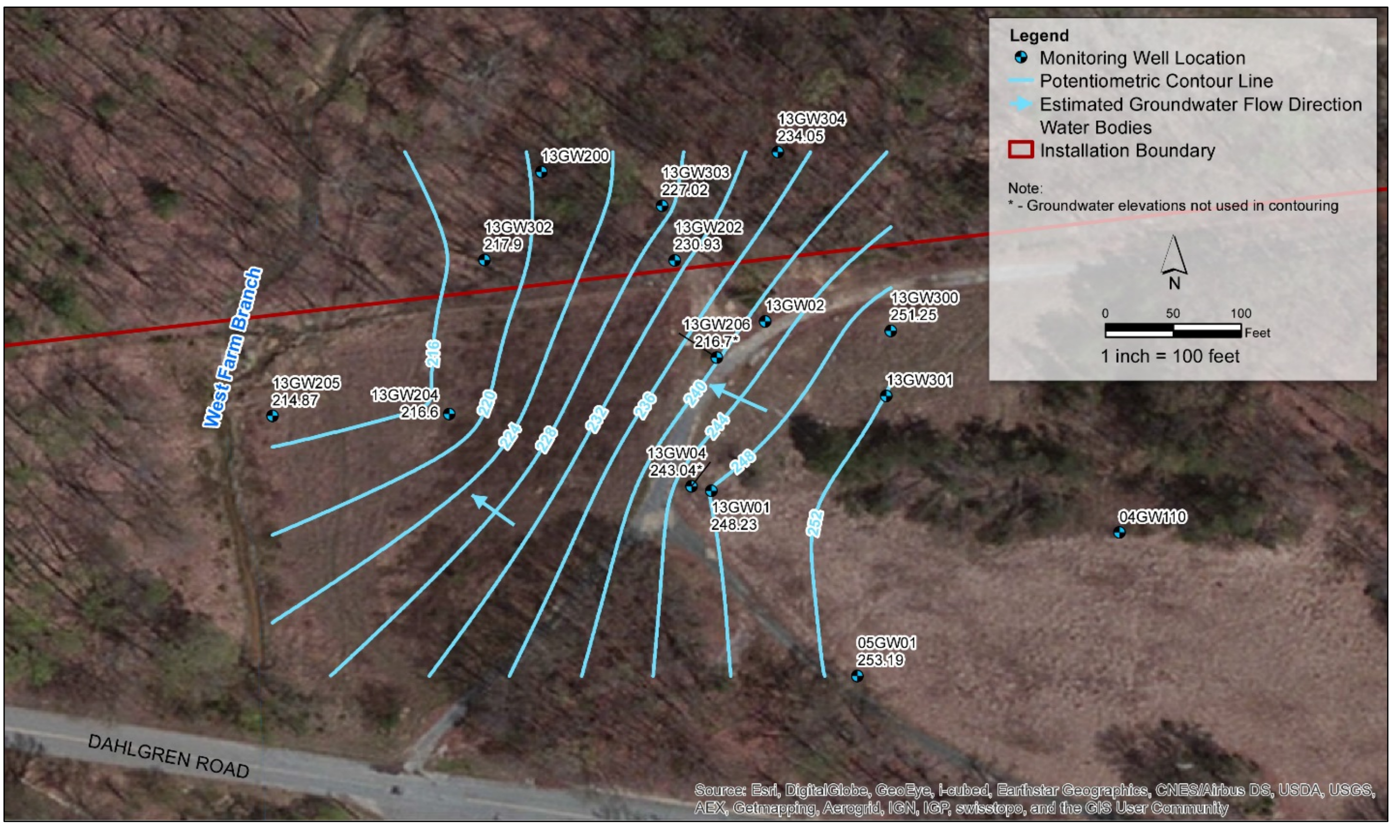


Figure WO-2. White Oak Site 13 Groundwater Contour Map (2014)

4.3 White Oak Site 13 Contaminant Distribution Prior to Treatment

The groundwater at Site 13 is impacted by 1,1,2,2-tetrachloroethane (1,1,2,2-PCA), PCE, TCE, cis 1,2-DCE, and VC. The groundwater plume at Site 13 extends off GSA property to the northwest toward West Farm Branch, on to private property owned by a sand and gravel quarry. Prior to the ZVI treatments, the total VOC concentrations in groundwater samples from several Site 13 wells were greater than 1,000 µg/L. The area of the defined Site 13 groundwater plume and the existing monitoring well network is shown in **Figure WO-3**.

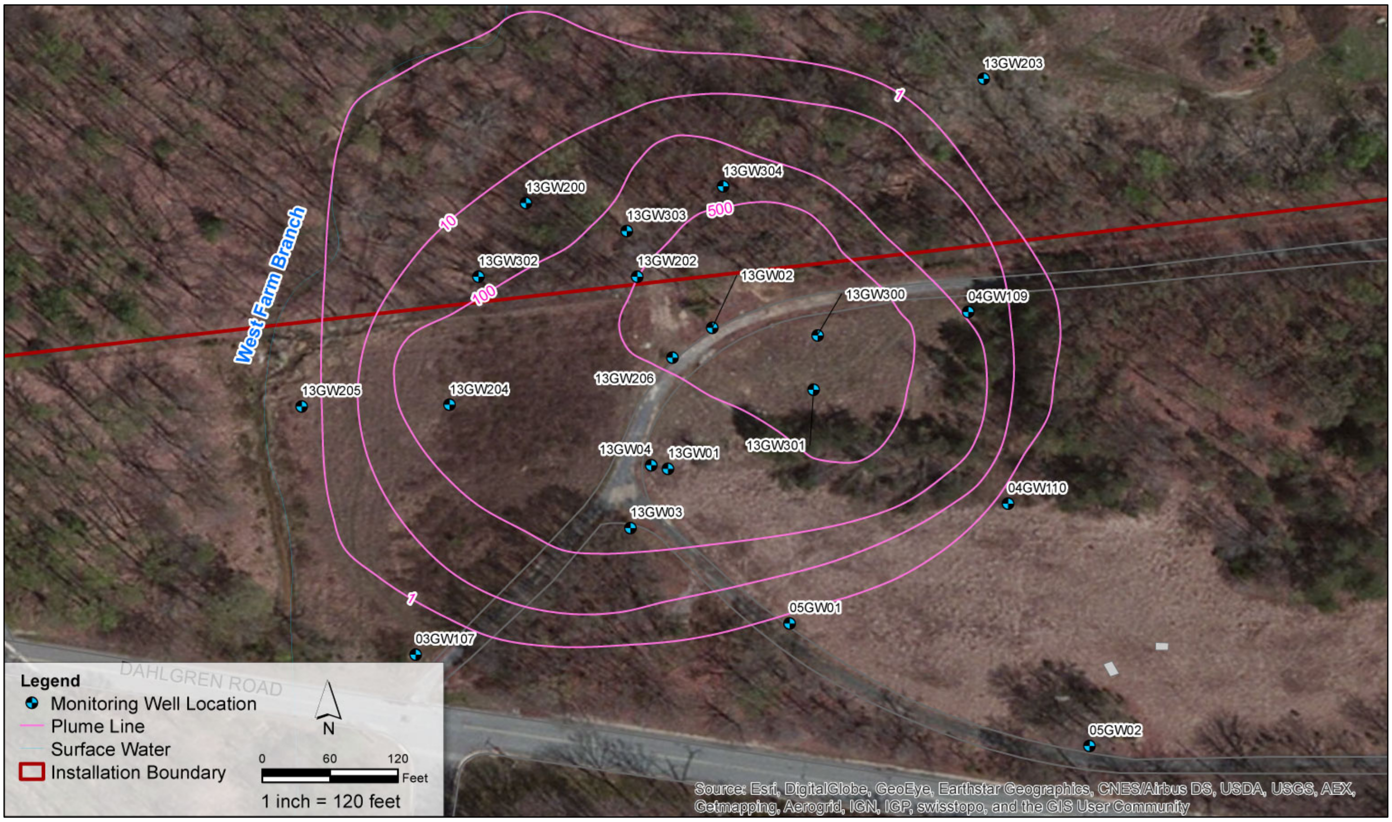


Figure WO-3. White Oak Site 13 Total VOC Plume (2004)

4.4 White Oak Site 13 ZVI Treatment Area and Wells Reviewed in Desktop Evaluation

In January and February 2005, fifteen injection borings ranging in depth from 28 to 41 feet bgs were drilled using a combination of hollow-stem auger (for surface casings) and air-rotary (for rock drilling) methods (**Figure WO-4**). Injection borings were drilled 3-feet into competent bedrock at the site. Saprolite was then pneumatically fractured in 3.5-foot intervals by applying high-pressure nitrogen gas for about 10 seconds. After fracturing each interval, ZVI powder was mixed with water in a slurry and injected into the fractured aquifer using a pressurized nitrogen system (Ferox). A total of 77,150 lbs of ZVI were injected, based on a dosage of 0.2 percent (lbs of ZVI per lb of soil) (Shaw, 2005).

In June 2010, while treatment onsite was successful, an untreated portion of the VOC-plume which had migrated offsite was determined to warrant additional treatment. A total of fifteen new injection borings were completed to address offsite contamination using the same methodology used during the first round of injections (**Figure WO-4**). The total depths of these boreholes ranged from 25 to 36 feet bgs. Due to excessive daylighting that occurred during the initial injection, hydraulic injections were used in some locations for the second injections. Four additional injection points were added using DPT to provide additional coverage and one existing point (IW01) was retreated. A total of 139,265 lbs of ZVI was injected during the second mobilization, based on a dosage of 0.5 percent (CH2M HILL, 2008b).

For this study, pre- and post-treatment data were evaluated from wells located in both treatment areas. Wells included in this desktop review are tabulated on **Table WO-1** and shown in **Figure WO-4**. DPT groundwater sampling results for the onsite portion of the base are also included in the evaluation for the purpose of completeness because no monitoring wells were installed across most of the onsite treatment area prior to or in the few years following the first injection.

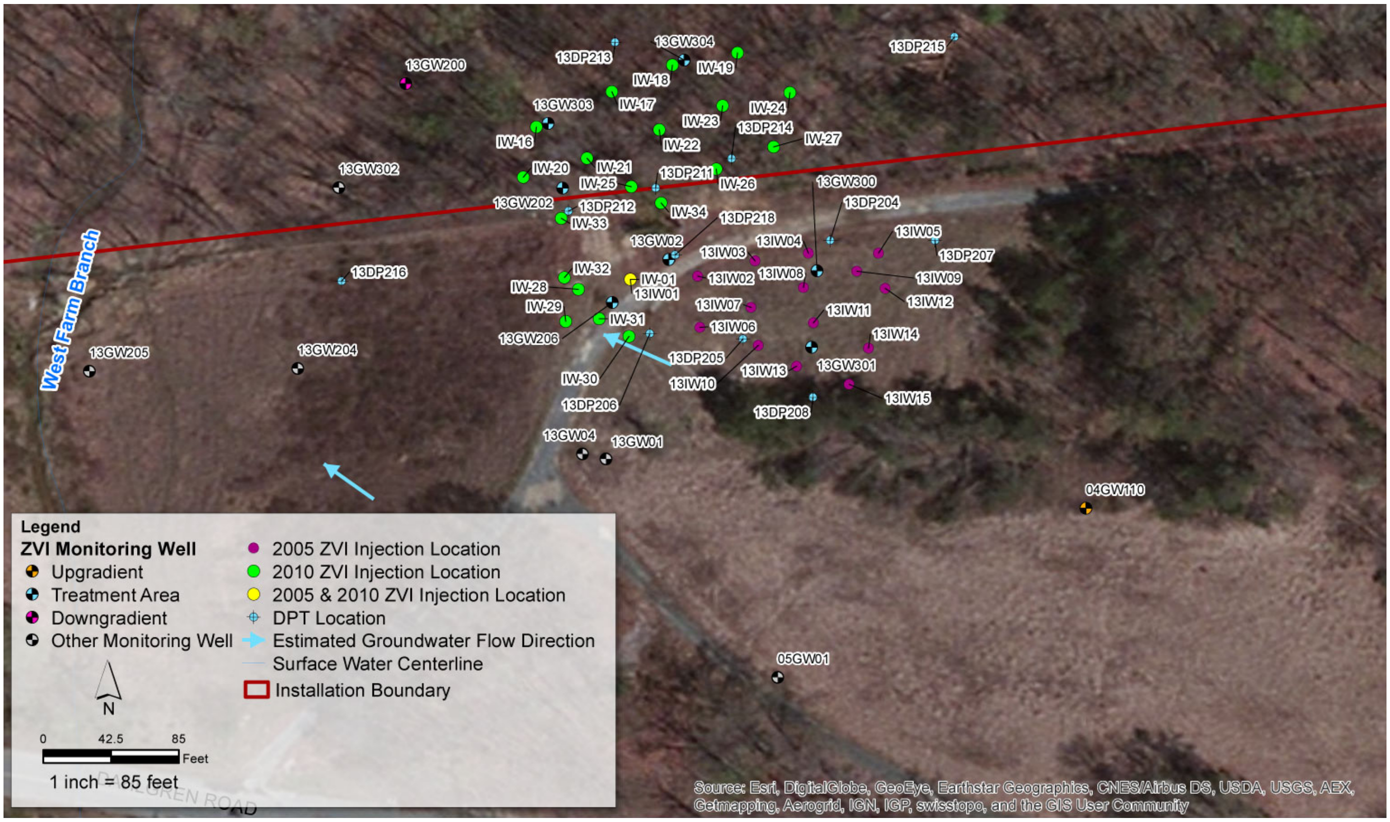


Figure WO-4. White Oak Site 13 Treatment Area and Wells Included in Desktop Review

Table WO-1. Wells Included in Desktop Review for White Oak Site 13

Onsite Treatment Area	13GW02, 13GW206, 2001 DPT locations (for VOCs only), 13GW300 (post 2010 only) and 13GW301 (post 2010 only)
Offsite Treatment Area	13GW202, 13GW303, and 13GW304

4.5 White Oak Site 13 Desktop Evaluation Results

This section presents an evaluation of the performance of the ZVI treatment (reduction in VOC concentrations) and groundwater geochemistry changes created by the ZVI treatment in the on-site and off-site treatment areas.

4.5.1 White Oak Site 13 Baseline Groundwater Conditions

Baseline sampling for the 2005 on-site injection event was completed in August of 2004. Baseline sampling for the June 2010 event was completed in May 2010. Because the plume at the site on which the design was based was delineated using DPT results for which only VOC concentrations were evaluated, the baseline geochemical conditions in the middle of the 2005 treatment area are unknown. The wells which are now in the center of the 2005 treatment area (13GW300 and 13GW301) were not installed until 2010. Consequently, this discussion is focused on 2004 data from three wells: 13GW02, 13GW202, and 13GW206. 13GW02 and 13GW206 are on the downgradient edge of the 2005 treatment area, but are upgradient of the 2010 treatment area. 13GW202 is within the 2010 treatment area. No baseline data from the wells installed immediately prior to the 2010 treatment are discussed in this section, as the first samples collected from these wells may have been impacted by the 2005 injection event. However, a summary of pre-treatment key geochemical parameters is provided in **Table WO-2** and this table includes May 2010 results for 13GW303 and 13GW304, the first round available for those two 2010 treatment area wells.

The 2005 pre-treatment results for 13GW02, 13GW202, and 13GW206 indicate the following baseline water conditions at the site:

- DO concentrations ranged from 0.5 mg/L to 7 mg/L
- pH ranged from 5.48 to 5.96
- ORP ranged from -1 mV to 238 mV
- Dissolved iron ranged from not detected (14.4 U µg/L) to 24,000 µg/L
- Nitrate ranged from 0.05 mg/L to 0.72 mg/L
- Sulfate ranged from 4.1 mg/L to 90.3 mg/L
- Chloride ranged from 60.2 mg/L to 100 mg/L
- Alkalinity ranged from 9.1 J mg/L to 73 J mg/L
- TOC was consistent across the 3 wells at 1 mg/L

Baseline geochemical conditions varied across the site. Conditions in the wells within the 2005 treatment area (13GW02 and 13GW206), were more oxic, while 13GW202, which is off-site and downgradient indicated reducing baseline conditions in 2004. Dissolved iron and methane concentrations were all considerably higher in the sample from 13GW202 than in the other two wells, while ORP and concentrations of DO, nitrate, and sulfate were all considerably lower in 13GW202 than in 13GW02 and 13GW206.

1,1,2,2-PCA was detected at a baseline concentration of 700 µg/L in the sample from 13GW02, but was not detected in the other two wells. However, this constituent was detected in samples from five DPT sampling stations (**Figure WO-4 and Table WO-2**) at concentrations up to 946 µg/L. For the chlorinated ethenes, cis-1,2-DCE was detected at the highest concentrations, with monitoring well results ranging from 84 µg/L to 400 µg/L and DPT detections ranging from 49.9 µg/L to 755 µg/L (23 to 28-ft bgs sample from 13DP218). TCE was detected at lower concentrations with well concentrations ranging from 9.5 J µg/L to 150 µg/L and 2001 DPT results ranging from 55 µg/L to 535D µg/L (16 to 21 ft-bgs sample from 13DP208). Trans-1,2-DCE was also detected at the site at a maximum concentration of 148D µg/L (16 to 21 ft-bgs sample from 13DP208). VC was not detected across most of the site and the highest detection was 10.3 µg/L, indicating incomplete dechlorination of cis-1,2-DCE and trans-1,2-DCE following generation of these daughter products during breakdown of TCE and 1,1,2,2-PCA.

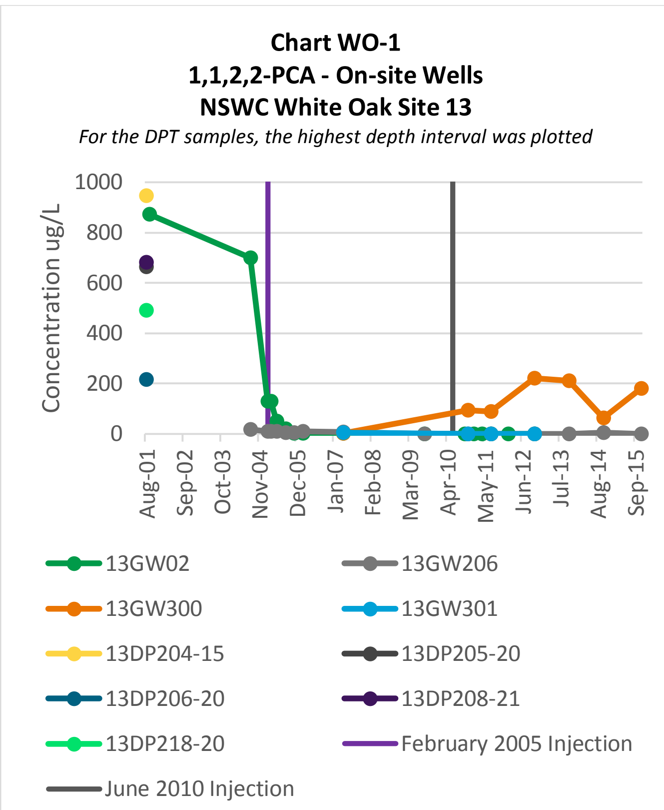
4.5.2 White Oak Site 13 Evaluation of Effectiveness of ZVI Injections

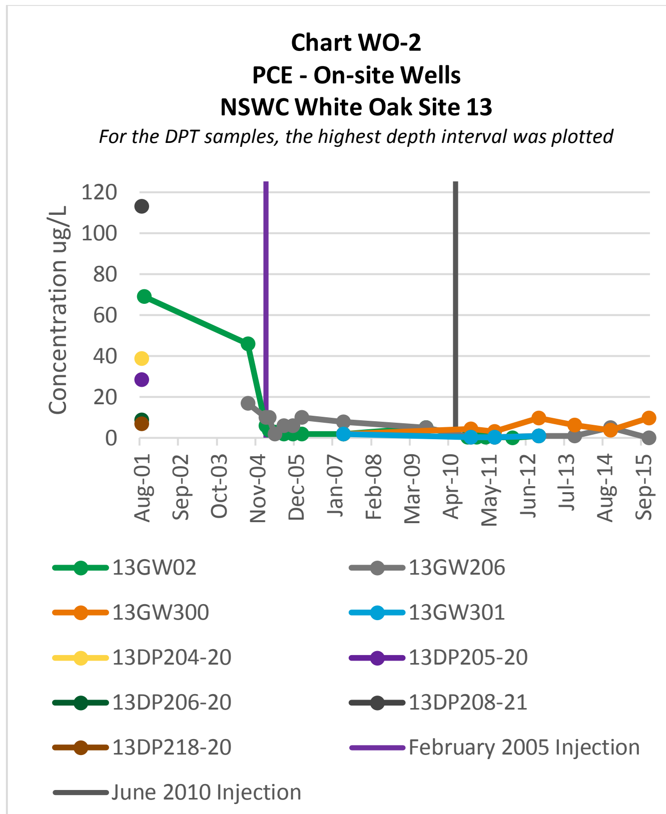
4.5.3 On-site Treatment Area

Baseline and the most recent post-injection VOC data (November 2015) for the on-site ZVI treatment area are presented in **Table WO-2**. **Charts WO-1 through WO-6** show temporal trends for VOCs. **Charts WO-7 through WO-14** show select geochemical and field parameter temporal trends for each injection area. DPT VOC results are shown for the on-site injection area in **Charts WO-1 through WO-6**, but are available for the 2001 event only and no geochemical or field data were collected for those samples. Nitrate data were not plotted as most results were not detected.

Reductions in VOC concentrations were variable across the on-site injection area, with very effective reduction observed in samples from 13GW02, and less effective reduction observed in 13GW206. Increases in VOCs (1,1,2,2-PCA, cis-1,2-DCE, trans-1,2-DCE and VC) were observed over time in samples from 13GW300, indicating some migration of contaminants may be occurring.

Highly reducing conditions (lowest ORP value of -398 mV) were achieved in 13GW02, but were not achieved in other monitoring wells possibly explaining the inconsistency in treatment efficacy across the on-site treatment area (**Chart WO-9**). DO concentrations were similarly optimal in samples from 13GW02, with concentrations less than 1 mg/L for most of the post-treatment monitoring period. Concentrations of DO in 13GW206 and 13GW300 were equal to or greater than 1 mg/L throughout the monitoring period (**Chart WO-7**). Increases in pH were observed in the sample from 13GW02 following both rounds of injection, as expected based on generation of the hydroxyl radical. An increase in pH was observed in the sample from 13GW206 following the first injection, but conditions returned to baseline within one year. No notable pH increases were observed in the other two on-site treatment area wells (13GW300 and 13GW301), which were not installed until a number of years after the 2005 injection was completed (**Chart WO-8**). Dissolved iron concentrations increased in all on-site treatment area wells with the exception of 13GW02 (**Chart WO-10**). Sulfate was not detected during most rounds of monitoring following the first injection in samples from 13GW02. Sulfate was also generally non-detect in samples from 13GW300 and 13GW301, but was consistently detected at a concentration greater than 15 mg/L in samples from 13GW206, indicating sulfate reducing conditions were never achieved in the vicinity of that monitoring well (**Chart WO-11**). Chloride concentrations demonstrated an increase following the 2005 injections in samples from 13GW02 and 13GW206, and have steadily increased over the monitoring period in samples from 13GW301. This may be a result of sample variability, as the lack of decreases in COC concentrations in samples from 13GW206 is not consistent with the increase in chloride (**Chart WO-12**). No meaningful trend in alkalinity was observed over the monitoring period (**Chart WO-13**). TOC concentrations increased in samples from 13GW02 and 13GW206 following the 2005 injections, but have since returned to baseline (**Chart WO-14**).





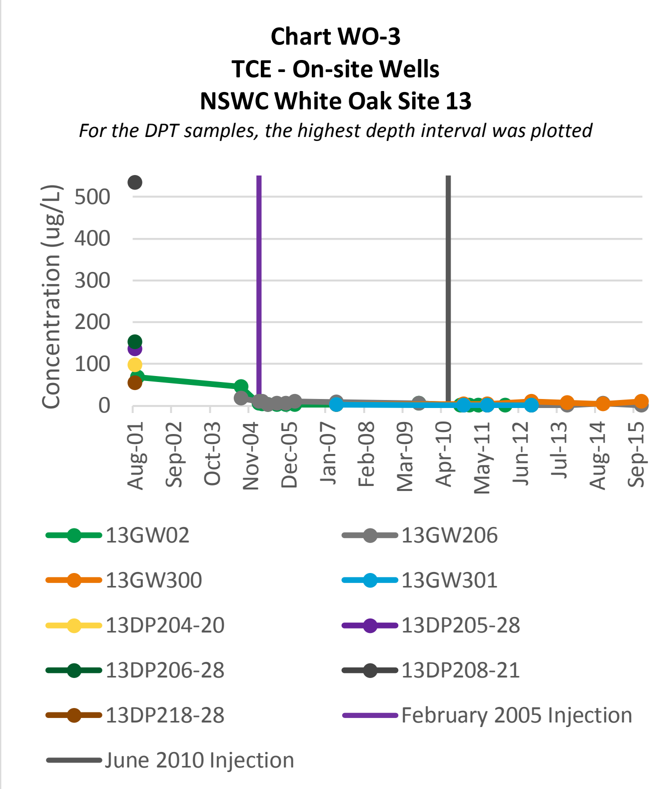


Chart WO-3
TCE - On-site Wells
NSWC White Oak Site 13
For the DPT samples, the highest depth interval was plotted
Concentration (ug/L)
500
400
300
200
100
0
Aug-01
Sep-02
Oct-03
Nov-04
Dec-05
Jan-07
Feb-08
Mar-09
Apr-10
May-11
Jun-12
Jul-13
Aug-14
Sep-15
13GW02
13GW206
13GW300
13GW301
13DP204-20
13DP205-28
13DP206-28
13DP208-21
13DP218-28
February 2005 Injection
June 2010 Injection

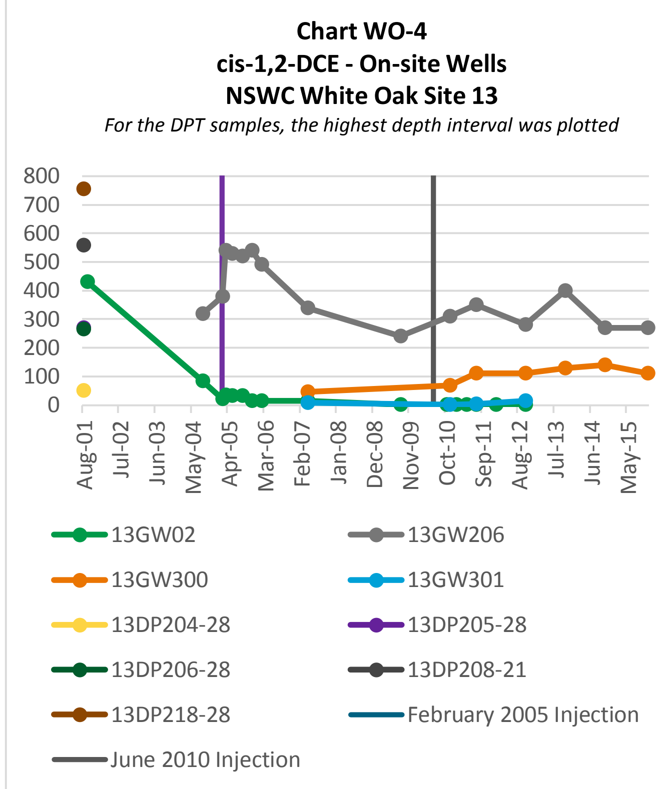


Chart WO-4
cis-1,2-DCE - On-site Wells
NSWC White Oak Site 13
For the DPT samples, the highest depth interval was plotted
800
700
600
500
400
300
200
100
0
Aug-01
Jul-02
Jun-03
May-04
Apr-05
Mar-06
Feb-07
Jan-08
Dec-08
Nov-09
Oct-10
Sep-11
Aug-12
Jul-13
Jun-14
May-15
13GW02
13GW206
13GW300
13GW301
13DP204-28
13DP205-28
13DP206-28
13DP208-21
13DP218-28
February 2005 Injection
June 2010 Injection

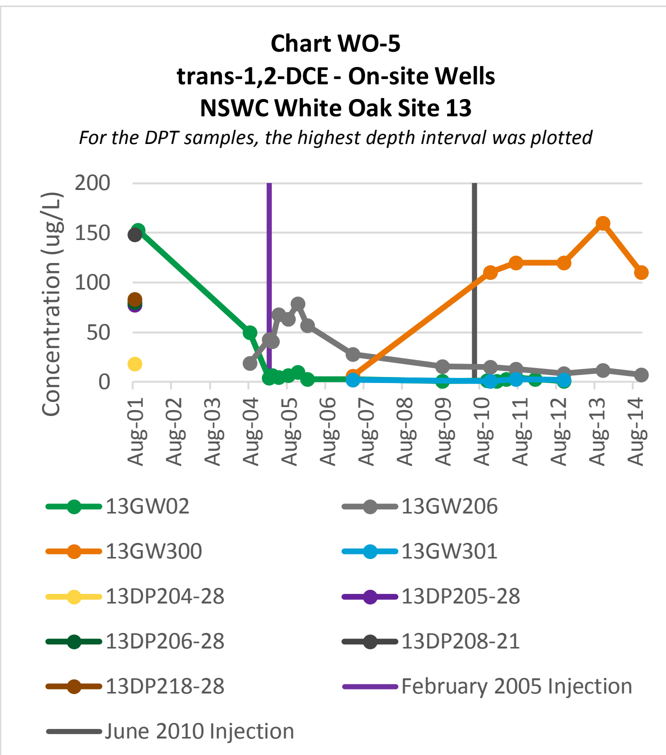


Chart WO-5
trans-1,2-DCE - On-site Wells
NSWC White Oak Site 13
For the DPT samples, the highest depth interval was plotted
Concentration (ug/L)
200
150
100
50
0
Aug-01
Aug-02
Aug-03
Aug-04
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Aug-11
Aug-12
Aug-13
Aug-14
13GW02
13GW206
13GW300
13GW301
13DP204-28
13DP205-28
13DP206-28
13DP208-21
13DP218-28
February 2005 Injection
June 2010 Injection

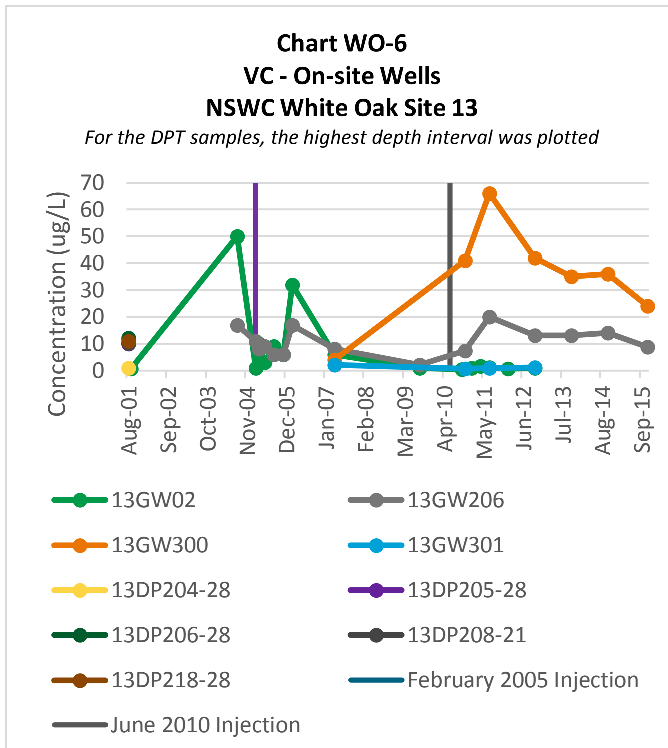


Chart WO-6
VC - On-site Wells
NSWC White Oak Site 13
For the DPT samples, the highest depth interval was plotted
Concentration (ug/L)
70
60
50
40
30
20
10
0
Aug-01
Sep-02
Oct-03
Nov-04
Dec-05
Jan-07
Feb-08
Mar-09
Apr-10
May-11
Jun-12
Jul-13
Aug-14
Sep-15
13GW02
13GW206
13GW300
13GW301
13DP204-28
13DP205-28
13DP206-28
13DP208-21
13DP218-28
February 2005 Injection
June 2010 Injection

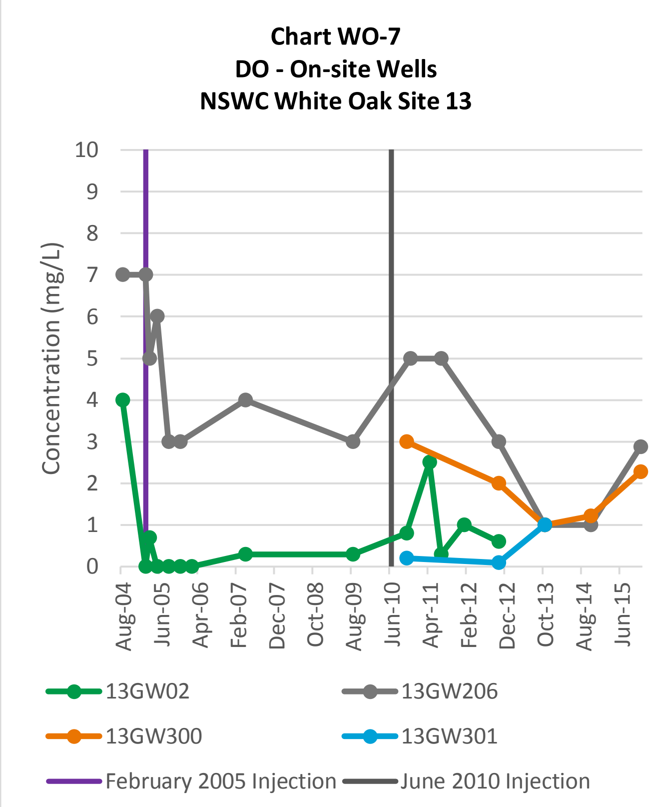


Chart WO-7
DO - On-site Wells
NSWC White Oak Site 13
Concentration (mg/L)
0
1
2
3
4
5
6
7
8
9
10
Aug-04
Jun-05
Apr-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12
Dec-12
Oct-13
Aug-14
Jun-15
13GW02
13GW206
13GW300
13GW301
February 2005 Injection
June 2010 Injection

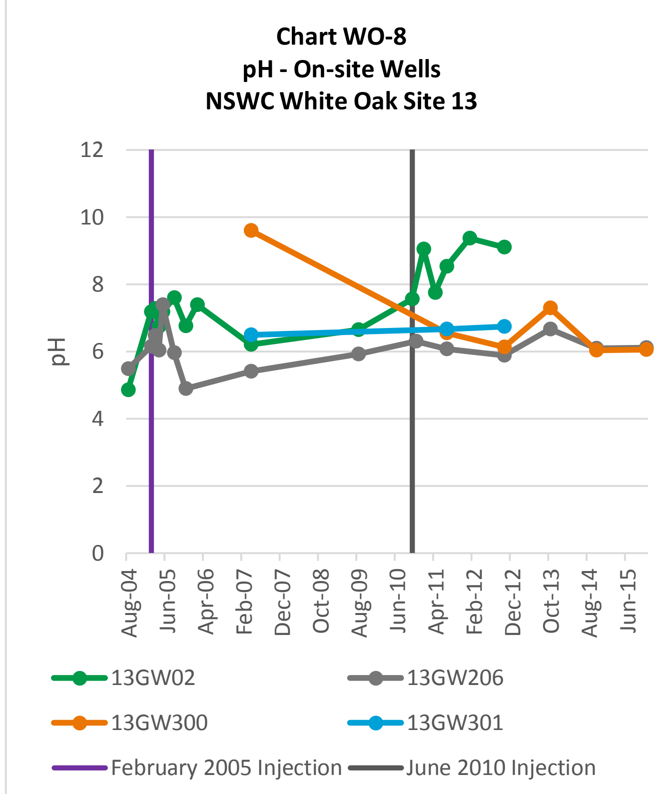


Chart WO-8
pH - On-site Wells
NSWC White Oak Site 13
pH
0
2
4
6
8
10
12
Aug-04
Jun-05
Apr-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12
Dec-12
Oct-13
Aug-14
Jun-15
13GW02
13GW206
13GW300
13GW301
February 2005 Injection
June 2010 Injection

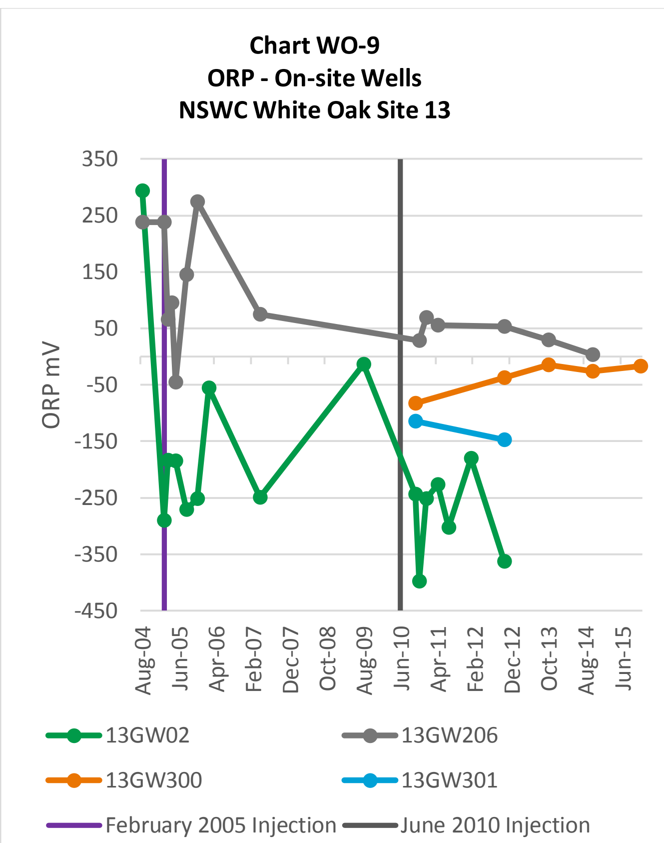


Chart WO-9
ORP - On-site Wells
NSWC White Oak Site 13
ORP mV
350
250
150
50
-50
-150
-250
-350
-450
Aug-04
Jun-05
Apr-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12
Dec-12
Oct-13
Aug-14
Jun-15
13GW02
13GW206
13GW300
13GW301
February 2005 Injection
June 2010 Injection

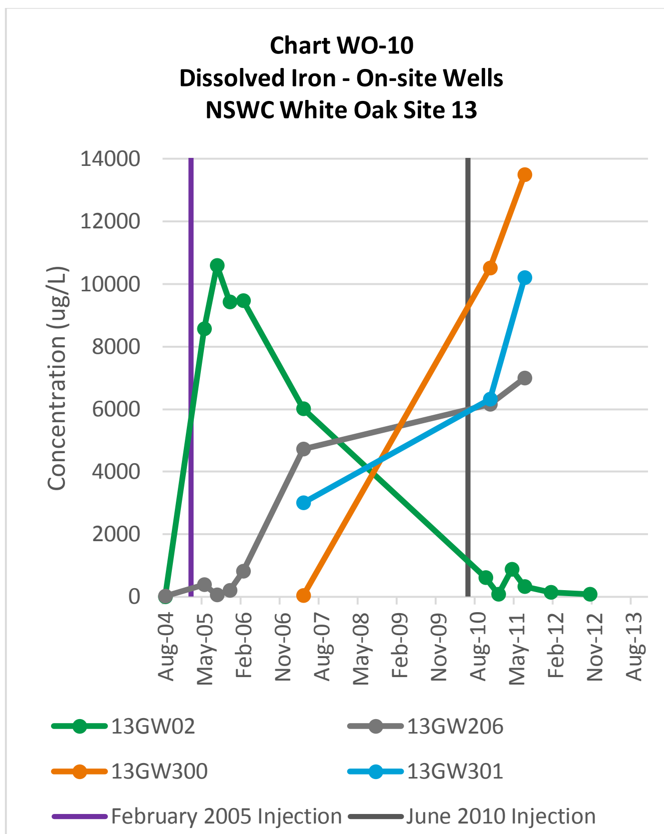
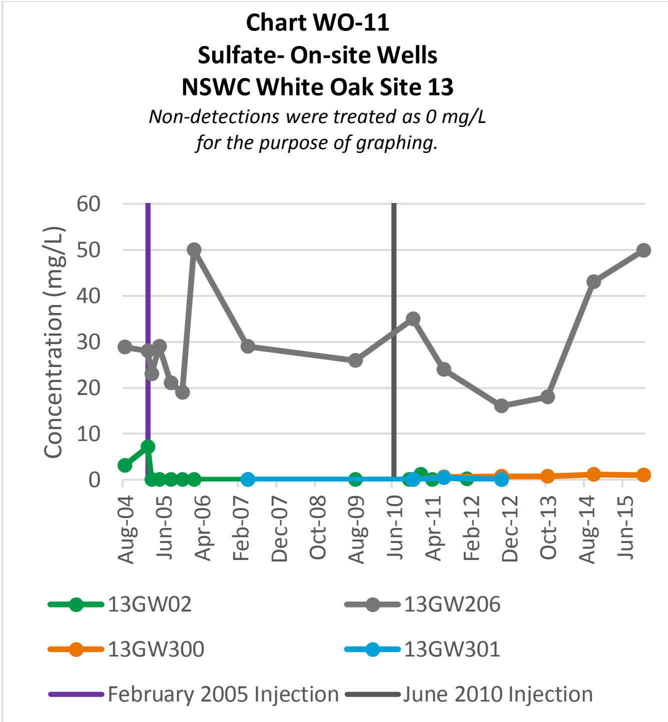
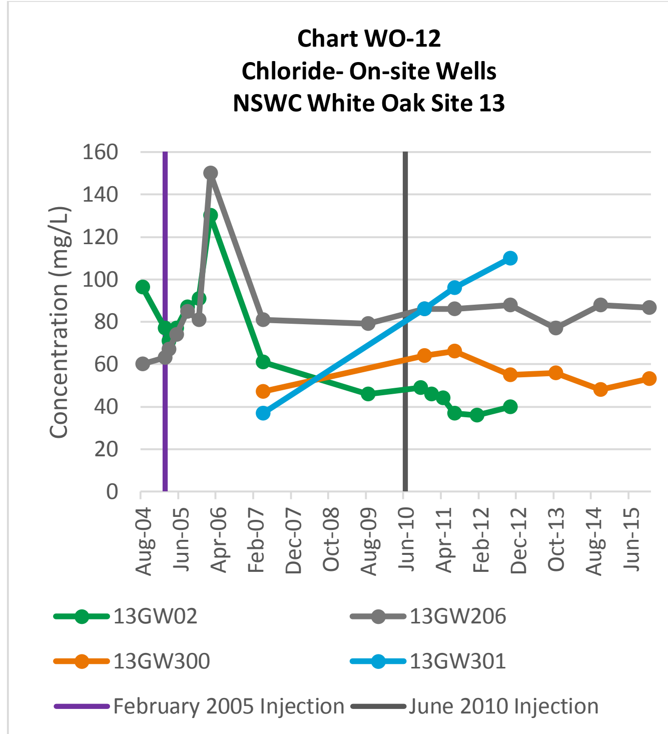
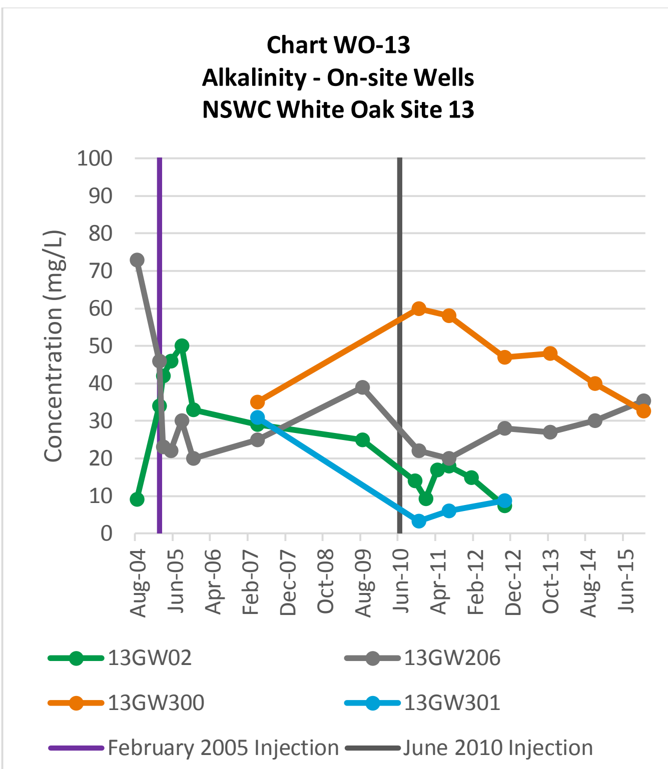
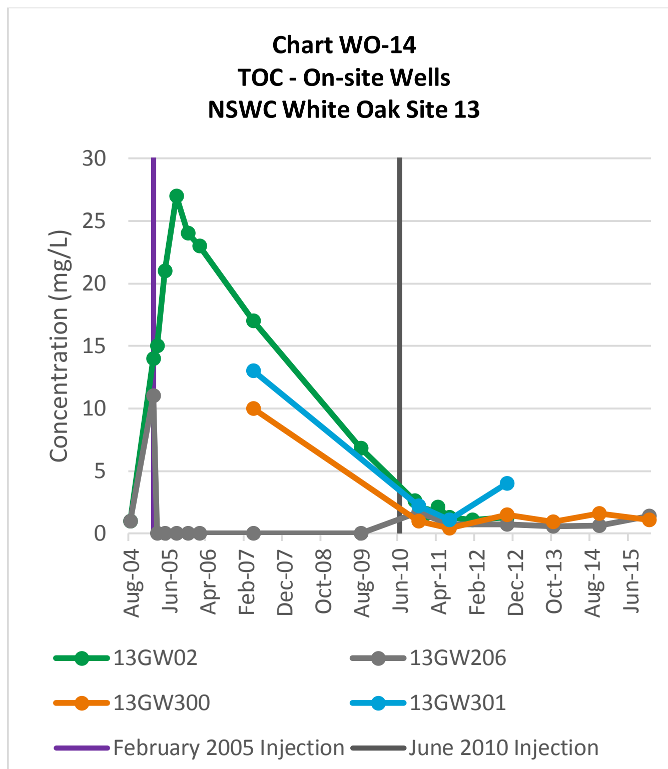


Chart WO-10
Dissolved Iron - On-site Wells
NSWC White Oak Site 13
Concentration (ug/L)
0
2000
4000
6000
8000
10000
12000
14000
Aug-04
May-05
Feb-06
Nov-06
Aug-07
May-08
Feb-09
Nov-09
Aug-10
May-11
Feb-12
Nov-12
Aug-13
13GW02
13GW206
13GW300
13GW301
February 2005 Injection
June 2010 Injection



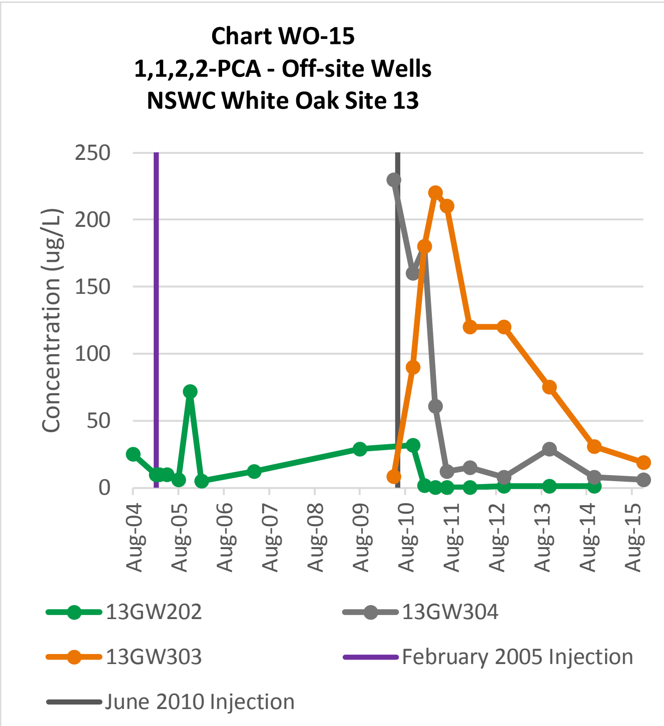


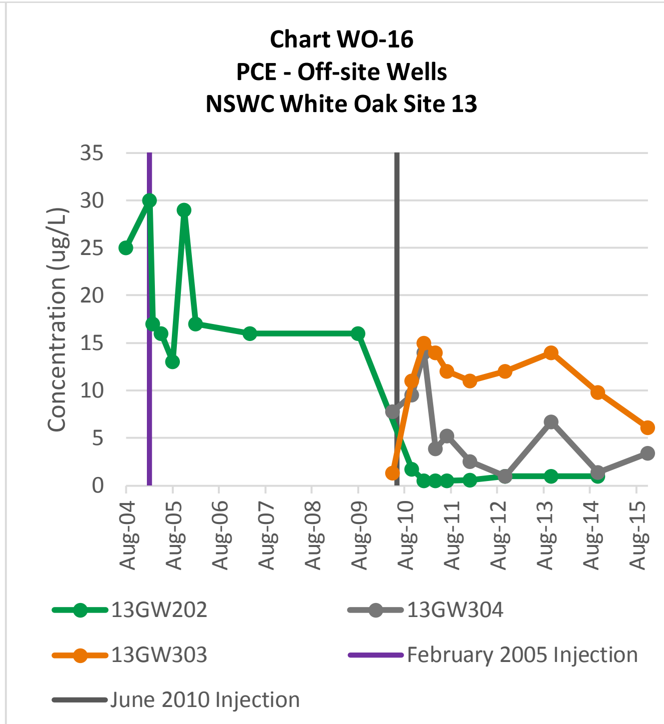




4.6 Offsite Treatment Area

Concentrations of COCs were reduced in most wells in the off-site treatment area following the 2010 injections, but only clean up goals (MCLs) were only achieved in one of the wells monitored, 13GW202. While concentrations in this well initially increased, they subsequently decreased substantially (**Charts WO-15 through WO-20**). Modest decreases in ORP and DO were observed in off-site wells, with optimal DO values of less than 1 mg/L and ORP values of less than -300 mV not achieved in any off-site wells (**Charts WO-21 and WO-23**). The most significant decreases in ORP were observed in samples from 13GW202, which is also the well that demonstrated the greatest decreases in VOC concentrations. Small increases in pH were observed immediately following the 2010 injections, but conditions have since returned to baseline in all wells with the exception of 13GW202 (**Chart WO-22**). Similarly, dissolved iron concentrations increased in samples from all three off-site wells following the 2010 injection, but have returned to baseline concentrations, or lower in subsequent events (**Chart WO-24**). Sulfate concentrations decreased in all three off-site wells, indicating sulfate-reducing conditions were achieved (**Chart WO-25**). Chloride and alkalinity decreased in all off-site wells following treatment, inconsistent with expected results (**Charts WO-26 and WO-27**). Similar to the on-site treatment area, TOC concentrations increased following the 2010 injections in the off-site treatment wells, and have since returned to baseline (**Chart WO-28**).





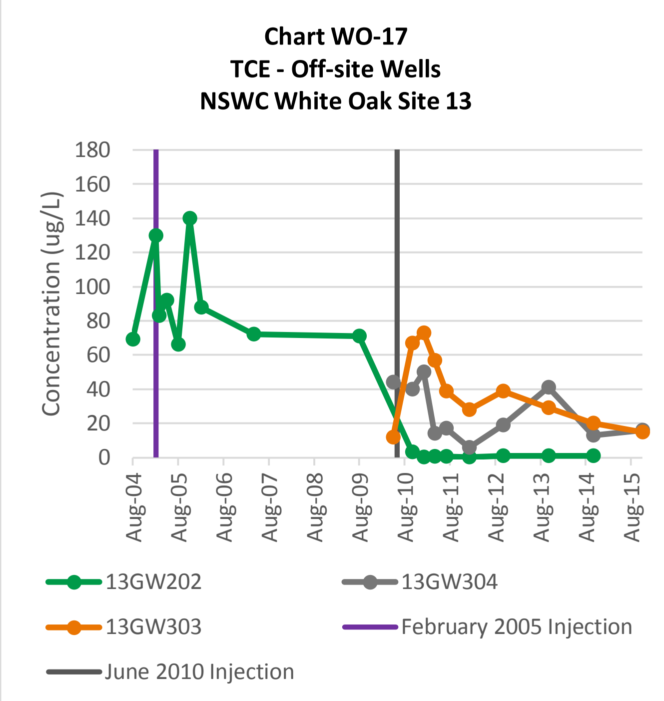


Chart WO-17
TCE - Off-site Wells
NSWC White Oak Site 13
Concentration (ug/L)
0
20
40
60
80
100
120
140
160
180
Aug-04
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Aug-11
Aug-12
Aug-13
Aug-14
Aug-15
13GW202
13GW304
13GW303
February 2005 Injection
June 2010 Injection

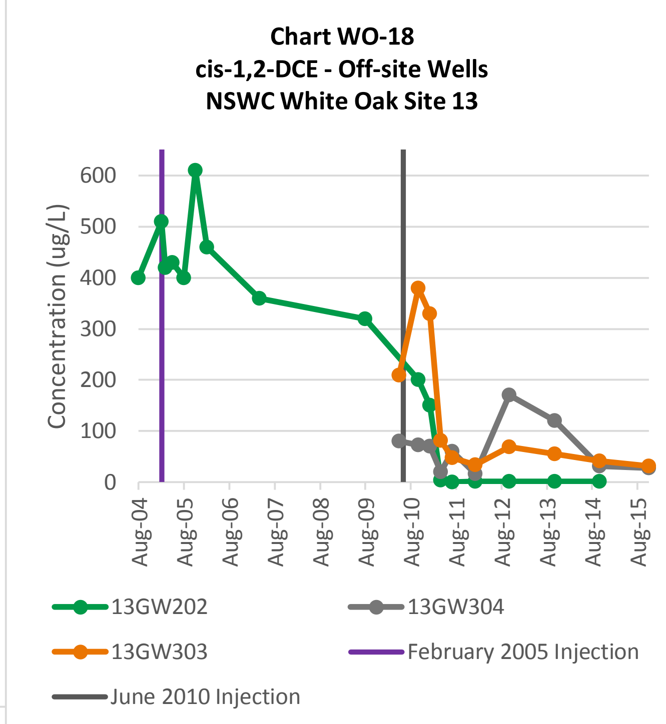


Chart WO-18
cis-1,2-DCE - Off-site Wells
NSWC White Oak Site 13
Concentration (ug/L)
0
100
200
300
400
500
600
Aug-04
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Aug-11
Aug-12
Aug-13
Aug-14
Aug-15
13GW202
13GW304
13GW303
February 2005 Injection
June 2010 Injection

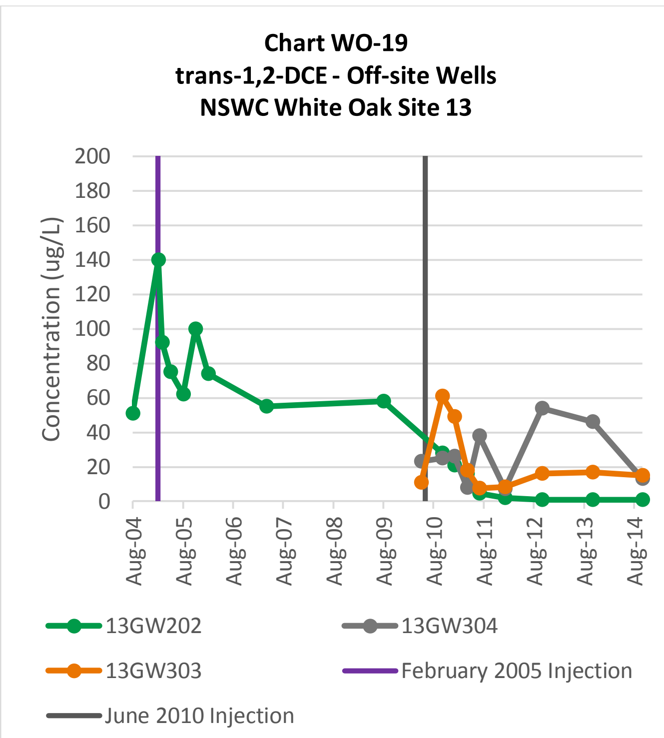


Chart WO-19
trans-1,2-DCE - Off-site Wells
NSWC White Oak Site 13
Concentration (ug/L)
0
20
40
60
80
100
120
140
160
180
200
Aug-04
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Aug-11
Aug-12
Aug-13
Aug-14
13GW202
13GW304
13GW303
February 2005 Injection
June 2010 Injection

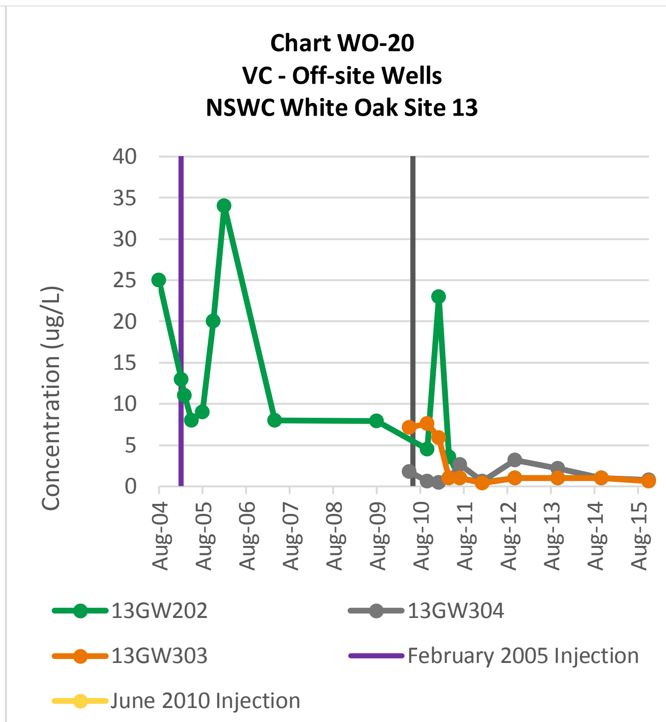


Chart WO-20
VC - Off-site Wells
NSWC White Oak Site 13
Concentration (ug/L)
0
5
10
15
20
25
30
35
40
Aug-04
Aug-05
Aug-06
Aug-07
Aug-08
Aug-09
Aug-10
Aug-11
Aug-12
Aug-13
Aug-14
Aug-15
13GW202
13GW304
13GW303
February 2005 Injection
June 2010 Injection

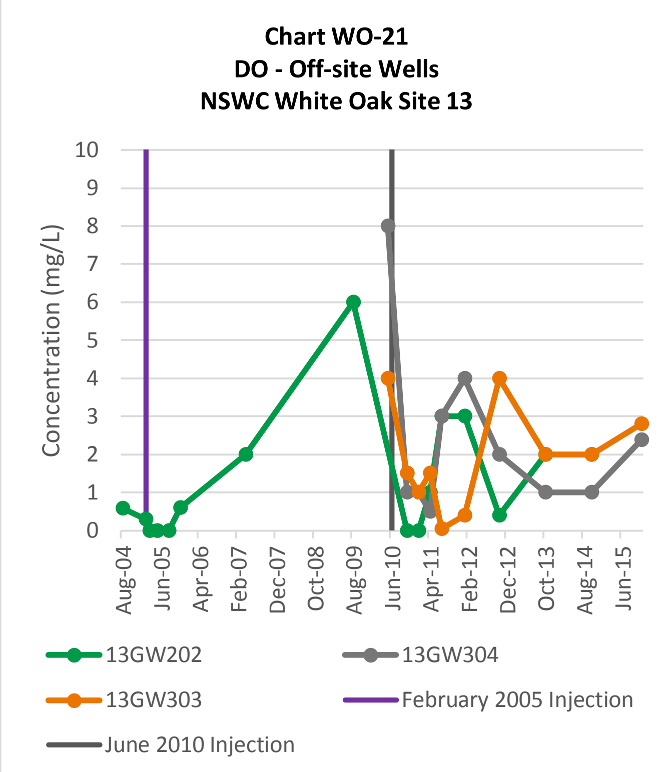


Chart WO-21
DO - Off-site Wells
NSWC White Oak Site 13
Concentration (mg/L)
10
9
8
7
6
5
4
3
2
1
0
Aug-04
Jun-05
Apr-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12
Dec-12
Oct-13
Aug-14
Jun-15
13GW202
13GW304
13GW303
February 2005 Injection
June 2010 Injection

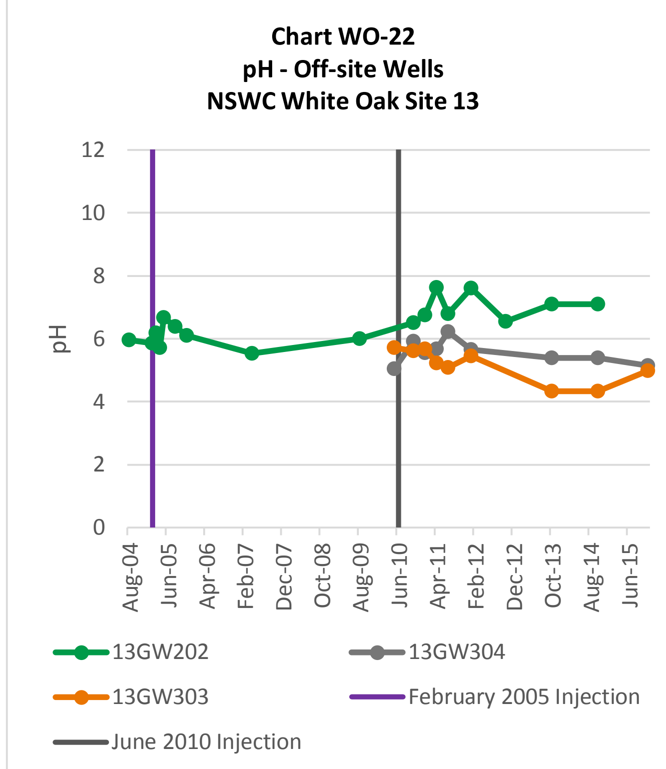


Chart WO-22
pH - Off-site Wells
NSWC White Oak Site 13
pH
12
10
8
6
4
2
0
Aug-04
Jun-05
Apr-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12
Dec-12
Oct-13
Aug-14
Jun-15
13GW202
13GW304
13GW303
February 2005 Injection
June 2010 Injection

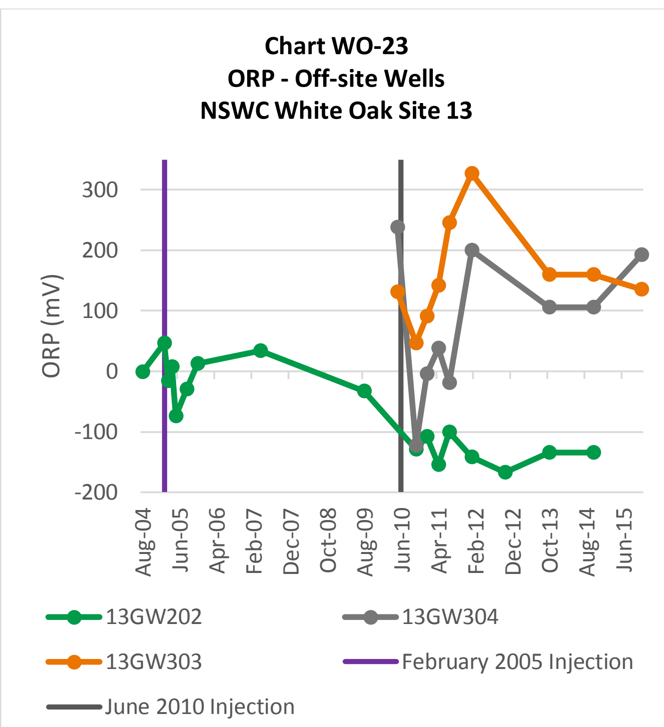


Chart WO-23
ORP - Off-site Wells
NSWC White Oak Site 13
ORP (mV)
300
200
100
0
-100
-200
Aug-04
Jun-05
Apr-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12
Dec-12
Oct-13
Aug-14
Jun-15
13GW202
13GW304
13GW303
February 2005 Injection
June 2010 Injection

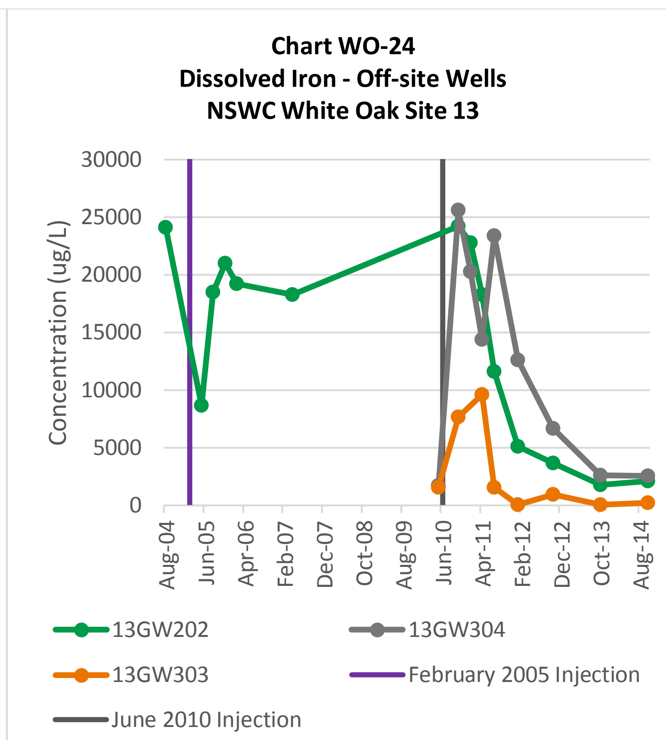
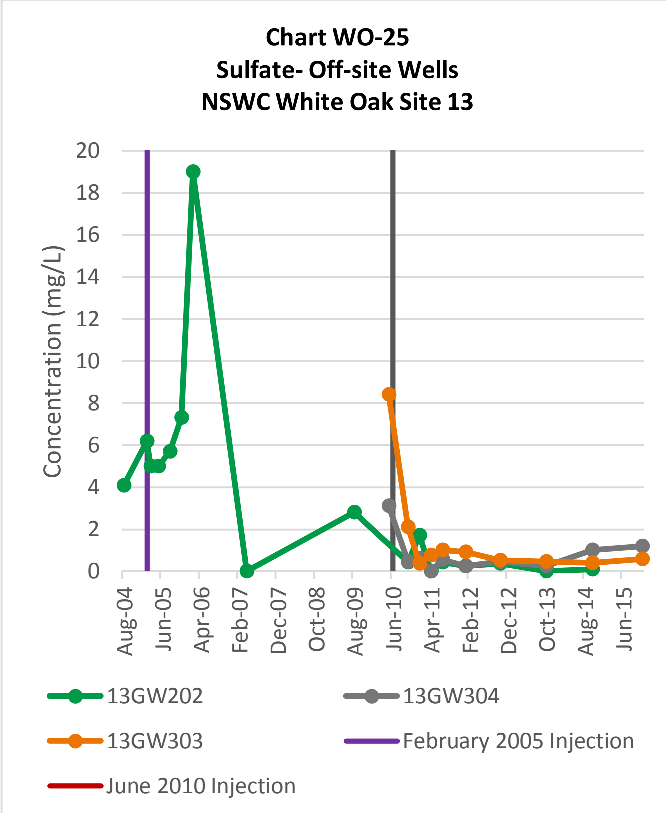
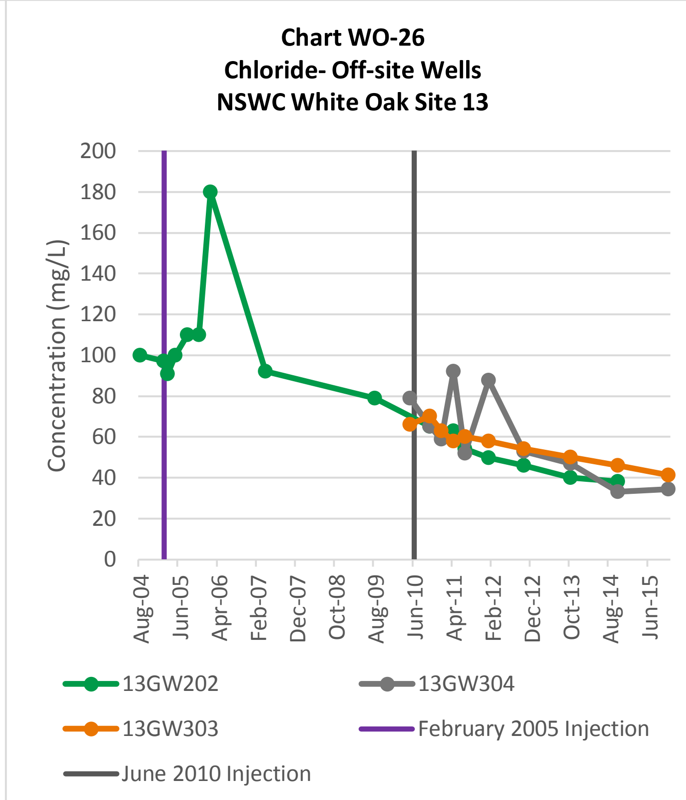
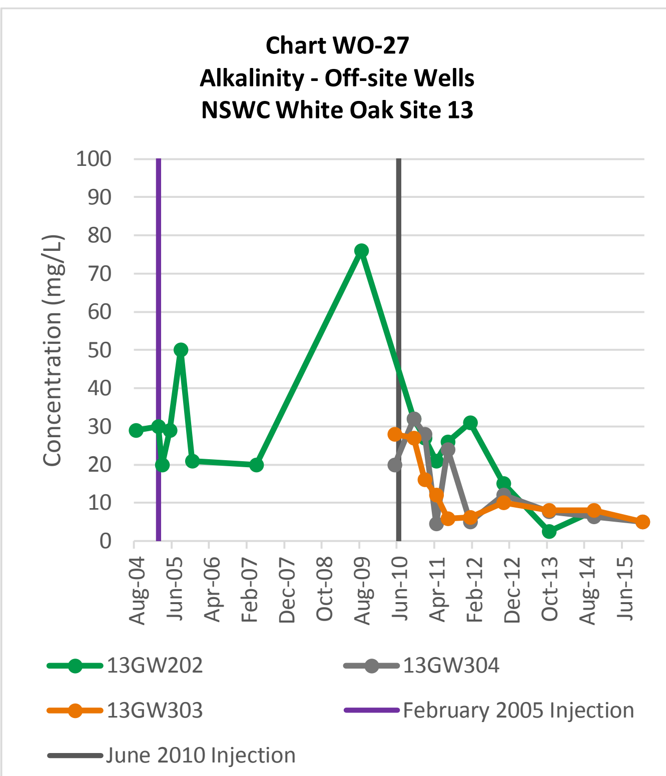
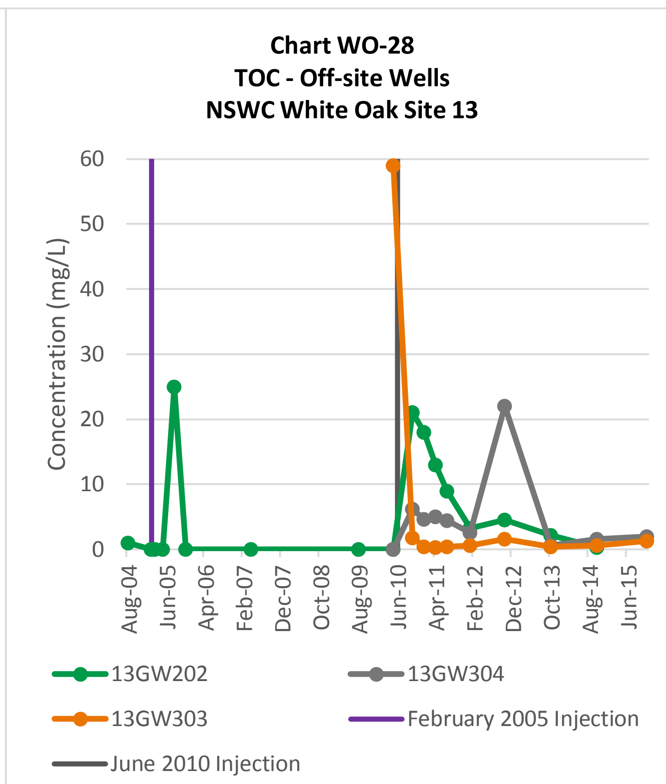


Chart WO-24
Dissolved Iron - Off-site Wells
NSWC White Oak Site 13
Concentration (ug/L)
30000
25000
20000
15000
10000
5000
0
Aug-04
Jun-05
Apr-06
Feb-07
Dec-07
Oct-08
Aug-09
Jun-10
Apr-11
Feb-12
Dec-12
Oct-13
Aug-14
13GW202
13GW304
13GW303
February 2005 Injection
June 2010 Injection









4.7 White Oak Site 13 Changes in Groundwater Flow

Groundwater flow maps from 2000 and 2015 are included in **Appendix B**. Based on these maps, no notable change in groundwater flow is noted due to injection operations. However, the well network is limited.

5 Savannah Air National Guard Base, Site 8, Garden City, Georgia

5.1 SANG Site 8 Site History

SANG is located in the northeast coastal region of Georgia, approximately 8 miles northwest of the City of Savannah in Garden City, Georgia. SANG is located adjacent to the eastern edge of the Savannah International Airport (SIA) (**Figure SV-1**). Property north and northwest of the airport is largely undeveloped and a substantial amount of this land is used for agricultural and commercial forest purposes. Commercial and limited residential developments occupy some of the land to the south. To the east and southeast, the Seaboard Coast Line and Central of Georgia Railroads occupy the majority of the land. Taxiways, along with approximately 180 buildings serving administrative and industrial purposes, comprise the SANG. The industrial buildings include aircraft hangars, vehicle maintenance and bulk fuel storage facilities, and other mission-support infrastructure. The SANG shares use of two runways with the SIA (ANG, 2008).

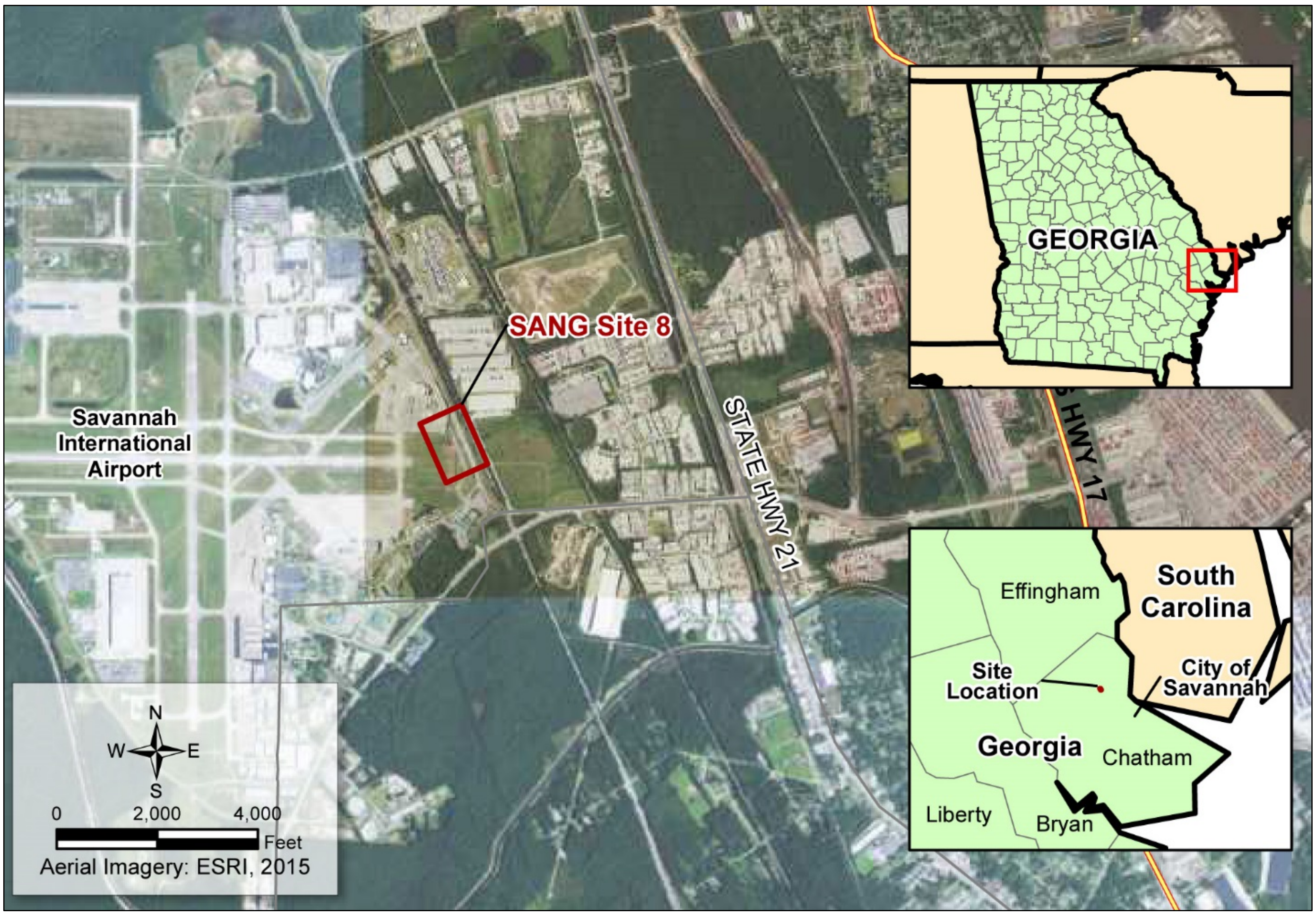


Figure SV-1. SANG Site 8 Location Map

Site 8, the Old 165th Aircraft Washrack, is located on the eastern edge of the SIA. The former aircraft washrack was used from 1961 to 1983 for aircraft degreasing and painting. During operations, wastewater from the washrack was collected into a storm drain and discharged to an adjacent drainage ditch. Anecdotal evidence suggests that during the course of operation at Site 8, detergents, paints, PD-680, TCE, and trichloroethane (TCA) were used at the site at an estimated rate of 40 gallons per month (estimated total discharge of 11,000 gallons). Spent solvents were collected in storm drains and discharged directly into an adjacent drainage ditch. Because a low-lying area surrounds the washrack/apron area, discharge runoff has historically been a pathway of concern (ANG, 2008).

5.2 SANG Site 8 Physical and Hydrogeologic Setting

The surficial aquifer at Site 8 is composed of undifferentiated deposits of silt, sand, and clay. Depth to water is between 2 to 10 feet bgs. The aquifer is approximately 80 feet thick at SANG and is bounded at the bottom by the Hawthorn Group, which is approximately 120 feet thick and acts as a confining unit (**Figure SV-2**). Underlying the Hawthorn Group is the Floridan aquifer. The Floridan aquifer is the principal aquifer system in the Savannah area; most industrial and municipal water users rely on it for water supply. Cross sections are provided in **Appendix A**.

Groundwater flow is to the east in the western portion of the site and to the south in the eastern portion of the site (**Figure SV-2**). Based on an average hydraulic gradient of 0.017 feet per foot, an assumed effective porosity of 0.30, and a hydraulic conductivity of 1.79 feet per day, the average seepage velocity is estimated to be 0.10 feet per day, or 37 feet per year.

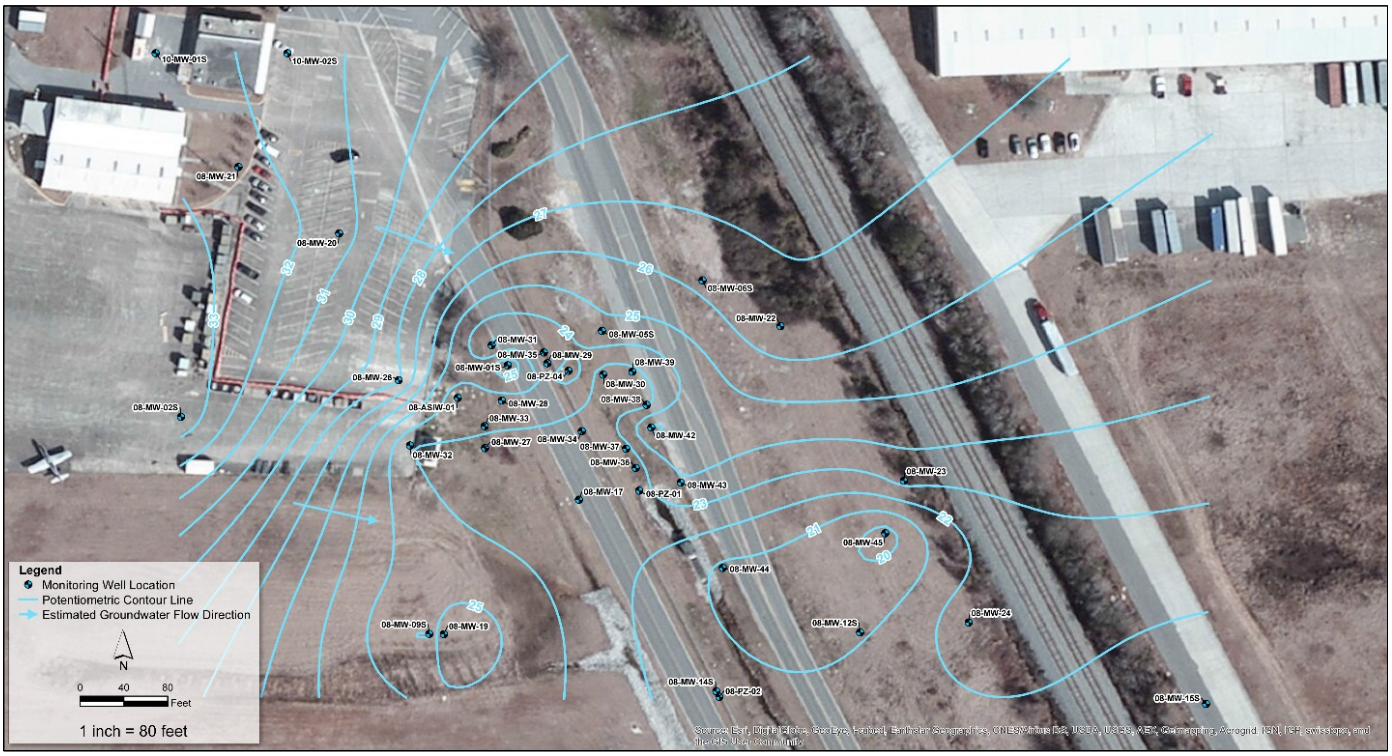


Figure SV-2. SANG Site 8 Groundwater Contour Map (2015)

5.3 SANG Site 8 Contaminant Distribution Prior to Treatment

The VOC plume at Site 8 originates in the southeast corner of the parking lot at the site near the storm drain which is a suspected source. Prior to any treatment, concentrations of numerous VOCs exceeded MCLs: TCE (maximum concentration of 100,000 µg/L), cis-1,2-DCE (maximum concentration of 86,000 µg/L), VC (maximum concentration of 3,900 µg/L), and 1,1,1-TCA (maximum concentration of 1,300 µg/L) were the primary contaminants. Baseline total VOC concentrations (before any type of treatment) are shown on **Figure SV-3**.

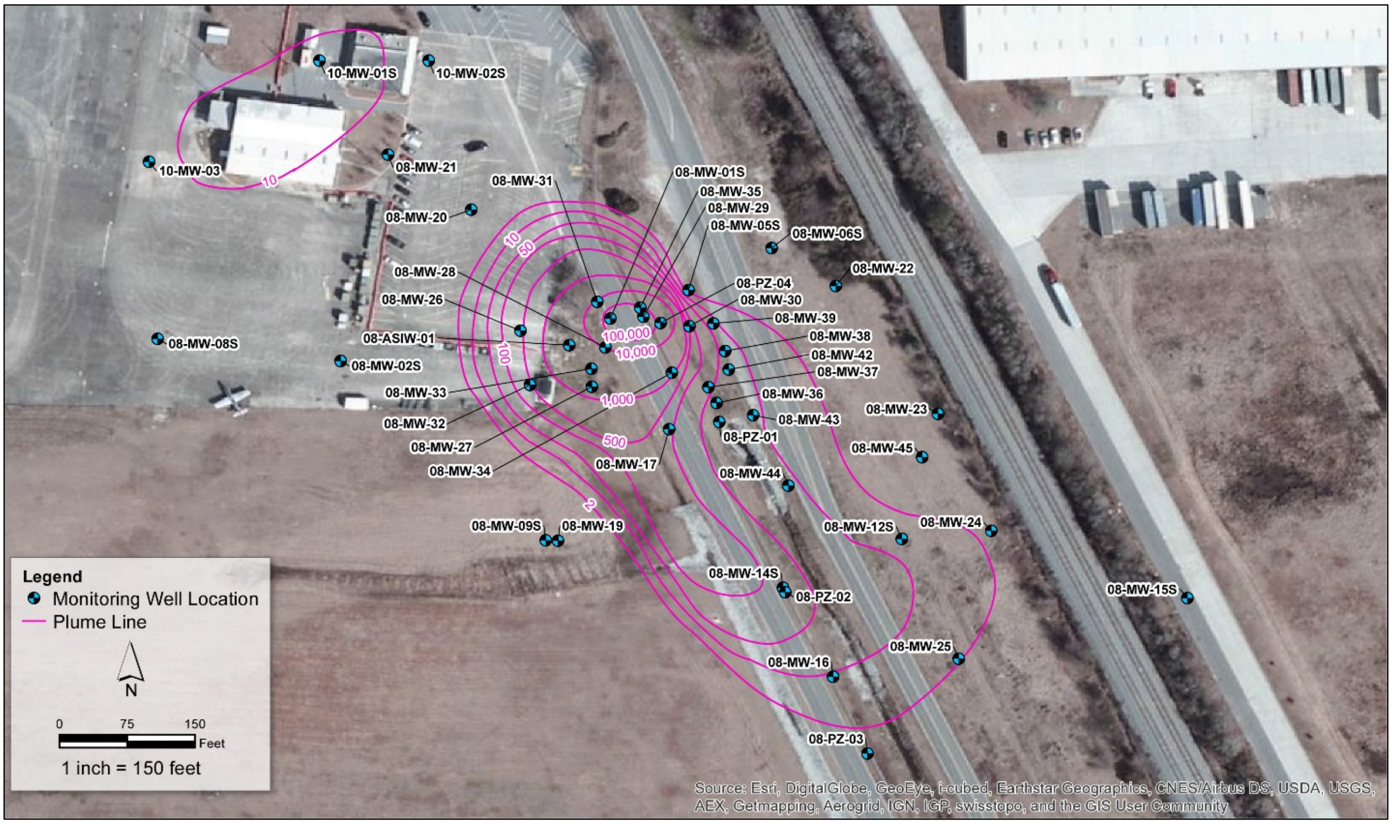


Figure SV-3. SANG Site 8 Total VOC Plume (2008-2010)

5.4 SANG Site 8 Treatment Area and Desktop Review

A number of treatments have been implemented at Site 8. The original remedy for groundwater at the site consisted of air sparging/soil vapor extraction (AS/SVE) in the source area with in situ bioremediation using emulsified vegetable oil with bioaugmentation culture, and pH buffer along the perimeter of the plume and also in the source zone after completion the AS/SVE. These initial treatments began in 2008. Although significant reduction in VOC concentrations were achieved within the source zone by the completion of AS/SVE followed by in situ bioremediation, residual concentrations were not anticipated to reach risk reduction standards (RRS) within a reasonable time after completion of the source zone remedies. Therefore, additional in situ treatment with ZVI was planned. Three rounds of ZVI treatment were completed using pneumatic fracturing methodology. During the first injection in February 2011, 6,350 lbs of powdered ZVI and 192 lbs of EVO were injected into nine fracturing and injection points. Iron dosage was based on 0.4 percent (lbs of ZVI per lb of soil). During the second injections in November/December 2011, additional injections were completed around 08-PZ-04 and 14,000 lb of ZVI and 9,700 lbs of EHC were injected through 13 points. The final injection was completed in February 2012. 1,900 lbs of ZVI and 2,800 lbs of EHC were injected into 12 locations during that effort. Injection points are shown on **Figure SV-4**.

Wells included in the desktop review are tabulated in **Table SV-1** and shown on **Figure SV-4**.

Table SV-1. Wells Included in Desktop Review for SANG Site 8

Source Area	08-MW01S, 08-MW18, 08-MW17
Downgradient	08-MW28

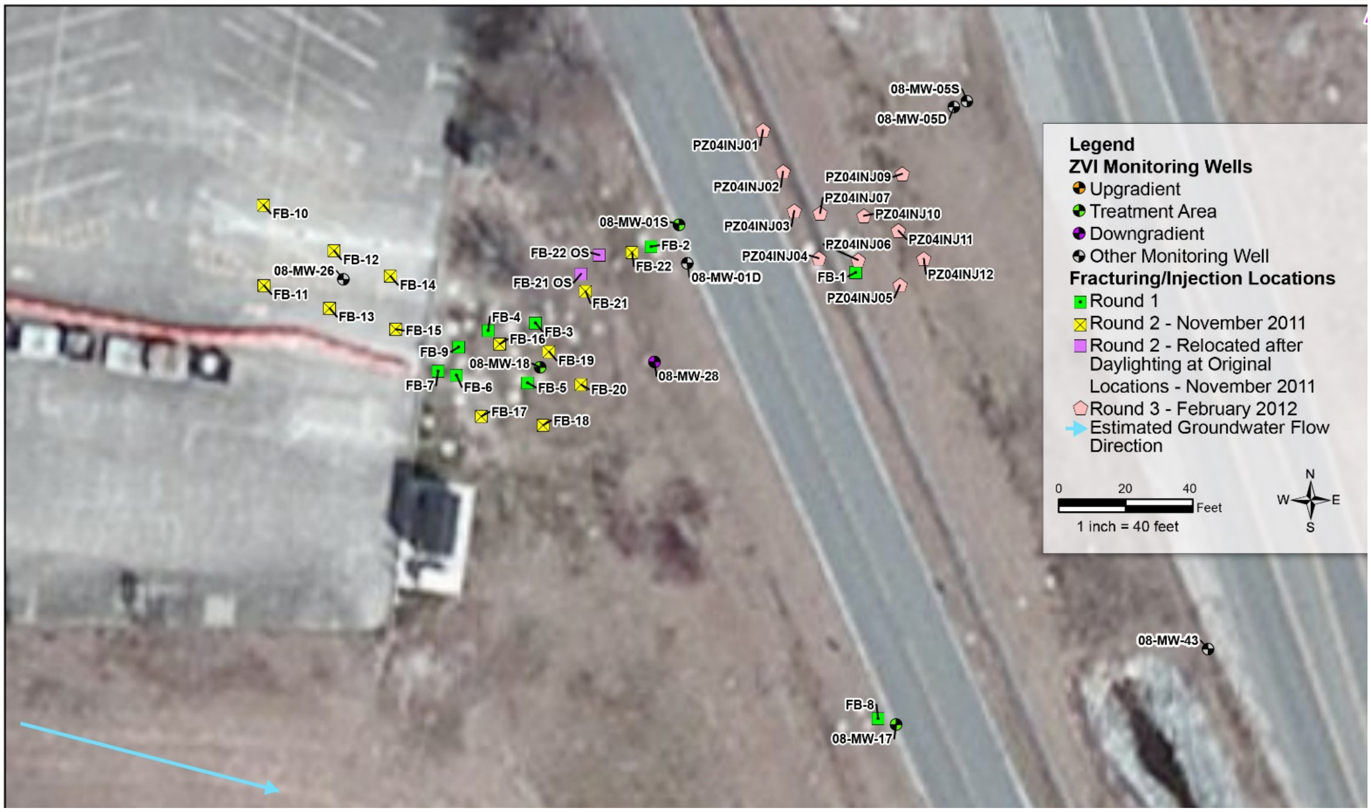


Figure SV-4. SANG Site 8 Treatment Area and Wells Included in Desktop Review

5.5 SANG Site 8 Desktop Evaluation Results

This section represents an evaluation of the performance of the ZVI treatment (reduction in VOC concentrations) and groundwater geochemistry changes created by the ZVI treatment in the injection areas.

5.5.1 SANG Site 8 Baseline Groundwater Conditions

No specific baseline event was completed for the ZVI injections at Site 8. However, the event preceding the initiation of the February 2011 injections was used as baseline data for each selected well (Date ranges from December 2008 through December 2010). A summary of pre-treatment key field parameters is provided in **Table SV-2**.

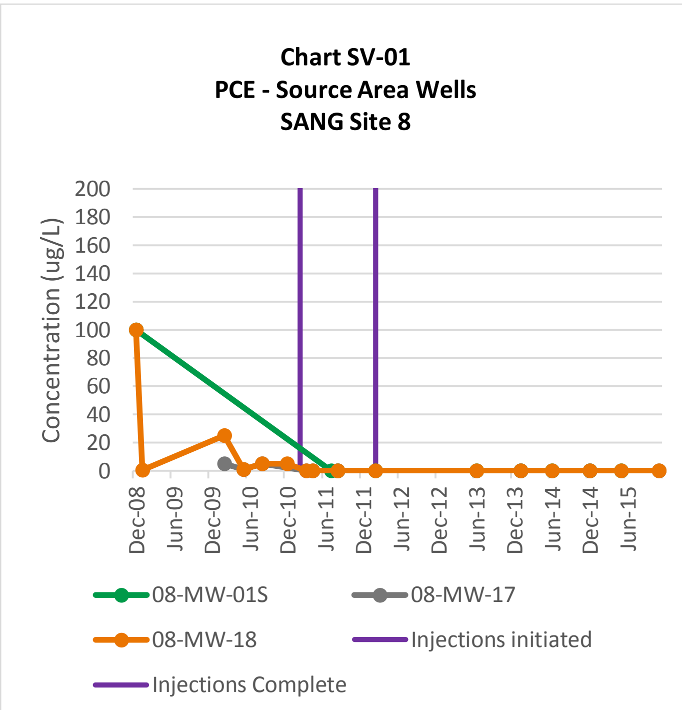
The pre-treatment results indicate the following baseline conditions for the treatment area of the site:

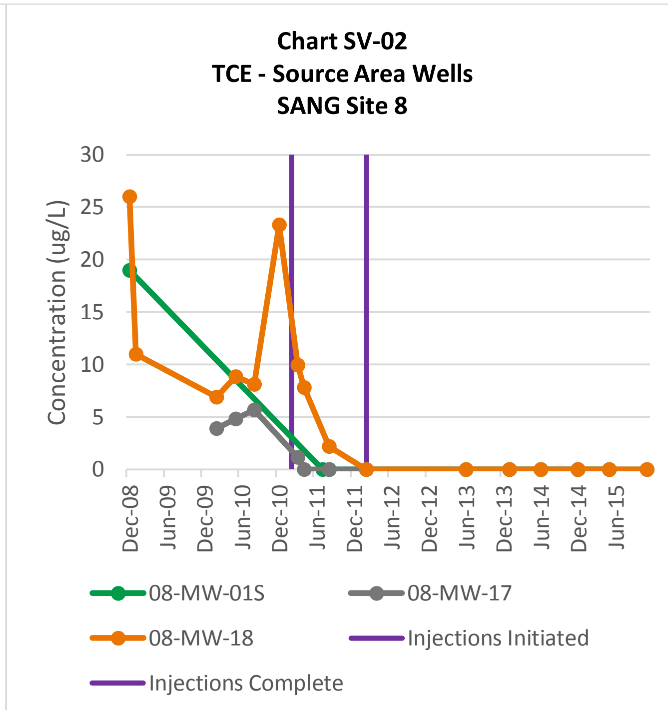
- DO concentrations ranged from 0.32 mg/L to 0.63 mg/L
- pH ranged from 4.02 to 4.76
- ORP ranged from -68.1 mV to -143 mV

These results indicate the treatment area of the site was under reducing and acidic conditions prior to treatment. The reducing conditions may be a result of the previous EVO injections in the area. The VOC detected at the highest concentration at the site was cis-1,2-DCE which was detected at a maximum concentration of 1,200 D µg/L (08MW01S). While PCE, TCE, trans-1,2-DCE, and VC were also detected, concentrations were generally an order of magnitude or more lower than the maximum cis-1,2-DCE concentration (**Table SV-2**).

5.5.2 SANG Site 8 Effectiveness of ZVI Injections for Treating COCs

Baseline and the most recent post-injection VOC data available for each well (May or November 2015) are presented in **Table SV-2**. **Charts SV-1 through SV-5** show temporal trends for VOCs. Data indicate concentrations were decreasing prior to ZVI injections being initiated and continued to decrease following injections. VC was generated in 08-MW-01S, but concentrations subsequently were reduced to levels below reporting limits. Overall, the injections, possibly in conjunction with previous treatments, were effective in reducing concentrations in samples from all source area locations. While no obvious downward trend in DO concentrations was observed, concentrations generally remained less than 1 mg/L throughout the post-treatment monitoring period (**Chart SV-6**). pH was increased following ZVI injections, which may have increased the degree of biological degradation occurring (**Chart SV-7**). ORP values decreased, but ideal levels, less than -400 mV (based on Gavaskar, 2005) were not achieved. Concentrations in downgradient well 08MW28 remained less than MCLs throughout the monitoring period, indicating no downward migration occurred.





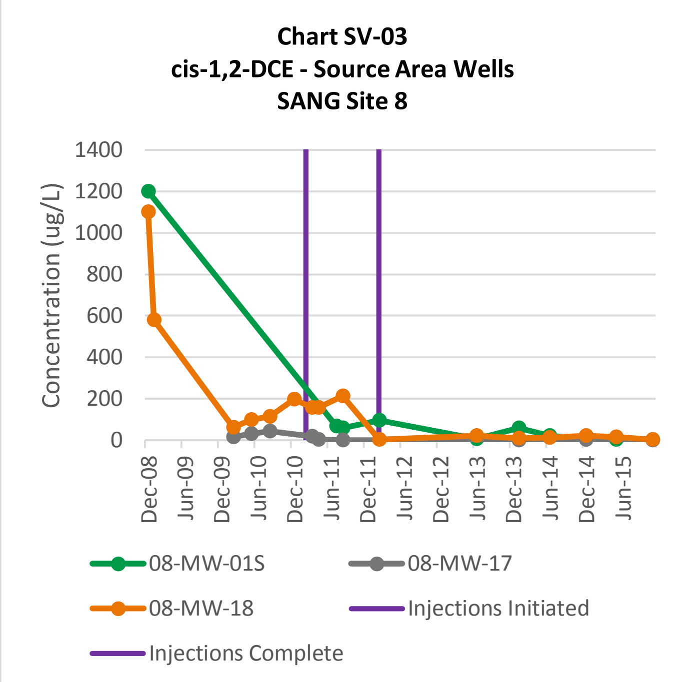


Chart SV-03
cis-1,2-DCE - Source Area Wells
SANG Site 8
Concentration (ug/L)
1400
1200
1000
800
600
400
200
0
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
08-MW-01S
08-MW-17
08-MW-18
Injections Initiated
Injections Complete

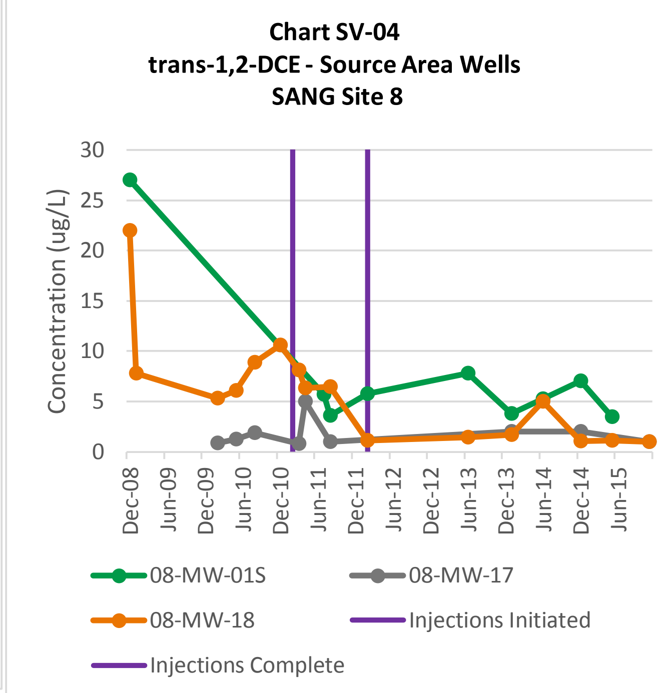


Chart SV-04
trans-1,2-DCE - Source Area Wells
SANG Site 8
Concentration (ug/L)
30
25
20
15
10
5
0
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
08-MW-01S
08-MW-17
08-MW-18
Injections Initiated
Injections Complete

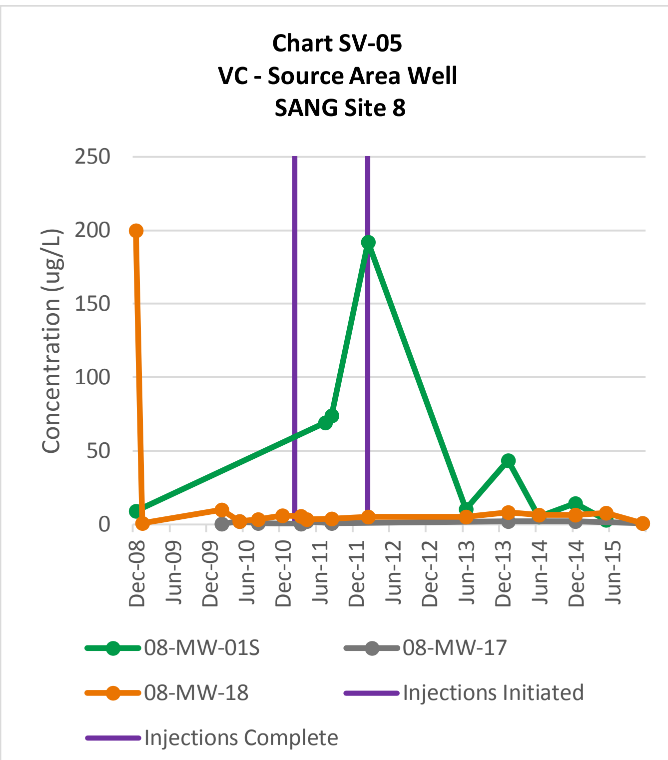


Chart SV-05
VC - Source Area Well
SANG Site 8
Concentration (ug/L)
250
200
150
100
50
0
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
Jun-15
08-MW-01S
08-MW-17
08-MW-18
Injections Initiated
Injections Complete

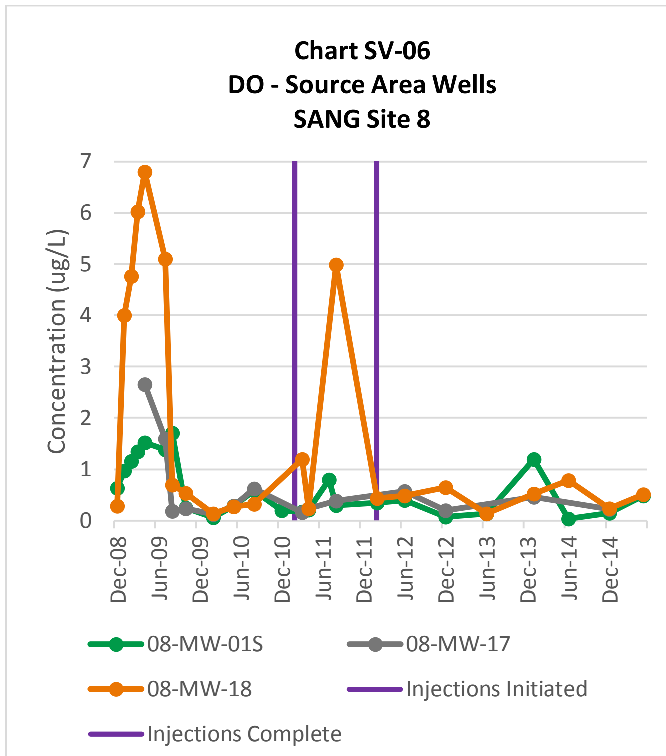
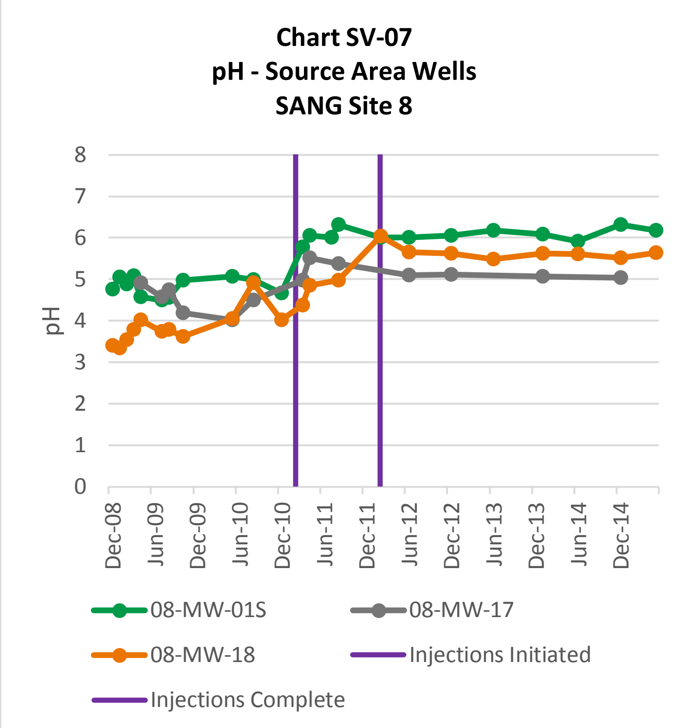
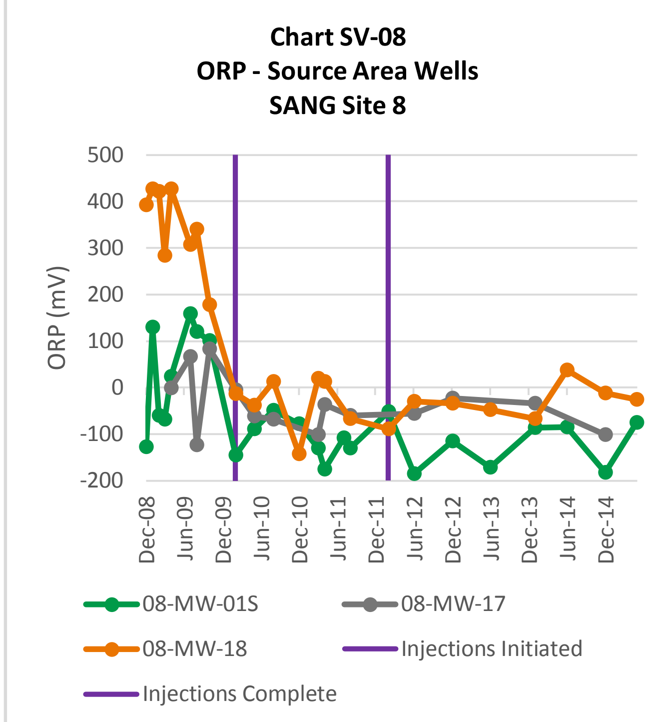


Chart SV-06
DO - Source Area Wells
SANG Site 8
Concentration (ug/L)
7
6
5
4
3
2
1
0
Dec-08
Jun-09
Dec-09
Jun-10
Dec-10
Jun-11
Dec-11
Jun-12
Dec-12
Jun-13
Dec-13
Jun-14
Dec-14
08-MW-01S
08-MW-17
08-MW-18
Injections Initiated
Injections Complete





5.6 SANG Site 8 Changes in Groundwater Flow

Groundwater flow maps from 2008, 2011, and 2015 are included in **Appendix B**. Based on evaluation of flow over time, there appears to be some mounding in the vicinity of the ZVI injections, but it is not clear whether or not this could be due to the ZVI treatment. No aquifer testing was completed to evaluate potential loss of hydraulic conductivity over time in the area.

6 Arnold AFB SWMU 16, Manchester, Tennessee Background

6.1 Arnold AFB Site 8 History

Arnold AFB is located in south-central Tennessee, straddling the boundaries of Coffee and Franklin Counties (**Figure AA-1**). Arnold AFB houses the Arnold Engineering Development Complex, where research and development is conducted for the United States Air Force (USAF), Department of Defense (DoD), and other government agencies. SWMU 16 is a former leach/burn area located near the Retention Reservoir at the installation. It consisted of a 20-foot by 20-foot concrete pad and a 50-foot-long concrete ditch that discharged into a 20-foot-diameter soil depression. In the 1950s and 1960s, the site was used to transfer fuels between trucks, and to burn and leach small amounts of fuels and propellants. Chlorinated hydrocarbon solvents and fuels were released at SWMU 16 during operation of the waste transfer facility. The site is currently covered with grass and gravel, and adjacent areas are wooded. The site is bounded to the east by the Retention Reservoir and to the north by Crumpton Creek, which originates as seepage through the Retention Reservoir's earthen dam (**Figure AA-2**).

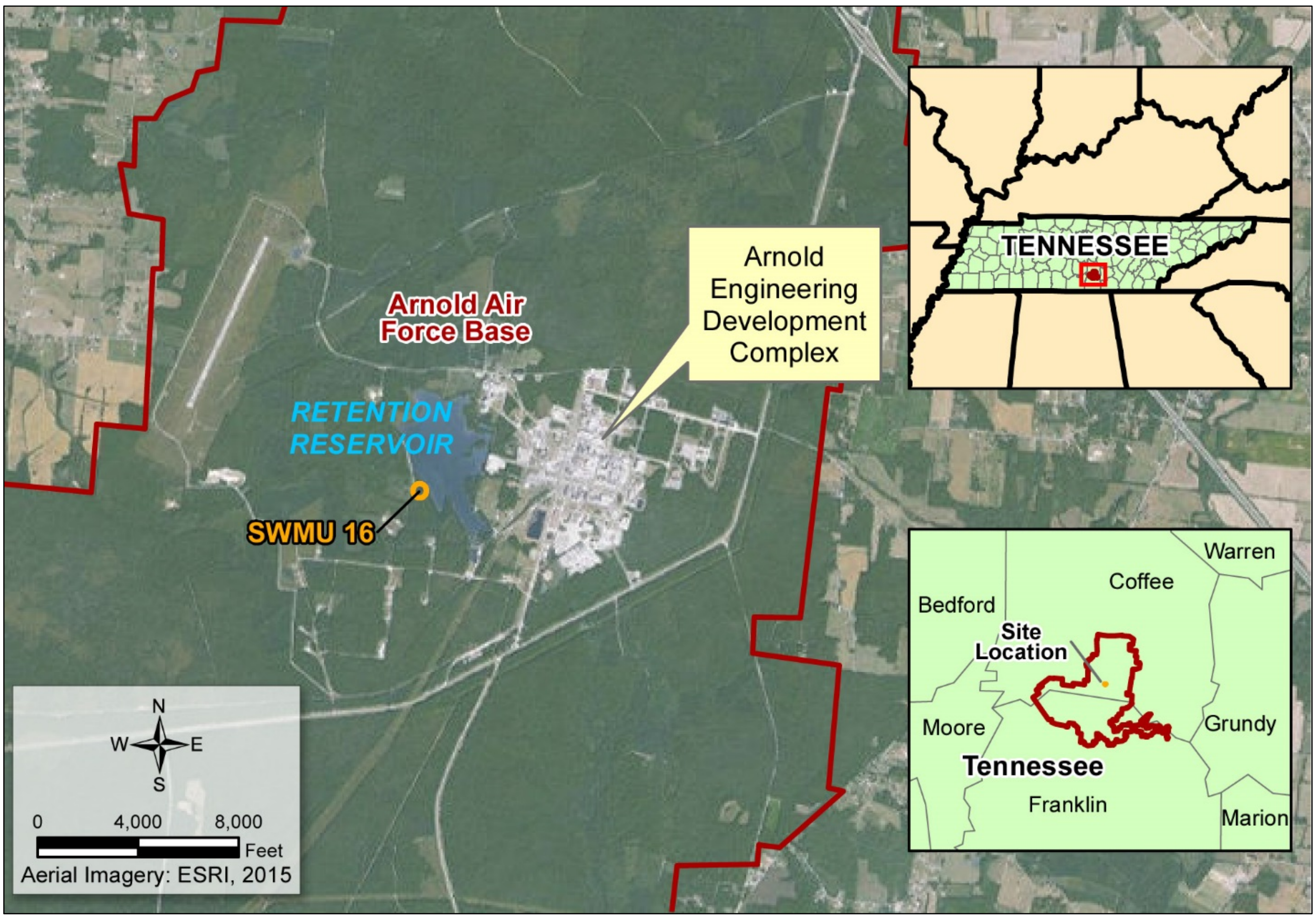


Figure AA-1. Arnold AFB SWMU 16 Location Map

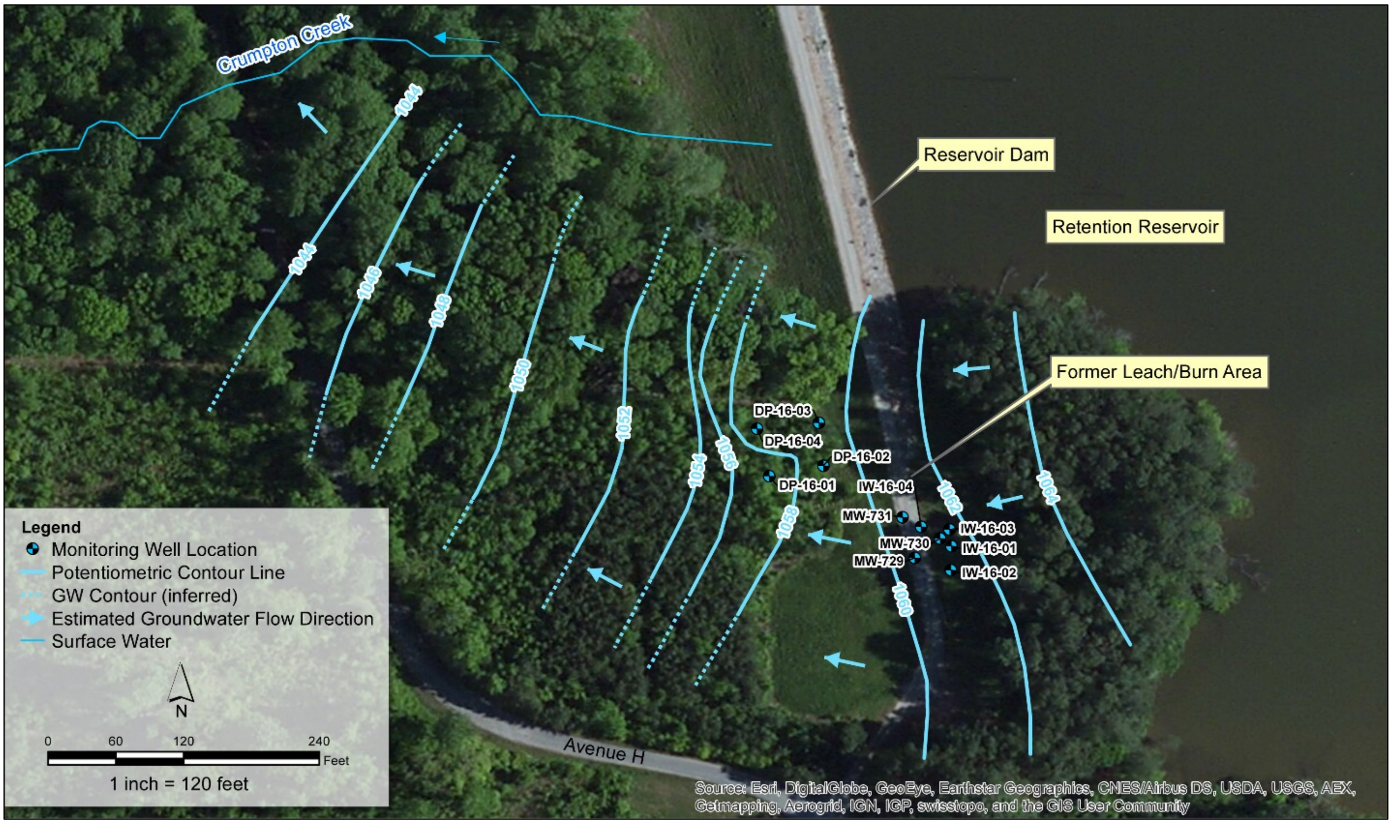


Figure AA-2. Arnold AFB SWMU 16 Groundwater Contour Map (2010)

6.2 Arnold AFB Site 8 Physical and Hydrogeologic Setting

The site is located at an elevation approximately 1,000 feet amsl. The ground surface slopes downward to the northwest from the site and descends approximately 30 feet in elevation over roughly 500 lateral feet before reaching Crumpton Creek below the base of the Retention Reservoir dam. SWMU 16 is underlain by approximately 70 to 90 feet of unconsolidated residual material consisting of silty clay, clayey sands, and clayey gravels. Depth to shallow groundwater is approximately 10 feet. The unconsolidated shallow aquifer overlies the Ft. Payne Limestone formation, present at roughly 70 to 90 feet bgs (**Appendix A**). The limestone is underlain by the Chattanooga Shale formation, which is approximately 30 feet thick beneath Arnold AFB. This shale is considered an aquitard, as well as the base of the Arnold AFB aquifer system.

Groundwater near the SWMU follows an approximate 600-foot flow path to the northwest (**Figure AA-2**). It begins as recharge near the former leach/burn area, extends downward to the upper portion of the intermediate aquifer, and returns to the surface near Crumpton Creek just below the Retention Reservoir dam. Deep and intermediate wells (> 30 feet bgs) in the unconsolidated over burden located near Crumpton Creek are often under artesian conditions, supporting this upward groundwater flow potential and discharge within the area of the creek. Groundwater velocity was estimated at 0.2 feet per day or 81 feet per year, based on a gradient of 0.013 feet per foot and a hydraulic conductivity of 4.25 feet per day.

6.3 Arnold AFB Site 8 Contaminant Distribution Prior to Treatment

The primary contaminants at SWMU 16 are VOCs and nitrate/nitrite. The nitrate/nitrites are present at the site as a result of a treatment completed in the 1990s to treat soils contaminated with benzene, toluene, ethylbenzene, and xylenes (BTEX) beneath the leach/burn area. Soil was excavated to the water table (approximately 15 feet) and then soil was biologically treated by mixing with chicken manure, wood shavings, and white rot fungus. The treated soil was then returned to the excavation. This treatment was effective in reducing BTEX concentrations in the soil to values at or below the detection limits, but the use of the chicken manure resulted in groundwater nitrate/nitrite as nitrogen (NO_3/NO_2-N) concentrations approaching 500 mg/L (CH2M HILL, 2006a).

The VOC plume at SWMU 16 extends from the source area near the Retention Reservoir approximately 500 feet to the northwest and discharges to Crumpton Creek through groundwater seeps. TCE is the most prevalent VOC in the plume. The highest measured concentrations (as high as 14,000 µg/L) were found in the shallow wells located near the source area (**Figure AA-3**) prior to the ZVI treatment (CH2M HILL, 2006b).

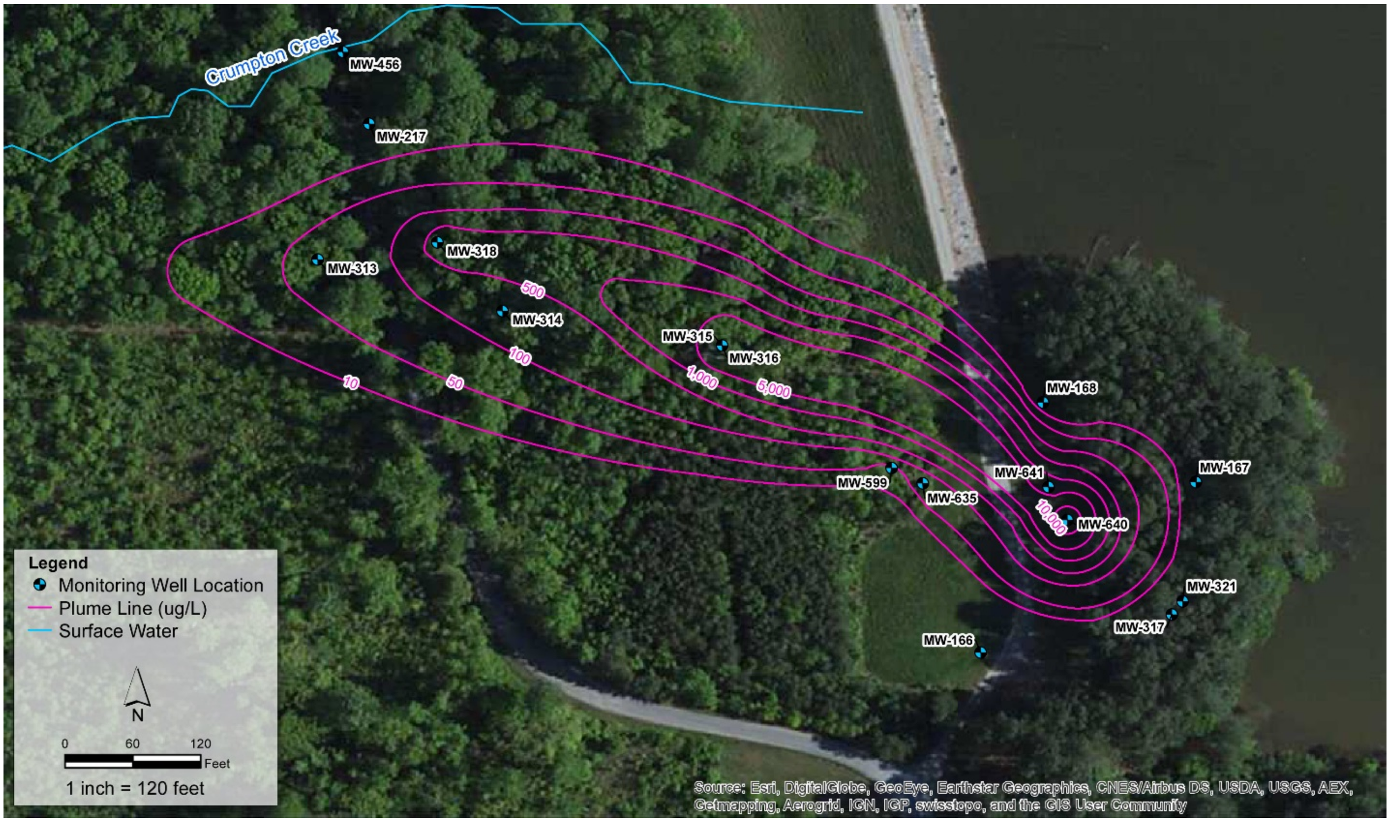


Figure AA-3. Arnold AFB SWMU 16 TCE Plume

6.4 Arnold AFB Site 8 Treatment Area and Wells Evaluated in Desktop Evaluation

Two ZVI treatability studies were conducted at SWMU 16. In May 2003, a pilot-scale Ferox ZVI treatability study was conducted to evaluate the effectiveness of ZVI emplaced using the Ferox process in destroying TCE and the effect of high NO_3/NO_2-N concentrations on that process (CH2M HILL, 2006a). During the injection process, nitrogen gas was used to first fracture the target zone to widen existing subsurface fractures and to create new ones. Upon fracture completion, the iron slurry (water and ZVI powder) was added to the nitrogen gas stream and carried to the subsurface, where it was impregnated into the matrix. Five injection borings were completed within the target treatment area (**Figure AA-4**). Packers were used to seal off the borehole and the injection vertical zone of influence was set at 2 ½ -foot increments. A total of 13,000 lbs of iron was injected into the subsurface based on an iron to TCE ratio of 2,000:1. This represents a dosage of approximately 0.2 percent (lbs of ZVI per lb of soil).

In 2005, a pilot-scale treatability study consisting of subsurface soil mixing with ZVI-bentonite gel injection was performed (EFS, Inc., 2006). The objective of this treatability study was to evaluate the effectiveness of the technology in destroying TCE and NO_3/NO_2-N in groundwater beneath the source area. A slurry of 2376-lb ZVI and 2970-lb bentonite was mixed onsite on a slurry mixing truck to treat each 100-cubic yard batch of soil (representing a dose of 0.8 percent). Slurry material was pumped with a slurry pump through a 4-inch line mounted on an excavator to fill cells. SWMU 16 was separated in cells which consisted of 10-foot by 10-foot, 15-foot deep areas. Each cell equaled approximately 55.55-cubic yards, with a mixing overlap of approximately 1-foot. Mixing was accomplished using a Lang Tool 290-LTC In-Situ blender mounted on a hydraulic excavator (EFS, 2006). The areal extent of the soil mixing area is shown on **Figure AA-4**.

Wells included in this desktop review are included in **Table AA-1** and shown on **Figure AA-4**. Note that the Demonstration Plan indicated that MW-317 would be discussed as an upgradient well. However, this well was only sampled for VOCs, and none were detected. No field data is available for this well. As such, it has been excluded from the discussion.

Figure AA-4. Arnold AFB SMWU 16 Treatment Area and Wells Included in Desktop Review

Table AA-1. Arnold Air Force Base SWMU 16 Wells Included in Desktop Review

Treatment Area	PZ-1601, MW-640 (baseline and post-Ferox only, removed during mixing), MW-641(baseline and post-Ferox only, removed during mixing)
Downgradient	DP-1601 and DP-1602

6.5 Arnold AFB Site 8 Desktop Evaluation Results

This section presents an evaluation of the performance of the ZVI treatment (reduction in VOC concentrations) and groundwater geochemistry changes created by the ZVI treatment. Because only two wells were present in the ZVI treatment area prior to treatment and only one temporary well was reinstalled in this area post-treatment, the treatment area discussion is limited to baseline data for MW-640 and MW641 and post-treatment data for PZ-1601.

6.5.1 Arnold AFB Site 8 Baseline Groundwater Conditions

Pre-injection groundwater geochemistry data for the wells listed in **Table AA-1** were collected between May 2000 and April 2003. Periodic monitoring of these wells continued through August 2011, although parameters monitored varied considerably from round to round. A summary of key geochemical parameters from the May 2000 and April 2003 rounds of monitoring and the August 2011 round is presented in **Table AA-2**.

The results indicate the following baseline groundwater conditions:

- Dissolved oxygen (DO) concentrations ranged from 0.07 mg/L to 0.13 mg/L
- pH ranged from 3.92 to 3.94 (May 2000 results, because 2003 results were not available)
- ORP ranged from 79 mV to 151 mV (May 2000 results, because 2003 results were not available)
- Chloride ranged from 8.1 mg/L to 8.4 mg/L
- Nitrate ranged from 22 mg/L to 147.9 mg/L
- Methane ranged from 56 µg/L to 3700 µg/L

Based on these results, baseline geochemical conditions in the ZVI treatment area appear to be oxic to slightly reducing. Strongly reducing conditions do not appear to have been present to a significant degree for baseline conditions. Baseline pH at the site was acidic. Some of the geochemical results, such as for nitrate and methane, may include residual impacts from the application of chicken manure and other bio-amendments during previous remediation activities.

Baseline concentrations of TCE in the treatment zone ranged from 692 µg/L to 5,616 µg/L. Concentrations of cis-1,2-DCE ranged from 7.71 µg/L to 64.02 µg/L. Baseline concentrations of VC ranged from 1.09 µg/L to 3.43 µg/L. Based on the relatively low concentrations of daughter products, significant reductive dechlorination was not occurring at the site at the time of the ZVI treatment.

6.5.2 Arnold AFB Site 8 Evaluation of Effectiveness of ZVI Injections

Baseline and the most recent post-treatment VOC data for the ZVI treatment area and two downgradient wells (DP-1601 and DP-1602) are presented in **Table AA-2**. These data indicate that the ZVI treatments effectively reduced the maximum TCE concentration in the treatment area from 5,616 µg/L (April 2003) to 480 µg/L (August 2011). However, concentrations of daughter products increased considerably, with the cis-1,2-DCE concentration rising from 64.02 µg/L to 15,500 µg/L and the VC concentration rising from 3.43 µg/L to 6,600 µg/L. These data are indicative of an incomplete reductive dechlorination pathway for degradation at this site, rather than the β-elimination pathway. Similar trends were observed in downgradient wells DP-1601 and DP-1602. Time series plots of TCE, DCE, and VC prior to and following treatment in the source area and in downgradient wells are presented in **Charts AA-1 through AA-6**.

The ZVI was effective in reducing nitrate concentrations in the source area from 148 mg/L to 9.69 mg/L. A time series plot for nitrate is included as **Chart AA-7**. It appears, based on the concentrations of nitrate in downgradient wells (**Chart AA-8**) that there may have been some migration downgradient; however, concentrations also decreased considerably in downgradient wells over time.

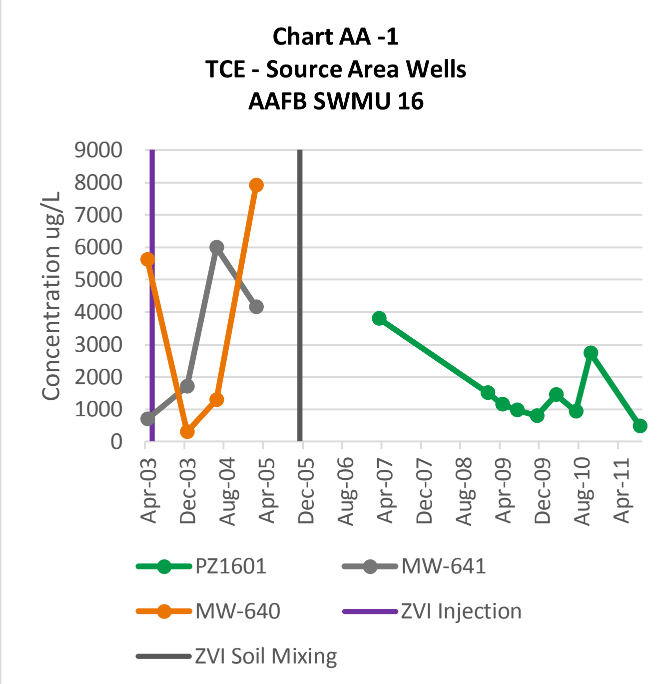


Chart AA -1
TCE - Source Area Wells
AAFB SWMU 16
Concentration ug/L
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Apr-03
Dec-03
Aug-04
Apr-05
Dec-05
Aug-06
Apr-07
Dec-07
Aug-08
Apr-09
Dec-09
Aug-10
Apr-11
PZ1601
MW-641
MW-640
ZVI Injection
ZVI Soil Mixing

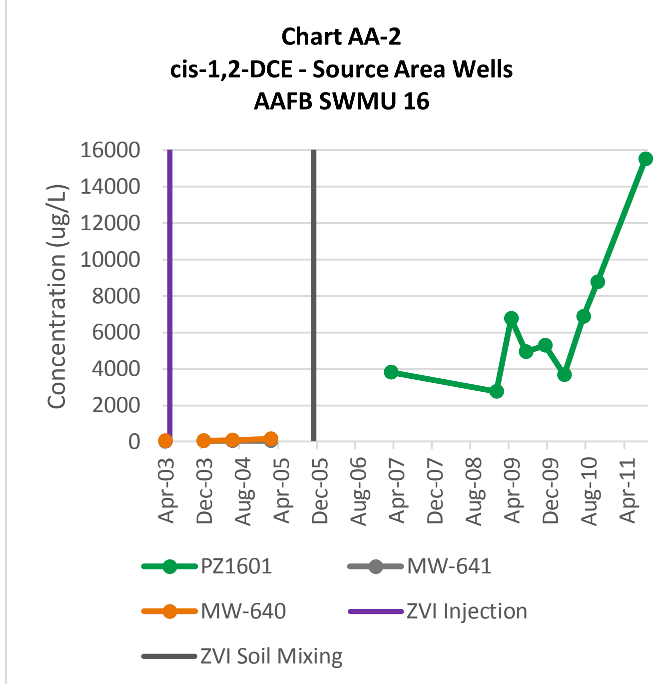


Chart AA-2
cis-1,2-DCE - Source Area Wells
AAFB SWMU 16
Concentration (ug/L)
16000
14000
12000
10000
8000
6000
4000
2000
0
Apr-03
Dec-03
Aug-04
Apr-05
Dec-05
Aug-06
Apr-07
Dec-07
Aug-08
Apr-09
Dec-09
Aug-10
Apr-11
PZ1601
MW-641
MW-640
ZVI Injection
ZVI Soil Mixing

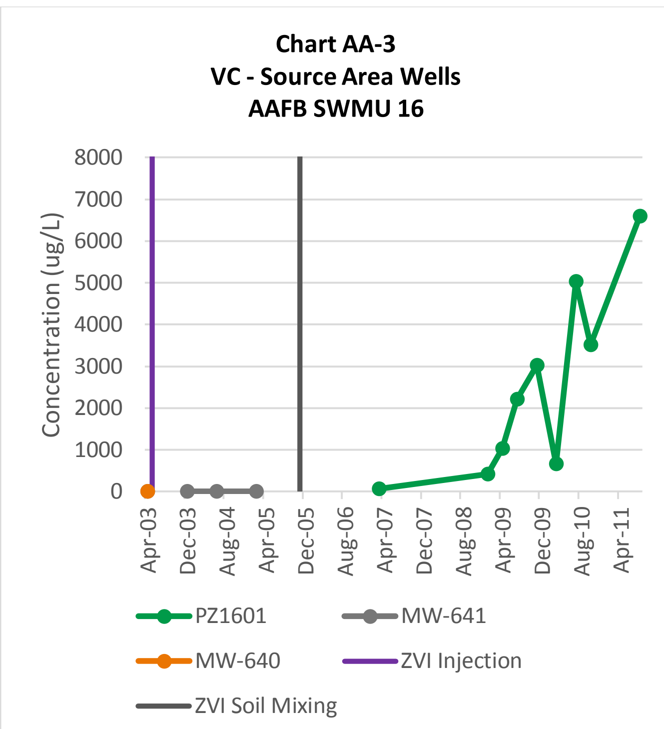


Chart AA-3
VC - Source Area Wells
AAFB SWMU 16
Concentration (ug/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
Apr-03
Dec-03
Aug-04
Apr-05
Dec-05
Aug-06
Apr-07
Dec-07
Aug-08
Apr-09
Dec-09
Aug-10
Apr-11
PZ1601
MW-641
MW-640
ZVI Injection
ZVI Soil Mixing

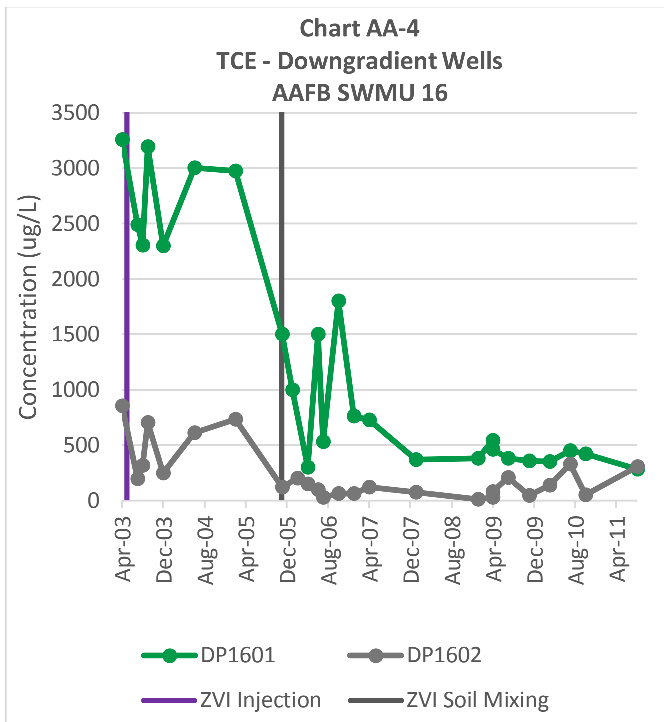


Chart AA-4
TCE - Downgradient Wells
AAFB SWMU 16
Concentration (ug/L)
3500
3000
2500
2000
1500
1000
500
0
Apr-03
Dec-03
Aug-04
Apr-05
Dec-05
Aug-06
Apr-07
Dec-07
Aug-08
Apr-09
Dec-09
Aug-10
Apr-11
DP1601
DP1602
ZVI Injection
ZVI Soil Mixing

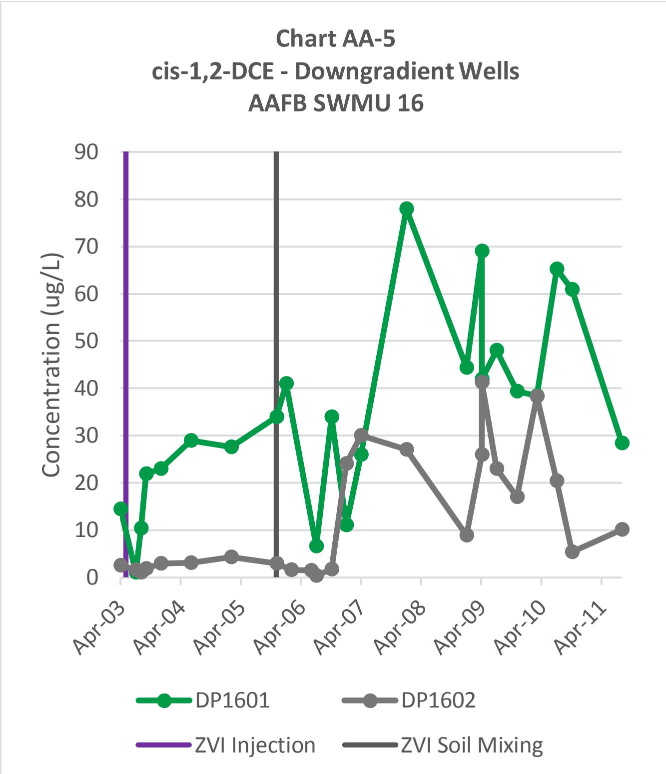


Chart AA-5
cis-1,2-DCE - Downgradient Wells
AAFB SWMU 16
Concentration (ug/L)
0
10
20
30
40
50
60
70
80
90
Apr-03
Apr-04
Apr-05
Apr-06
Apr-07
Apr-08
Apr-09
Apr-10
Apr-11
DP1601
DP1602
ZVI Injection
ZVI Soil Mixing

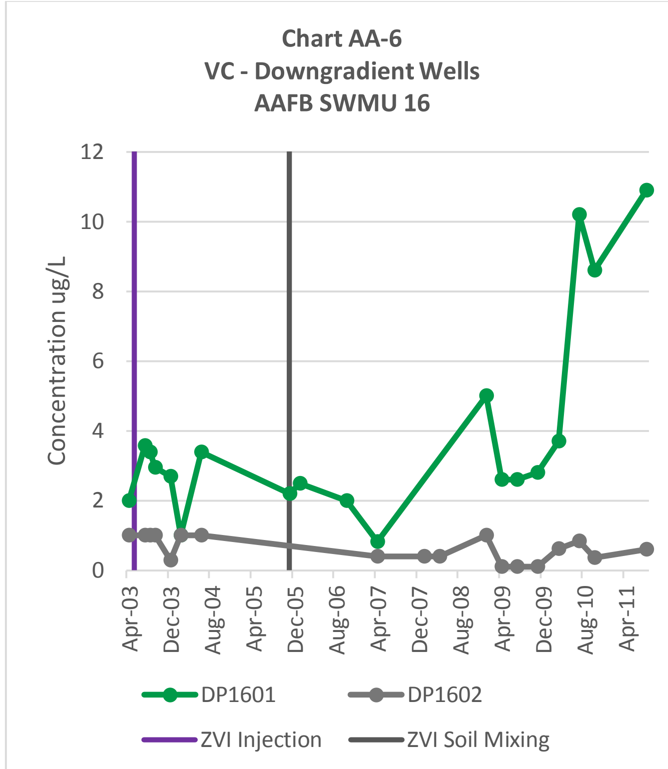


Chart AA-6
VC - Downgradient Wells
AAFB SWMU 16
Concentration ug/L
0
2
4
6
8
10
12
Apr-03
Dec-03
Aug-04
Apr-05
Dec-05
Aug-06
Apr-07
Dec-07
Aug-08
Apr-09
Dec-09
Aug-10
Apr-11
DP1601
DP1602
ZVI Injection
ZVI Soil Mixing

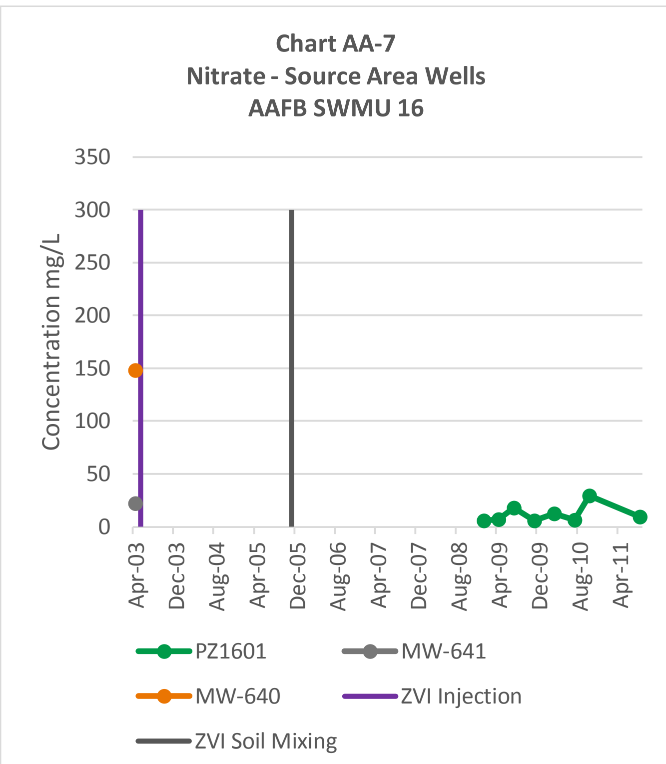


Chart AA-7
Nitrate - Source Area Wells
AAFB SWMU 16
Concentration mg/L
0
50
100
150
200
250
300
350
Apr-03
Dec-03
Aug-04
Apr-05
Dec-05
Aug-06
Apr-07
Dec-07
Aug-08
Apr-09
Dec-09
Aug-10
Apr-11
PZ1601
MW-641
MW-640
ZVI Injection
ZVI Soil Mixing

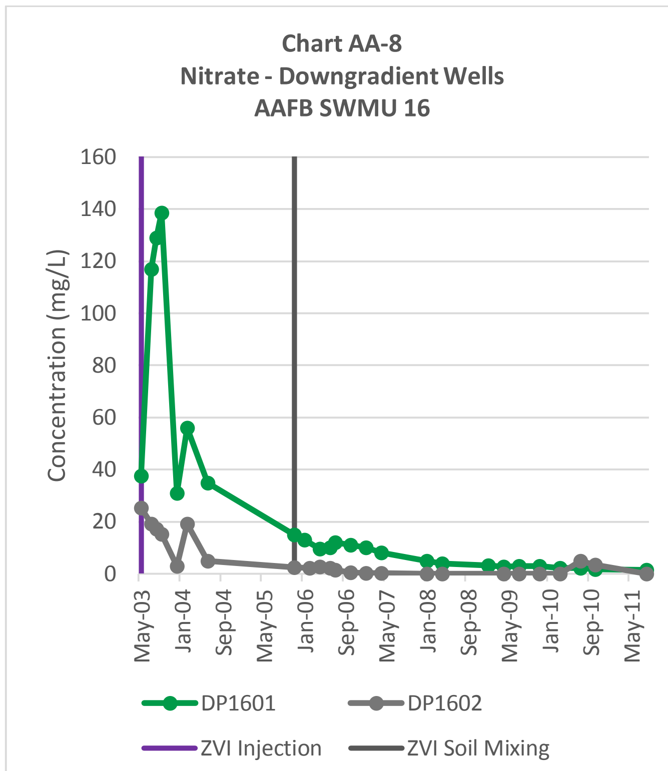
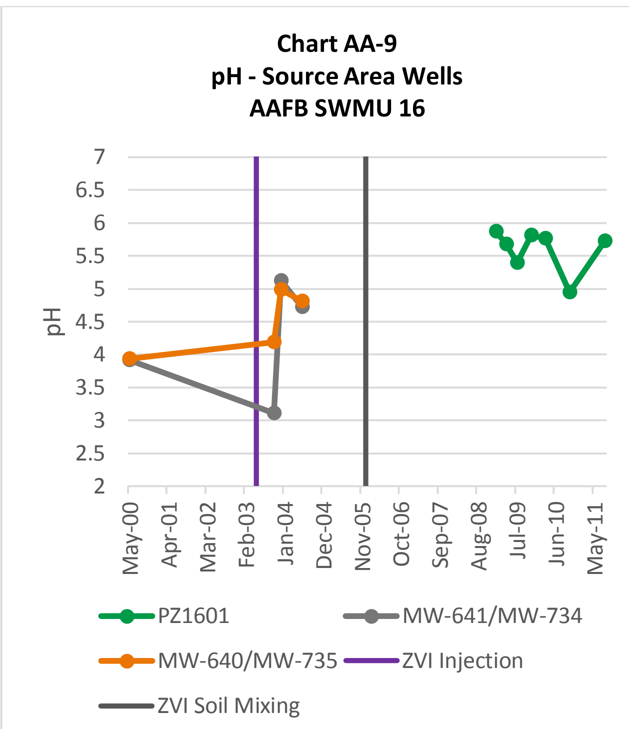


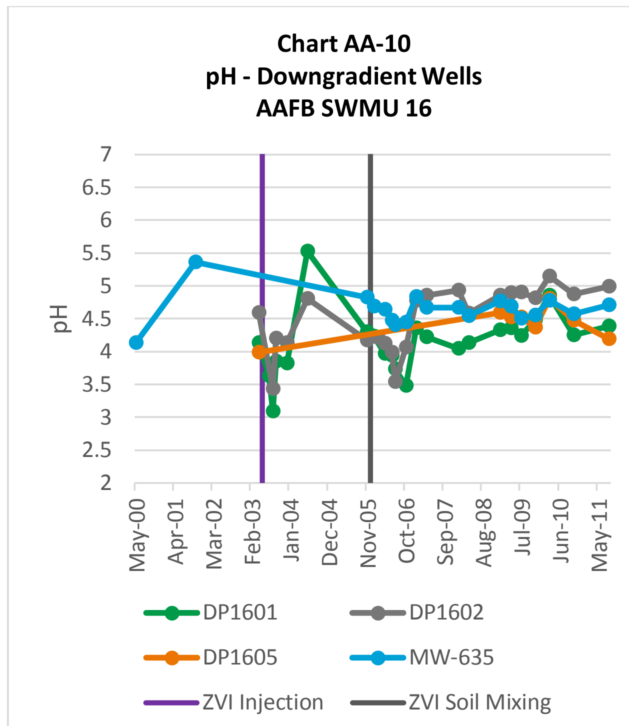
Chart AA-8
Nitrate - Downgradient Wells
AAFB SWMU 16
Concentration (mg/L)
0
20
40
60
80
100
120
140
160
May-03
Jan-04
Sep-04
May-05
Jan-06
Sep-06
May-07
Jan-08
Sep-08
May-09
Jan-10
Sep-10
May-11
DP1601
DP1602
ZVI Injection
ZVI Soil Mixing

6.5.3 Geochemistry Changes

Data presented in **Table AA-2** indicates that the ZVI treatment caused minor changes in monitored geochemical parameters in groundwater within the ZVI treatment zone. Time series plots for available pH, ORP, DO, and chloride data are shown in **Charts AA-9 through AA-16**.

- pH increased during the post-treatment monitoring period in the source area and to a lesser extent in downgradient wells. This increase is not unexpected given that the reaction of ZVI and water generates OH^- anion
- ORP decreased following treatment, particularly in the source area, but very low ORP values favorable for β-elimination (-400 mV, based on Gavaskar, 2005) were never achieved, even in the ZVI mixing area. Decreases in the downgradient area were minor and conditions have returned to baseline levels in downgradient wells.
- DO concentrations in the source area have fluctuated over time and did not demonstrate any meaningful trend. However, downgradient DO concentrations did decrease following treatment.
- Chloride concentrations have increased over time, an indication of dechlorination of CVOCs.





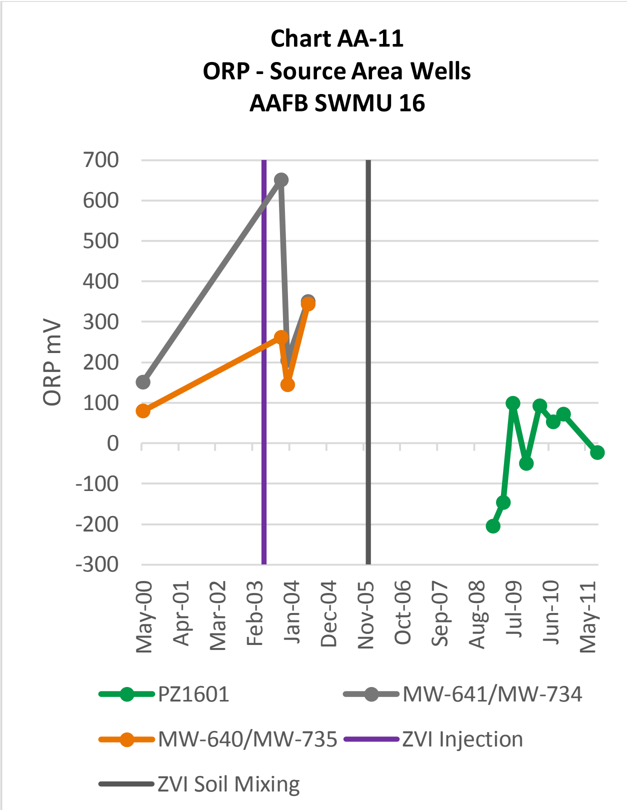


Chart AA-11
ORP - Source Area Wells
AAFB SWMU 16
ORP mV
700
600
500
400
300
200
100
0
-100
-200
-300
May-00
Apr-01
Mar-02
Feb-03
Jan-04
Dec-04
Nov-05
Oct-06
Sep-07
Aug-08
Jul-09
Jun-10
May-11
PZ1601
MW-641/MW-734
MW-640/MW-735
ZVI Injection
ZVI Soil Mixing

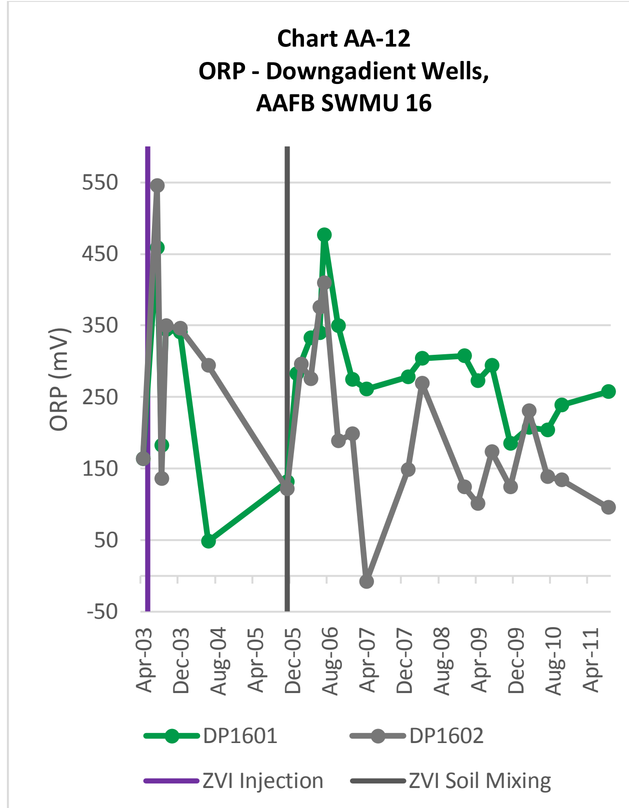


Chart AA-12
ORP - Downgadient Wells,
AAFB SWMU 16
ORP (mV)
550
450
350
250
150
50
-50
Apr-03
Dec-03
Aug-04
Apr-05
Dec-05
Aug-06
Apr-07
Dec-07
Aug-08
Apr-09
Dec-09
Aug-10
Apr-11
DP1601
DP1602
ZVI Injection
ZVI Soil Mixing

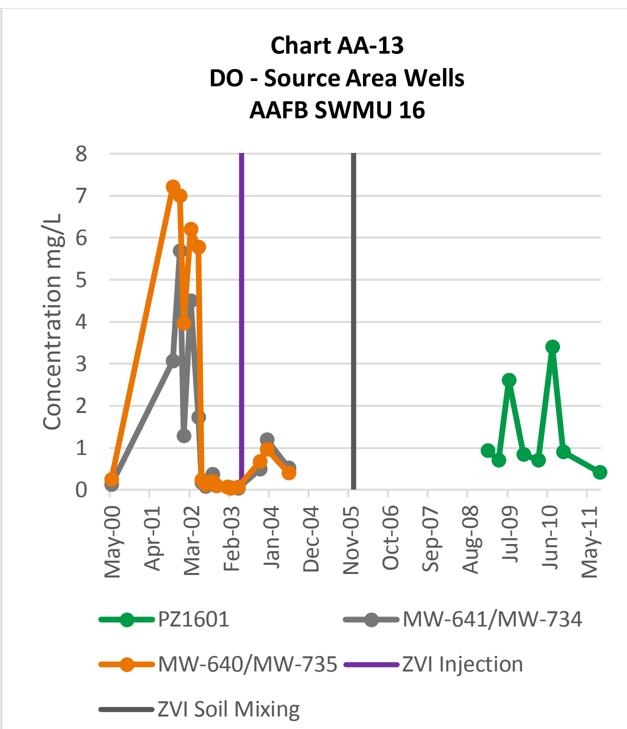


Chart AA-13
DO - Source Area Wells
AAFB SWMU 16
Concentration mg/L
8
7
6
5
4
3
2
1
0
May-00
Apr-01
Mar-02
Feb-03
Jan-04
Dec-04
Nov-05
Oct-06
Sep-07
Aug-08
Jul-09
Jun-10
May-11
PZ1601
MW-641/MW-734
MW-640/MW-735
ZVI Injection
ZVI Soil Mixing

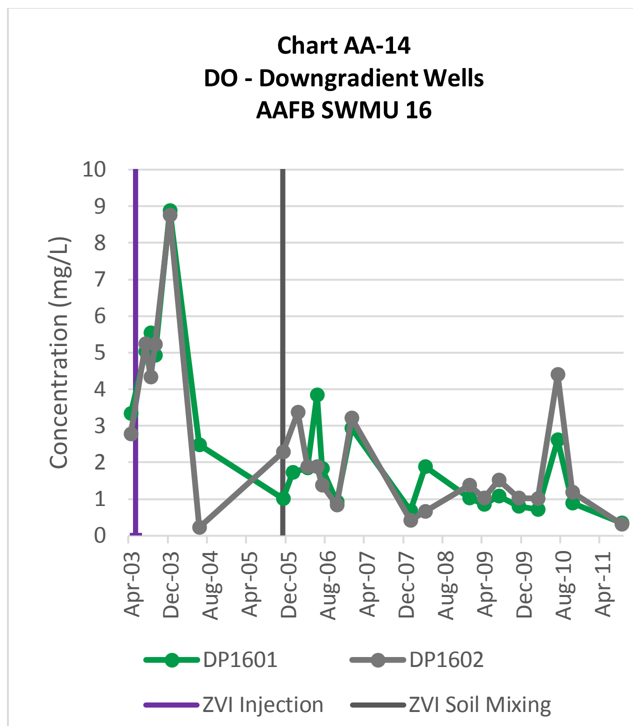
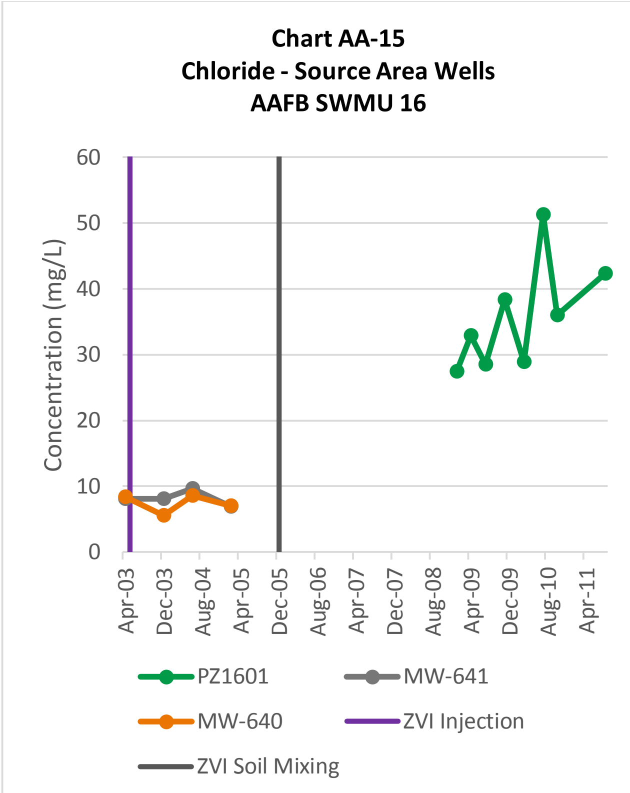
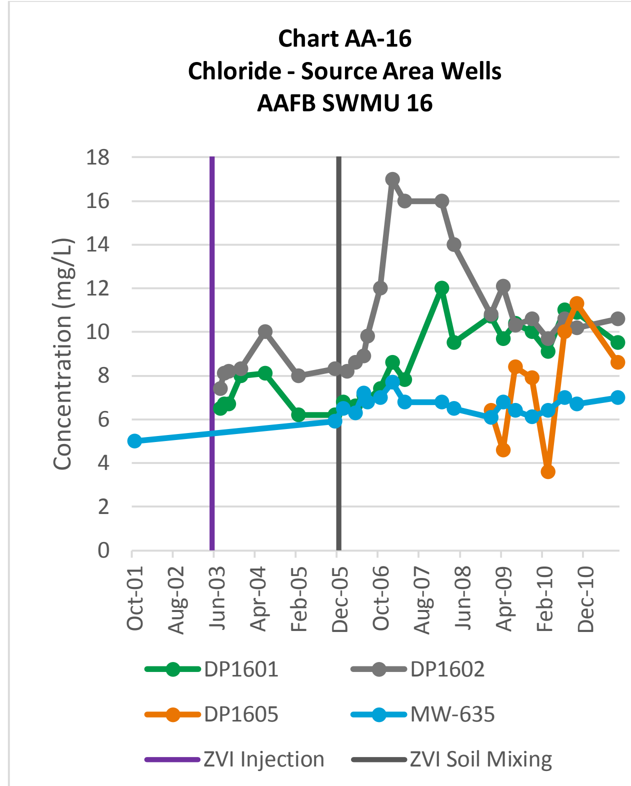


Chart AA-14
DO - Downgradient Wells
AAFB SWMU 16
Concentration (mg/L)
10
9
8
7
6
5
4
3
2
1
0
Apr-03
Dec-03
Aug-04
Apr-05
Dec-05
Aug-06
Apr-07
Dec-07
Aug-08
Apr-09
Dec-09
Aug-10
Apr-11
DP1601
DP1602
ZVI Injection
ZVI Soil Mixing





6.5.4 AAFB SWMU 16 Changes in Groundwater Flow

Groundwater flow maps from May 2000 (pre-injection and soil mixing) and March, July, and October 2010 (most recent events in which wells were gauged) are included in **Appendix B**. Based on these maps, no notable change in groundwater flow is noted due to ZVI treatment. However, because the well network is very limited in the source area, changes in flow may be difficult to observe.

7 USACE St. Louis Ordnance Plant Operable Unit (OU) 1, St. Louis, Missouri

7.1 St. Louis Ordnance Depot OU1 Site History

The St. Louis Ordnance Plant is located on the western boundary of the city limits of St. Louis (**Figure SL-1**). The St. Louis Ordnance Plant operated from 1941 to 1945 as a small arms ammunition production facility. The plant was divided into two areas designated No. 1 (east of Goodfellow Boulevard) and No. 2 (west of Goodfellow Boulevard). The former Hanley Area consists of the 14.68 acres at the northeastern end of Plant Area No. 2 at the intersection of Stratford Avenue and Goodfellow Boulevard (**Figure SL-1**). The processes there consisted of the blending of primary explosives, incendiary compounds, and the tracer charging of .30- and .50-caliber projectiles as part of the assembly of the final product. Powder wells installed in 1941 received wastewater from buildings and magazines until 1945. The powder wells provided sediment collection before discharge to the sanitary sewer. The former Hanley Area takes its name from Hanley Industries, Inc., which leased the area in 1959 and conducted operations there through 1979. Hanley used the site for research, development, manufacture, and testing of various explosives. Over that time, Hanley produced specialty ordnance and non-ordnance devices for the U.S. military and the National Aeronautics and Space Administration. Hanley used most of the buildings to load detonators and primers and to mix explosives. Explosives were dried in magazines by leaving cans of explosives exposed to the air, and a lead azide reactor was operated in one of the magazines, the location of which is unknown. Hanley reportedly did not use the powder wells or sumps on the property for wastewater disposal (USACE, 2010).

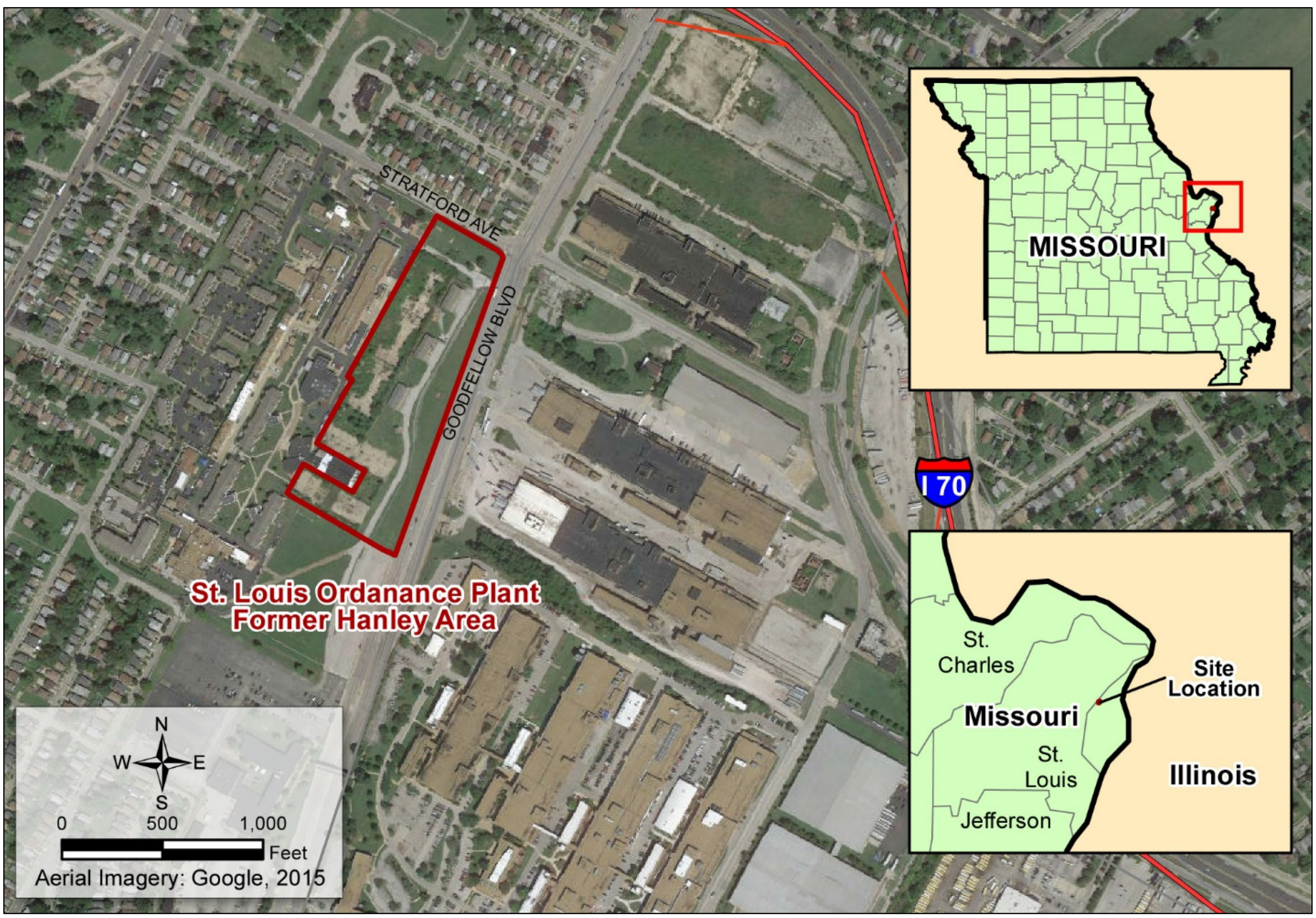


Figure SL-1. St. Louis Ordnance Plant OU1 Site Location Map

The site ground surface consists of paved areas and landscaped vegetation. The site is completely fenced (partially with iron fencing and the remaining with a 6-foot-tall chain link fence). The site contains underground rooms (former basements and bunkers), tunnels for service utilities, and a combined underground wastewater and stormwater collection system. The underground structures are still intact. Most other buildings have been demolished or are currently only used for storage. Building 219G is occupied during business hours (USACE, 2010).

7.2 St. Louis Ordnance Depot OU1 Physical and Hydrogeologic Setting

Overburden soils at the site consist primarily of clay. Fill material including gravel, concrete rubble, brick debris, and sand has been observed in portions of the site as deep as 11 feet. A layer of interbedded clay and silt is observed between roughly 20 to 25 feet bgs in the north part of the former Hanley Area. A hard, dry, completely weathered shale is present beneath the clay (USACE, 2010). The thickness of the weathered shale ranges from 6 to 12 feet in boreholes advanced to depths at which the competent bedrock is encountered. Groundwater is present within more permeable silt and clay lenses that are locally discontinuous within the upper clay unit. Saturated conditions are not observed within the weathered shale beneath the clay unit. **Appendix A** includes a cross section and cross section location. Groundwater is encountered in a 6-inch saturated coal layer within the competent shale zone. Groundwater within the coal does not appear to be connected to groundwater in the discontinuous silt and clay lenses. Groundwater generally flows from the south and west to the east-northeast. There is a local groundwater high west of former Building 220 in the northern part of the site (**Figure SL-2**).

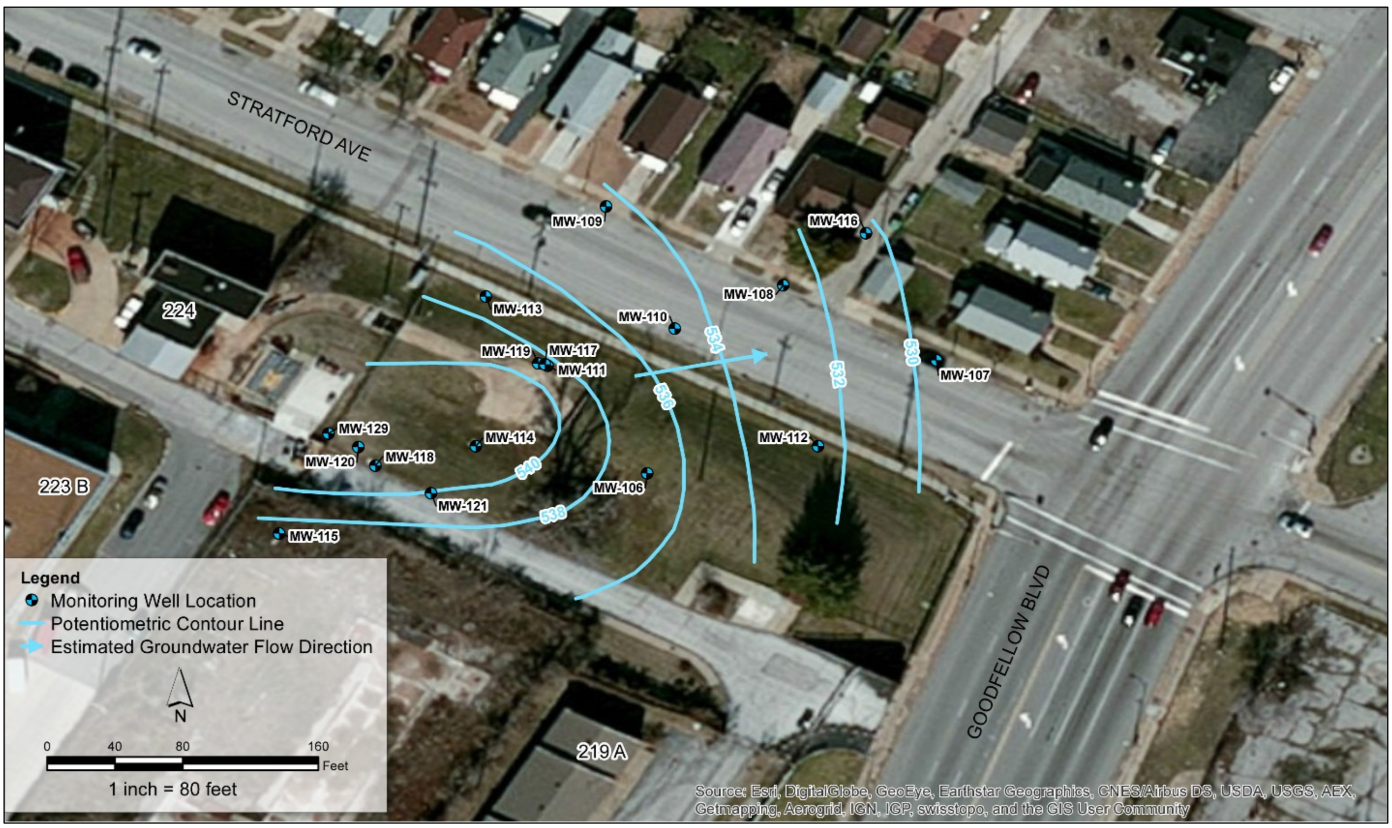


Figure SL-2. St. Louis Ordnance Plant OU1 Groundwater Contour Map (2015)

7.3 St. Louis Ordnance Depot OU1 Contaminant Distribution

Dissolved-phase groundwater contamination was identified in three distinct plumes containing one or more chlorinated VOCs at the site. Only one of these plumes was treated with ZVI. Consequently, the remainder of this nature and extent description is focused on that area, designated as Plume A. Plume A consisted of elevated concentrations of PCE, TCE, and cis-1,2-DCE, with PCE at a maximum concentration of 43,300 µg/L. The plume originates on the northside of a parking lot near a sewer system. A former building (220) was previously located in this area and is suspected to have been the source. The presence of TCE and cis-1,2-DCE may be attributed to reductive dechlorination of PCE. There is no historical record of a single large spill, but sporadic discharge of small quantities of spent product is assumed to have occurred. **Figure SL-3** illustrates areal extent of total VOC concentrations in and around the treatment area prior to the RA. The depth of groundwater contamination extends from the water table to the weathered shale interface at roughly 26 to 28 feet bgs.

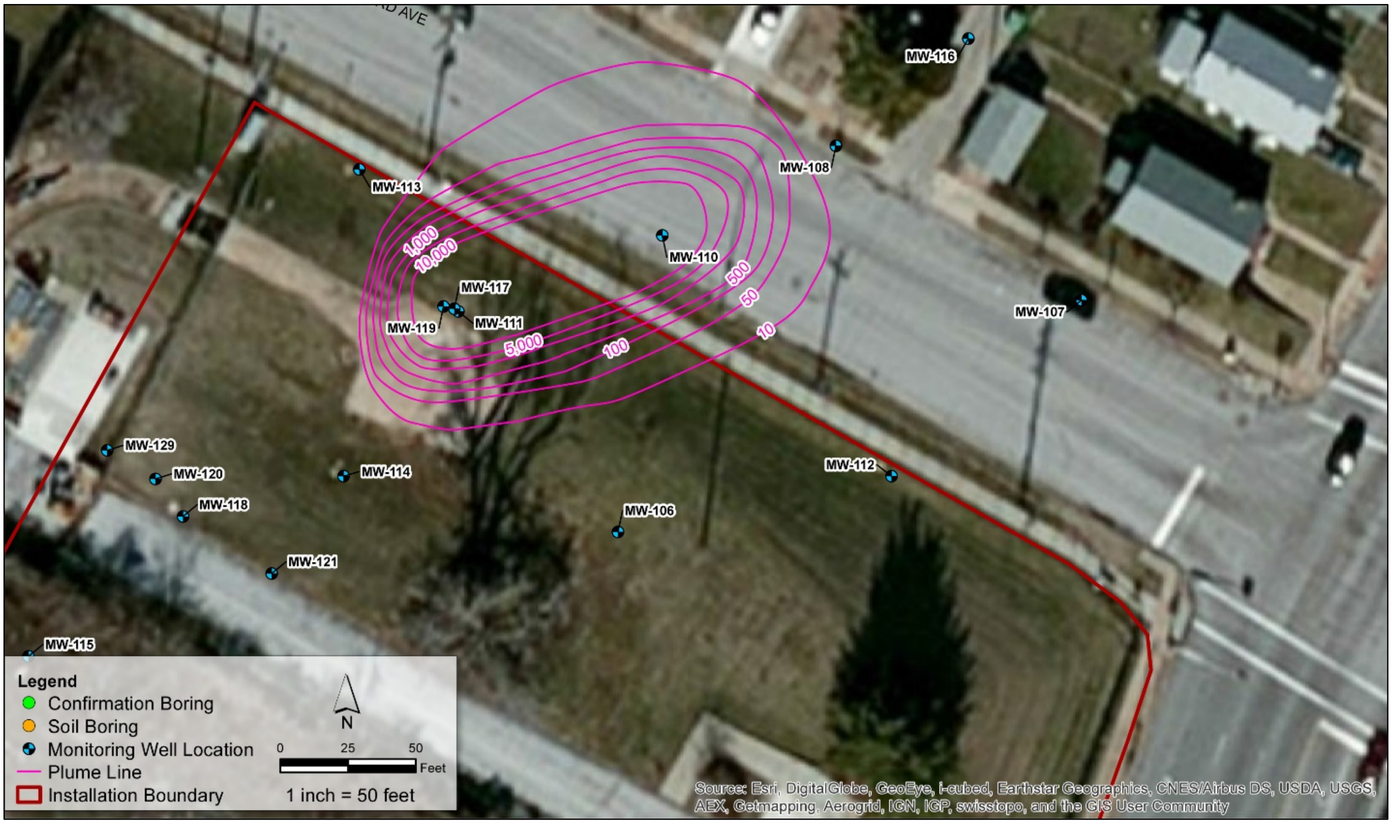


Figure SL-3. St. Louis Ordnance Plant OU1 Total VOC Plume

7.4 St. Louis Ordnance Depot OU1 ZVI Treatment Area and Wells Reviewed in Desktop Review

In March 2012, soil mixing was performed to reduce PCE concentrations in groundwater below the active treatment remediation goal of 21,000 µg/L. ZVI soil mixing occurred over an area of 1,491 square feet to an average depth of 25.05 feet, for a total treatment volume of 1,383 cubic yards of soil. The treatment depth was based on the depth to the weathered shale bedrock. To mix the soil, ZVI was placed directly into an open borehole advanced to the depth of each column. The column was then mixed using an auger 5 feet in diameter.

An estimated 659 pounds of contaminant mass were present in the subsurface within the treatment area: 23 pounds dissolved in groundwater and 636 pounds adsorbed to soil. The mass of contaminants dissolved in groundwater and adsorbed to the soil was estimated based on various site assumptions including estimated porosity (0.25), soil density (1.5 tons per cubic yard), average concentrations of PCE detected in soil (169 mg/kg), and maximum concentrations of PCE in groundwater (43,300 µg/L). Based on those calculations and a factor of safety of 25, a minimum ZVI dosage of 0.6 percent by mass was determined to be needed to effectively treat PCE in groundwater and adsorbed to soil. A remediation dosage of 1 percent ZVI, by mass of soil, was used. Twenty-two tons of ZVI were incorporated into 1,383 cubic yards of soil. One-quarter ton of ZVI was introduced into each of 88 soil mixing columns (**Figure SL-4**) to distribute the ZVI evenly throughout the treatment area. Soil mixing was conducted without adding water.

Wells reviewed as part of this desktop study are included in **Table SL-1** and shown on **Figure SL-4**.

Figure SL-4. St. Louis Ordnance Plant OU1 Treatment Area and Wells Included in Desktop Review

Table SL-1. Wells Evaluated for St. Louis Ordnance Plant OUI

Source Area	MW-111 (pre-mixing) and replacement well (MW-119)
Downgradient	MW-107, MW-108, MW-110 and MW-116

7.5 St. Louis Ordnance Plant OU1 Desktop Evaluation Results

This section represents an evaluation of the performance of the ZVI treatment (reduction in VOC concentrations) and groundwater geochemistry changes created by the ZVI treatment in the soil mixing area.

7.5.1 St. Louis Ordnance Plant OU1 Baseline Groundwater Conditions

Baseline data were collected for soil-mixing area well MW-111 and downgradient wells MW107 and MW110 in December 2011. Samples from August 2010 were used as baseline data for other downgradient wells (MW-108 and MW-116), as data were not collected from those wells in December 2011. A summary of pre-treatment key geochemical parameters is provided in **Table SL-2**.

The pre-treatment results indicate the following baseline conditions for the treatment area of the site:

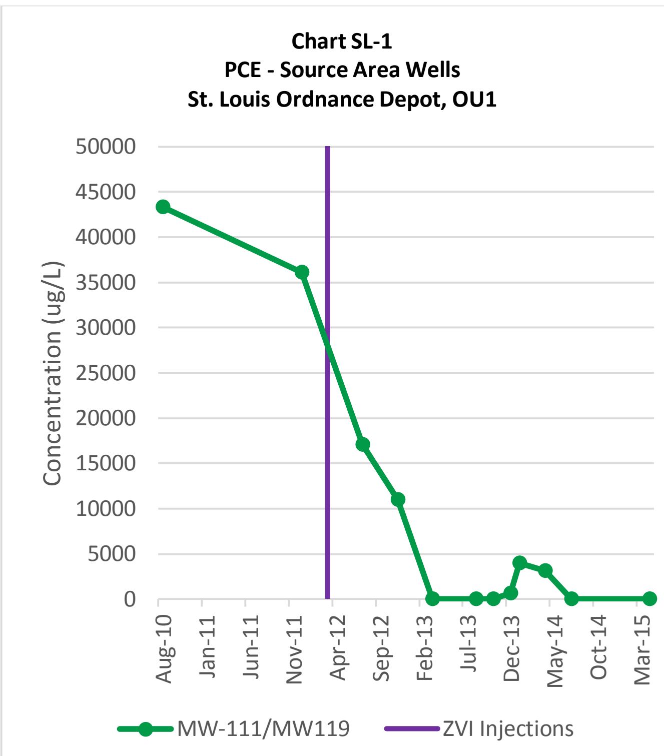
- DO concentrations ranged from 0.11 mg/L to 6.77 mg/L, although all but one of the reviewed wells had a baseline DO of less than 1.
- pH ranged from 5.79 to 6.3.
- ORP ranged from 98.7 mV to 232.2 mV.

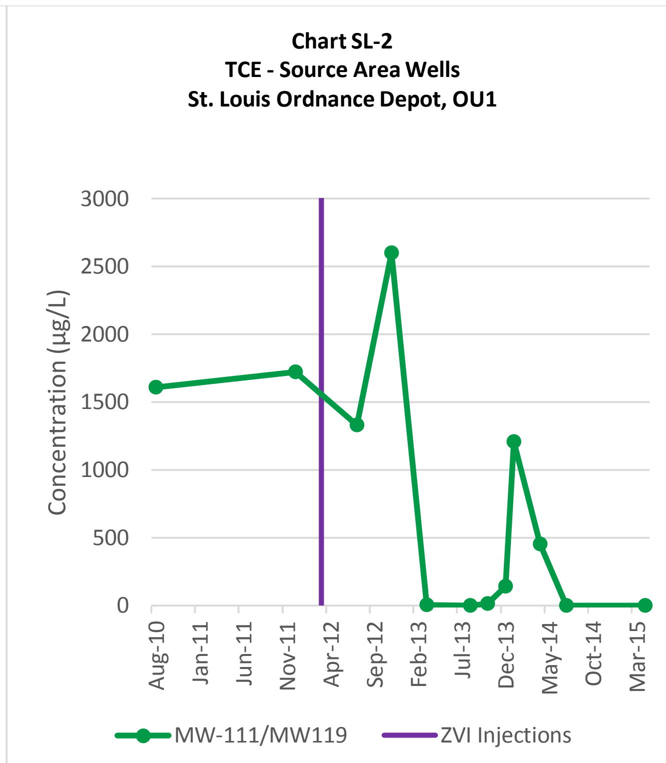
These results indicate the treatment area of the site was under slightly oxic to slightly reducing conditions prior to treatment. Highest baseline concentrations of PCE (36,100 µg/L), TCE (1,720 µg/L), and cis-1,2-DCE (324 µg/L) were detected in the sample from MW-111. Trans-1,2-DCE and VC were not detected during the baseline round of monitoring, indicating complete reductive dechlorination was not occurring prior to ZVI treatment **Table SL-2**.

7.5.2 St. Louis Ordnance Plant OU1 Effectiveness of ZVI Injections

Baseline and the most recent post-injection VOC data available for each well (April 2015) are presented in **Table SL-2**. **Charts SL-1 through SL-3** show temporal trends for PCE, TCE, and cis-1,2-DCE in the source area (MW-111/MW119). **Charts SL-4 through SL-6** should temporal trends for PCE, TCE, and cis-1,2-DCE in downgradient wells (MW-107, MW-108, MW-110, and MW-116). Data indicate significant decreases in PCE concentrations in the source/treatment area (from 36,100 µg/L to not-detected) and to a lesser extent in downgradient well MW-110 (from 9,380 µg/L to 7,980 µg/L). In the source area, TCE and cis-1,2-DCE concentrations increased temporarily following injections, but were subsequently reduced to 0.73 J µg/L and 70.5 µg/L, respectively, indicating some reductive dechlorination occurred. TCE and cis-1,2-DCE increased in downgradient well MW-110, but did not subsequently decrease and remain at greater than baseline levels based on the April 2015 sampling event (**Table SL-1** and **Charts SL-5 and SL-6**). Overall, the injections were effective in reducing concentrations in the source area to around or less than MCLs, and the site clean-up goal of 21,000 µg/L was achieved in all monitoring locations.

Field parameters indicate highly reducing conditions were reached in the mixing area (ORP of -383 mV, DO concentration of 0.01 mg/L). ORP increased to -65.8 by April 2015. pH also increased from 6.17 (baseline in December 2011) to 8.5 (August 2013), but has since decreased to 7.45 (April 2015). Decreases in ORP were not noted in downgradient wells, though pH increased slightly and DO decreased (**Charts SL-10 through SL-12**)





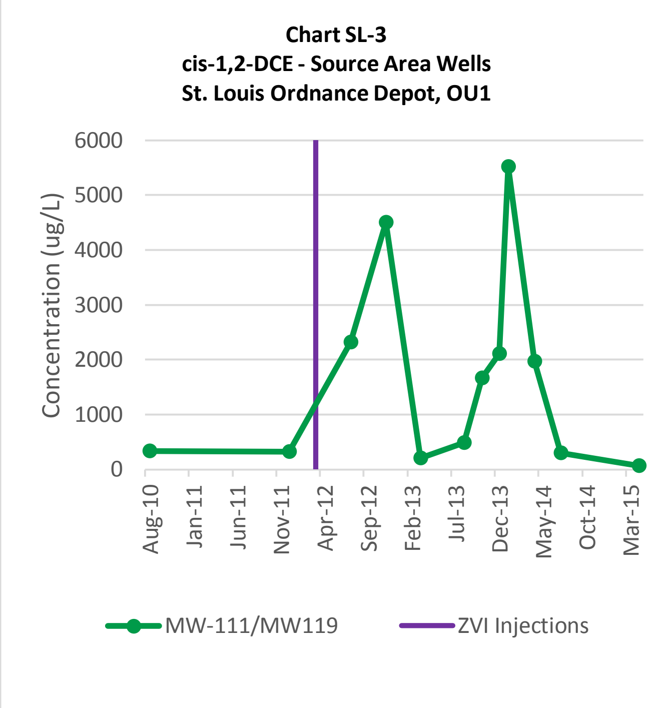


Chart SL-3
cis-1,2-DCE - Source Area Wells
St. Louis Ordnance Depot, OU1
Concentration (ug/L)
0
1000
2000
3000
4000
5000
6000
Aug-10
Jan-11
Jun-11
Nov-11
Apr-12
Sep-12
Feb-13
Jul-13
Dec-13
May-14
Oct-14
Mar-15
MW-111/MW119
ZVI Injections

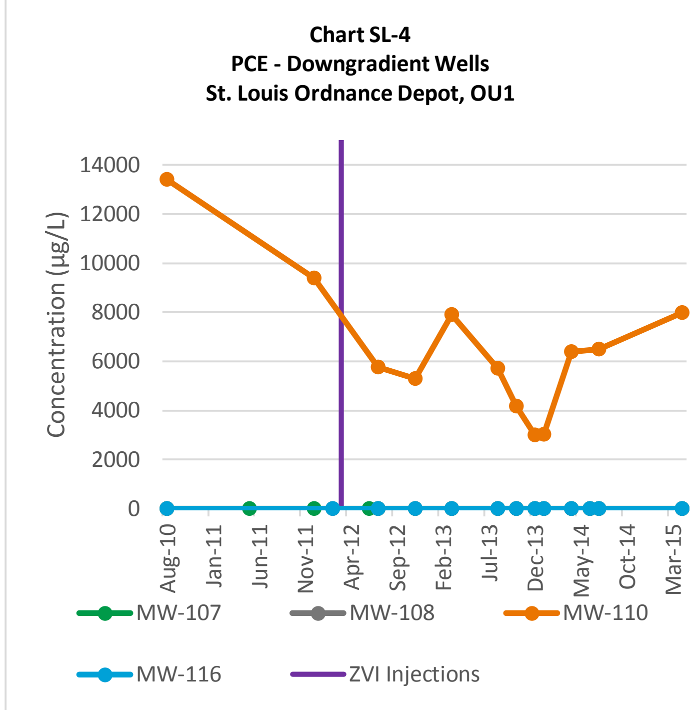


Chart SL-4
PCE - Downgradient Wells
St. Louis Ordnance Depot, OU1
Concentration (µg/L)
0
2000
4000
6000
8000
10000
12000
14000
Aug-10
Jan-11
Jun-11
Nov-11
Apr-12
Sep-12
Feb-13
Jul-13
Dec-13
May-14
Oct-14
Mar-15
MW-107
MW-108
MW-110
MW-116
ZVI Injections

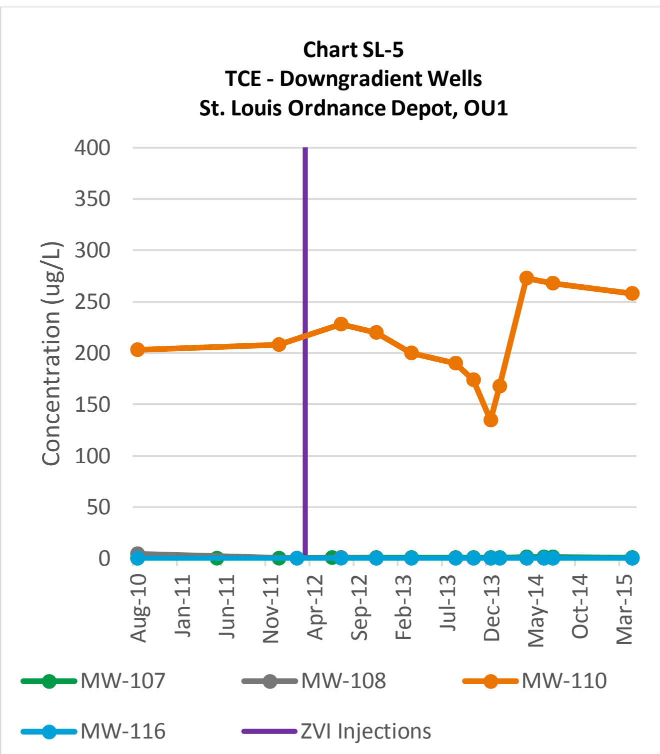


Chart SL-5
TCE - Downgradient Wells
St. Louis Ordnance Depot, OU1
Concentration (ug/L)
0
50
100
150
200
250
300
350
400
Aug-10
Jan-11
Jun-11
Nov-11
Apr-12
Sep-12
Feb-13
Jul-13
Dec-13
May-14
Oct-14
Mar-15
MW-107
MW-108
MW-110
MW-116
ZVI Injections

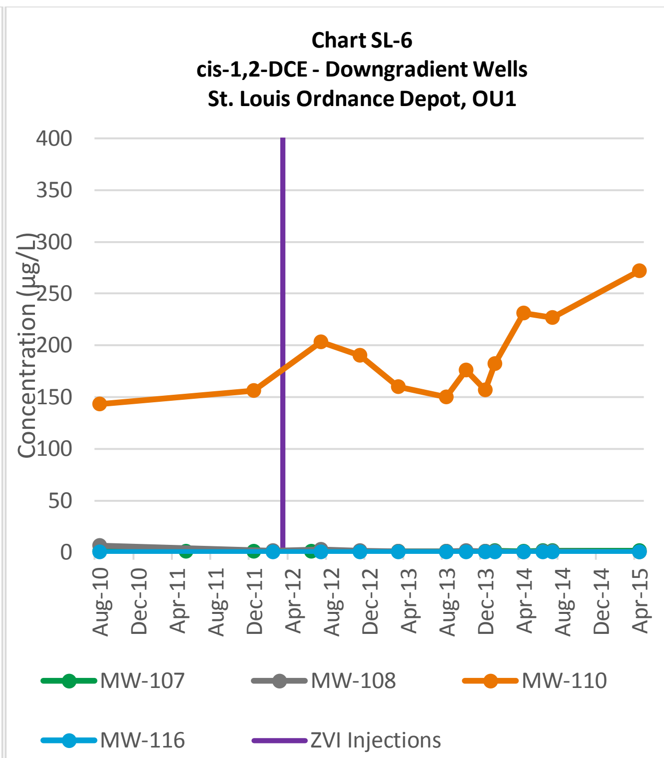


Chart SL-6
cis-1,2-DCE - Downgradient Wells
St. Louis Ordnance Depot, OU1
Concentration (µg/L)
0
50
100
150
200
250
300
350
400
Aug-10
Dec-10
Apr-11
Aug-11
Dec-11
Apr-12
Aug-12
Dec-12
Apr-13
Aug-13
Dec-13
Apr-14
Aug-14
Dec-14
Apr-15
MW-107
MW-108
MW-110
MW-116
ZVI Injections

Chart SL-7
DO - Source Area Wells
St. Louis Ordnance Depot, OU1

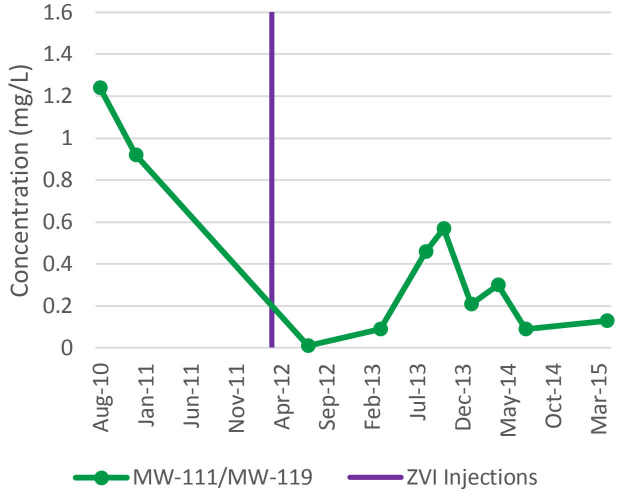


Chart SL-8
pH - Source Area Wells
St. Louis Ordnance Depot, OU1

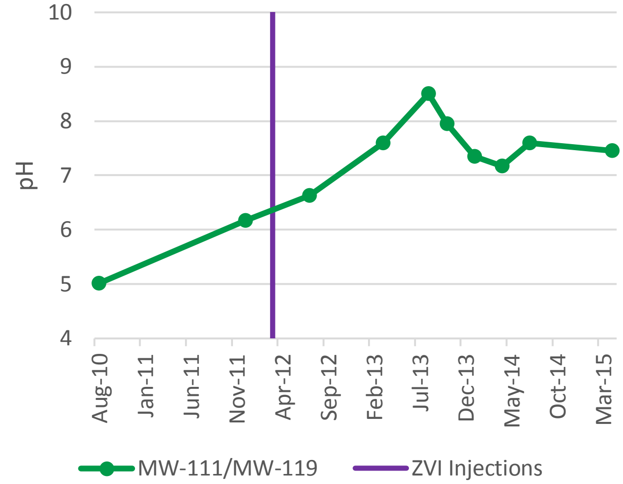


Chart SL-9
ORP - Source Area Wells
St. Louis Ordnance Depot, OU1

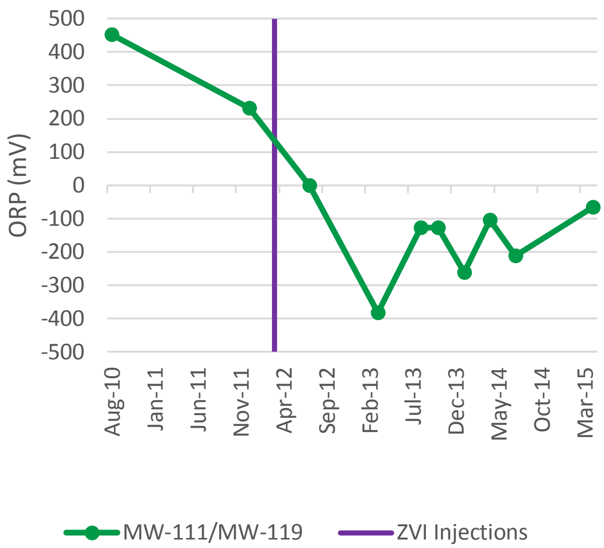
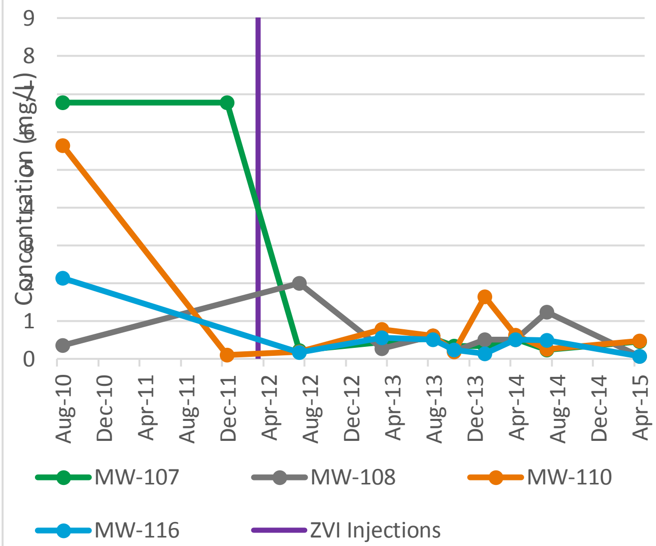
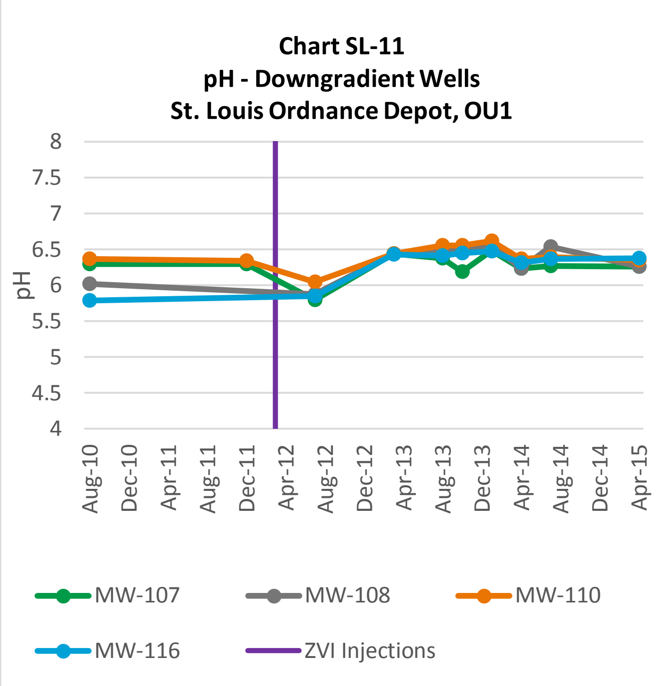
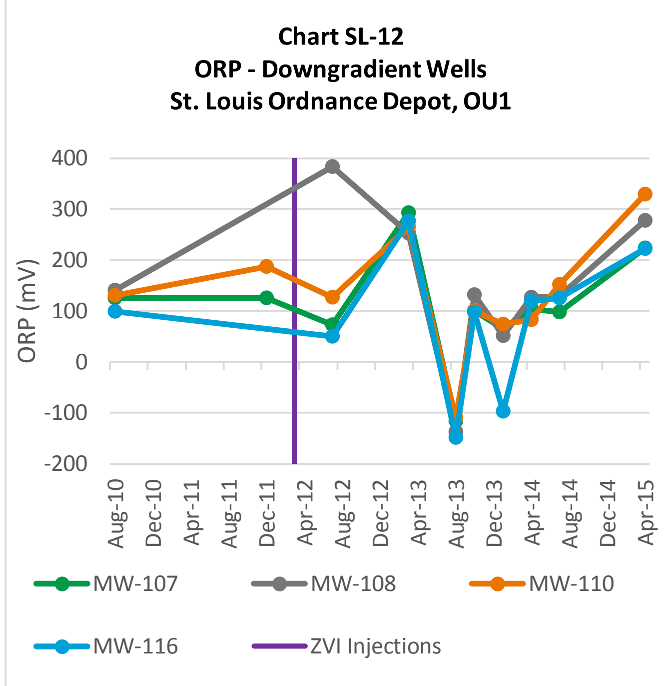


Chart SL-10
DO - Downgradient Wells
St. Louis Ordnance Depot, OU1







7.6 St. Louis Ordnance Plant OU1 Changes in Groundwater Flow

Groundwater flow maps from 2008 and 2015 are included in **Appendix B**. Based on evaluation of flow over time, there does not appear to be any change in groundwater flow resulting from the ZVI injections.

8 MCB Camp Lejeune Site 89, Jacksonville, North Carolina

8.1 Camp Lejeune Site 89 History

MCB Camp Lejeune is located in Onslow County, North Carolina (**Figure CL-1**). The Base covers 236 square miles and is bisected by the New River, which flows in a southeasterly direction and forms a large estuary before entering the Atlantic Ocean. The Atlantic Ocean borders the base on the southeast. The mission of Camp Lejeune is to maintain combat-ready units for expeditionary deployment (www.lejeune.marines.mil). Site 89 is located to the west of the New River, on Camp Geiger. The Site 89 investigative area includes the Former Defense Reutilization and Marketing Office (DRMO), the woods to the east and the south of the former DRMO, and a portion of Camp Geiger to the west. The former DRMO, operated by the Defense Logistics Agency, was used as a storage yard for miscellaneous items such as scrap and surplus metal, electronic equipment, vehicles, rubber tires, and fuel bladders (mobile storage tanks) until 2000. According to historical records, the Base Motor Pool operated at the site until 1988. Reportedly, various solvents, such as acetone, TCE, and 2-butanone (methyl-ethyl-ketone [MEK]) were used by the Base Motor Pool for cleaning parts and equipment. Historical records also indicate that a 550-gallon underground storage tank (UST), identified as UST STC-868, was installed at the site in 1983 and used to store waste oil. The UST was removed in 1993. The site has not been used since the DRMO relocated in 2000 (CH2M HILL 2008d).

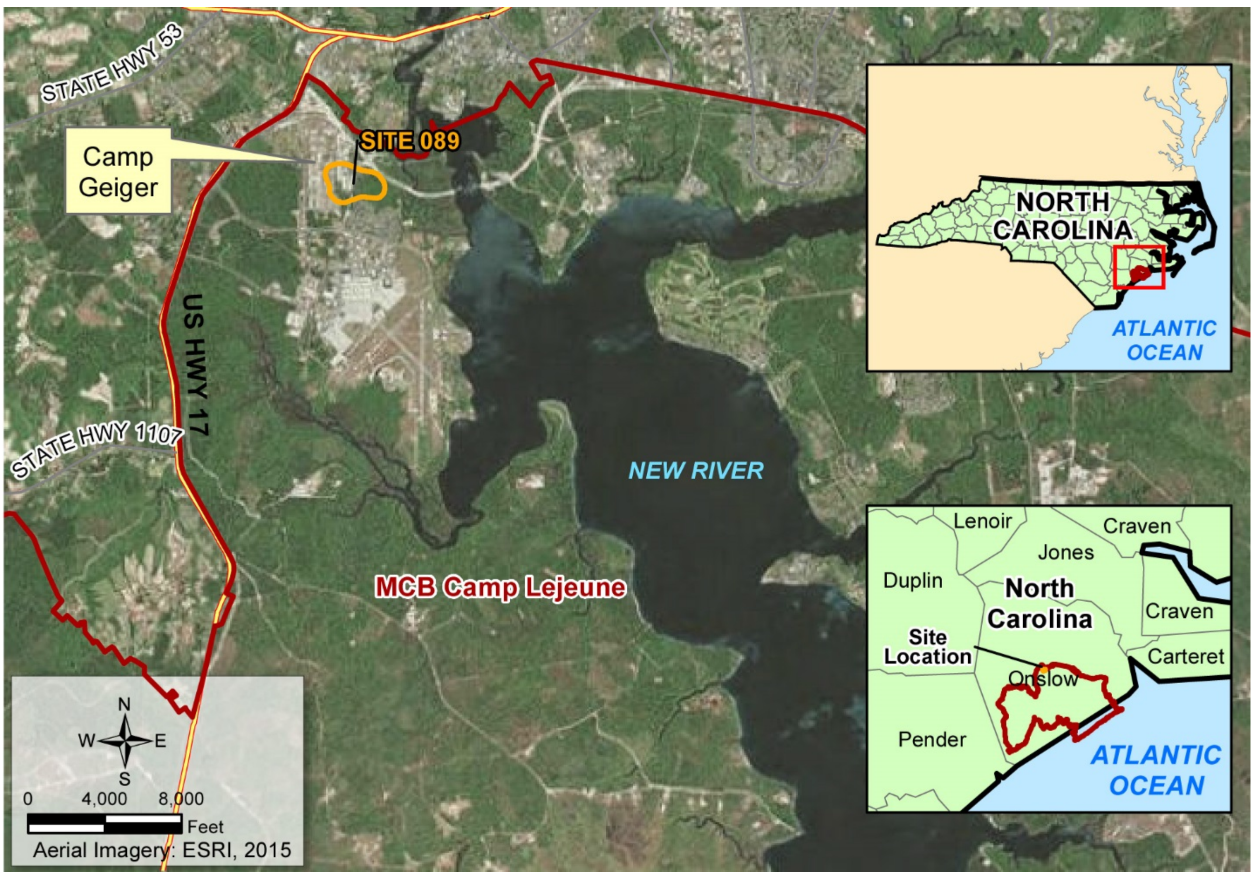


Figure CL-1. Camp Lejeune Site 89 Location Map

8.2 Camp Lejeune Site 89 Physical and Hydrogeologic Setting

Site 89 is located within an interstream area of MCB Camp Lejeune and has little topographic relief. Edwards Creek is located to the west and south of the site and eventually flows into the New River.

Site 89 is underlain by the unconfined surficial aquifer (**Appendix A**). The Surficial aquifer is underlain by a semi-confining unit (Upper Castle Hayne Confining unit) that ranges in thickness from 20 to 40 feet. This laterally discontinuous semi-confining unit separates the surficial aquifer from the deeper Castle Hayne aquifer and consists of silty sands, clays, and shell fragments. Groundwater flow within the surficial aquifer at Site 89 is to the south/southeast and is influenced by Edwards Creek (**Figure CL-2**). Groundwater flow within Castle Hayne aquifer is southeastward toward the New River. Groundwater flow velocity was estimated at 17 to 55 feet per year (CH2M HILL, 2012).

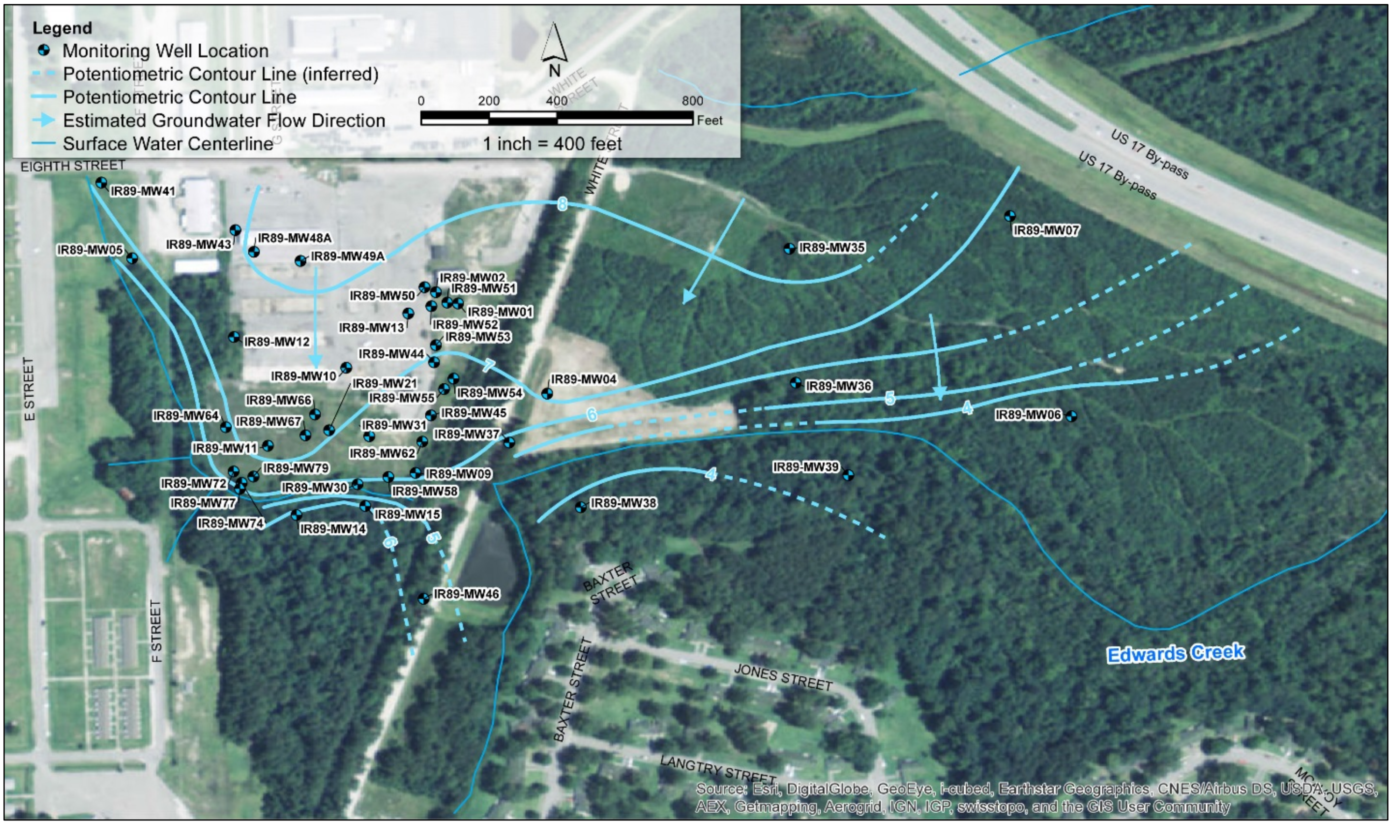


Figure CL-2. Camp Lejeune Site 89 Surficial Aquifer Groundwater Contour Map

8.3 Camp Lejeune Site 89 Contaminant Distribution Prior to Treatment

The primary contaminants at Site 89 are 1,1-2,2-PCA and TCE. 1,1,2,2-PCA was reported at a maximum concentration of 250,000 µg/L while TCE was reported at a maximum concentration of 440,000 µg/L. Other VOCs detected include PCE and daughter products of PCE and TCE (cis-1,2-DCE and VC). Highest concentrations were detected in the Surficial aquifer. Concentrations of up to 3,100 µg/L for TCE were also detected in the Upper Castle Hayne aquifer. VOCs were not detected in the Lower Castle Hayne aquifer. Pre-groundwater treatment isoconcentrations of total TCE and 1,1,2,2-PCA are shown on **Figures CL-3a and CL-3b** for the Surficial and Upper Castle Hayne aquifers, respectively. DNAPL has not been identified as a continuous layer in the subsurface but it was speculated to be present in pockets and ganglia.

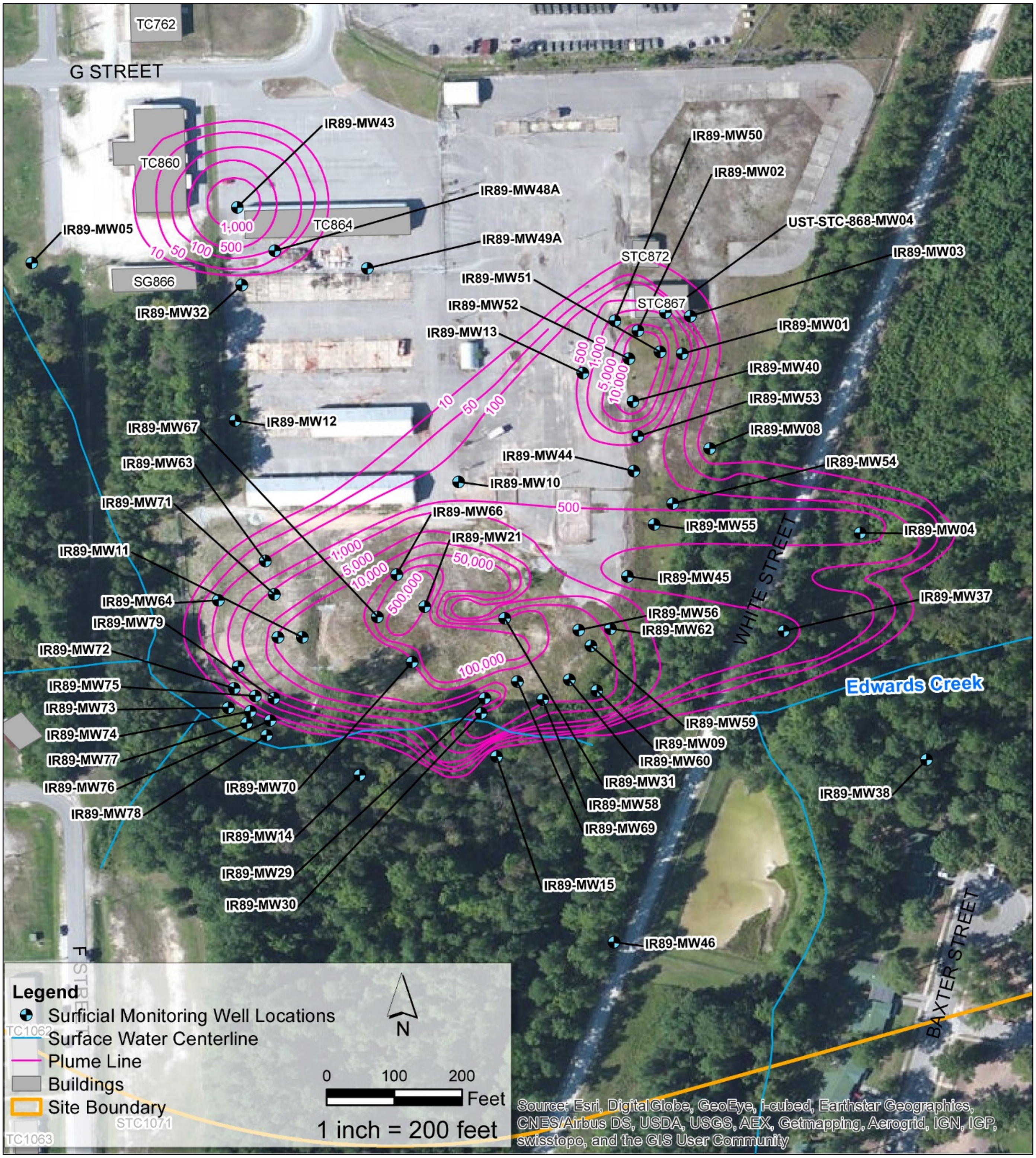


Figure CL-3a. Camp Lejeune Site 89 Total TCE and 1,1,2,2-PCA Plume, Surficial Aquifer

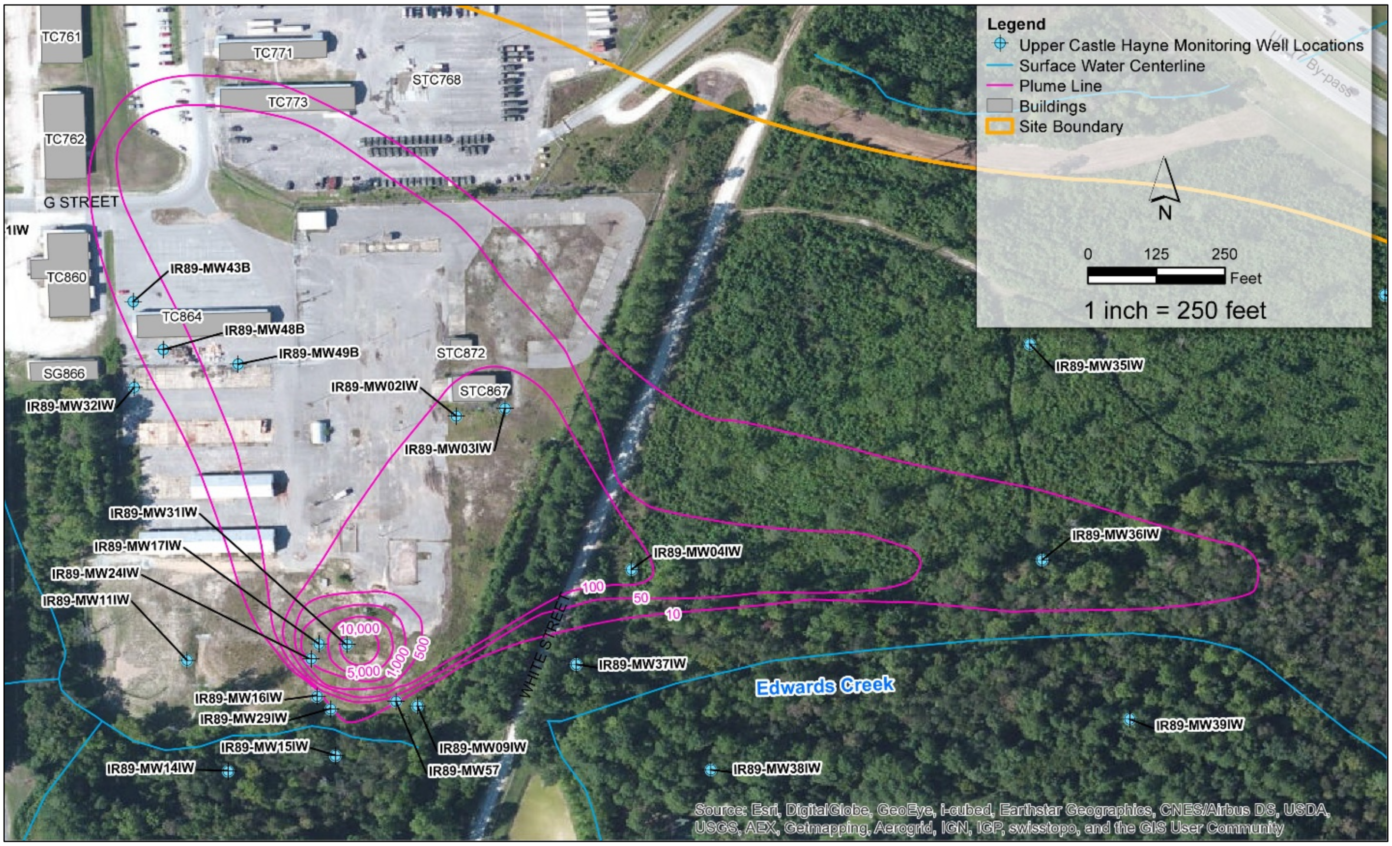


Figure CL-3b. Camp Lejeune Site 89 Total TCE and 1,1,2,2-PCA Plume, Upper Castle Hayne Aquifer

8.4 Camp Lejeune Treatment Area and Wells Reviewed in Desktop Evaluation

Based on the findings of the environmental investigations, a time-critical removal action was completed in October 2000. Low temperature thermal desorption units were used to treat approximately 32,000 tons of contaminated soil. In addition, an aeration system was installed in Edwards Creek to assist in the remediation of VOCs in the creek. In 2004, an electrical resistance heating (ERH) pilot study was conducted as a remedial action (RA) for one area of DNAPL (**Figure CL-4**). An estimated 48,000 pounds of VOCs were removed during the thermal treatment (AGVIQ/CH2M HILL, 2010d).

Three other areas of Site 89 were treated with ZVI soil mixing in May through August 2008. Soil mixing activities were conducted over approximately 32,400 square feet to treat approximately 30,000 cubic yards of soil. As shown on **Figure CL-4**, a total of 515 soil mixing columns were laid out in a grid pattern, with 18 percent column overlap to achieve complete coverage of the treatment area. Mixing was conducted in a 25-foot column after removing approximately the top 3 feet of overburden. A batch plant was constructed on site to prepare the ZVI-bentonite slurry mixture to the project specifications (2-percent ZVI and 3-percent bentonite, by mass of soil). For each 10-foot diameter column, approximately 3,495 pounds of ZVI and 5,243 pounds of bentonite were used. In total, 924 tons of ZVI, 1,423 tons of bentonite, and 1,372,000 gallons of water were mixed into the treatment zone.

Wells evaluated as part of this desktop study are included in **Table CL-1** and shown on **Figure CL-4**. Downgradient wells were not included because all wells downgradient of the soil mixing areas were installed over a year after mixing was completed.

Table CL-1. Camp Lejeune Site 89 Wells Included in Desktop Review

Source Area	IR89-MW20/67, IR89-MW22/63, IR89-MW23/70, IR89-MW27/65, and IR89-MW28/69

Figure CL-4. Camp Lejeune Site 89 Treatment Area and Wells Included in Desktop Review

8.5 Camp Lejeune Site 89 Desktop Evaluation Results

This section represents an evaluation of the performance of the ZVI treatment (reduction in VOC concentrations) and groundwater geochemistry changes created by the ZVI treatment in the soil mixing area.

8.6 Camp Lejeune Site 89 Baseline Geochemical Conditions

Baseline data were collected at Site 89 in April of 2008. A summary of pre-treatment key field parameters is provided in **Table CL-2**.

The pre-treatment results indicate the following baseline conditions for the treatment area of the site:

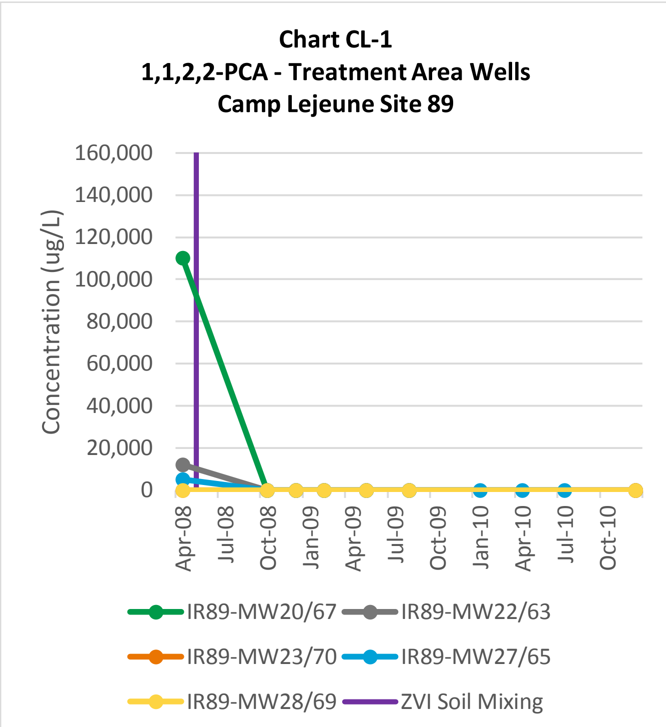
- DO concentrations ranged from 0.82 mg/L to 2.21 mg/L
- pH ranged from 6.28 to 6.66
- ORP ranged from -71 mV to -51 mV

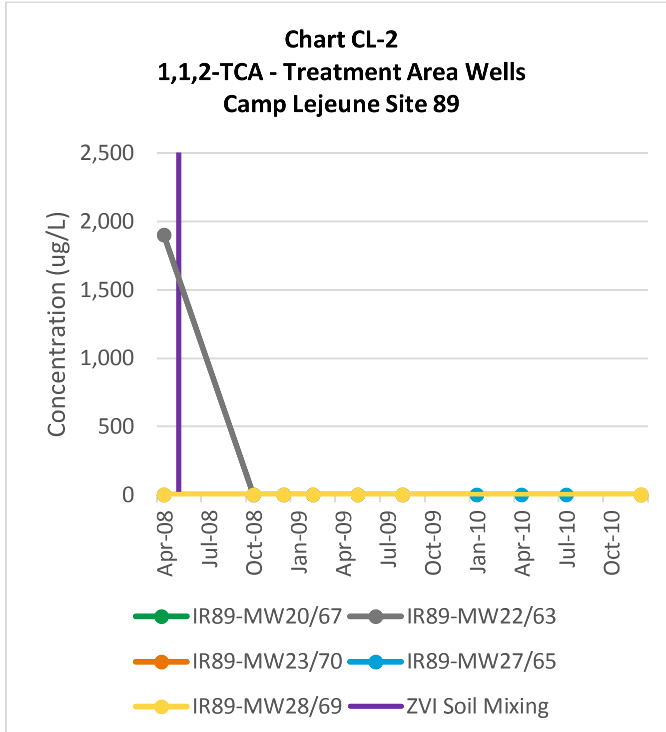
These results indicate the treatment area of the site was under slightly oxic to slightly reducing conditions prior to treatment. Highest baseline concentrations of contaminants where were detected in the sample from IR89-MW20 (reinstalled following injection at IR89-MW67). TCE was detected in this well at a concentration of 490,000 µg/L and 1,1,2,2-PCA was detected at a concentration of 110,000 ug/L. Daughter products of these chemicals were also detected at levels greater than 1,000 µg/L (**Table CL-2**).

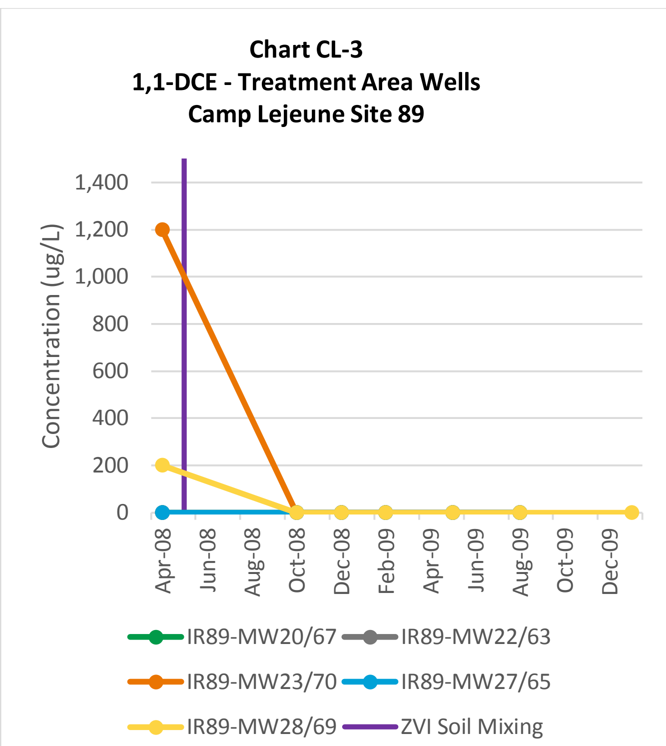
8.7 Camp Lejeune Site 89 Effectiveness of ZVI Injections

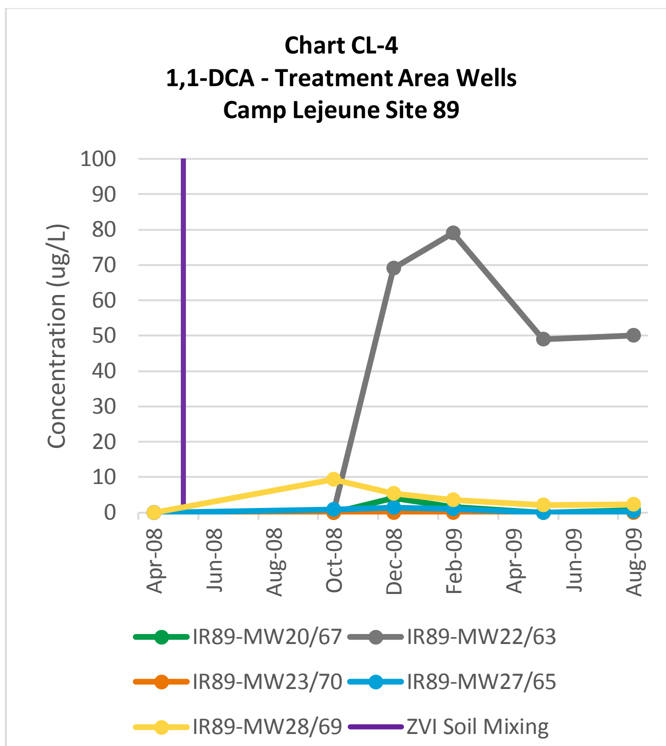
Baseline and the most recent post-injection VOC data available for each well are presented in **Table CL-2**. **Charts CL-1 through CL-8** show temporal trends for 1,1,2,2-PCA, 1,1,2-TCA, 1,1-DCE, 1,1-DCA, cis-1,2-DCE, trans-1,2-DCE, TCE, and VC. Data indicate significant decreases in concentrations of all VOCs to levels near or less than laboratory detection limits in all treatment area wells. No generation of significant amount of daughter products was observed.

Field parameters indicate highly reducing conditions were reached in the mixing area (ORP of -711 mV and DO concentrations of <1 mg/L). However, DO and ORP both returned to baseline levels within a year after treatment was completed. pH also increased from around 6.5 (baseline in August 2008) to as high as 11.12 (May 2009), but has since decreased to around 9.5.









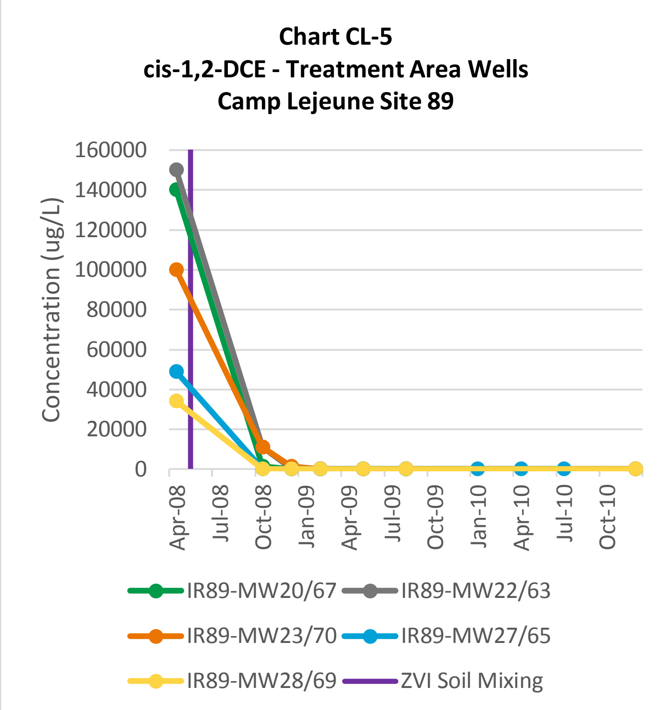


Chart CL-5
cis-1,2-DCE - Treatment Area Wells
Camp Lejeune Site 89
Concentration (ug/L)
160000
140000
120000
100000
80000
60000
40000
20000
0
Apr-08
Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
Jul-10
Oct-10
IR89-MW20/67
IR89-MW22/63
IR89-MW23/70
IR89-MW27/65
IR89-MW28/69
ZVI Soil Mixing

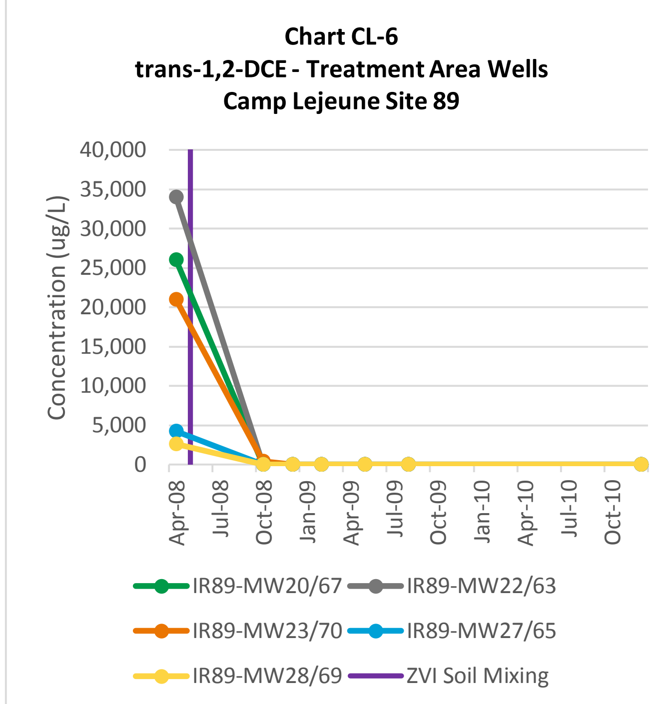


Chart CL-6
trans-1,2-DCE - Treatment Area Wells
Camp Lejeune Site 89
Concentration (ug/L)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Apr-08
Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
Jul-10
Oct-10
IR89-MW20/67
IR89-MW22/63
IR89-MW23/70
IR89-MW27/65
IR89-MW28/69
ZVI Soil Mixing

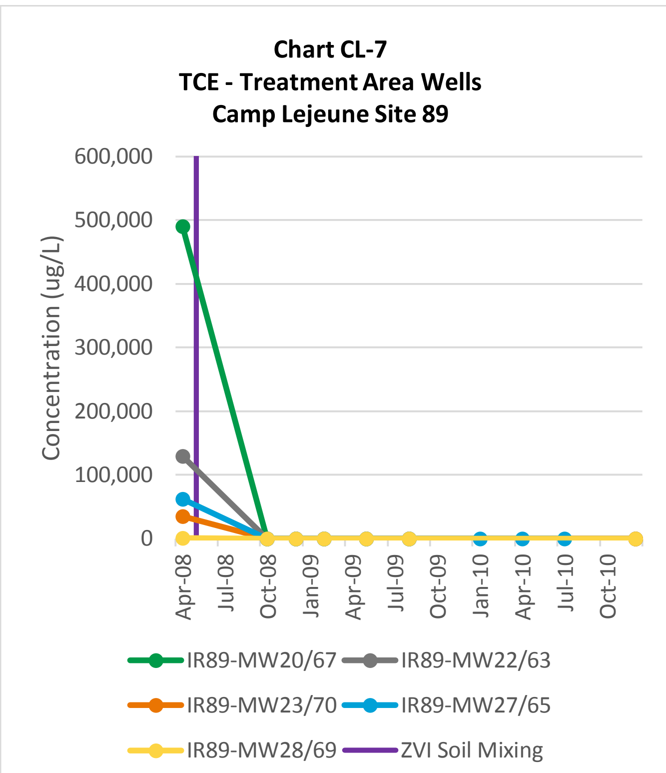


Chart CL-7
TCE - Treatment Area Wells
Camp Lejeune Site 89
Concentration (ug/L)
600,000
500,000
400,000
300,000
200,000
100,000
0
Apr-08
Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
Jul-10
Oct-10
IR89-MW20/67
IR89-MW22/63
IR89-MW23/70
IR89-MW27/65
IR89-MW28/69
ZVI Soil Mixing

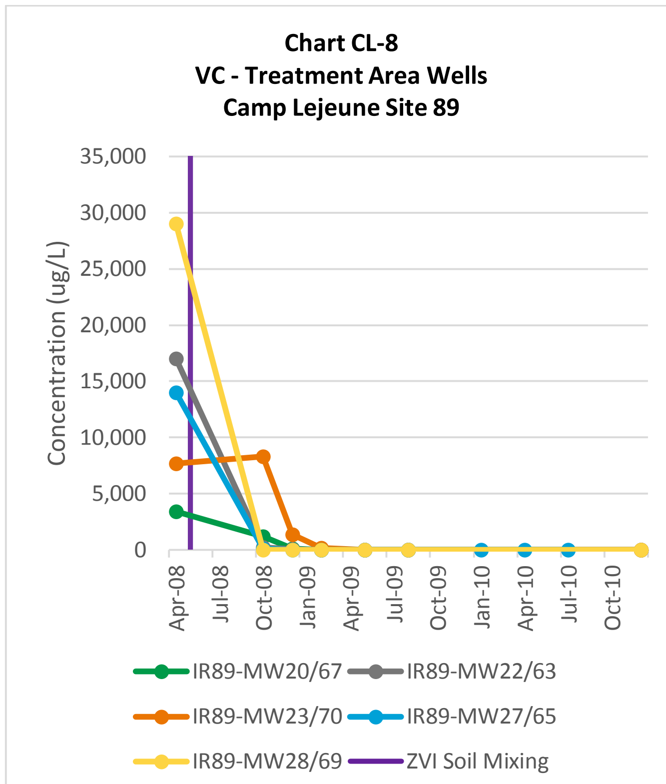
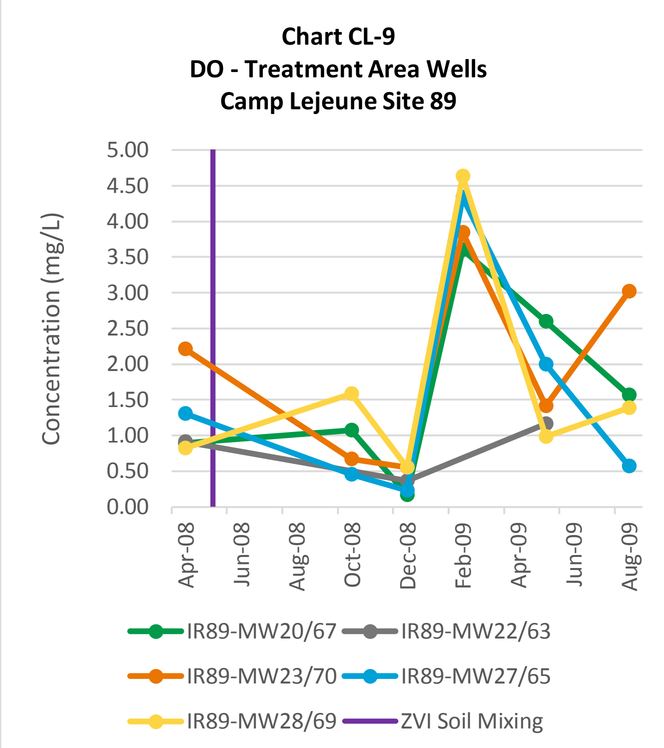
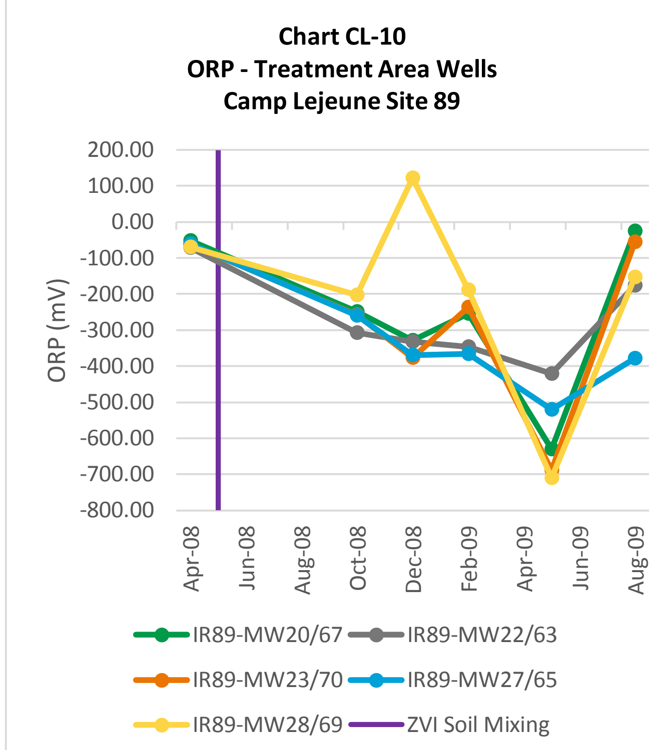
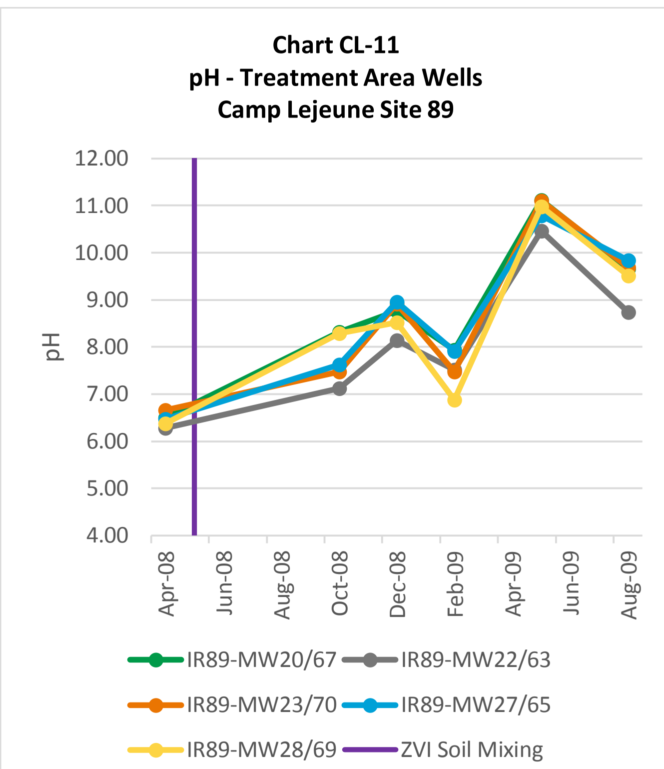
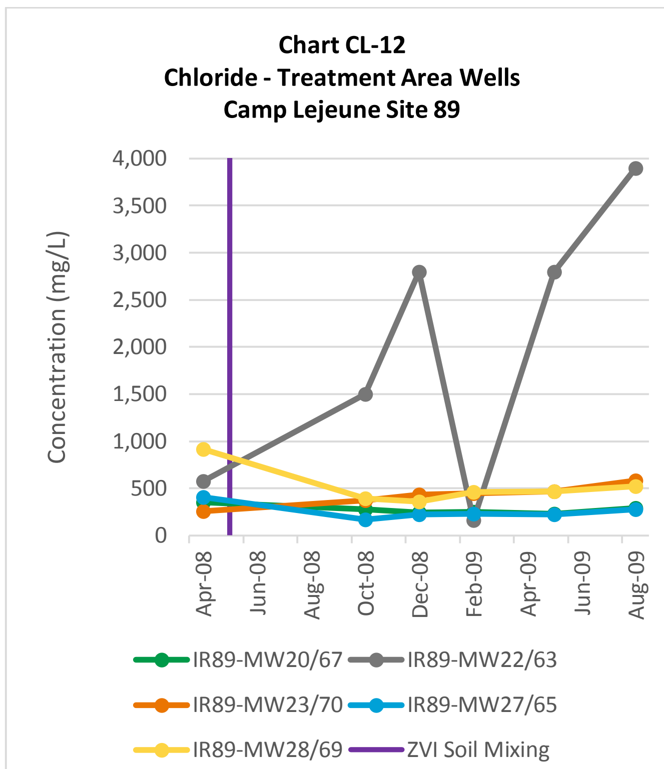


Chart CL-8
VC - Treatment Area Wells
Camp Lejeune Site 89
Concentration (ug/L)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Apr-08
Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
Jul-10
Oct-10
IR89-MW20/67
IR89-MW22/63
IR89-MW23/70
IR89-MW27/65
IR89-MW28/69
ZVI Soil Mixing









8.8 Camp Lejeune Site 89 Changes in Groundwater Flow

A groundwater contour map with pre-treatment conditions for Site 89 was not available. Consequently, no evaluation of changes to concentrations could be completed.

9 Naval Support Facility Indian Head, Site 17, Indian Head, Maryland Background

9.1 Indian Head Site 17 Site History

NSF Indian Head is located on the Potomac River and Mattawoman Creek (**Figure IH-1**), less than 30 miles south of Washington, D.C. NSF Indian Head was founded in 1890 as a gun test facility and has evolved and expanded to include numerous scientific and response-force missions serving all branches of the military (http://www.cnic.navy.mil).

Site 17 is in the southeast portion of the facility (**Figure IH-1**) and is defined as a 1,000-foot stretch of Mattawoman Creek shoreline where metal parts were discarded. A portion of the land at the site was created by filling the swamp/wetland with imported materials from other areas within NSF Indian Head. The defined area of Site 17 was expanded in 1997 to include the forested area 100 feet from the shoreline where dozens of rusted drums were identified. The site covers approximately 3.5 acres and was used for disposal of rocket motor casings, shipping containers, drums, and various metal parts from the 1960s until early 1980 (CH2M HILL, 2004)

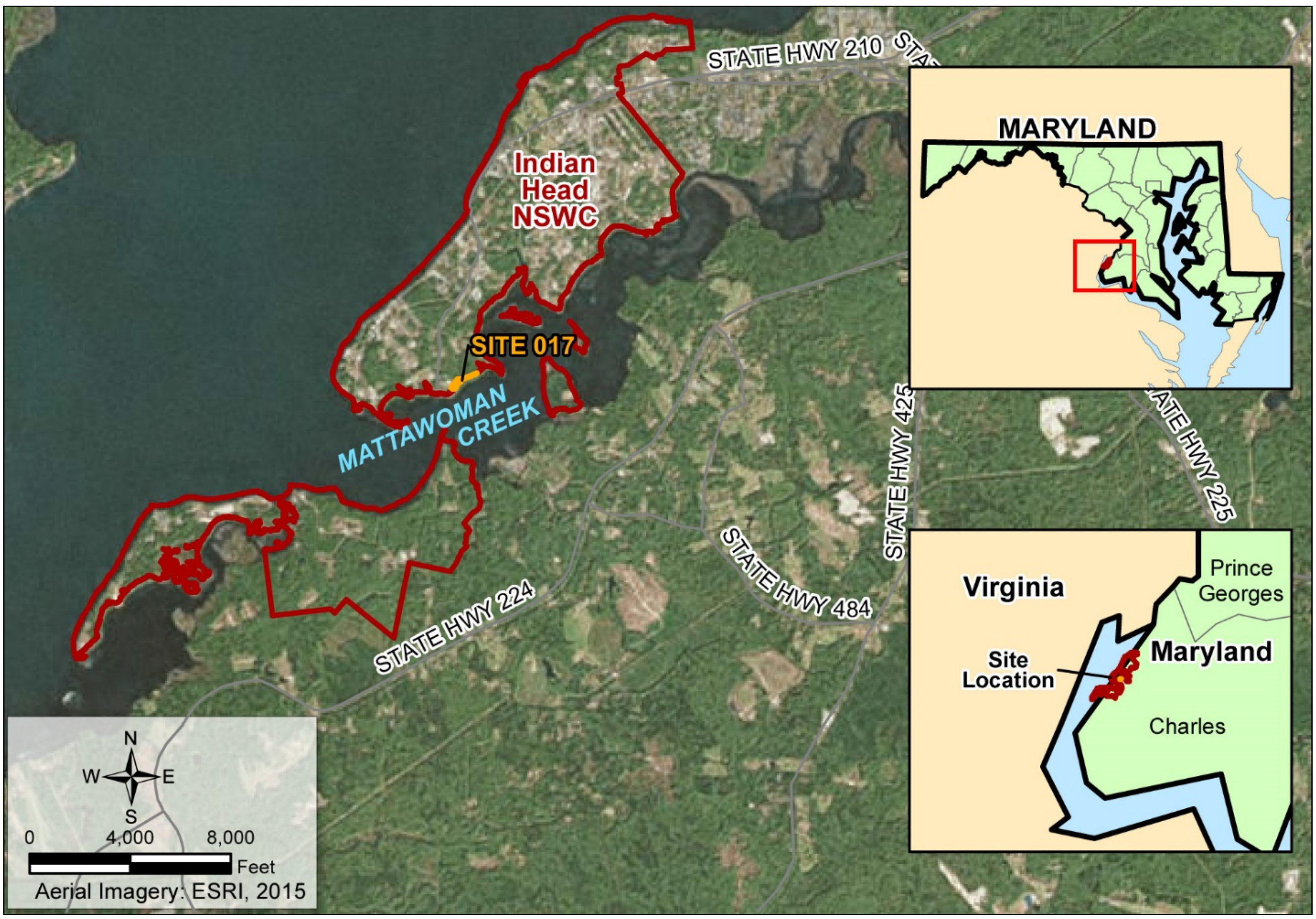


Figure IH-1. Indian Head Site 17 Location Map

9.2 Indian Head Site 17 Physical and Hydrogeologic Setting

The majority of the Site 17 ground surface is covered with light vegetation. Soil at Site 17 consists of fill material from the ground surface to an approximate depth of 10 to 12 feet bgs. The fill is characterized by a mixture of silty sand, sandy silt, and wood fragments. The fill layer is underlain by a silty clay layer from 10 to 12 feet bgs to 18 to 20 feet bgs. Underlying the silt is a clay layer from an approximate depth of 18 to 20 feet bgs to depths greater than 25 feet bgs, although its total thickness is not known. A cross section of site geology is provided in **Appendix A**.

Depth to shallow groundwater is between 5 and 15 feet bgs. Shallow groundwater generally flows from northwest to southeast towards Mattawoman Creek (CH2M HILL, 2013b) (**Figure IH-2**). Groundwater flow velocity was estimated to be between 43 and 400 feet per year (CH2M HILL, 2008c).

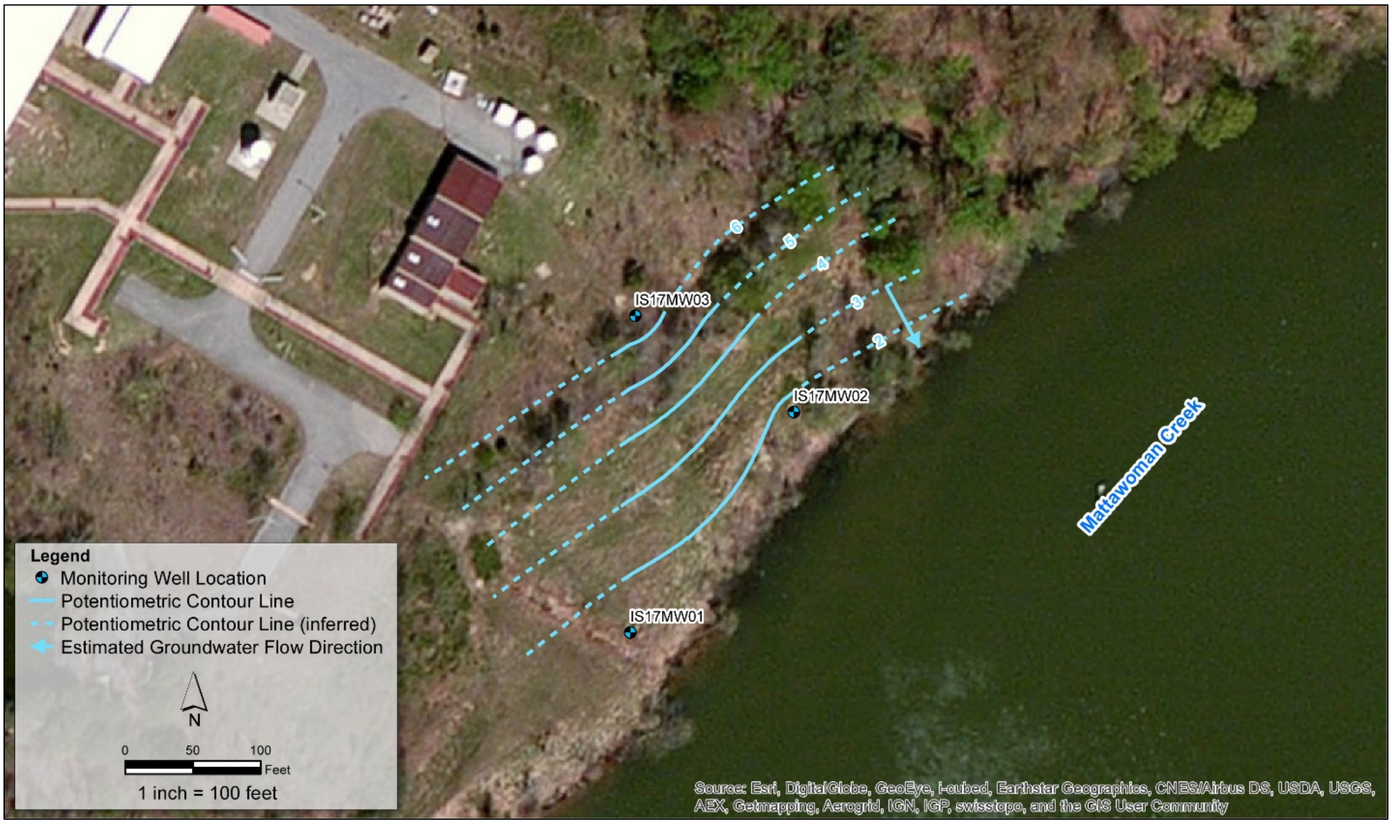


Figure IH-2. Indian Head Site 17 Groundwater Contour Map (2000)

9.3 Indian Head Site 17 Contaminant Distribution Prior to Treatment

TCE is the primary contaminant of concern at Site 17 with a maximum concentration of 490,000 µg/L prior to treatment in the upper surficial aquifer and 870,000 µg/L prior to treatment in the lower surficial aquifer (**Figures IH-3a and IH-3b**). Two distinct plumes concentration were identified at the site. The North Plume covered approximately 2,000 square feet and the South Plume covered approximately 38,000 square feet. The North Plume consists primarily of low concentrations of VOCs, while a much higher concentrations of VOCs were observed in the South Plume (CH2M HILL, 2008c).

Figure IH-3a. Indian Head Site 17 TCE Plume, Upper Surficial Aquifer (2005)

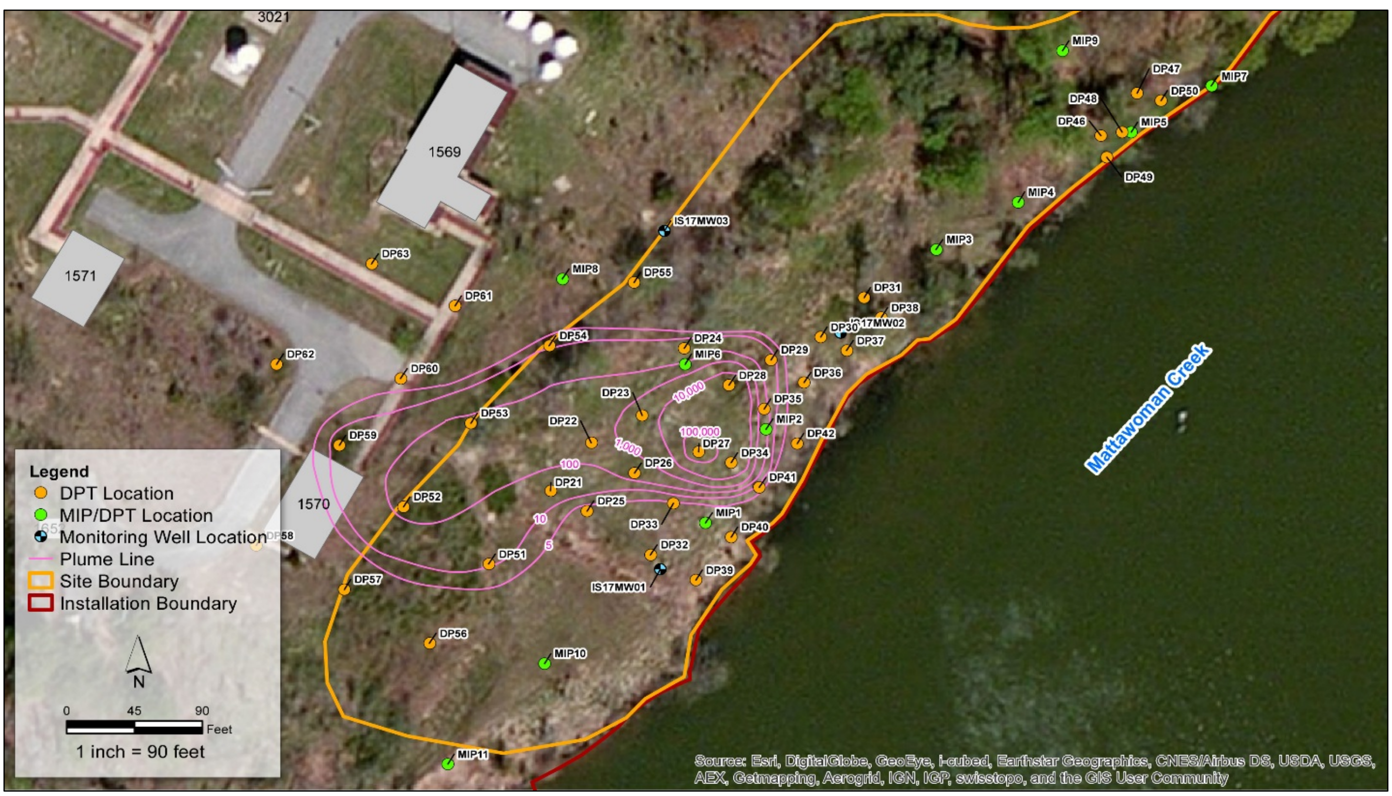


Figure IH-3b. Indian Head Site 17 TCE Plume, Lower Surficial Aquifer (2005)

9.4 Indian Head Site 17 Treatment Area and Wells Evaluated for Desktop Review

In November 2012, the RA for Site 17 groundwater was completed. ZVI-soil mixing was conducted in the area where TCE concentrations exceeded 1,000 µg/L through the depth interval of 8 feet to 18 feet bgs. The target treatment zone had a surface area of 3,500 square feet and a volume of approximately 1,296 cubic yards. A refined column layout of 70 columns was developed (**Figure IH-4**), and 9-foot augers were used for mixing. Although most of the VOC mass resided within the interval of 8 to 18 feet bgs, soil mixing occurred between 2 feet and 18 feet bgs. Bentonite slurry was mixed at a batch plant onsite and used to facilitate the drilling. A total of 30 tons of bentonite were used; approximately 16 tons were used as part of the 61,500 gallons of slurry while the remaining 14 tons were used in the spoils and top 8 inches of the soil mixing to help dry the spoils and firm up the ground surface. Once the augers had been advanced to 8 feet bgs, ZVI was also added to the slurry to distribute it throughout the treatment zone. ZVI dosing was calculated based on 1 percent ZVI (lbs of ZVI per lb of soil) and an average soil density of 118 pounds per cubic foot (lb/ft^3). Between 875 and 1,050 pounds of ZVI were mixed at each typical soil column (CH2M HILL, 2013b).

Data for Site 17 are sparse, with only VOC DPT data available in the source area prior to treatment. For this study, DP27 was used for the baseline data in the treatment area, while IS17-MW07 and IS17-MW08 were used for post-treatment data. The location of IS17MW08 roughly corresponds to the location of former DP27. **Figure IH-4** shows wells to be included in this analysis as well as the location of former DP27. Some data from crossgradient, downgradient, and upgradient wells was reviewed for the purpose of determining baseline geochemistry and effectiveness downgradient, but because of infrequency in data collection in these areas, trends were not assessed.

Figure IH-4. Indian Site 17 Treatment Area and Wells Included in Desktop Review

Table 6. Indian Head Site 17 Wells Included in Desktop Review

Upgradient	IS17MW03
Source Area	IS17MW07 and IS17MW08
Downgradient	IS17MW10
Crossgradient (to evaluate diversion of groundwater around treatment)	IW17MW02 and IW17MW06

9.5 Indian Head Site 17 Desktop Evaluation Results

This section represents an evaluation of the performance of the ZVI treatment (reduction in VOC concentrations) in the soil mixing area.

9.5.1 Indian Head Site 17 Baseline Conditions

Because baseline geochemical data were not collected from the treatment area, this discussion is based on upgradient well IS17MW03 and cross-gradient well IS17-MW02. Data are included on **Table IH-2**.

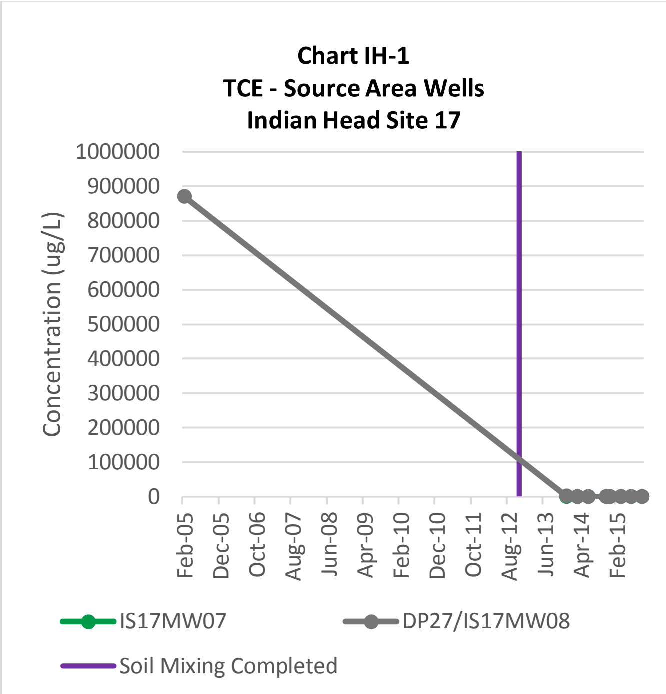
The pre-treatment results indicate the following baseline conditions for the treatment area of the site:

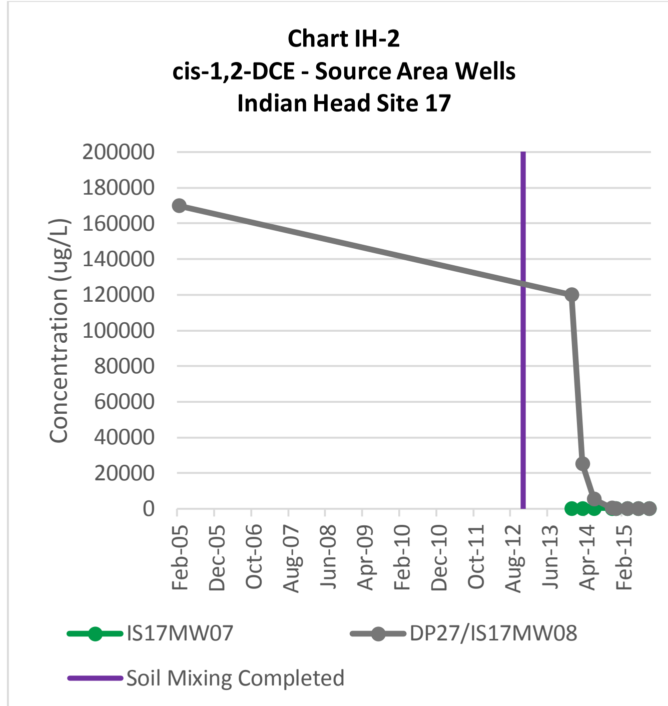
- DO concentrations measured ranged from 10.1 mg/L to 13.11 mg/L
- pH ranged from 4.92 to 5.87
- ORP ranged from -54 mV to 123 mV

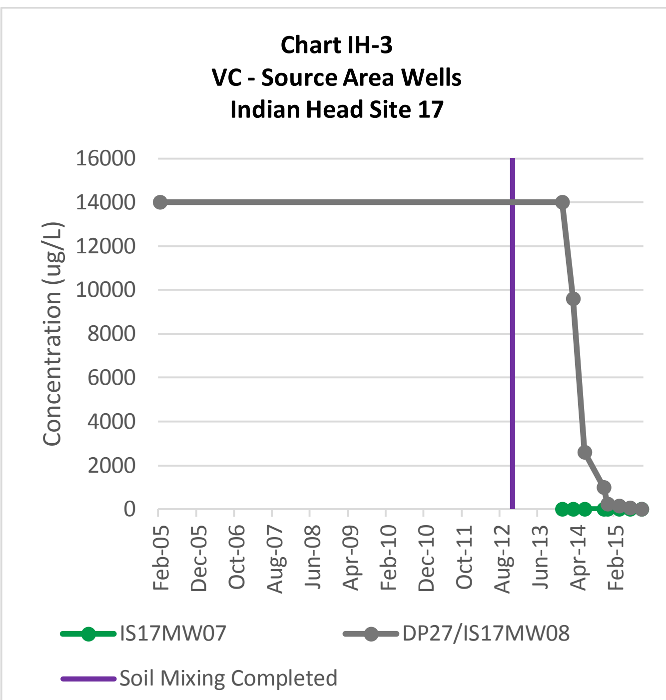
These results indicate the treatment area of the site was under oxic and acidic conditions prior to treatment. (**Table CL-2**). Maximum concentrations of TCE, cis-1,2-DCE, and VC were 870,000 µg/L, 170,000 µg/L, and 14,000 µg/L, respectively. The presence of some reductive dechlorination daughter products indicates reducing conditions are likely present in microzones at the site.

9.5.2 Indian Head Site 17 Effectiveness of ZVI Injections

Baseline and the most recent post-injection VOC data available for each well are presented in **Table IH-2**. **Charts IH-1 through IH-3** show temporal trends for TCE, cis-1,2-DCE, and VC. Data indicate significant decreases in concentrations of all VOCs. While concentrations of daughter products did not increase during the monitoring period, there was a noticeable lag in decreases in daughter product concentrations, relative to the decreases in TCE concentrations, indicating some concentration decreases were likely a result of reductive dechlorination.







Field parameters indicate reducing conditions were reached in the mixing area (ORP of -351 mV and DO concentrations of <1 mg/L). pH also increased to 8.57.

9.5.2.1 Indian Head Site 17 Changes in Groundwater Flow

Because only three wells were present prior to soil mixing and no recent groundwater flow maps have been generated, insufficient data were available to determine whether changes to hydraulic characteristics or groundwater flow occurred as a result of the treatment.

10 Conclusions and Recommendations for Further Study

10.1 Desktop Review Summary

Table 10-1 summarizes the results of the desktop review for each site.

Table 10-1. Nine Site Summary of ZVI Treatment Performance

Site Name	Primary Contaminants and Highest Baseline Concentration(s)	Groundwater Velocity (ft/year)	ZVI Dosage (lbs ZVI/lb soil)	Conclusions and Comments
PRB Sites				
ABL Site 1	TCE: 110 µg/L	293	40 percent -8+50 mesh Envirometal ZVI/60 percent sand PRB (trenched)	Reductions of 70% observed downgradient of the PRB. pH downgradient of the PRB continues to increase (a positive indicator of continued flow through the PRB). ORP has returned to near baseline levels in downgradient wells, but is still lower than in upgradient wells. Other geochemisty parameters (e.g. sulfate) do not indicate highly reducing conditions.
McGuire OT-16	TCE: 400 µg/L	376	0.5 percent Hepure ZVI, injected PRB using Ferox (nitrogen) process	Average reduction of 33% was observed, based on wells within, downgradient, and crossgradient of the PRB. No generation of daughter products was observed. Minimal and short-lived changes in field parameters (pH, ORP, DO) were observed. No changes in hydraulic characteristics were observed.
Injection Sites				
St. Julien's Creek Site 21	TCE: 12,500 µg/L	72	0.8 percent Hepure ZVI using Ferox	ZVI injections very effective in reducing all chlorinated VOCs to levels at or near MCLs in all monitoring wells within the ZVI treatment areas. A 96% reduction in total VOCs was observed. Geochemical changes and concentrations trends indicate mechanisms behind the CVOC reductions are both β-elimination and reductive dechlorination. Elevated pH and alkalinity remain in treatment areas. Indicators of reducing conditions, such as sulfide, have returned to near baseline levels. Arsenic concentrations have increased significantly.
White Oak Site 13	1,1,2,2-PCA: 946 µg/L TCE: 535 µg/L cis-1,2-DCE: 755 µg/L trans-1,2-DCE: 148 µg/L	35	0.2 percent (on-site) 0.4 percent (off-site) Hepure ZVI injected using Ferox	ZVI effective in reducing concentrations of CVOCs by ~85% both on and off-site. Efficacy was inconsistent from location to location, particularly in the on-site wells. Highly reducing conditions were achieved in only one well (13GW02) and of the wells in the treatment areas, clean up goals were only attained in 13GW02 and 13GW202. Inconsistent treatment in the on-site area may be a result of the lower dose used in that area, varying redox conditions across the site or possible sorbed mass in the source zone resulting in continued back diffusion following treatment.

Table 10-1. Nine Site Summary of ZVI Treatment Performance

Site Name	Primary Contaminants and Highest Baseline Concentration(s)	Groundwater Velocity (ft/year)	ZVI Dosage (lbs ZVI/lb soil)	Conclusions and Comments
SANG Site 8	cis-1,2-DCE: 1,200 µg/L	37	0.4 percent Hepure ZVI injected using Ferox	Concentrations of COCs in monitoring wells within the treatment area reduced to less than MCLs (~99.4%). Because concentrations were already decreasing as a result of previous treatments in the area, it is uncertain the degree to which the ZVI contributed to site clean-up. pH increased following treatment, and DO was maintained at levels less than 1 mg/L throughout most of the post-treatment monitoring period. ORP was also reduced, but not to levels ideal for abiotic reduction of chlorinated ethenes.
Mixing Sites				
Arnold AFB SWMU 16	TCE: 5,616 µg/L	81	0.2-percent (injections) 0.8-percent ZVI (mixing)	Substantial decreases of TCE observed in the source area as well as in downgradient wells. Nitrate also effectively treated with ZVI. Strongly reducing conditions were not achieved at this site and significant generation of daughter products occurred. This in conjunction with probably movement of contaminants resulted in an overall increase of total VOCs at the site. Daughter products did not subsequently degrade.
St. Louis Ordnance Depot OU1	PCE: 36,100 µg/L	No aquifer testing completed	1-percent ZVI – mixed with no clay addition or water	Concentrations of COCs in monitoring wells within the treatment area and the downgradient area reduced to less than the site clean-up goal of 21,000 µg/L (average reduction of 99.8%) . Highly reducing conditions favorable for β-elimination achieved in the mixing area. Some evidence of reductive dechlorination also observed. pH increased and DO maintained at levels less than 1 mg/L throughout post-treatment monitoring period in the soil-mixing area. DO also reduced to less than 1 mg/L during most rounds of downgradient well monitoring. Some reduction in concentrations downgradient also occurred.
Camp Lejeune Site 89	1,1,2,2-PCA: 110,000 µg/L TCE: 490,000 µg/L cis-1,2-DCE: 140,000 µg/L trans-1,2-DCE: 26,000 µg/L VC: 3,400 µg/L	17-55	2-percent ZVI, 3-percent bentonite mixture	Concentrations reduced by >99.9% in all treatment area wells (in most cases to less than laboratory detection levels). No rebound of VOCs observed. ORP reduced to -711 mV. DO was also reduced and pH increased, but some rebound of these parameters has occurred.

Table 10-1. Nine Site Summary of ZVI Treatment Performance

Site Name	Primary Contaminants and Highest Baseline Concentration(s)	Groundwater Velocity (ft/year)	ZVI Dosage (lbs ZVI/lb soil)	Conclusions and Comments
Indian Head Site 17	TCE: 870,000 µg/L cis-1,2-DCE: 170,000 µg/L VC: 14,000 µg/L	43-400	1-percent ZVI, ZVI/bentonite slurry	Concentrations reduced by >99%, to levels just greater than MCLs. Highly reducing conditions achieved in the mixing area. pH increased following treatment, DO was reduced to levels less than 1 mg/L. No rebound of contaminants observed.

10.2 General Conclusions and Recommendations:

The amount of performance data available for the ZVI treatment systems varied widely between sites. In most cases, the amount of upgradient, treatment zone, and downgradient data was less than optimal, if not insufficient, for conducting a comprehensive evaluation of VOC and geochemical changes achieved throughout the treatment periods. Teams planning the implementation of ZVI treatment systems should consider the type of long term VOC and geochemical monitoring needed to fully document system performance and provide appropriate monitoring points for data collection. Insufficient characterization was also problematic during implementation of the RA at some of the sites. This was especially true for the PRB sites, where insufficient data around the PRBs at the time of installation resulted in placement of the PRBs either upgradient of the highest levels of contamination (both ABL Site 5 and McGuire) or left the PRB too short to intercept all contaminated groundwater (McGuire). Teams designing treatments based on DPT data only should consider collecting baseline geochemistry data prior to treatment to allow for comparison following treatment. Additionally, changes in hydraulic characteristics following ZVI treatment where not assessed at most sites and would be of benefit in determining long term effectiveness of ZVI.

The degree of VOC degradation achieved by the various ZVI treatment systems varied from as little as 33 percent to nearly 100 percent. The greatest degree of VOC treatment was achieved within ZVI soil mixing zones. The PRB sites reviewed were relatively ineffective, primarily due to placement, but also possibly due to insufficient iron at the McGuire site, where the iron was unable to achieve long-lasting reducing conditions. Injected ZVI treatment systems had the greatest variability in VOC degradation results, with one site resulting in an overall increase in VOC concentrations, while other sites achieved clean-up levels of >99 percent. VOC performance appears related to ZVI dose (ZVI to soil ratio) as well as site conditions prior to treatment (sites already under reducing conditions performed better).

Evidence of degradation through the sequential reductive dechlorination pathway was found at all of the injected ZVI treatment systems, downgradient of one PRB, and at two of the four soil mixing sites. The least amount of evidence for the reductive dechlorination pathway was found at Camp Lejeune Site 89 (dose of 2 percent) and Indian Head Site 17 (dose of 1 percent). **Table 10-2** shows performance at each site as well as ORP achieved, dosage, and daughter product generation.

Table 10-2. ZVI Design Metrics and Performance

Site	Iron Dose (ZVI:soil mass ratio)	Lowest ORP Achieved During Treatment (mV)1	Percent Reduction/Increase in Concentrations1	Generation of Daughter Products Observed	If Yes, with or without subsequent Reductions
ABL Site 5	40*	-212	-70.7%	Yes (but may be due to migration)	Without
McGuire OT-16	0.5	-501.4	-33%	No	NA
St. Julien's Creek Site 21	0.8	-418.1	-96.3%	Yes	With
White Oak Site 13	0.2 (onsite)/0.5 (offsite)	-303	-58.6% (onsite)/-85.6% (offsite)	Yes	With
Savannah ANG Site 8	0.4	-184.9	-99.4%	Yes	With
Arnold Air Force Base SWMU 16	0.2	-205	+397%	Yes	Without
St. Louis Ordnance Depot OU1	1	-400	-99.8%	Yes	With (source area)
Camp Lejeune Site 89	2	-711	-99.99%	No	NA
Indian Head Site 17	1	-308	-99.98%	No	NA

* Based iron: sand ratio in PRB

[1] Treatment Area, or downgradient for the ABL PRB

Downgradient geochemical changes in groundwater quality most frequently observed include increases in pH and decreases in ORP, DO and other terminal electron acceptors (e.g. sulfate). At the only site where arsenic data were available (St. Julien's Creek Site 21), arsenic concentrations increased considerably in ZVI treatment areas. Additional investigation may be helpful in evaluating arsenic mobilization at ZVI sites.

Many parameters indicative of ZVI performance rebounded to baseline conditions within months of treatment, indicating long-term effectiveness of ZVI may be limited, particularly with respect to generation of conditions favorable for β-elimination. **Table 10-3** shows time to ORP rebound for each site evaluated. However, because increased pH and more mildly reducing conditions are more favorable for reductive dechlorination, ZVI may maintain sufficient reactivity to facilitate continuing biological reactions.

Table 10-3. ORP Time to Rebound

Site	Time to ORP Rebound in Treatment Area (days)	Time to ORP Rebound in Downgradient Wells (days)
ABL Site 5	N/A	1461
McGuire OT-16	151	609
St. Julien's Creek Site 21	1826	N/A
White Oak Site 13 (on site)	N/A*	N/A
White Oak Site 13 (off site)	N/A*	N/A
Savannah ANG Site 8	N/A*	N/A
Arnold Air Force Base SWMU 16	304	1218
St. Louis Ordnance Depot OU1	1673	915
Camp Lejeune Site 89	426	N/A
Indian Head Site 17	NR	NR

*Time to rebound not calculated for White Oak and Savannah ANG as ORP results are still decreasing as of the most recent sampling event

NR indicates baseline data not recorded

11 References

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Tables

TABLE AB-2

Allegany Ballistic Lab Site 5

Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	**Upgradient of PRB**				**Downgradient of PRB**					
	5GW13	**5GW13**	**5GW17**	**5GW17**	**5GW18**	**5GW18**	**5GW22**	**5GW22**	**5GW25**	**5GW25**
Location	**UG**	**UG**	**UG**	**UG**	**UG**	**UG**	**UG**	**UG**	**UG**	**UG**
Sample Date	**Oct-05**	**Jan-15**	**Oct-05**	**Jan-15**	**Oct-05**	**Jan-15**	**Oct-05**	**Jan-15**	**Oct-05**	**Jan-15**
Parameter										
DO, mg/L	0	0	0	0	0	0	2.46	NS	NS	0
Total Iron, ug/L	1480	550	729	83.2	1310	7470	5720	NS	NS	2460
Total Manganese ug/L	3420	957	883	462	57.1	207	393	NS	NS	322
Total Arsenic ug/L	2.3 UL	NA	2.3 U	NA	29.6	NM	2.3 UL	NS	NS	NM
Dissolved Iron, ug/L	NM	679	NM	47.9	NM	5970	NM	NS	NS	2250
Dissolved Manganese (mg/L)	NM	916 L		492		191 L	NM	NS	NS	296 L
Chloride	30	NA	20	NM	16	NM	13	NS	NS	NM
Bicarbonate	77	NA	71	NM	180	NM	100	NS	NS	NM
Sulfate, mg/L	280	NA	200	NM	43	NM	170	NS	NS	NM
Methane, ug/L	180 J	NA	34	NM	38	NM	3.3 U	NS	NS	NM
pH, SU	6.51	6.72	5.05	5.87	6.13	6.89	6.2	NS	NS	7.7
ORP, mV	8	82	198	135	128	-34	-18	NS	NS	0.97
Alkalinity, mg/L as CaCO3	77	NA	71	NM	180	NM	100	NS	NS	NM
TOC, mg/L	2.1	NA	2.4 B	NM	1.6 B	NM	1 U	NS	NS	NM
VOCs										
TCE, ug/L	15	10	19 B	12	80	13	83	NS	NS	1 U
cis-1,2-DCE, ug/L	6.4	3	4.5	10	12	7	13	NS	NS	7
trans-1,2-DCE, ug/L	0.5 U	1 U	0.5 U	1 U	0.5 U	5	1 U	NS	NS	1 U
VC, ug/L	0.5 U	1 U	0.5 U	1 U	0.5 U	2	1 U	NS	NS	1 U
Sum of 4 VOC Detections	21.4	13	4.5	22	92	27	96	NS	NS	7

Notes:

Shading indicates post-investigation

No Shading indicates pre-investigation

NA - Not analyzed

ND - Not Detected

NS - Not sampled

U - Not detected at reporting level shown

J - Detected, value estimated

TABLE OT-2

Joint Base McGuire-Fort Dix-Lakehurst OT-16

Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	**Average Within PRB**		**Average Downgradient of PRB**		**Average Upgradient of PRB**		**Average Cross Gradient of PRB (South of Wall)**		**Average Cross Gradient of PRB (North of Wall)**		**Beneath PRB**	
Sample Date	Mar-12	Feb-15	Mar-12	Feb-15	Mar-12	Feb-15	May-13	Feb-15	May-13	Feb-15	May-13	Feb-15
DO, mg/L*	4.64	1.37	4.43	1.25	4.25	3.14	5.08	5.55	4.61	4.31	2.74	0.31
Methane, ug/L	6.4	77	NM	103	NM	44	NM	NM	NM	NM	NM	NM
Ethane, ug/L	NM	7	NM	6	NM	5	NM	NM	NM	NM	NM	NM
Ethene, ug/L	NM	ND	NM	ND	NM	ND	NM	NM	NM	NM	NM	NM
pH, SU*	5.31	5.52	4.83	4.73	5.5	4.62	5.49	4.96	7.36	5.17	6.02	4.61
ORP, mV*	19.92	-49.62	9.17	178.54	31.85	333	82	328	57	263	15	111
VOCs												
TCE, ug/L	113	75	28	144	132	112	105	134	44.45	41.65	1.68	3.25
cis-1,2-DCE, ug/L	2.9	1.9	1.2	4.1	3	2.4	2.5	4.9	0.71	0.78	ND	ND
VC, ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sum of 4 VOC Detections	115.9	76.9	29.2	148.1	135	114.4	107.5	138.9	45.16	42.43	1.68	3.25

Notes:

Shading indicates post-investigation

No Shading indicates pre-investigation

NA - Not analyzed

ND - Not Detected

NS - Not sampled

U - Not detected at reporting level shown

J - Detected, value estimated

For MW27SR, geochemical data for November 2013 rather than November 2015 were available.

TABLE SJ-2

St. Julien's Creek Annex Site 21

Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	Eastern ZVI Treatment Area				Western ZVI Treatment Area								
	MW27SR	**MW27SR**	**MW16S**	**MW16S**	**MW15S**	**MW12S**	**MW12S**	**MW20SR**	**MW20SR**	**MW02S**	**MW02S**	**MW14S**	**MW14S**
Sample Date	**Nov-10**	**Nov 2015 for VOCs; Nov 2013 for geochem**	**Nov-10**	**Nov-15**	**Nov-15**	**Nov-10**	**Nov-15**	**Nov-10**	**Nov-15**	**Nov-10**	**Nov-15**	**Nov-10**	**Nov-15**
Parameter													
DO, mg/L	1.25	0.2	1	0	0.2	0.4	NA	1	3	0.96	1	0.4	3
Dissolved Iron, mg/L	2.29	18.7	0.756	0.317	19	4.2	16	5.78	13	1.64	0.050 U	2.19	23
Sulfate, mg/L	22.7	4.5	24.9	11.6	27.7	99.1	76.7	7.2	2.9	39	11.8	51.6	14.7
Sulfide, mg/L	0.6 U	1.5 U	0.6 U	1 U	1 U	0.6 U	0.21 J	0.6 U	1 U	0.6 U	1 U	0.6 U	1 U
Methane, ug/L	30.9	10,800	48.9	27.2	3,560	145	2,460	582	3,490	297	320	246	5,390
Ethane, ug/L	0.32 U	106	0.32 U	5 U	118	1.5	154	2.43	32.9	1.2	9.3 J	0.86 J	50.3
Ethene, ug/L	1.9	5.3	0.83 J	5 U	26.8	0.99 J	73.8	4.02	5 U	1.2	5 U	0.54 J	6.5 J
pH, SU	5.59	6.9	6.74	6.8	6.86	6.32	NA	6.46	8.36	5.97	7.5	5.76	7.56
ORP, mV	128.5	-56	-2.8	98	98	-46.4	NA	14.9	-52	64.2	141	186.9	-72
Alkalinity, mg/L as CaCO3	12.5	196	30.8	136	127	125	230	127	157	70.7	54.6	36.6	397
TOC, mg/L													
VOCs													
TCE, ug/L	5,440	0.5 U	3,770	2	0.5 U	1,610	1.6 U	152	0.5 U	15.4	0.5 U	27.6	0.5 U
cis-1,2-DCE, ug/L	1,560	0.5 U	598	0.5 U	0.76 J	550	237	906	1.3	2,020	14.7	1,300	13.9
1,1-DCE, ug/L	23	0.5 U	29.6	0.5 U	0.5 U	4.6	1 U	3.4	0.5 U	5.8 U	0.5 U	4.6	0.5 U
VC, ug/L	22	0.5 U	33.8	0.59 J	3	9.1	78.2	33.4	12.2	42.4	3.6	12.8	34.9
Sum of 5 VOC Detections	7,045	ND	4,431	2.59	3.76	2,174	315.2	1094.8	13.5	2,078	18.3	1345	48.8

Notes:

Shading indicates post-investigation

No Shading indicates pre-investigation

NA - Not analyzed

ND - Not Detected

U - Not detected at reporting level shown

J - Detected, value estimated

TABLE WO-2

Naval Surface Warfare Center White Oak, Site 13

Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	Onsite Treatment Area										
	13DP204-15	**13DP205-20**	**13DP206-20**	**13DP208-21**	**13DP218-20**	**13GW02**	**13GW02**	**13GW206**	**13GW206**	**13GW300**	**13GW301**
Sample Date	**Aug-01**	**Aug-01**	**Aug-01**	**Aug-01**	**Aug-01**	**Aug-04**	**Oct-12**	**Aug-04**	**Nov-15**	**Nov-15**	**Oct-12**
Parameter											
DO, mg/L	NA	NA	NA	NA	NA	4	0.6	7	2.88	2.27	1
Dissolved Iron, ug/L	NA	NA	NA	NA	NA	61.6 B	75.3	14.4 U	6990*	13,500	10,200
Nitrate, mg/L	NA	NA	NA	NA	NA	0.72	0.052U	0.16	0.05 U	0.05 U	0.052 U
Chloride, mg/L	NA	NA	NA	NA	NA	96.4	40	60.2	86.8	53.2	110
Sulfate, mg/L	NA	NA	NA	NA	NA	3.1	0.26 U	28.8	49.9	1.02	0.26 U
Methane, mg/L	NA	NA	NA	NA	NA	0.0042	7.87	NA	0.42	NA	NA
pH, SU	NA	NA	NA	NA	NA	5.74	9.11	5.48	6.12	6.05	6.75
ORP, mV	NA	NA	NA	NA	NA	186	-363	238	-19	-17	-147
Alkalinity, mg/L as CaCO3	NA	NA	NA	NA	NA	9.1 J	7.4	73 J	35.4	32.6	8.7
TOC, mg/L	NA	NA	NA	NA	NA	1	1.3	1	1.41	1.1	4
VOCs											
PCE, ug/L	38.9	28.6	8.92	113	6.89	46 J	0.26 U	17 U	0.2 U	9.9 U	1U
TCE, ug/L	98	135	153	535 D	55	150	1 U	9.5 J	2.5	9.9 U	1 U
cis-1,2-DCE, ug/L	49.9	270	265	558	755	84	1 U	320	270	110	14
trans-1,2-DCE, ug/L	18.4	77.5	79.5	148	83.5	50 U	1 U	19	7.1 J	110	2 J
VC, ug/L	1	9.92	12.1	10.3	11	50 U	1 U	17 U	8.7	24	1.2 J
1,1,2,2 PCA, ug/L	946	664	215	683	490	700	1 U	17 U	0.54 U	180	1 U
Sum of 7 VOC Detections	1152	1185	734	1512	1401	980	ND	348.5	288.3	424	17.2

Notes:

Shading indicates post-investigation

No Shading indicates pre-investigation

NA - Not analyzed

ND - Not Detected

NS - Not Sampled

U - Not detected at reporting level shown

J - Detected, value estimated

* Result is from sample collected in July 2011

** Result is from sample collected in October 2012

*** Result is from sample collected in October 2014

TABLE WO-2

Naval Surface Warfare Center White Oak, Site 13

Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	**Offsite Treatment Area**					
	13GW202	**13GW202**	**13GW303**	**13GW303**	**13GW304**	**13GW304**
Sample Date	**Aug-04**	**Oct-14**	**May-10**	**Nov-15**	**May-10**	**Nov-15**
Parameter						
DO, mg/L	0.59	1	8	2.39	4	2.81
Dissolved Iron, ug/L	24,000	3650**	1550	25.5J**	1460	6640**
Nitrate, mg/L	0.05	0.21 U	0.04	0.21 U	0.022	0.21 U
Chloride, mg/L	100	38	66	41.2	79	34.5
Sulfate, mg/L	4.1	0.1	8.4	0.598	3.1	1.21
Methane, mg/L	0.74	8.7	0.00072	1.4	0.0021	1.1
pH, SU	5.96	6.34	5.72	4.99	5.05	5.15
ORP, mV	-1	-134	131	193	239	135
Alkalinity, mg/L as CaCO3	29 J	7.8	28	5***	20	5
TOC, mg/L	1	0.36	59	1.29	10	202
VOCs						
PCE, ug/L	13 J	1 U	1.3	6.1	8.8	3.4
TCE, ug/L	69	1 U	12	15	44	16
cis-1,2-DCE, ug/L	400	1 U	210	32	80	28
trans-1,2-DCE, ug/L	51	1 U	11	15***	23	13***
VC, ug/L	25 U	1 U	7.1	0.59	1.8	0.73
1,1,2,2 PCA, ug/L	25 U	0.54 U	8.5	19	230	5.9
Sum of 7 VOC Detections	533	ND	250	73	388	54

Notes:

Shading indicates post-investigation
No Shading indicates pre-investigation
NA - Not analyzed
ND - Not Detected
NS - Not Sampled
U - Not detected at reporting level shown
J - Detected, value estimated
* Result is from sample collected in July 2011
** Result is from sample collected in October 2012
*** Result is from sample collected in October 2014

TABLE SV-2

Savannah Air National Guard Base Site 8

Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	Source Area						Downgradient	
	08MW01S	08MW01S	08MW18	08MW18	08MW17	08MW17	08MW28	08MW28
Sample Date	**Dec-08**	**May-15**	**Dec-10**	**Nov-15**	**Aug-10**	**Nov-15**	**Feb-10**	**Nov-15**
Parameter								
DO, mg/L	0.63	0.49**	0.32***	0.51**	0.62	0.22*	0.27	0.65**
pH, SU	4.76	6.17**	4.02	5.64**	4.5	5.03*	3.98	4.61**
ORP, mV	-128	-74.8**	-143	-26.4**	-68.1	-102*	34	117.2**
VOCs								
PCE, ug/L	100 UD	2 U	5 U	1 U	5 U	1 U	5 U	1 U
TCE, ug/L	19 JD	2 U	23.3	1 U	5.7	1 U	5 U	1 U
cis-1,2-DCE, ug/L	1200 D	3.8 D	197 N	2.89 D	1 U	1 U	0.48 J	1 U
trans-1,2-DCE, ug/L	27 JD	3.5 D	10.6	1 U	1.86 J	1 U	5 U	1 U
VC, ug/L	9.2 J*	5 U	5.86	1 UX	0.767 J	1 U	2 U	1 U
Sum of 5 VOC Detections	1,355	7	237	3	8	ND	0.48	ND

Notes:

Shading indicates post-investigation

No Shading indicates pre-investigation

NA - Not analyzed

ND - Not Detected

U - Not detected at reporting level shown

J - Detected, value estimated

*Data collected in December of 2014

** Data collected in May 2015

***Data collected in August 2010

****Data collected in June 2013

TABLE AA-2

Arnold Air Force Base Site 8

Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	Source Area			Downgradient			
	MW-640	MW-641	PZ-1601	DP-1601	DP-1601	DP-1602	DP-1602
Sample Date	**Apr-03**	**Apr-03**	**Aug-11**	**Apr-03**	**Aug-11**	**Apr-03**	**Aug-11**
Parameter							
DO, mg/L	0.07	0.13*	0.41	3.33	0.34	2.78	0.31
Nitrate, mg/L	147.9	22	9.69	NA	1,38	NA	0.01
Chloride, mg/L	8.4	8.1	42.3	NA	9.5	NA	10.6
Methane, ug/L	3,700	56	1500	NA	1	NA	1100
pH, SU	3.94*	3.92*	5.73	4.13	4.39	4.59	4.99
ORP, mV	79*	151*	-23.1	163.4	258	163.3	95.5
VOCs							
TCE, ug/L	5,616	692	480	3,259	284	853	303
cis-1,2-DCE, ug/L	64.02	7.71	15,500	14	28.4	2.57	10.1
VC, ug/L	3.43	1.09	6,600	2	10.9	0	0.6
Sum of 3 VOC Detections	5,683	701	22,580	3,275	323	856	314

Notes:

Shading indicates post-investigation

No Shading indicates pre-investigation

NA - Not analyzed

ND - Not Detected

NS - Not Sampled

U - Not detected at reporting level shown

J - Detected, value estimated

*Value is from May 2000 field event because April 2003 result was not available.

TABLE SL-2

St. Louis Ordnance Depot OU1

Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	**Source Area**		**Downgradient**							
	MW-111	**MW-119**	**MW-107**	**MW-107**	**MW-108**	**MW-108**	**MW-110**	**MW-110**	**MW-116**	**MW-116**
Sample Date	**Dec-11**	**Apr-15**	**Dec-11**	**Apr-15**	**Aug-10**	**Apr-15**	**Dec-11**	**Apr-15**	**Aug-10**	**Apr-15**
Parameter										
DO, mg/L	0.92	0.13	6.77	0.47	0.37	0.08	0.11	0.48	2.24	0.08
pH, SU	6.17	7.45	6.3	6.26	6.02	6.26	6.3	6.35	5.79	6.38
ORP, mV	232.2	-65.8	125.6	223.2	141.2	277.7	187.2	329.7	98.7	222.8
VOCs										
PCE, ug/L	36,100	0.5 U	1.1 U	0.5 U	13,400	0.5 U	9,380	7980	1.1 U	0.5 U
TCE, ug/L	1,720	0.73 J	0.58	1.1	4.6	0.5 U	208	258	0.5 U	0.5 U
cis-1,2-DCE, ug/L	324	70.5	0.71	1.2	6.6	0.28 J	156	272	0.5 U	0.5 U
trans-1,2-DCE, ug/L	50 U	0.5 U	0.5 U	0.5 U	25 U	0.5 U	25 U	50 U	0.5 U	0.5 U
VC, ug/L	100 U	0.26 J	1 U	0.5 U	0.19 F	0.5 U	50 U	50 U	1 U	0.5 U
Sum of 5 VOC Detections	38,144	71	1	2	13,411	0.28	9744	8238	ND	ND

Notes:

Shading indicates post-investigation

No Shading indicates pre-investigation

NA - Not analyzed

ND - Not Detected

NS - Not Sampled

U - Not detected at reporting level shown

J - Detected, value estimated

TABLE CL-2

Camp Lejeune Site 89

Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	**ZVI Soil Mixing Areas**									
	IR89-MW20/67	**IR89-MW20/67**	**IR89-MW22/63**	**IR89-MW22/63**	**IR89-MW23/70**	**IR89-MW23/70**	**R89-MW27/65**	**IR89-MW27/65**	**IR89-MW28/69**	**IR89-MW28/69**
Sample Date	**Apr-08**	**Dec-10**	**Apr-08**	**Jun-15**	**Apr-08**	**Jul-15**	**Apr-08**	**Jul-10**	**Apr-08**	**Dec-10**
Parameter										
DO, mg/L	0.89*	1.57*	0.85*	0.53*	2.21*	0.11*	1.31	0.25*	0.82*	1.39*
Ferrous Iron (mg/L)	2.8*	0.4*	1.3*	3*	1.6*	NM	1.2*	0.4*	2.5*	0.4*
pH, SU	6.5*	9.66*	6.28*	9.25*	6.66*	8.6*	6.47	9.84*	6.37*	9.51*
ORP, mV	-51*	-25.40*	-71	-271.7*	-62*	-180.4*	-61	-378*	-70*	-153.6*
Chloride (mg/L)	349	290*	579	3450	257	580*	403	280*	913	520*
VOCs										
TCE, ug/L	490,000	0.42 J	130,000	1 U	35,000	0.5 U	62,000	0.5 U	960	0.5 U
cis-1,2-DCE, ug/L	140,000	1.8	150,000	1 U	100,000	0.87	49,000	0.7	34,000	0.3
trans-1,2-DCE, ug/L	26,000	0.5 U	34,000	1 U	21,000	0.5 U	4,200	0.5 U	2,600	0.5 U
VC, ug/L	3,400 J	0.35 J	17,000	1 U	7,700	0.5 U	14,000	0.5 U	29,000	1 U
1,1,2,2-tetrachloroethane	110,000	0.5 U	12,000	1 U	2,500 U	0.5 U	5,100	0.5 U	830 U	0.5 U
1,1,2-trichloroethane	13,000 U	0.5 U	1,900 J	1 U	2,500 U	0.5 U	2,500 U	0.5 U	830 U	0.5 U
1,1-dichloroethane	13,000 U	NM	5,000 U	NM	2,500 U	NM	2,500 U	NM	830 U	NM
1,1-dichloroethene	13,000 U	NM	5,000 U	NM	1,200	NM	2,500 U	NM	200	NM
Sum of 8 VOC Detections	769,400	2.57	344,900	ND	164,900	0.87	134,300	0.7	66,760	0.3
	*Field Parameters from 4/15/08	*Field parameters from 8/6/09	*Field Parameters from 4/15/08	*Field parameters from 6/15/14	*Field Parameters from 4/14/08	*Field Parameters from 6/9/14	*Field Parameters from 4/14/08	*Field Parameters from 8/6/09	*Field Parameters from 4/15/08	*Field Parameters from 8/6/09

Notes:

Shading indicates post-investigation

No Shading indicates pre-investigation

NA - Not analyzed

ND - Not Detected

NS - Not Sampled

U - Not detected at reporting level shown

J - Detected, value estimated

Baseline data

Most recent round of post-treatment data

TABLE IH-2
Indian Head Site 17
Pre- and Post-ZVI Treatment Groundwater Concentrations

Well	Upgradient		Source Area				Downgradient	Crossgradient	
	IS17MW03	IS17MW03	DP27 (4-6 ft)	DP27 (8-10 ft)	IS17MW07	IS17MW08	IS17MW10	IW17MW02	IW17MW02
Sample Date	**Feb-05**	**Sep-15**	**Feb-05**	**Feb-05**	**Sep-15**	**Sep-15**	**Sep-15**	**Feb-05**	**Sep-15**
Parameter									
DO, mg/L	13.11	0.55	NM	NM	0.44	2.07	0.42	10.1	2.45
pH, SU	4.92	5.35	NM	NM	8.57	8.57	6.16	5.87	6.1
ORP, mV	123	-3	NM	NM	-351	-351	-92	-54	-61
Acetate, mg/L	NA	0.2 U	NM	NM	0.2 U	87	0.2 U	NA	0.2 U
alkalinity, mg/L	NA	34	NM	NM	120	140	440	NA	180
Butyrate, mg/L	NA	0.1 U	NM	NM	0.1 U	0.1 U	0.1 U	NA	0.1 U
Chloride, mg/L	NA	20	NM	NM	110D	690 D	360 D	NA	60
Ethane, mg/L	NA	0.00196 U	NM	NM	0.0588	1.33	0.445	NA	2.14
Ethene, mg/L	NA	0.00271 U	NM	NM	0.00271 U	0.166	0.00137 J	NA	0.859
Lactic Acid, mg/L	NA	0.14 U	NM	NM	0.14 U	0.14 U	0.14 U	NA	0.14 U
Methane, ug/L	NA	0.00307	NM	NM	2.75	8.29	11.4	NA	6.88
Nitrate, mg/L	NA	0.21 U	NM	NM	0.21 U	0.21 U	0.21 U	NA	0.21 U
Nitrite, mg/L	NA	0.07 U	NM	NM	0.07 U	0.07 U	0.07	NA	0.07 U
Propionic Acid mg/L	NA	0.1 U	NM	NM	0.1 U	1.3	0.1 U	NA	0.1 U
Pyruvate, mg/L	NA	0.07 U	NM	NM	0.07 U	0.07	0.07 U	NA	0.07 U
Sulfate, mg/L	NA	31	NM	NM	23	1	1.4 J	NA	2.7 J
Sulfide, mg/L	NA	1 U	NM	NM	1 U	3	1 U	NA	0.81 J
VOCs									
TCE, ug/L	1 U	0.5 U	490,000	870,000	24.3	53.4	1 U	1 U	0.658 J
cis-1,2-DCE, ug/L	1 U	0.5 U	170,000	73,000	11.5	17.4	1 U	5500	142
VC, ug/L	1 U	0.5 U	14,000	10,000 U	1.88 J	13.1	1 U	1700	399
Sum of 3 VOC Detections	ND	ND	674,000	943,000	38	84	ND	7200	399.658

Notes:
Shading indicates post-investigation
No Shading indicates pre-investigation
NA - Not analyzed
ND - Not Detected
NS - Not Sampled
U - Not detected at reporting level shown
J - Detected, value estimated
NM - Not measured

Appendix A
Cross Sections

Allegany Ballistics Laboratory, Site 5

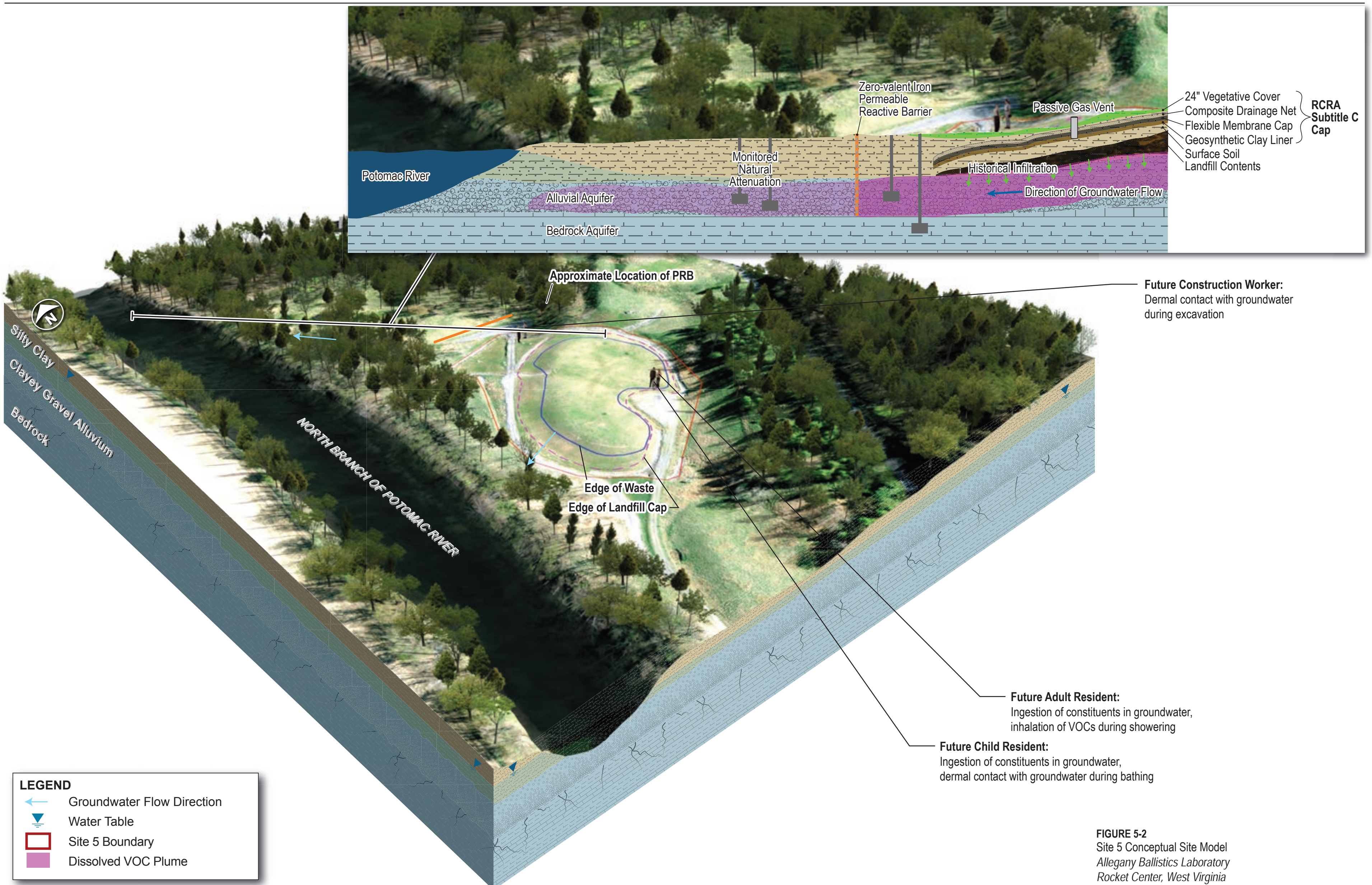
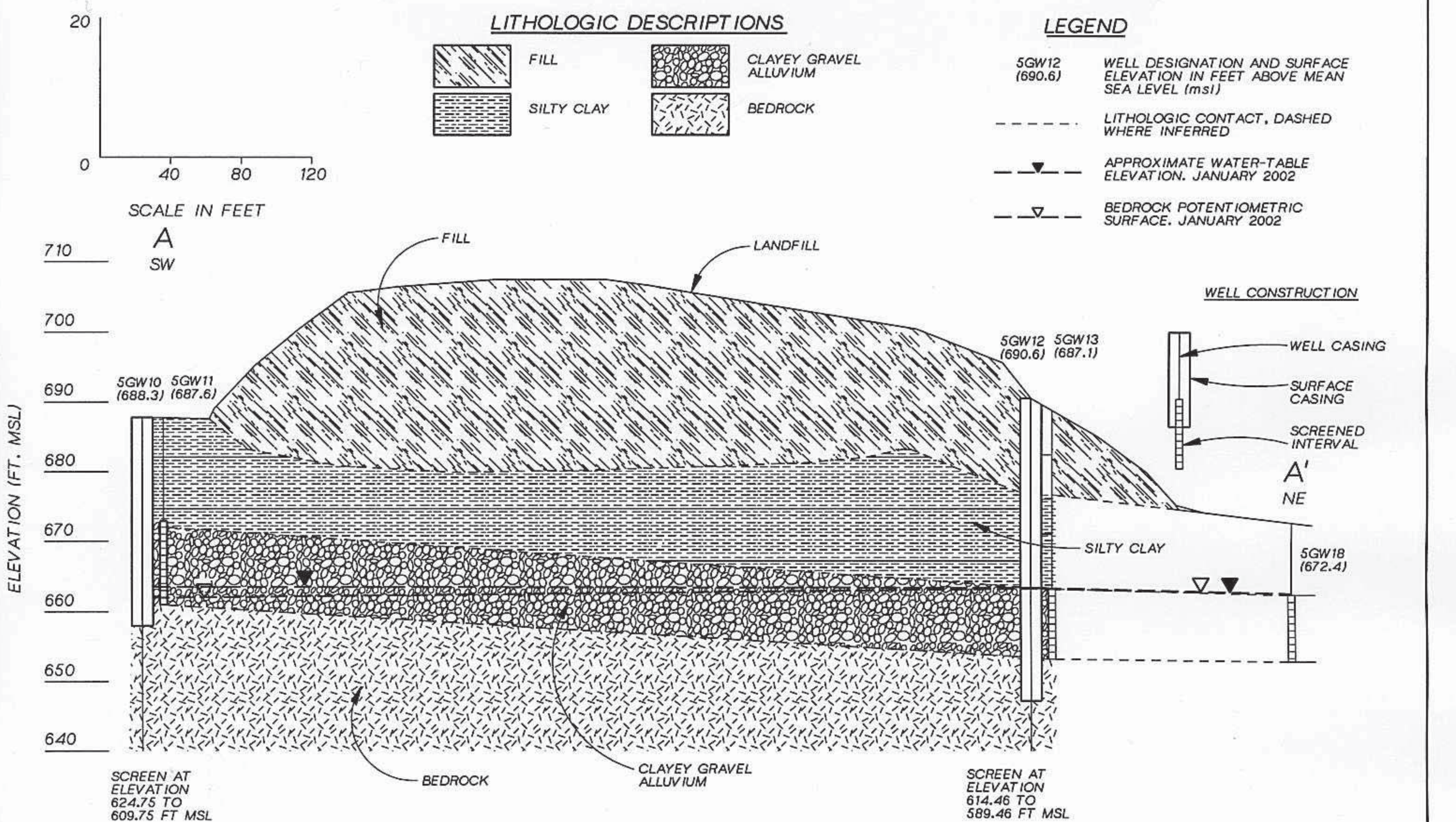


FIGURE 5-2
Site 5 Conceptual Site Model
Allegany Ballistics Laboratory
Rocket Center, West Virginia

ES120312143449SAC ABL_Site5_CSM_V6.ai 06.26.2013 tdaus

CH2MHILL



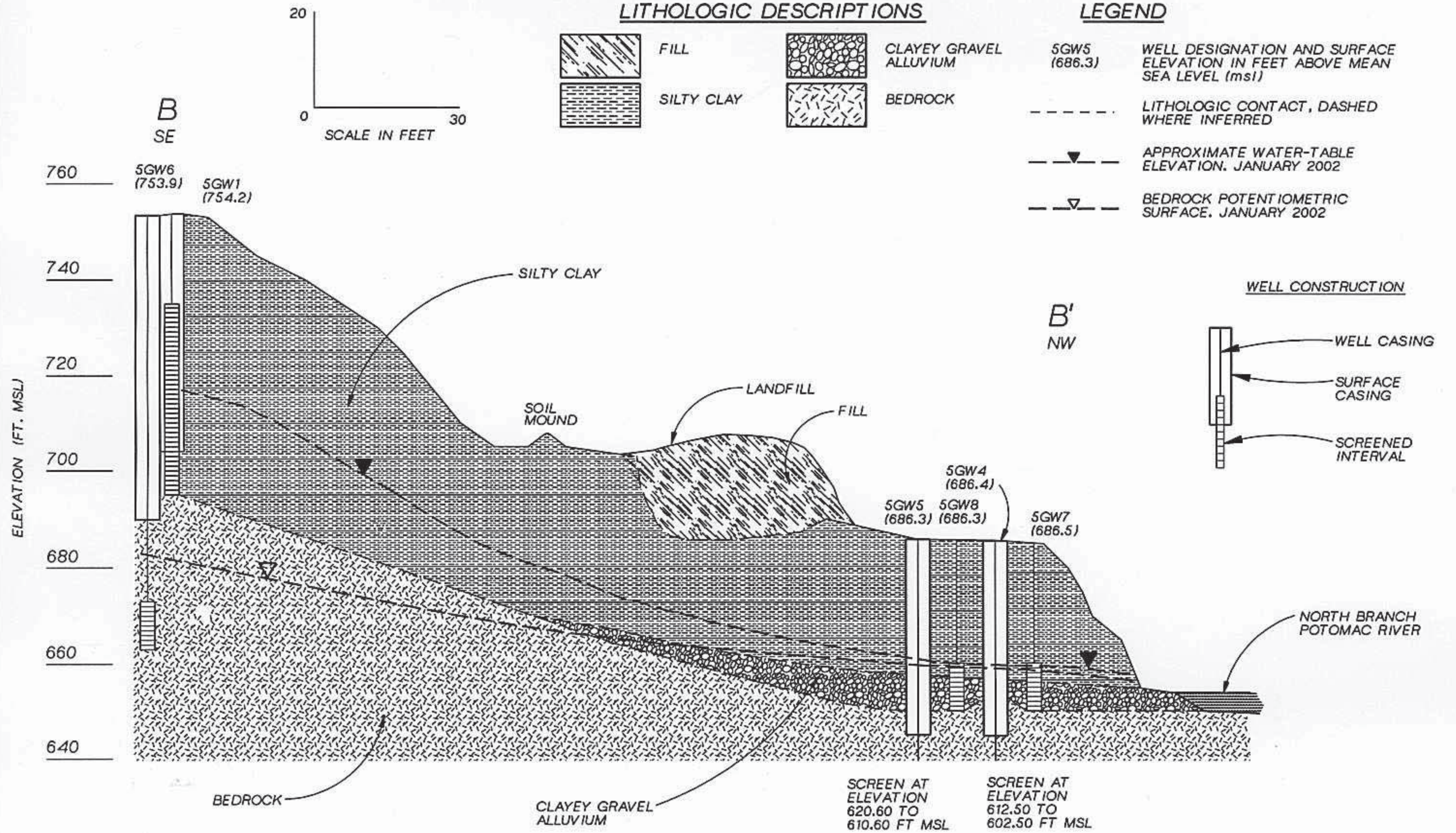
NOTES:

THIS CROSS SECTION WAS INTERPOLATED BETWEEN MONITORING WELL LOCATIONS. ACTUAL CONDITIONS MAY DIFFER FROM THOSE SHOWN HERE. CROSS SECTION LOCATION IS SHOWN IN FIGURE 2-1.

FIGURE 4-2
CROSS SECTION A-A'
FOCUSED RI/FS
SITE 5, ALLEGANY BALLISTICS LABORATORY
ROCKET CENTER, WEST VIRGINIA

CH2MHILL

11-JUN-2003 8292f015.dgn



NOTES:

THIS CROSS SECTION WAS INTERPOLATED BETWEEN MONITORING WELL LOCATIONS. ACTUAL CONDITIONS MAY DIFFER FROM THOSE SHOWN HERE. CROSS SECTION LOCATION IS SHOWN IN FIGURE 2-1.

FIGURE 4-3
CROSS SECTION B-B'
FOCUSED RI/FS
SITE 5, ALLEGANY BALLISTICS LABORATORY
ROCKET CENTER, WEST VIRGINIA

CH2MHILL

19-AUG-2004 8292f016.dgn

R:\USNavFacEngCom405450\ZVI\MapFiles\Figure_X-Geologic_CrossSection_ABL.mxd1/29/2016CGauthier ch2mhillen

Legend

- Monitoring Well - Alluvial
- Monitoring Well - Bedrock
- Cross Section
- Site Boundary
- Installation Boundary

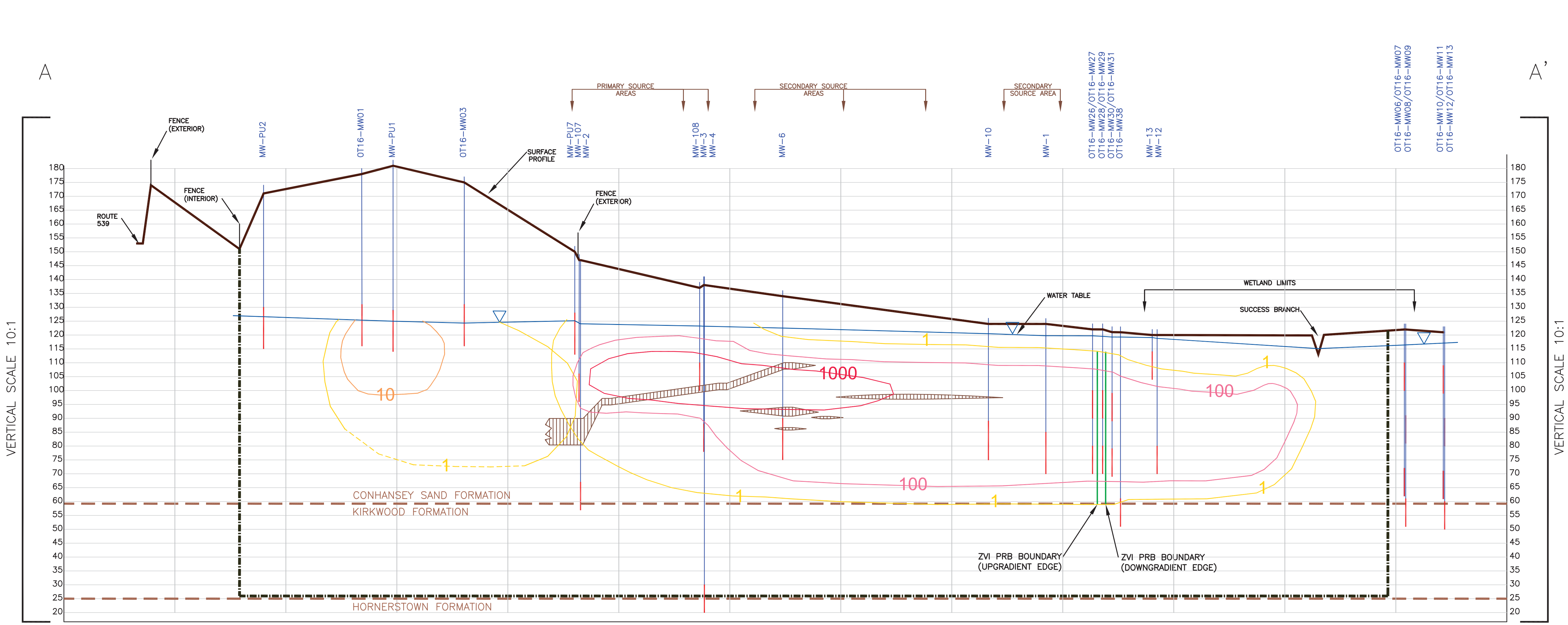
N
W E
S

0 125 250
Feet

Figure X
Site 5
ESTCP ZVI
Allegany Ballistics Laboratory
Rocket Center, West Virginia

ch2m

McGuire Air Force Base, Site OT-16



CROSS-SECTION A-A'

Notes:

1. The location of the peat zones are referenced from Figure 2–1.
2. The top of the clay confining layer is the Hornerstown Formation occurring at approximately 25 ft MSL (USGS, 2003).
3. The vertical depth of the proposed Classification Exceptions Area (CEA)/Well Restriction Area (WRA) is to the top of the first confining unit (i.e. Hornerstown Formation) beneath the dissolved TCE–contaminated groundwater plume.

400' 0 400'

SCALE 1"=400'

LEGEND:

- WATER TABLE
- WELL SCREEN
- TCE CONTOUR (in ug/L)
- PROPOSED CEA BOUNDARY
- PEAT LAYER (DISCONTINUOUS)

AIR FORCE
CIVIL ENGINEER CENTER
ENVIRONMENTAL RESTORATION PROGRAM

BOMARC MISSILE SITE
CROSS SECTION A-A'

JOINT BASE McGUIRE-DIX-LAKEHURST
NEW JERSEY

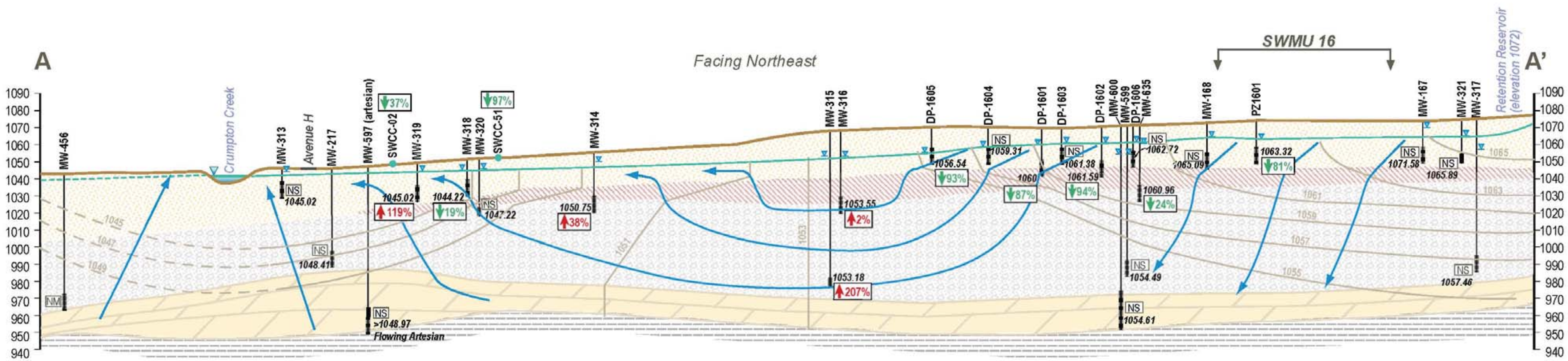
Shaw Environmental, Inc.

FIGURE NO. 5-9

DRAWN	CHECKED BY	APPROVED BY	DRAWING NUMBER
AY 06/16/10	PA 06/16/10	PA 06/16/10	X-SEC A-A C-C.OT-16.DWG

File: C:\Documents and Settings\james.richman\My Documents\McGuire\Grp4\Figures – BOMARC\OT-16 RAWP\X-SEC A-A, C-C.OT-16.dwg
Plot Date/Time: Jan 23, 2013 – 7:36pm
Plotted By: James.Richman

Arnold Air Force Base, SWMU 16



LEGEND

- Water Table
- Equipotential Line (ft amsl)
- Groundwater Flow Line
- Screened Interval
- Static Water Level
- Seep or Spring
- Clay with Silt, Sand, and Gravel
- Sandy Clay
- Clayey Gravel
- Limestone
- Shale

1045.02 Potentiometric Surface Elevation (ft amsl)

19% TCE Reduction as of October 2010

NOTES

Potentiometric data collected on March 15, 2010 (ft amsl)

NM= Not Measured

NS= Not Sampled

Percent reduction is based upon the change in TCE concentration from before FeroxSM Injection to the October 2010 Sampling Event.

SCALE

Horizontal: 1" = 60'

Vertical: 1" = 60'

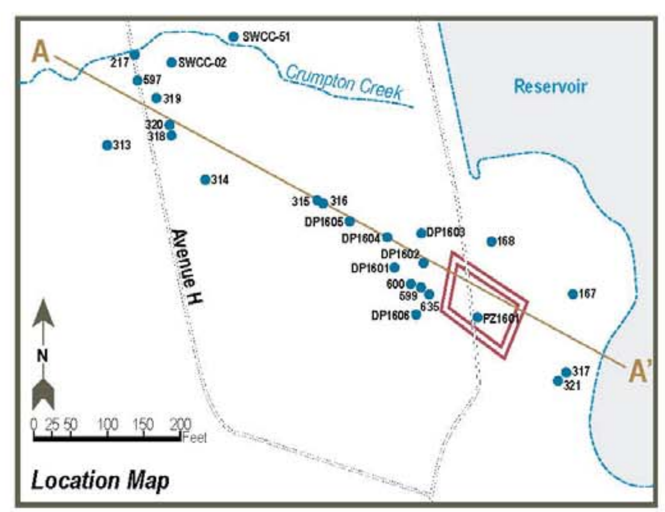
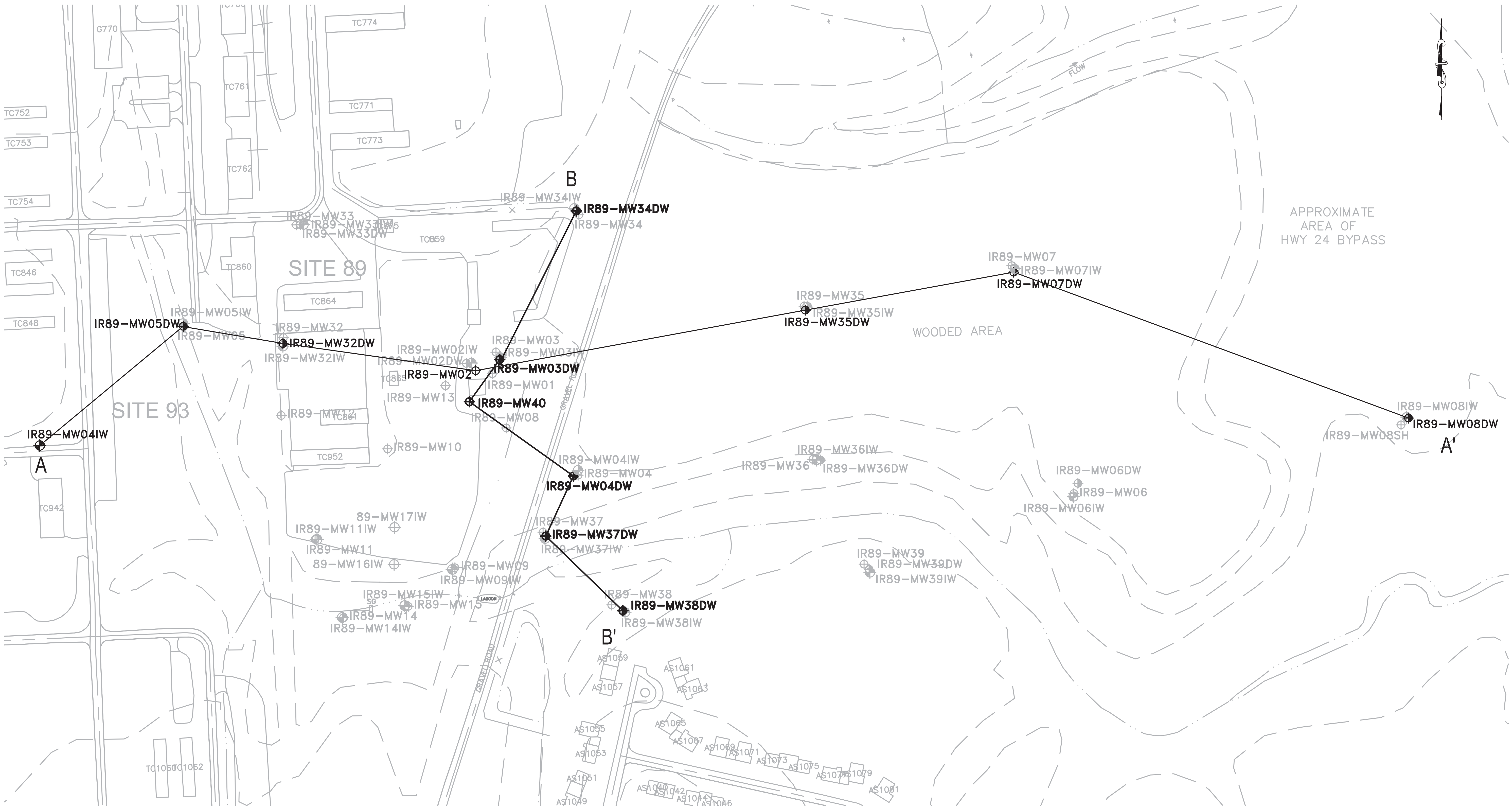


FIGURE 5-7
Flow Net Diagram and Percent TCE Reduction
SWMU 16 Performance Monitoring
Summary Report, January 2009 - October 2010
Arnold AFB

CH2MHILL

ES022811182928KNV

Marine Corps Base Camp Lejeune, Site 89



LEGEND

- INTERMEDIATE GROUNDWATER MONITORING WELL
- SHALLOW GROUNDWATER MONITORING WELL
- DEEP GROUNDWATER MONITORING WELL

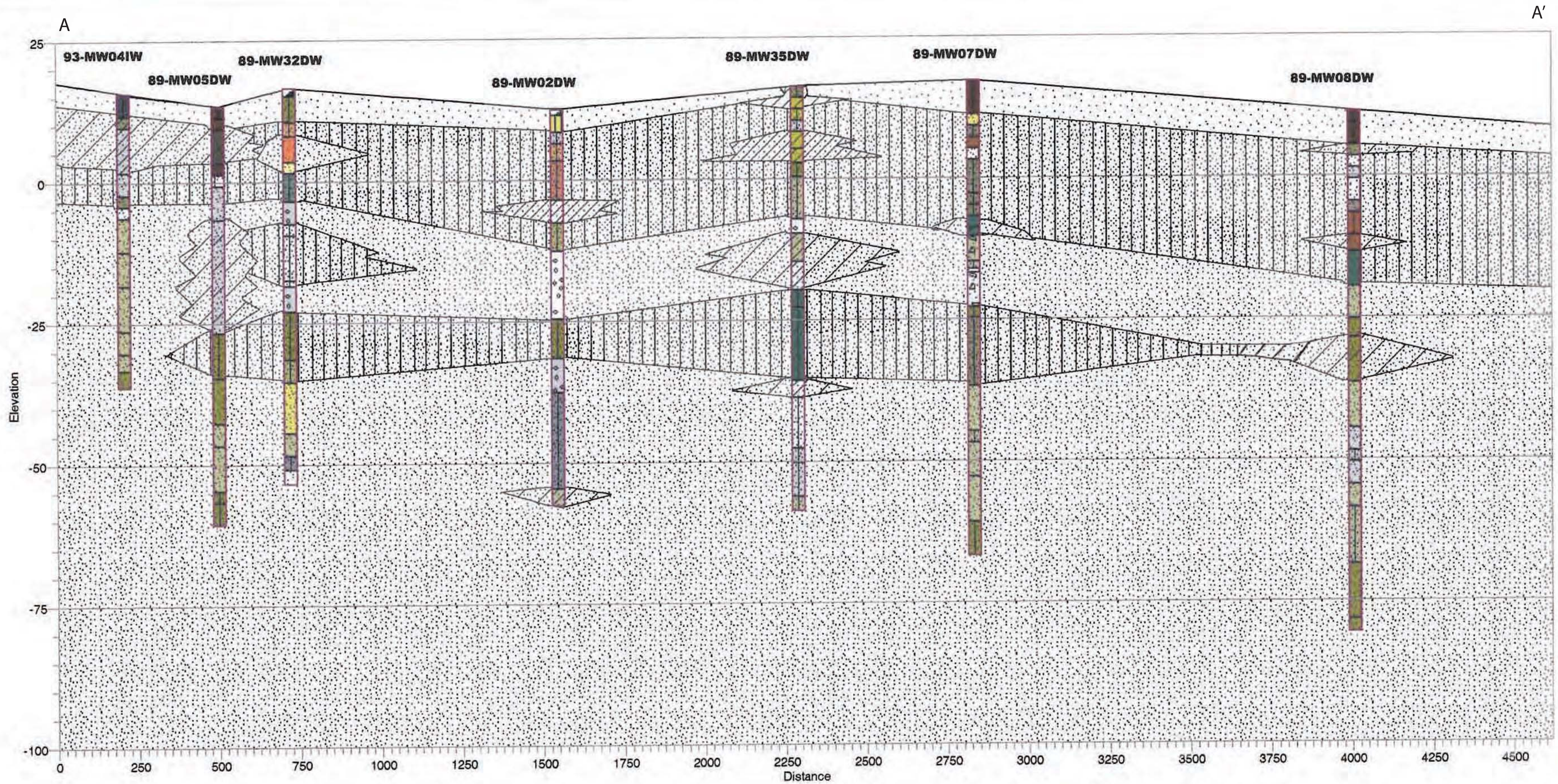
250 0 125 250
1 inch = 250 ft.

FIGURE 4-5
GEOLOGIC CROSS SECTION LOCATION MAP
SITE 89 COMPREHENSIVE RI
MCB CAMP LEJEUNE,
NORTH CAROLINA

CH2MHILL

EBL\NAVY CLEAN\CAMPLEJCADD\SITE 89\Final_RI\FIGURE 4-5.dwg

SOURCE: MCB, CAMP LEJEUNE, MARCH 2000



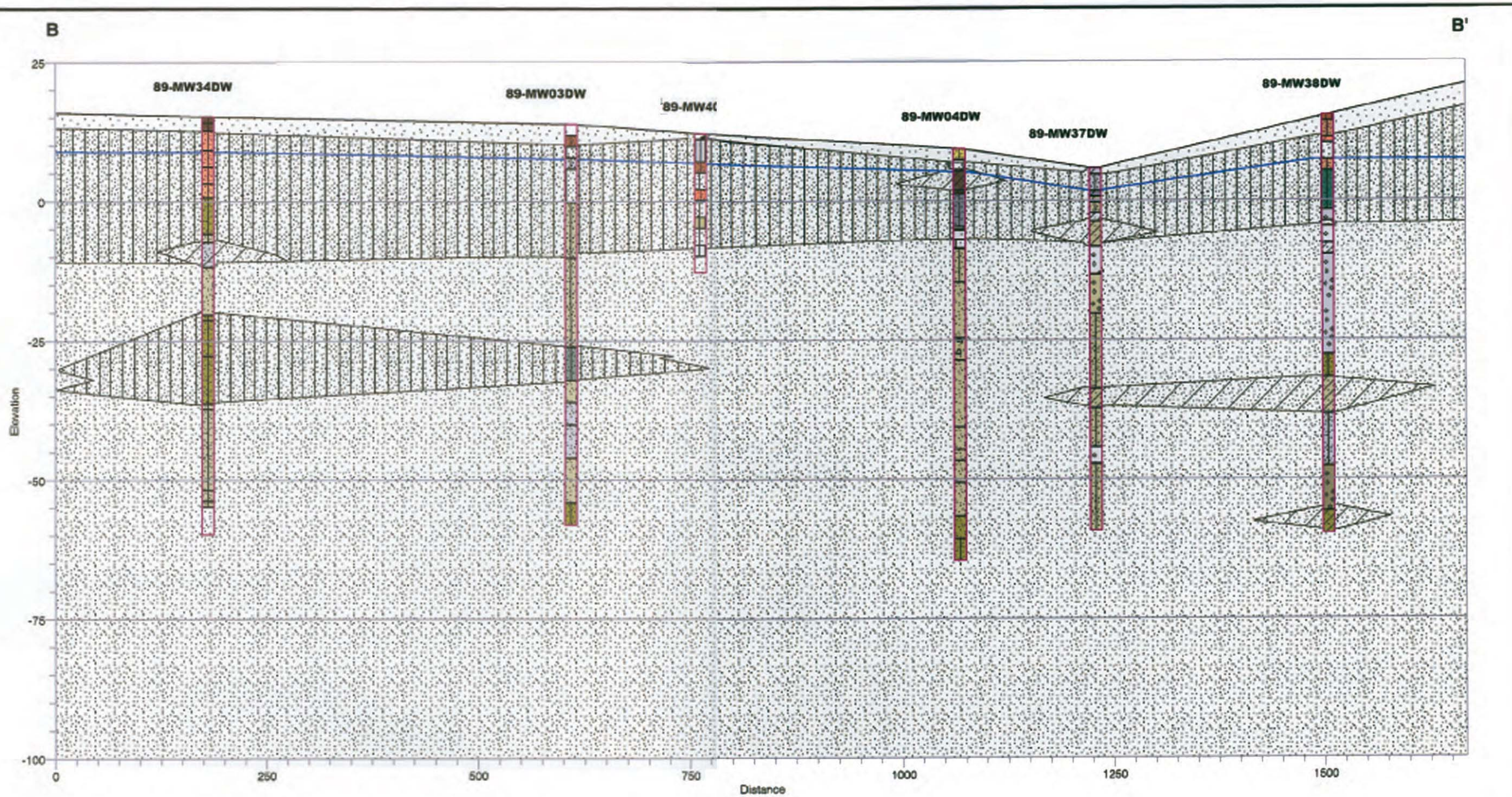
CH2MHILL

Figure 4-6
Cross Section A-A'
Site 89 Comprehensive RI
MCB Camp Lejeune, North Carolina

Legend

- **Overburden** — Silty, fine to medium sands and organic soils, loose, dry to damp
- **Silty Sand** — Silty, fine to medium sands, trace clay, shell fragments in lenses of sand unit, dense, damp to wet
- **Sand** — Fine to coarse sands, some cementation, silt and clay lenses, loose to medium dense, wet
- **Clayey Silty Sand** — Non-continuous, clayey silty sand, shell fragments in lenses of sand unit, dense, damp to moist

*This soil boring information is considered to be representative of the subsurface conditions at the respective soil boring locations. Subsurface conditions interpolated between borings are estimated based on geologic judgment.



CH2MHILL

Figure 4-7
Cross Section B-B'
Site 89 Comprehensive RI
MCB Camp Lejeune, North Carolina

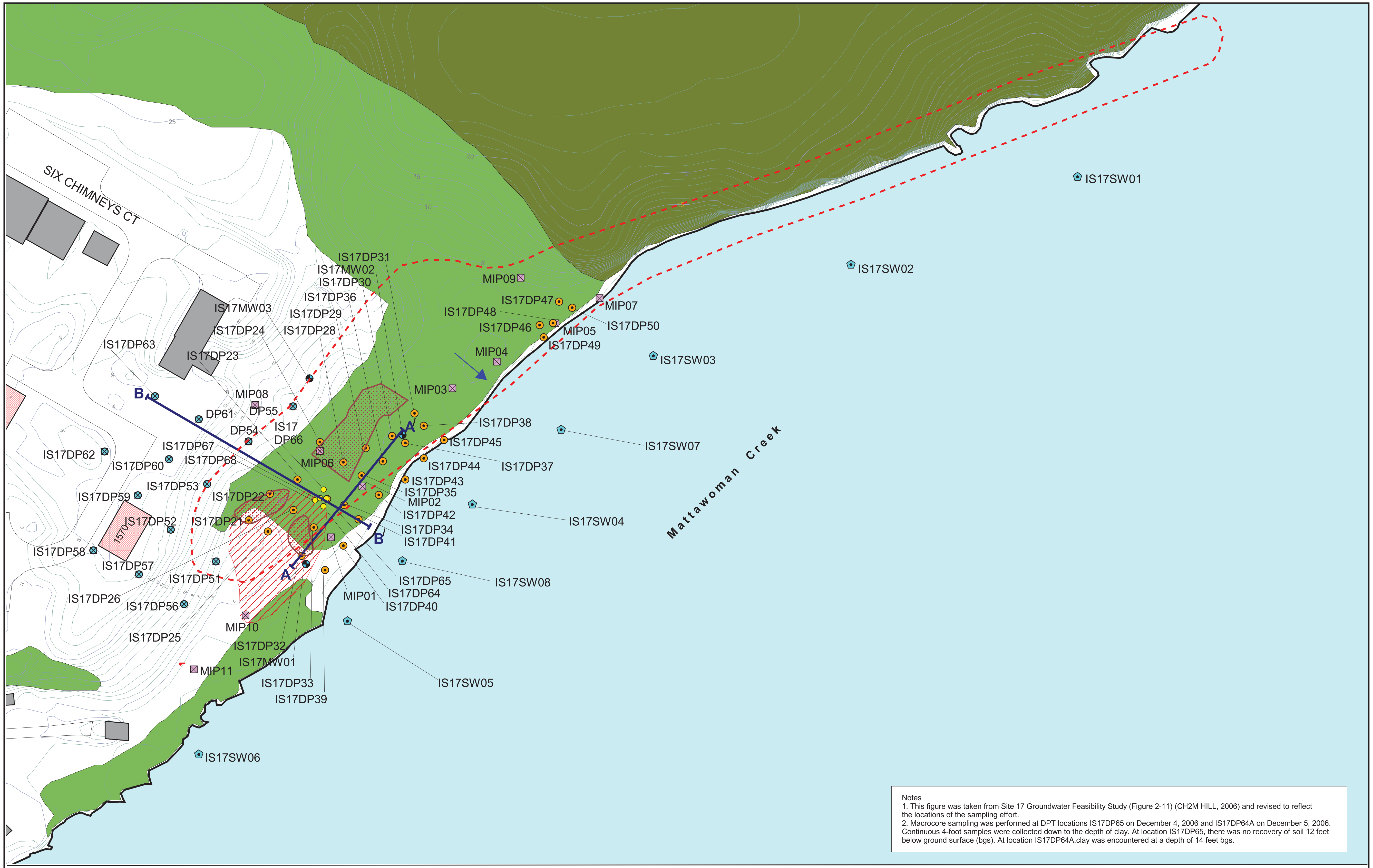
Legend

- **Overburden** — Silty, fine to medium sands and organic soils, loose, dry to damp
- **Silty Sand** — Silty, fine to medium sands, trace clay, shell fragments in lenses of sand unit, dense, damp to wet
- **Sand** — Fine to coarse sands, some cementation, silt and clay lenses, loose to medium dense, wet
- **Clayey Silty Sand** — Non-continuous, clayey silty sand, shell fragments in lenses of sand unit, dense, damp to moist

*This soil boring information is considered to be representative of the subsurface conditions at the respective soil boring locations. Subsurface conditions interpolated between borings are estimated based on geologic judgment.

Naval Support Facility Indian Head, Site 17

File Path: V:\\aphrodite\proj\18gis\IndianHead\figures\Site17\site17_crosssections.apr



Notes
1. This figure was taken from Site 17 Groundwater Feasibility Study (Figure 2-11) (CH2M HILL, 2006) and revised to reflect the locations of the sampling effort.
2. Macrocore sampling was performed at DPT locations IS17DP65 on December 4, 2006 and IS17DP64A on December 5, 2006. Continuous 4-foot samples were collected down to the depth of clay. At location IS17DP65, there was no recovery of soil 12 feet below ground surface (bgs). At location IS17DP64A,clay was encountered at a depth of 14 feet bgs.

LEGEND
- Monitoring Wells
- July 2002 Membrane Interface Probe/Direct Push Technique Locations
- December 2004 MIP/DPT and March 2005 DPT Locations
- August 2005 MIP/DPT Locations
- December 2006 DPT Locations
- Surface Water Sample Location
- Buildings
- Demolished Buildings
- Excavation Area; backfill with 1-foot layer of soil and 0.5-foot layer of gravel (2005 NTCRA; FSSI, 2006)
- Wooded Area
- Drum Removal Area (2005 NTCRA; FSSI, 2006)
- Approximate IR Site Boundary
- Road
- Topographic Elevation Contours (1 foot Intervals)
- Base Boundary
- Cross Section Location
- Groundwater Flow Direction

N

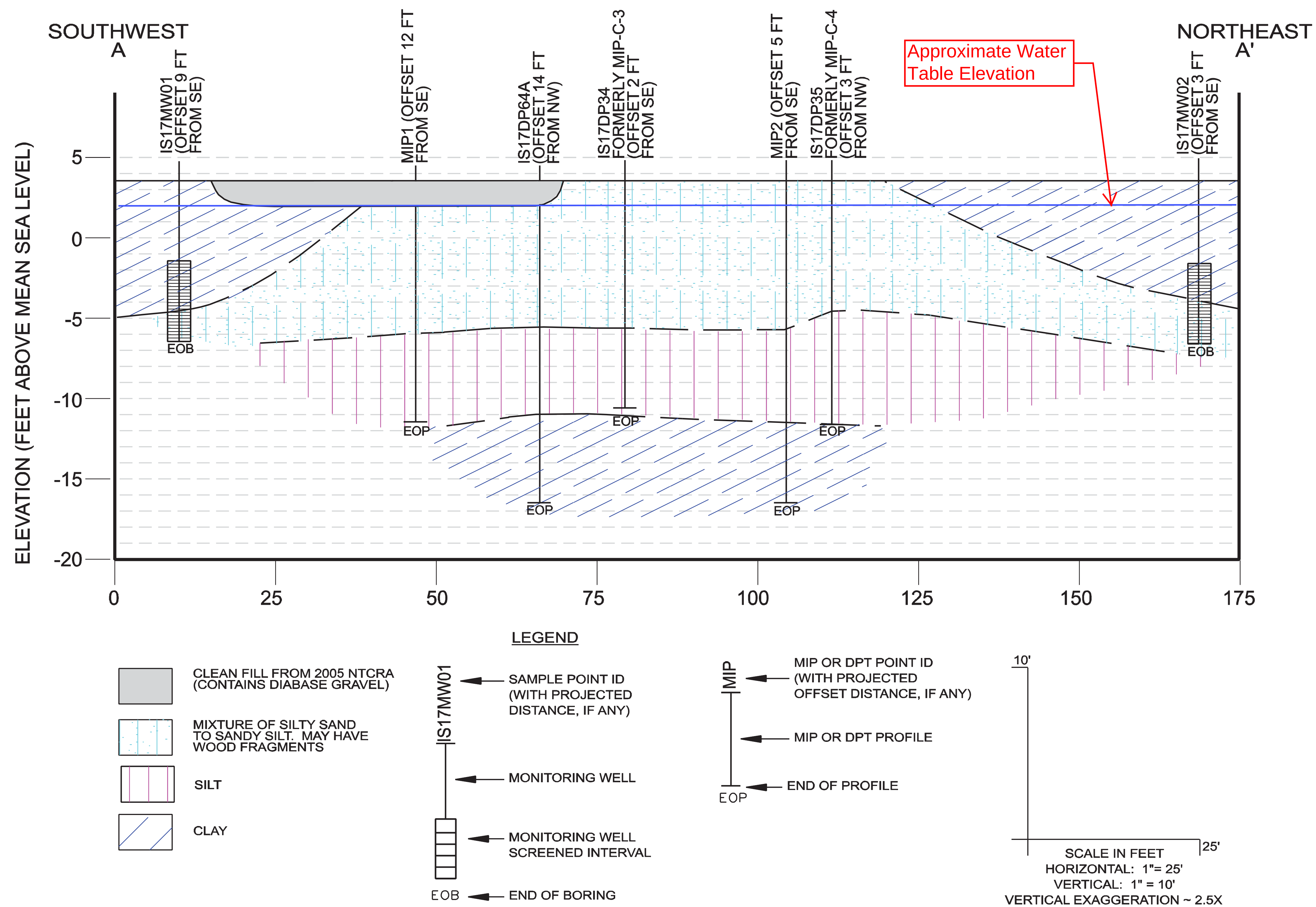
0 70 140 Feet

1" = 70

Figure 2-1
Locations of Groundwater Samples and Geologic Cross Sections
Site 17 Groundwater Feasibility Study
NSF-IH, Indian Head, Maryland

CH2MHILL

f01_314446.dgn (NDM | WDC)



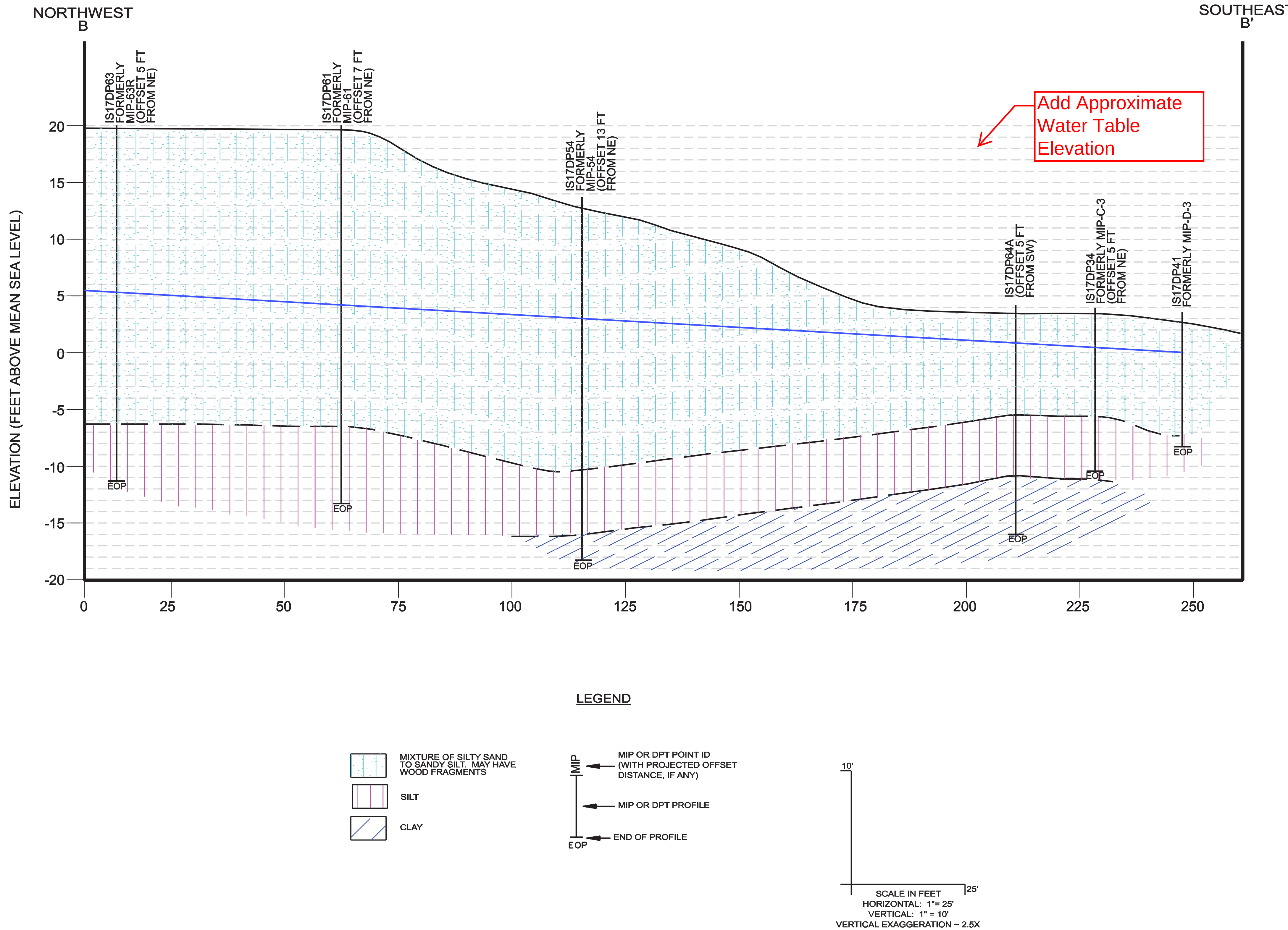
NOTES:

1. MONITORING WELLS WERE SURVEYED BY BALDWIN AND GREGG OF NORFOLK, VA.
2. DIRECT PUSH TECHNIQUE (DPT) AND MEMBRANE INTERFACE PROBE (MIP) LOCATIONS WERE SURVEYED WITH A GLOBAL POSITIONING SYSTEM (GPS) UNIT BY CH2M HILL AT THE TIME THE WORK WAS DONE.
3. DESCRIPTION OF THE LITHOLOGY IS OBTAINED FROM SOIL BORING AND MONITORING WELL LOGS AND INFERRED BASED ON MIP PROFILES.
4. SEE APPENDICES A AND B IN THE FINAL REMEDIAL INVESTIGATION REPORT (CH2M HILL , 2004) FOR SOIL BORING AND MONITORING WELL LOGS.
5. SEE APPENDICES B AND C IN THE DRAFT FEASIBILITY STUDY REPORT (CH2M HILL, 2006) FOR THE MIP PROFILES.
6. LOCATIONS OF THE UNIT BOUNDARIES SHOWN ON THE CROSS SECTION ARE ESTIMATED AND ARE BASED ON BORING LOGS AND MIP PROFILES.
7. NTCRA - NON TIME CRITICAL REMOVAL ACTION (FSS, 2006 REPORT).

Figure 2-2
Geologic Cross Section A - A'
Site 17 Groundwater Feasibility Study
NSF-IH, Indian Head, Maryland

CH2MHILL

f02_314446.dgn (NDM | WDC)



NOTES:

1. MONITORING WELLS WERE SURVEYED BY BALDWIN AND GREGG OF NORFOLK, VA.
2. DIRECT PUSH TECHNIQUE (DPT) AND MEMBRANE INTERFACE PROBE (MIP) LOCATIONS WERE SURVEYED WITH A GLOBAL POSITIONING SYSTEM (GPS) UNIT BY CH2M HILL AT THE TIME THE WORK WAS DONE.
3. DESCRIPTION OF THE LITHOLOGY IS OBTAINED FROM SOIL BORING AND MONITORING WELL LOGS AND INFERRED BASED ON MIP PROFILES.
4. SEE APPENDICES A AND B IN THE FINAL REMEDIAL INVESTIGATION REPORT (CH2M HILL , 2004) FOR SOIL BORING AND MONITORING WELL LOGS.
5. SEE APPENDICES B AND C IN THE DRAFT FEASIBILITY STUDY REPORT (CH2M HILL, 2006) FOR THE MIP PROFILES.
6. LOCATIONS OF THE UNIT BOUNDARIES SHOWN ON THE CROSS SECTION ARE ESTIMATED AND ARE BASED ON BORING LOGS AND MIP PROFILES.

Figure 2-3
Geologic Cross Section B - B'
Site 17 Groundwater Feasibility Study
NSF-IH, Indian Head, Maryland

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St. Louis Ordnance Depot

LEGEND

- Monitoring Well
- Monitoring Well Abandoned in 2012
- Soil Boring
- Confirmation Boring
- Cross Section
- Site Boundary
- 220 Former Building

Approximate Utilities

- Natural Gas
- Sanitary Sewer
- Telephone
- Water

N

0 30 60 Feet

FIGURE 1-3
LOCATION OF CROSS-SECTION A-A'
St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

CH2MHILL

RDD \\BALDUR\PROJ\SLOP_349765\MAPFILES\RACR\FIG1-3_CROSSECTION_A_A_RACR.MXD MSCHROCK 6/12/2012 1:18:57 PM

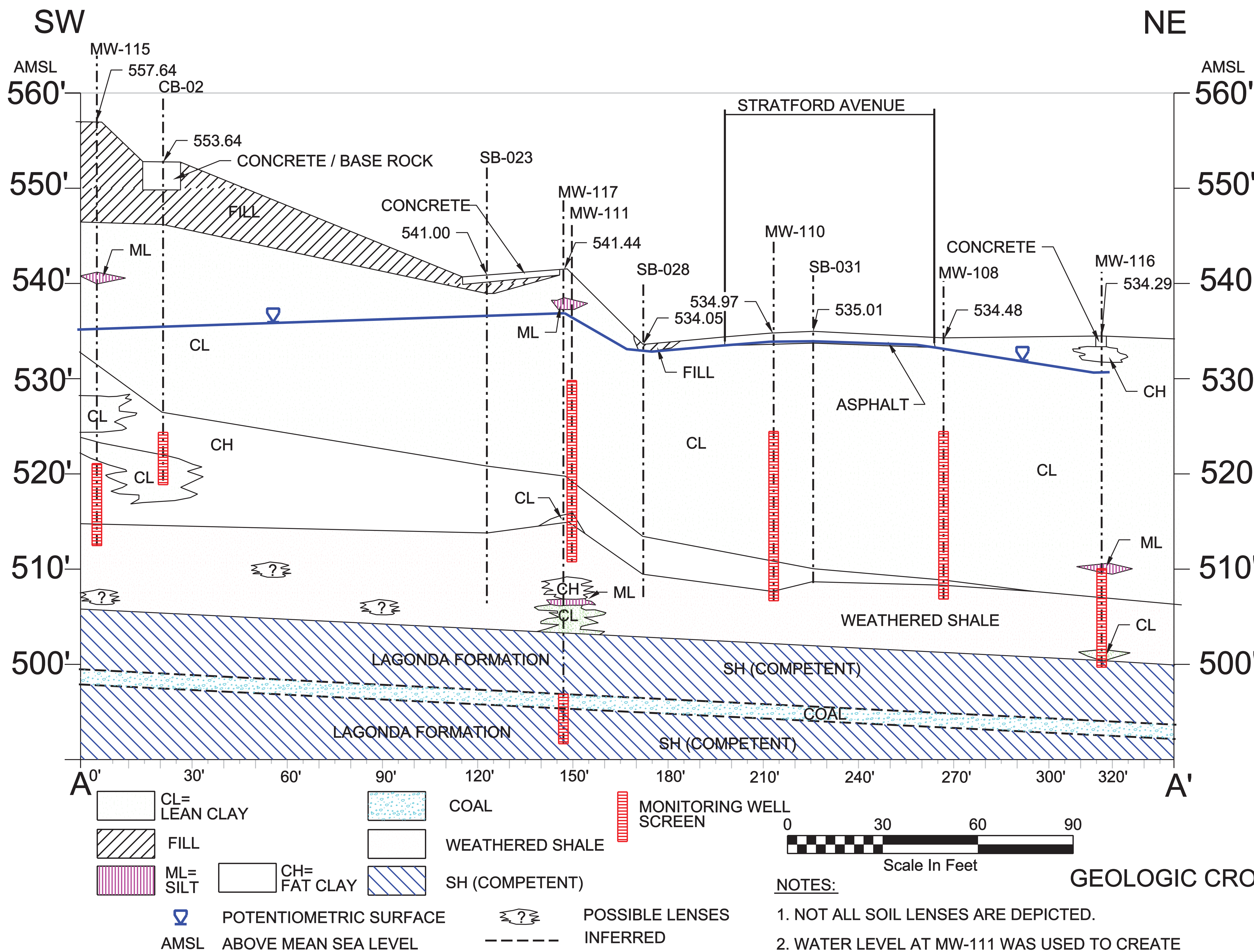


FIGURE 1-4
GEOLOGIC CROSS - SECTION A-A'

St. Louis Ordnance Plant
Former Hanley Area
St. Louis, Missouri

NOTES:

1. NOT ALL SOIL LENSES ARE DEPICTED.
2. WATER LEVEL AT MW-111 WAS USED TO CREATE POTENTIOMETRIC SURFACE NEAR MW-117

01nf003d_364298.dgn

St. Juliens Creek Annex, Site 21

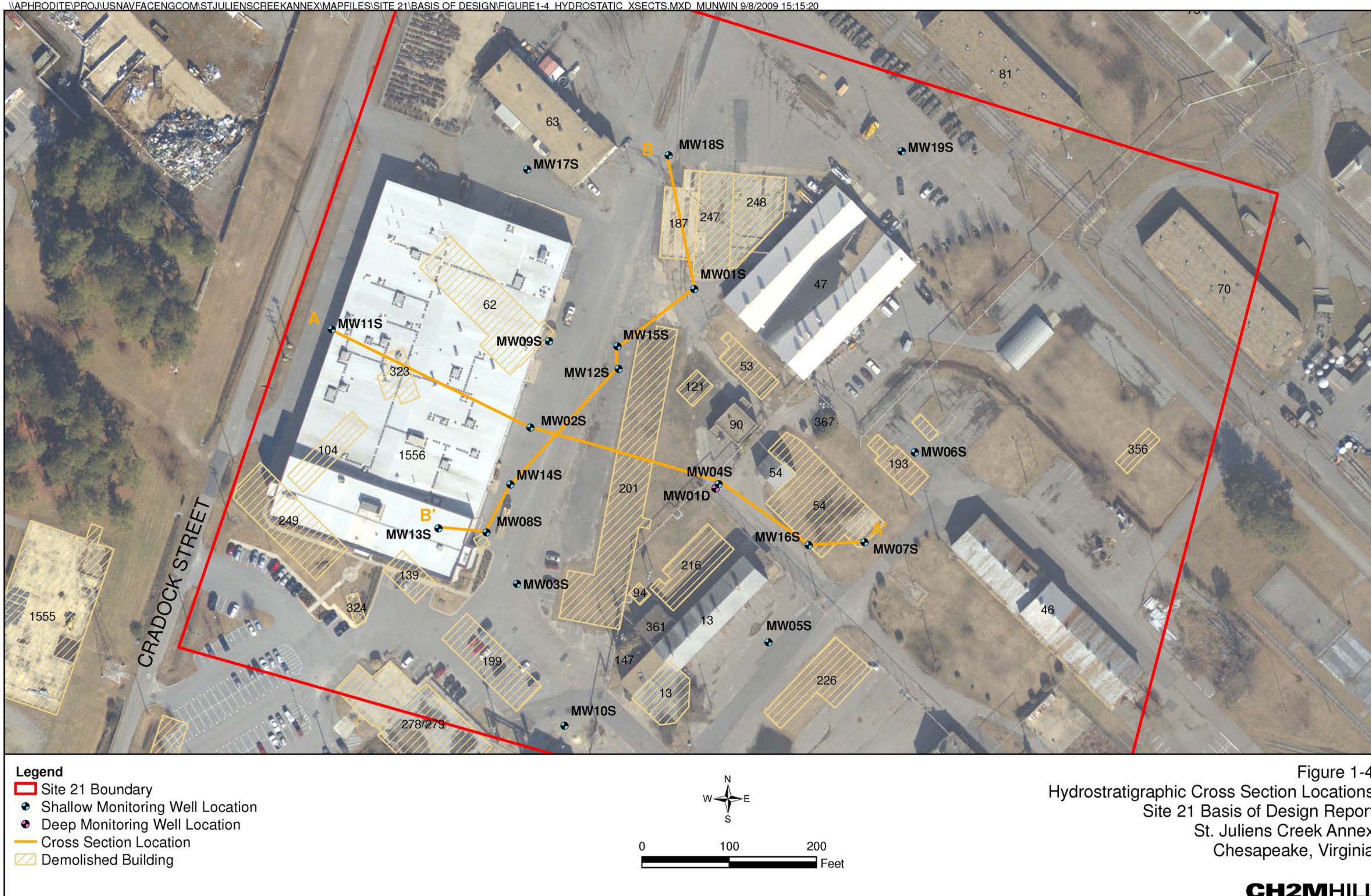
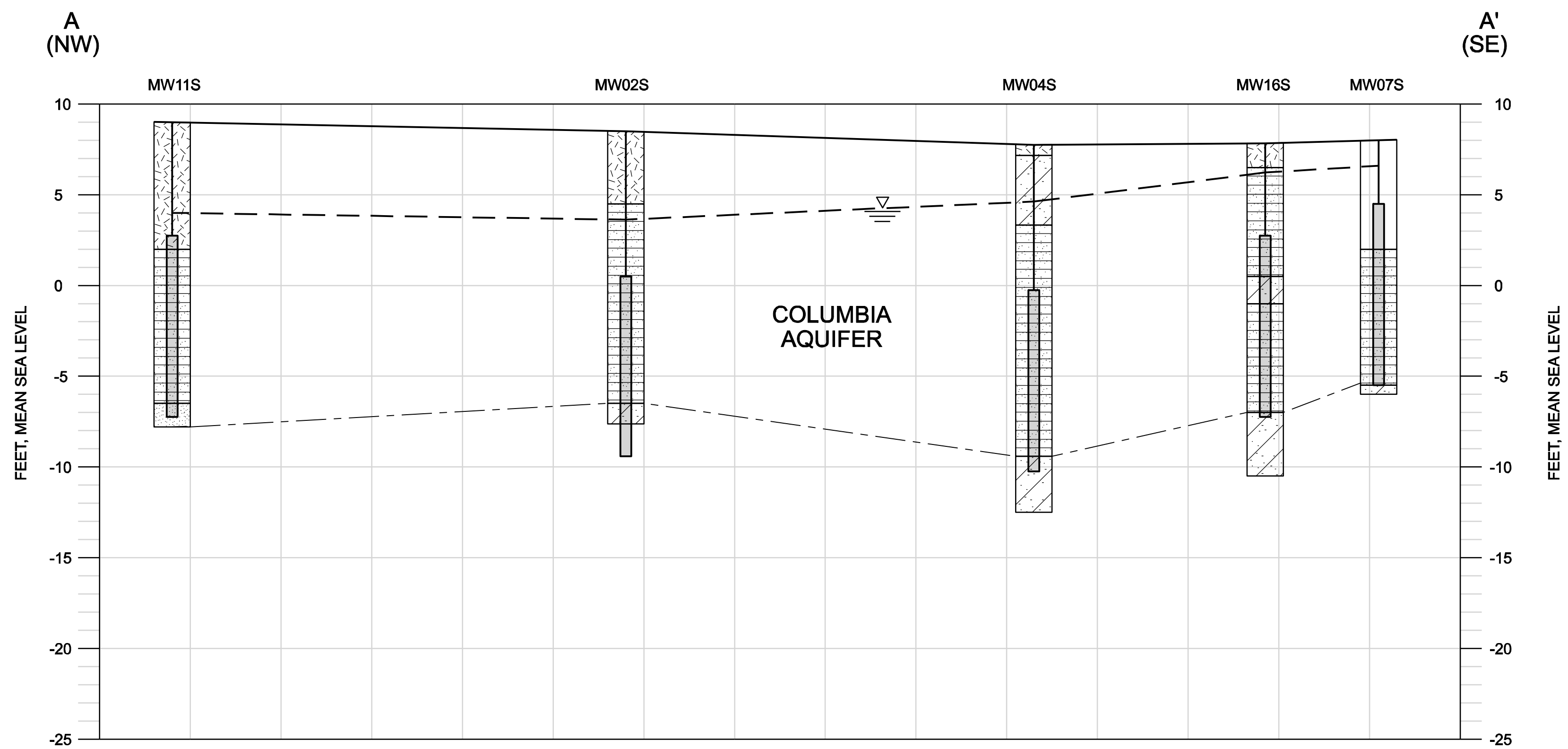
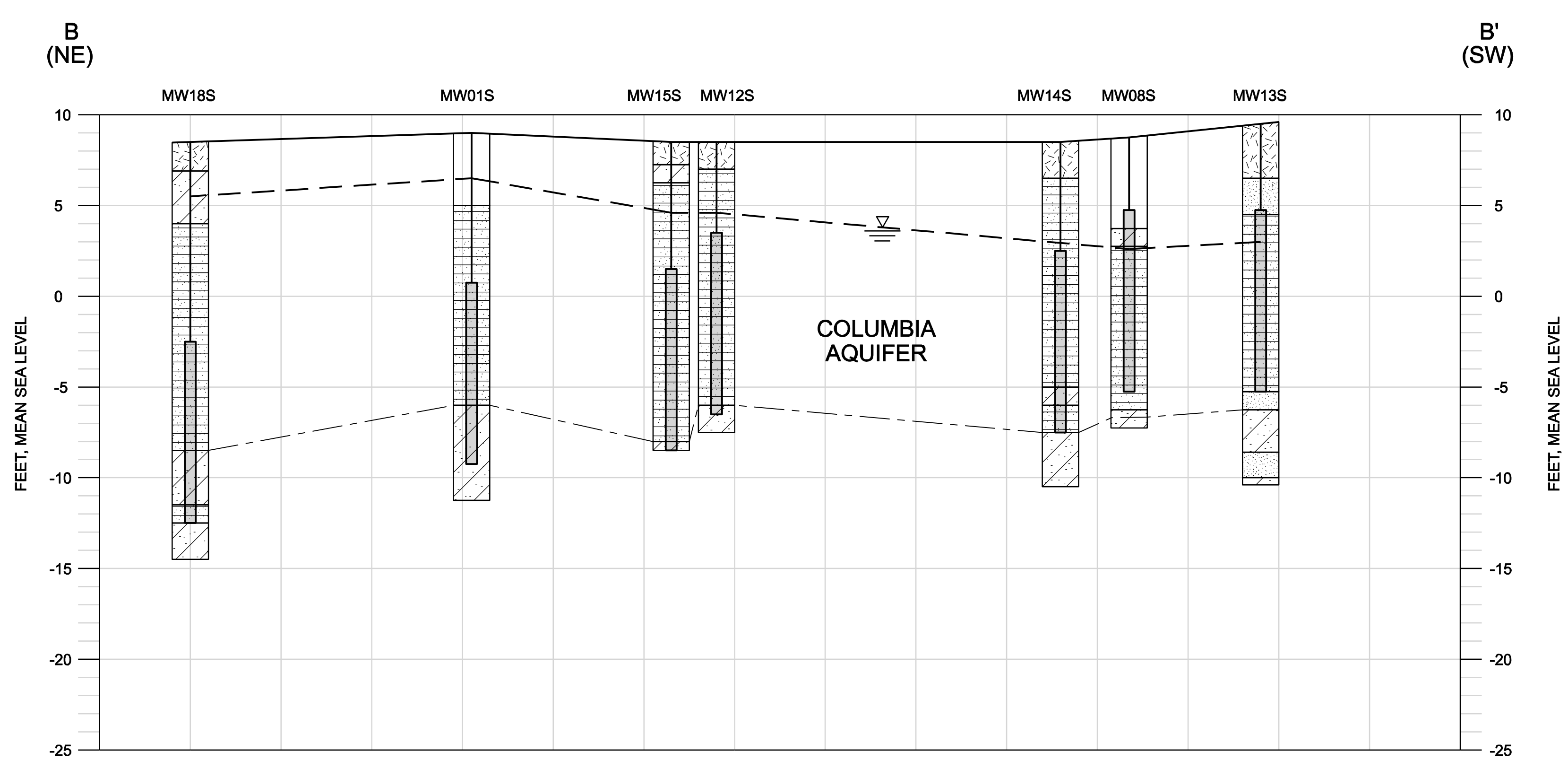


Figure 1-4
Hydrostratigraphic Cross Section Locations
Site 21 Basis of Design Report
St. Juliens Creek Annex
Chesapeake, Virginia

CH2MHILL





LEGEND

MONITORING WELL SCREENED INTERVAL

WATER TABLE

STRATIGRAPHY

GROUND SURFACE

HYDROSTRATIGRAPHIC CONTACT

INTERPOLATED WATER TABLE

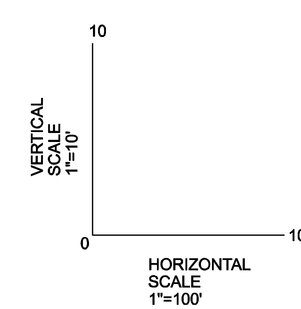
LITHOLOGY/USCS DESCRIPTION

FILL MATERIAL: ASPHALT

WELL GRADED SAND

FINE TO MEDIUM SAND

SILTY CLAY



NOTE:

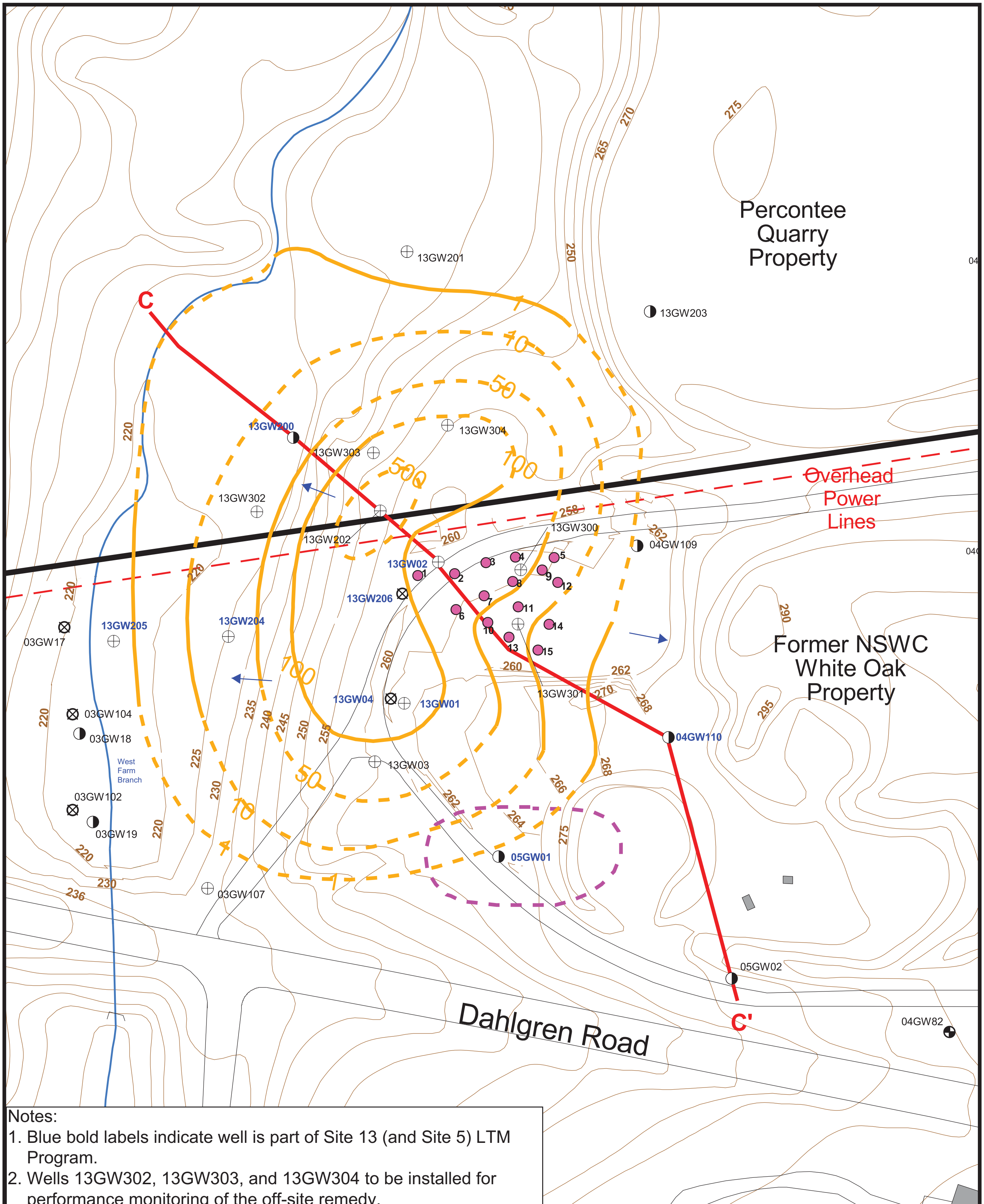
1. THIS CROSS SECTION IS INTERPRETIVE AND WAS PREPARED BY INTERPOLATION BETWEEN BORING LOCATIONS. ACTUAL CONDITIONS BETWEEN BORINGS MAY DIFFER FROM THOSE SHOWN HERE.

FIGURE 1-5
HYDROSTRATIGRAPHIC CROSS-SECTIONS
SITE 21 BASIS OF DESIGN REPORT
ST. JULIENS CREEK ANNEX
CHESAPEAKE, VA

ES092009001CVO SJCA_Fig1-05_01

CH2MHILL

White Oak, Site 13



Legend

2005 ZVI Injection Location

LTM Program Wells With Screened Formation

- Shallow Coastal Plain or Alluvial
- Deep Coastal Plain
- Bedrock
- Saprolite

BASE MAP FEATURES

- Overhead Power Lines
- Elevation Contours
- Roads and Paved Areas
- Property Boundary of Former NSWC White Oak
- Groundwater Flow Direction
- Transects
- Total CVOCs Contour (µg/L; April 2007) (dashed where inferred)
- Inferred RDX above PRG (µg/L; April 2007)

N W E S

125 0 125 Feet

Figure 1-1
Site 13 - Extent of CVOCs in Groundwater (April 2007)
Off-Site 13 Basis of Design
Former NSWC-White Oak, Silver Spring, Maryland

File path: v:\18gis\whiteoak\figures\site_13_long_term_monitoring_plan.apr

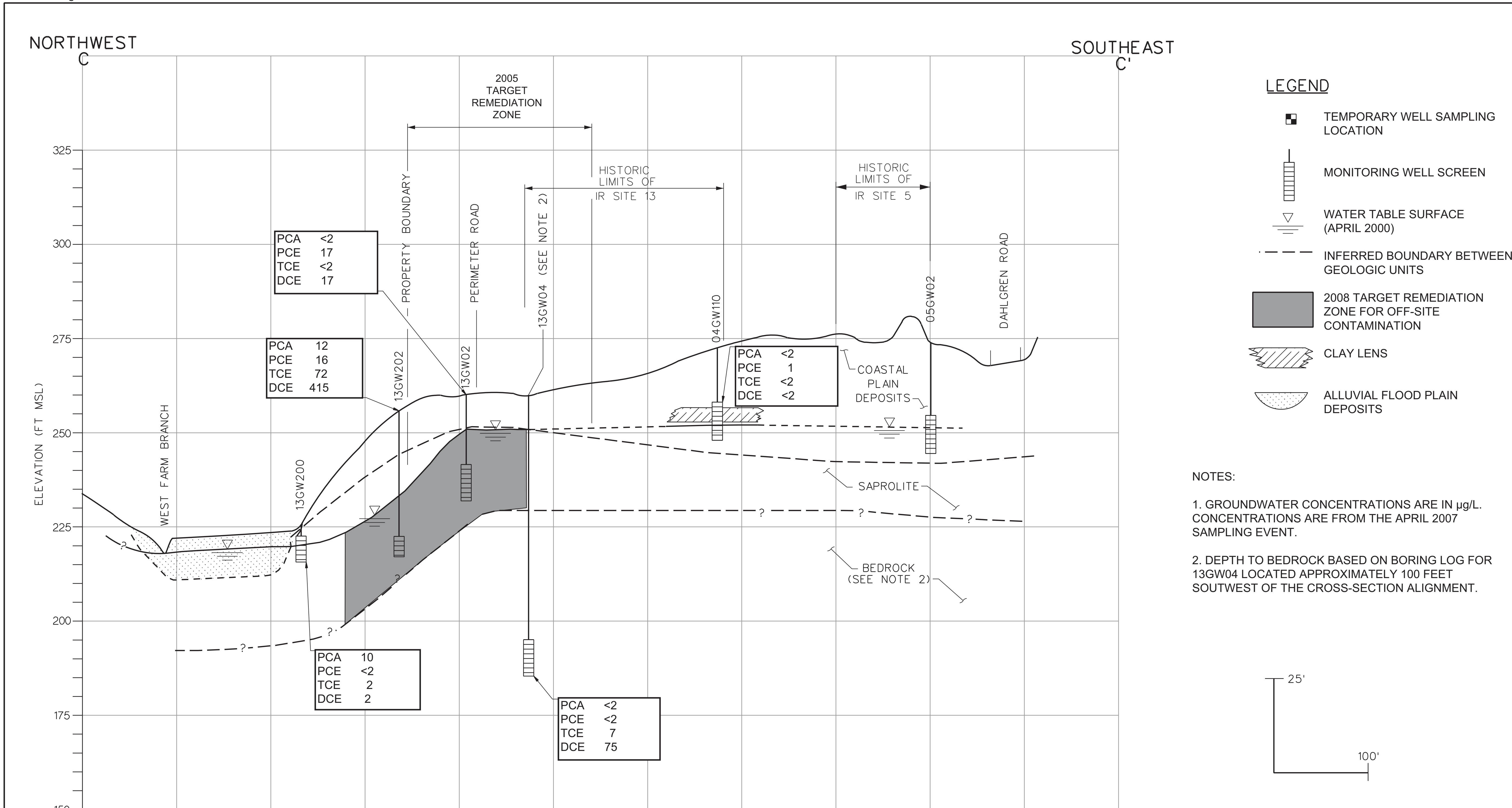
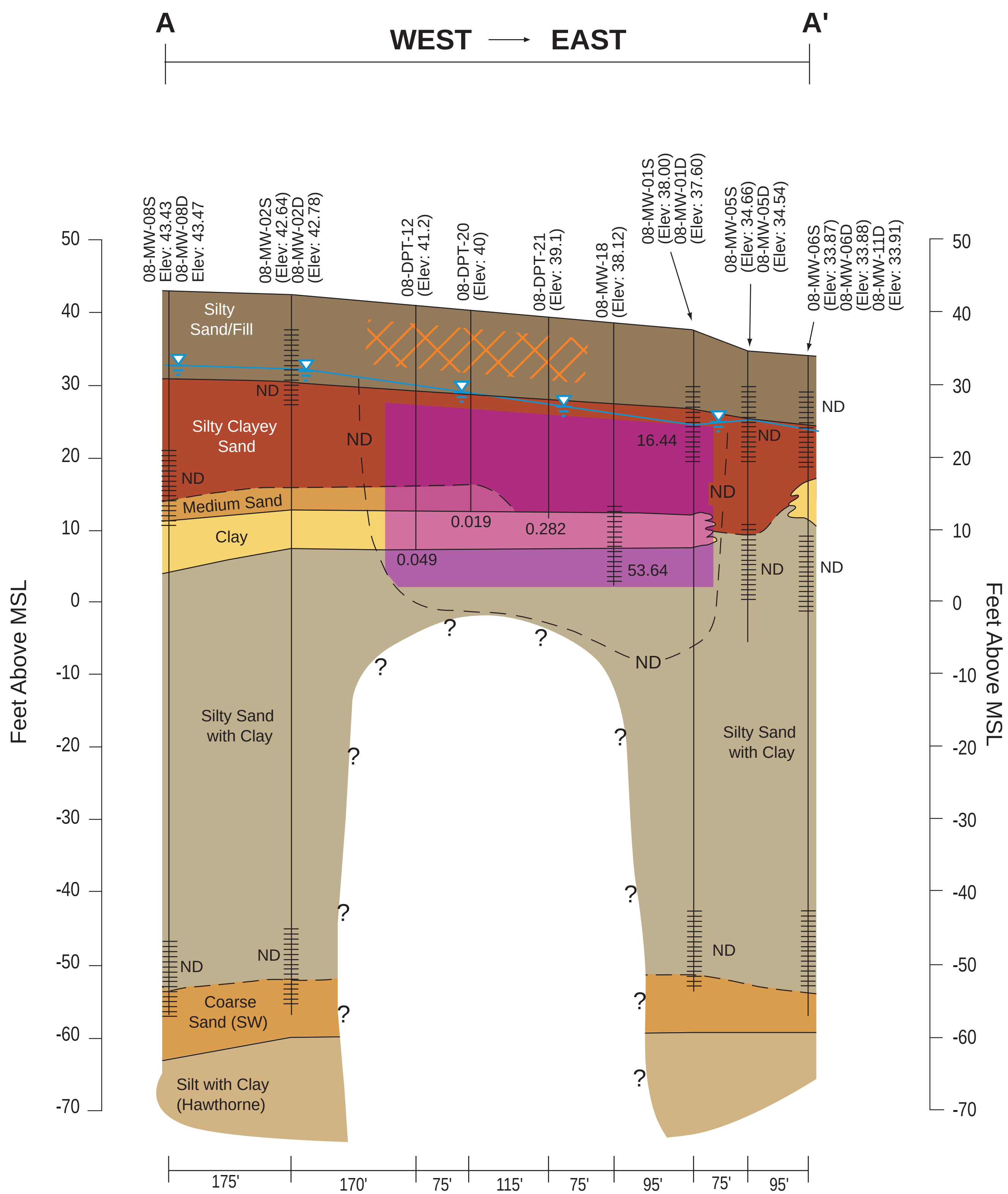


Figure 1-2
Cross-Section C-C'
Off-Site 13 Basis of Design
Former NSWC-White Oak, Silver Spring, Maryland

CH2MHILL

Savannah Site 8



LEGEND

- Well Screen Interval
- Measured Groundwater Elevation
- MSL — Mean Sea Level
- Interpreted Geologic Contact
- Transitional Geologic Contact
- Inferred Geologic Contact
- Silty Sand/Fill (SM)
- Silty Clayey Sand (SC)
- Clay (CL)
- Silty Sand with Clay (SM)
- Sand (SW)
- Silt with Clay (Hawthorne) (ML)
- ND — Groundwater VOCs Below Detection Limits
- 16.44 — Total VOCs in Shallow Groundwater Results (2005)
- ? — No Lithological Data at this Depth
- Potential Area for AS and In-Situ Bioremediation
- Potential Area for SVE

NOTE

1. Groundwater elevations measured 12/5/2005.
2. Groundwater concentrations measured in mg/L.

SCALE

Vertical Scale 1" = 30'

Horizontal Scale 1" = 300'

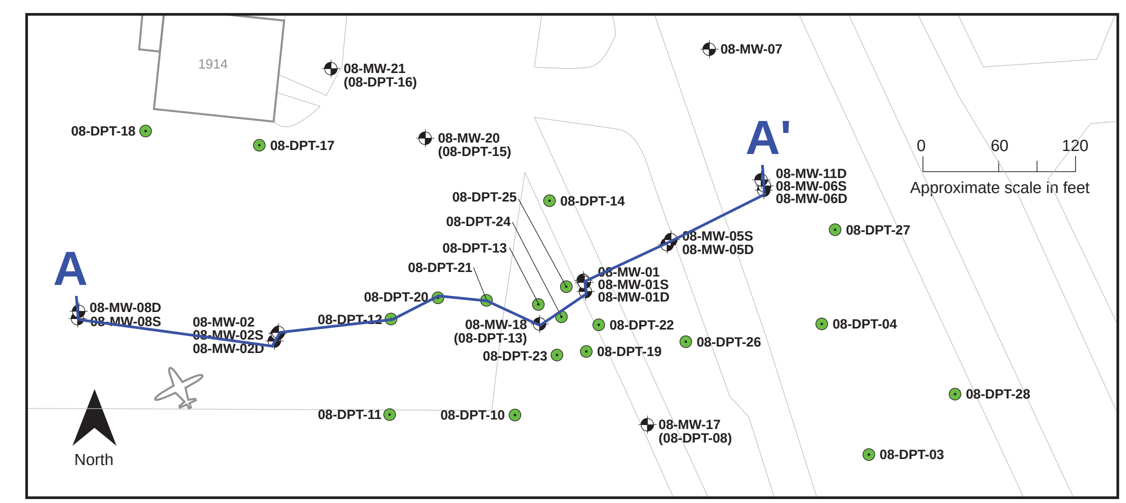
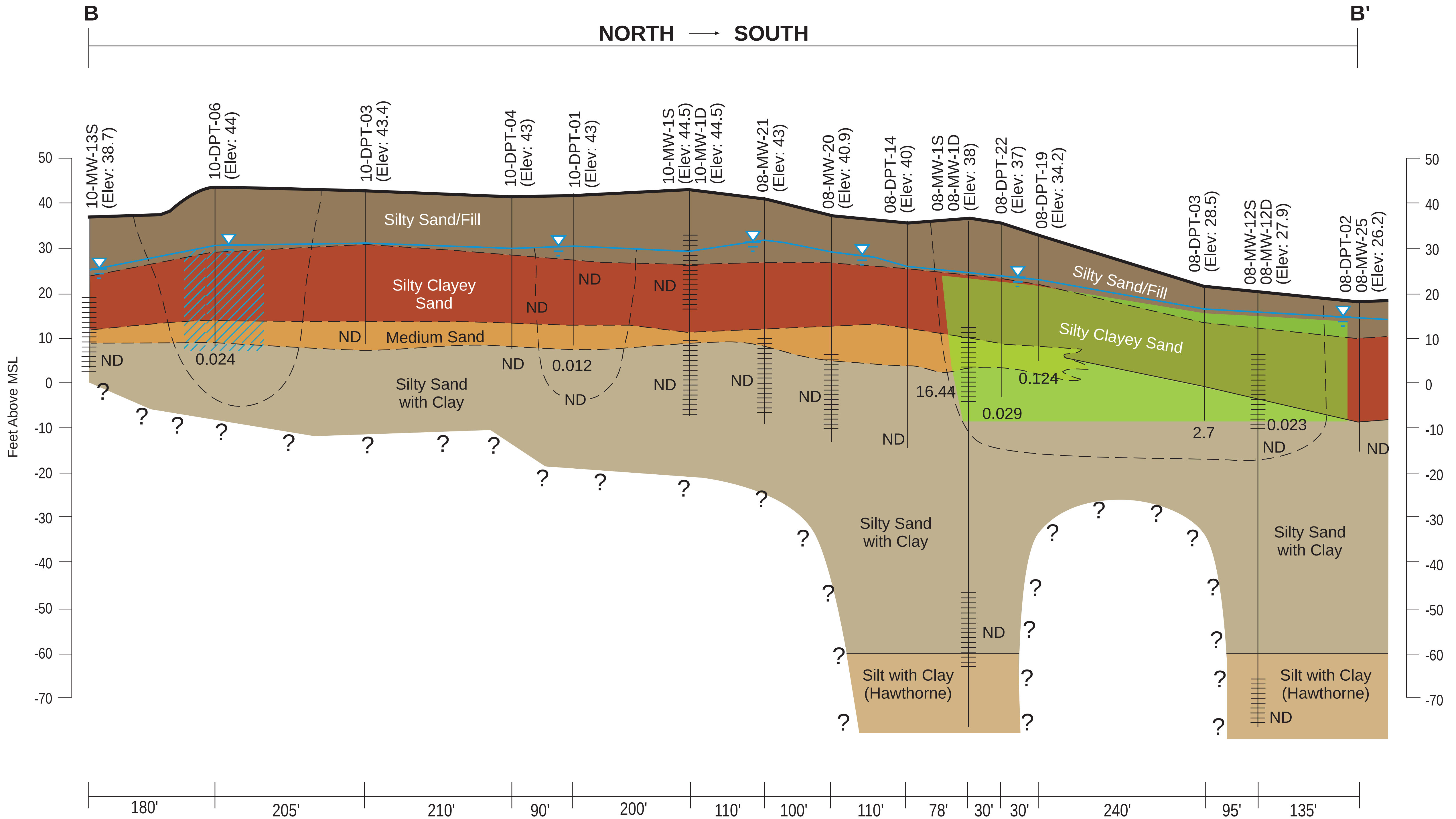
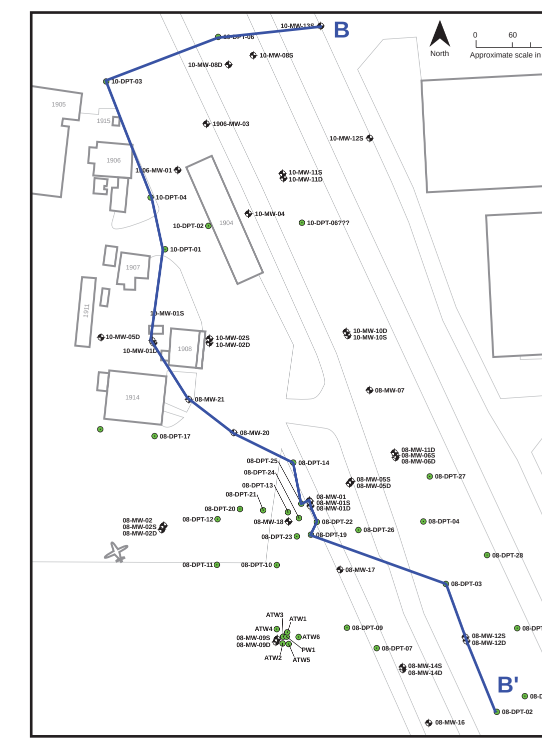


FIGURE 1-5
Cross-Section A-A' Potential Vertical Extent for AS, SVE, and In-Situ Bioremediation
Annual O&M Performance Monitoring Report
Sites 8 and 10 Savannah Air National Guard Base
Garden City, Georgia





LEGEND

ǂ	Well Screen Interval
▽	Measured Groundwater Elevation
MSL	Mean Sea Level
——	Interpreted Geologic Contact
- - -	Transitional Geologic Contact
- -?- -	Inferred Geologic Contact
—ND- -	Groundwater VOCs Below Detection Limits
16.44	Total VOCs in Shallow Groundwater Results (2005)
?	No Lithological Data at this Depth
	Potential Area for AS
	Potential Area for In-Situ Bioremediation
	Silty Sand/Fill (SM)
	Silty Clayey Sand (SC)
	Silty Sand with Clay (SM)
	Medium Sand (SW)
	Silt with Clay (Hawthorne) (ML)

NOTES

1. Groundwater elevations measured 12/5/2005.
2. Groundwater concentrations measured in mg/L.

SCALE

Vertical Scale 1" = 50'

Horizontal Scale 1" = 350'

FIGURE 1-6
Cross-Section B-B' Potential Vertical Extent for AS, SVE, and In-Situ Bioremediation
Annual O&M Performance Monitoring Report
Sites 8 and 10 Savannah Air National Guard Base
Garden City, Georgia

CH2MHILL

ES120409231428ATL

Appendix B
Groundwater Contour Maps

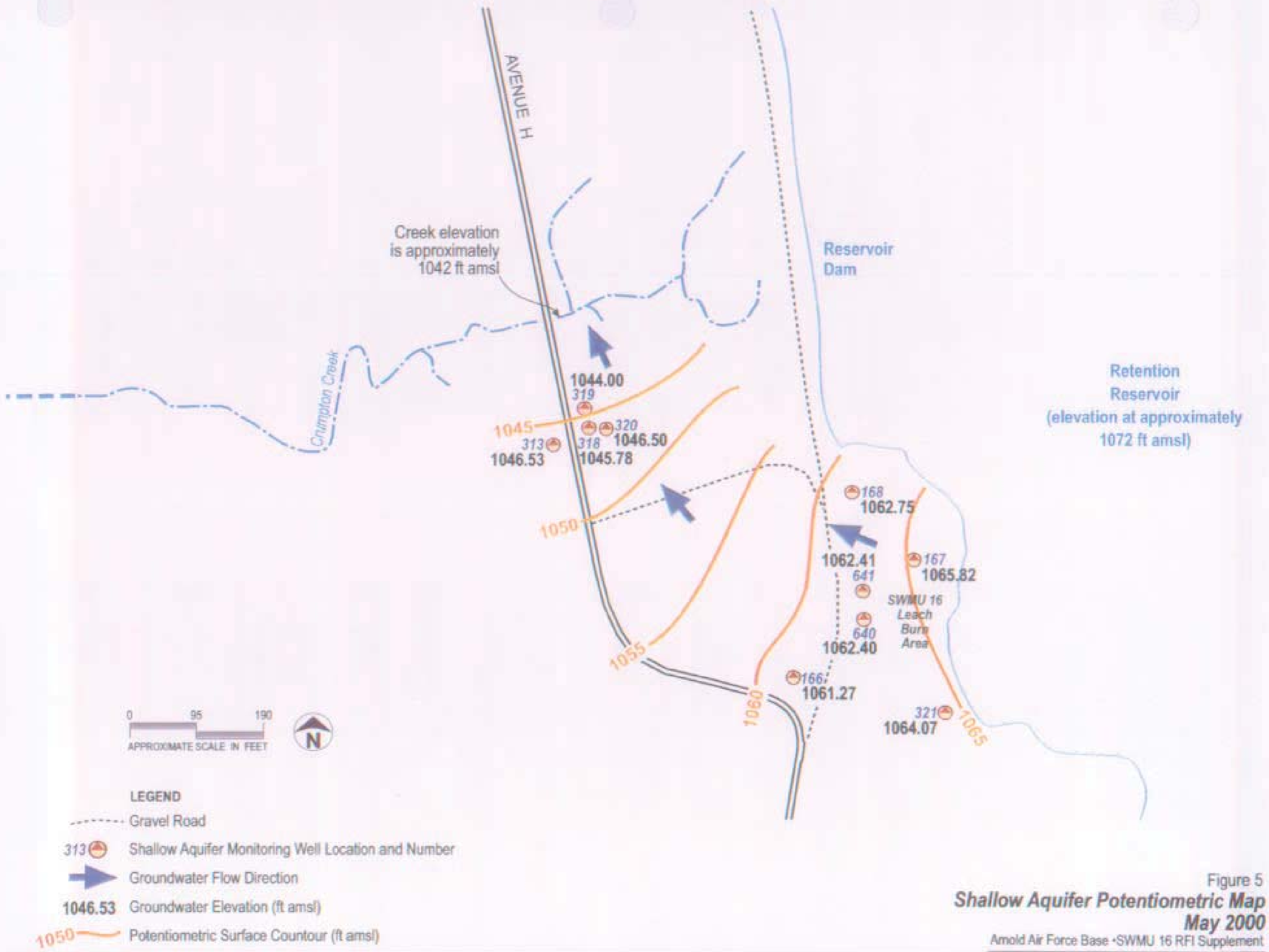


Figure 5
Shallow Aquifer Potentiometric Map May 2000
Arnold Air Force Base •SWMU 16 RFI Supplement

1051 37

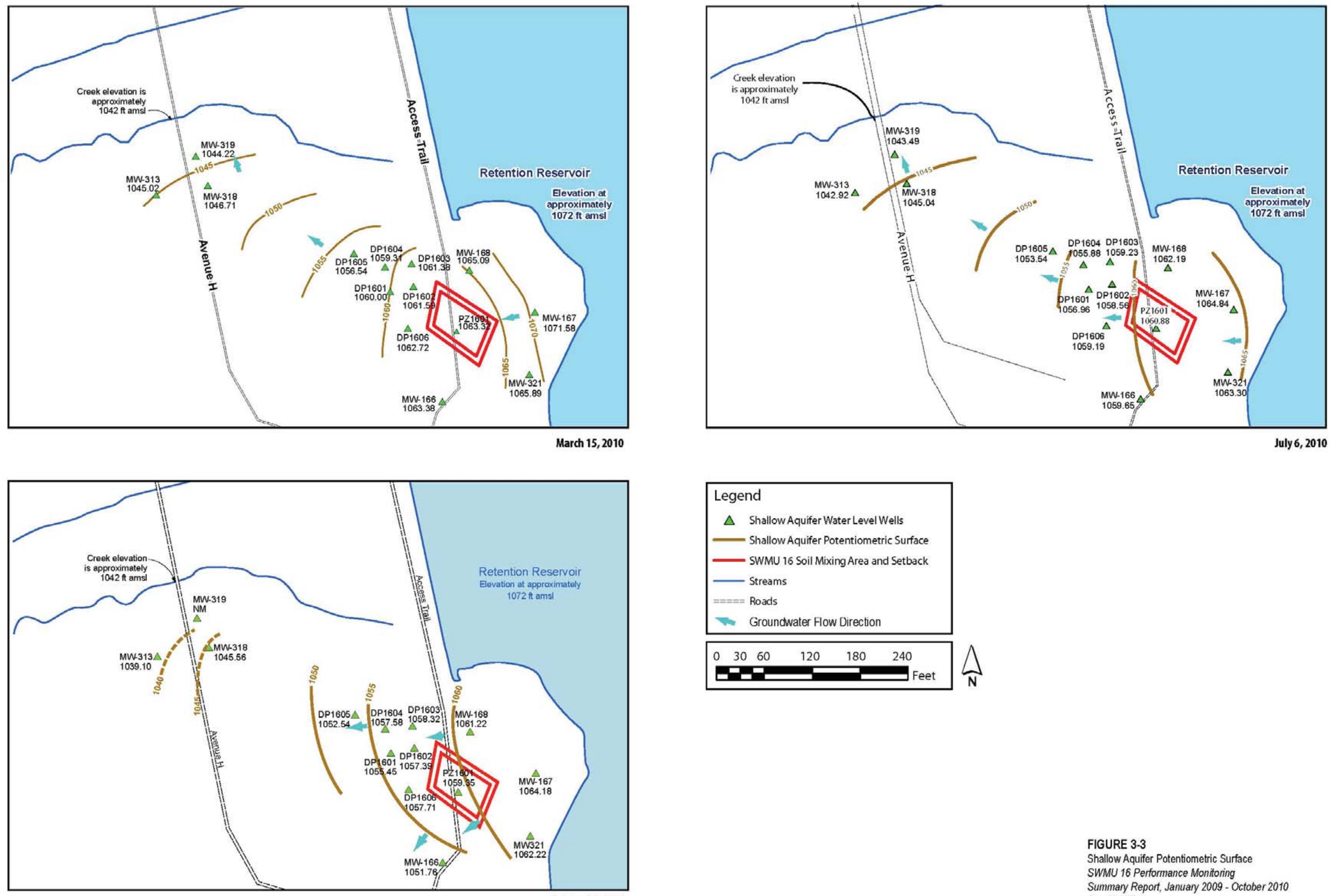


FIGURE 3-3
Shallow Aquifer Potentiometric Surface
SWMU 16 Performance Monitoring
Summary Report, January 2009 - October 2010
Arnold AFB

CH2MHILL.

ES022811182928KNV

R:\USNAVFACENGCOM405450\ABL\MAPFILES\430115_5_YEAR_ROD_REVIEW_REPORT\FIG5_3_SITE_5_GW_ELEV_AUG2012.MXD BALDRIDGE 8/20/2013 11:03:22 AM

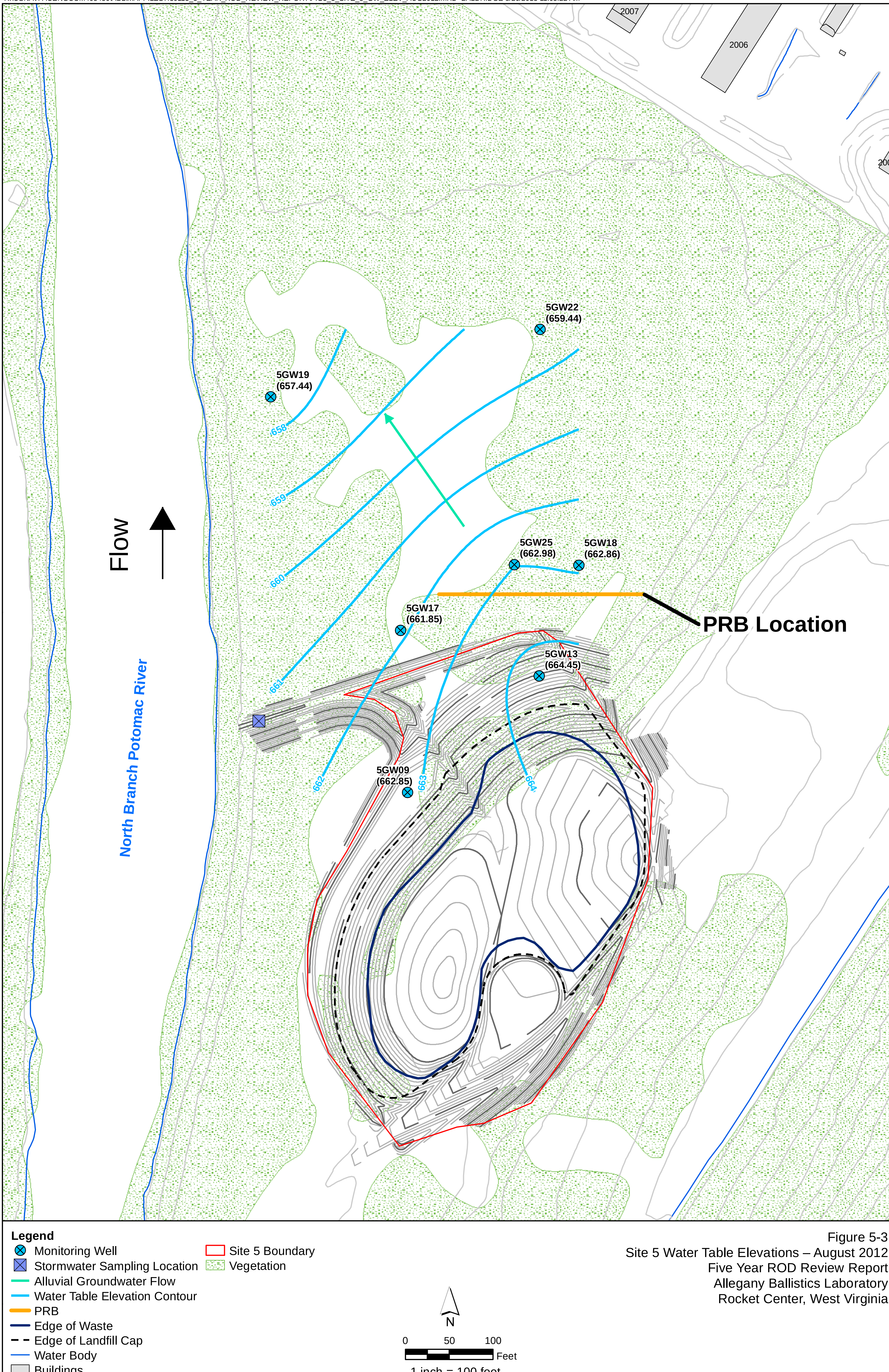


Figure 5-3
Site 5 Water Table Elevations – August 2012
Five Year ROD Review Report
Allegany Ballistics Laboratory
Rocket Center, West Virginia

CH2MHILL

File Path: v:\18gis\abl\figures\long-term_monitoring_report.apr

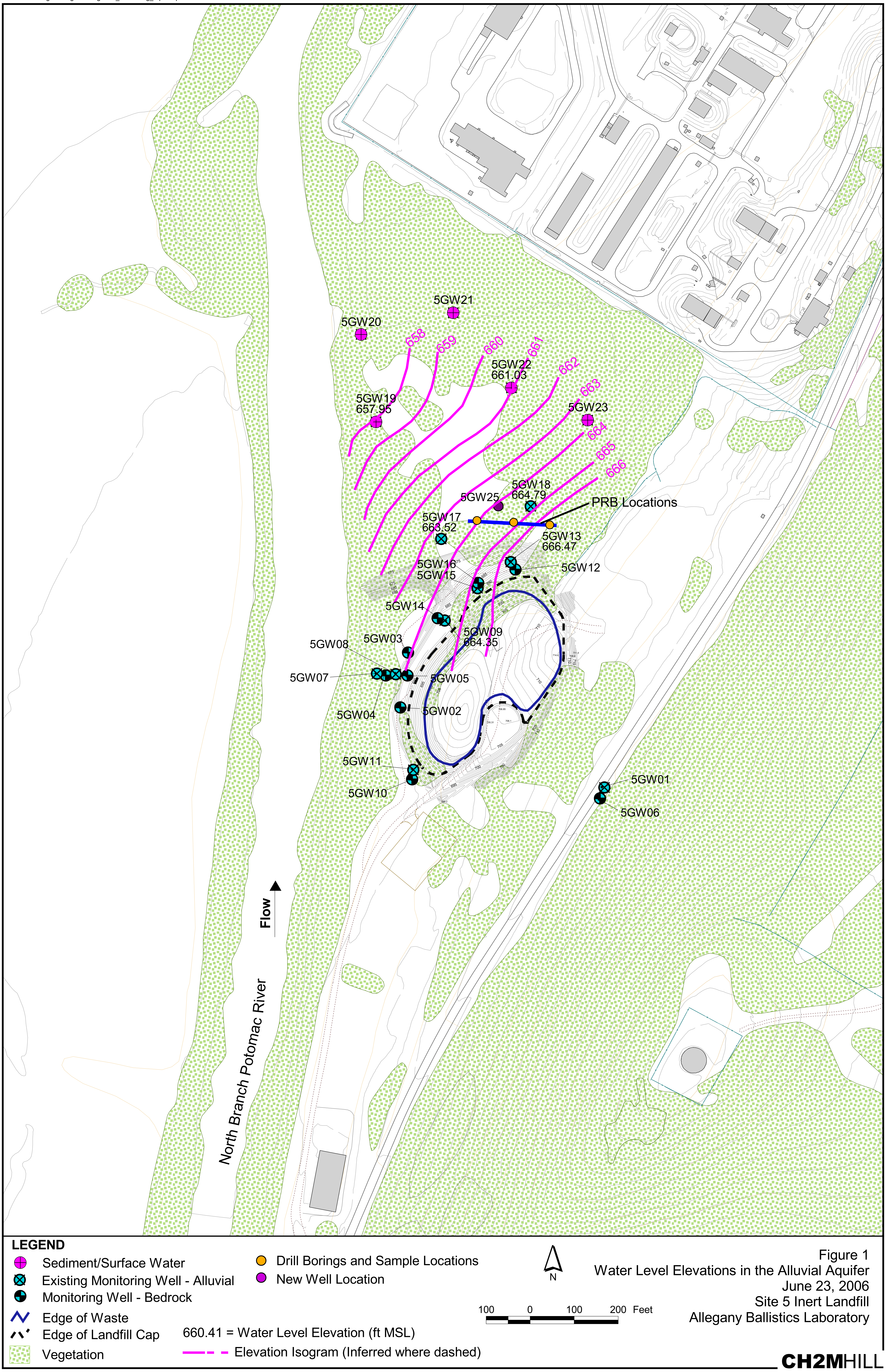
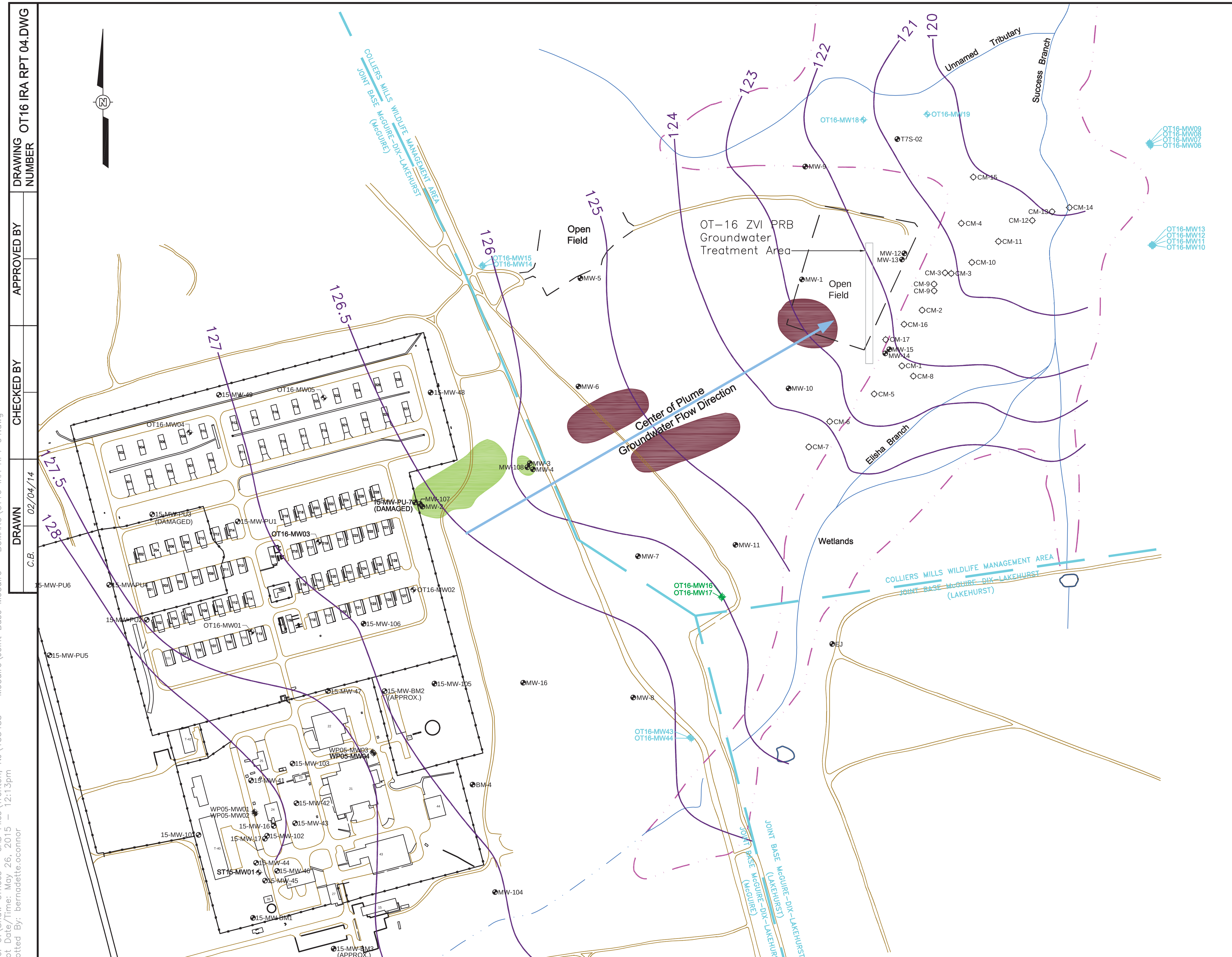


Figure 1
Water Level Elevations in the Alluvial Aquifer
June 23, 2006
Site 5 Inert Landfill
Allegany Ballistics Laboratory

CH2MHILL



LEGEND

- Existing Building
- Stream/Water Body
- Approximate Wetlands Boundary
- Groundwater Flow Direction
- Fence Line
- Sand Roads
- 125 Groundwater Contour (in feet above mean sea level)
- Existing Monitoring Well
- Monitoring Well (2009)
- Monitoring Well (2012)
- Piezometer (USGS, 2001)
- Sentinel Well (new)
- Primary Peat Zones (SAIC, 2005)
- Secondary Peat Zones (SAIC, 2008)

400' 0 400'

SCALE 1"=400'

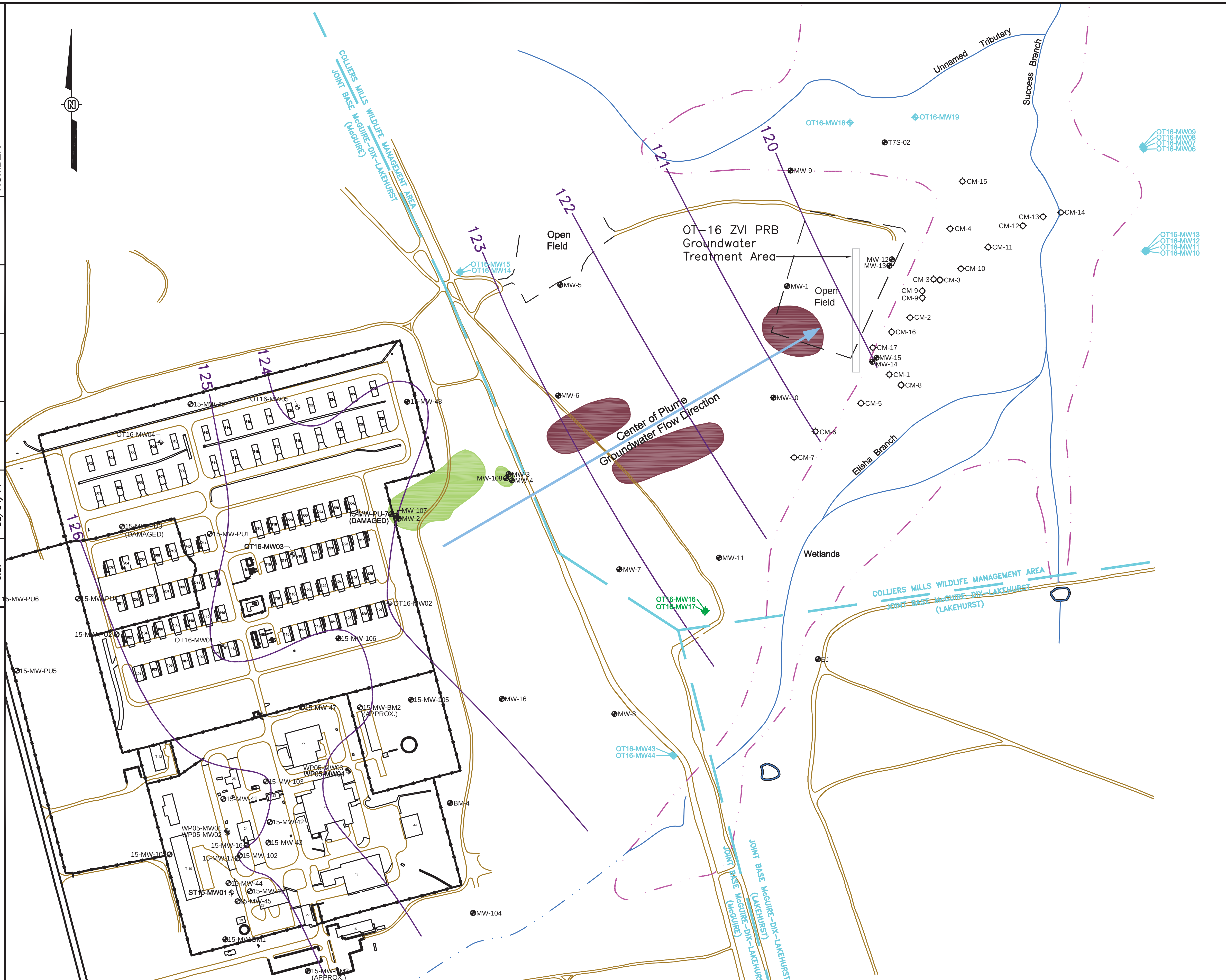
AIR FORCE
CIVIL ENGINEER CENTER
ENVIRONMENTAL RESTORATION PROGRAM

BOMARC OT-16
GROUNDWATER FLOW
MARCH 30, 2000 (USGS, 2001)

JOINT BASE McGUIRE-DIX-LAKEHURST
NEW JERSEY

CB&I
(formally Shaw Environmental, Inc.)
111 Howard Blvd., Suite 110
Mt Arlington, NJ 07856

FIGURE NO.
2-3



LEGEND

- Existing Building
- Stream/Water Body
- Approximate Wetlands Boundary
- Groundwater Flow Direction
- Fence LIne
- Sand Roads
- 125 Groundwater Contour (in feet above mean sea level)
- Existing Monitoring Well
- Monitoring Well (2009)
- Monitoring Well (2012)
- Piezometer (USGS, 2001)
- Sentinel Well (new)
- Primary Peat Zones (SAIC, 2005)
- Secondary Peat Zones (SAIC, 2008)

400' 0 400'

SCALE 1"=400'

AIR FORCE
CIVIL ENGINEER CENTER
ENVIRONMENTAL RESTORATION PROGRAM

BOMARC OT-16 GROUNDWATER FLOW JANUARY 2014

JOINT BASE McGUIRE-DIX-LAKEHURST
NEW JERSEY

CB&I
(formally Shaw Environmental, Inc.)
111 Howard Blvd., Suite 110
Mt Arlington, NJ 07856

FIGURE NO. 2-4

DRAWN	CHECKED BY	APPROVED BY	DRAWING NUMBER
C.B. 02/04/14			OT16 IRA RPT 05.DWG

File: O:\Shaw Offices – CAD Files\Trenton, NJ\133485 – McGuire\Joint Base McGuire – BOMARC\OT16 IRA RPT 05.dwg
Plot Date/Time: May 26, 2015 – 11:42am
Plotted By: bernadette.oconnor

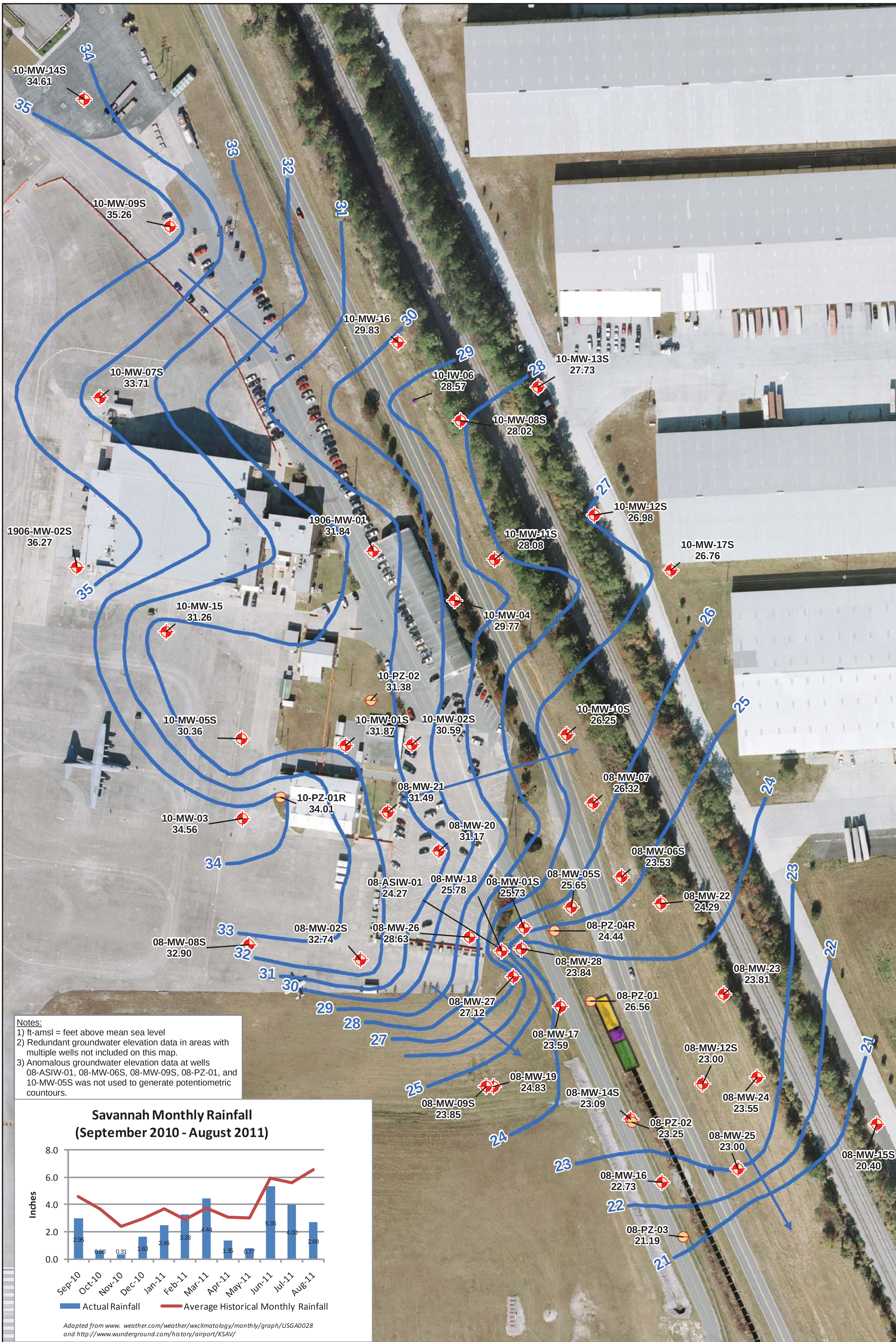
Legend

- Groundwater Contour (2 ft contour interval)
- Monitoring Well
- Piezometer

N

0 75 150 300 Feet

Figure X-X
Site 8 and 10 Potentiometric Surface Map (July 27, 2008)
1st Semiannual Effectiveness Report
Site 8 and 10 Savannah Air National Guard Base
Garden City, Georgia

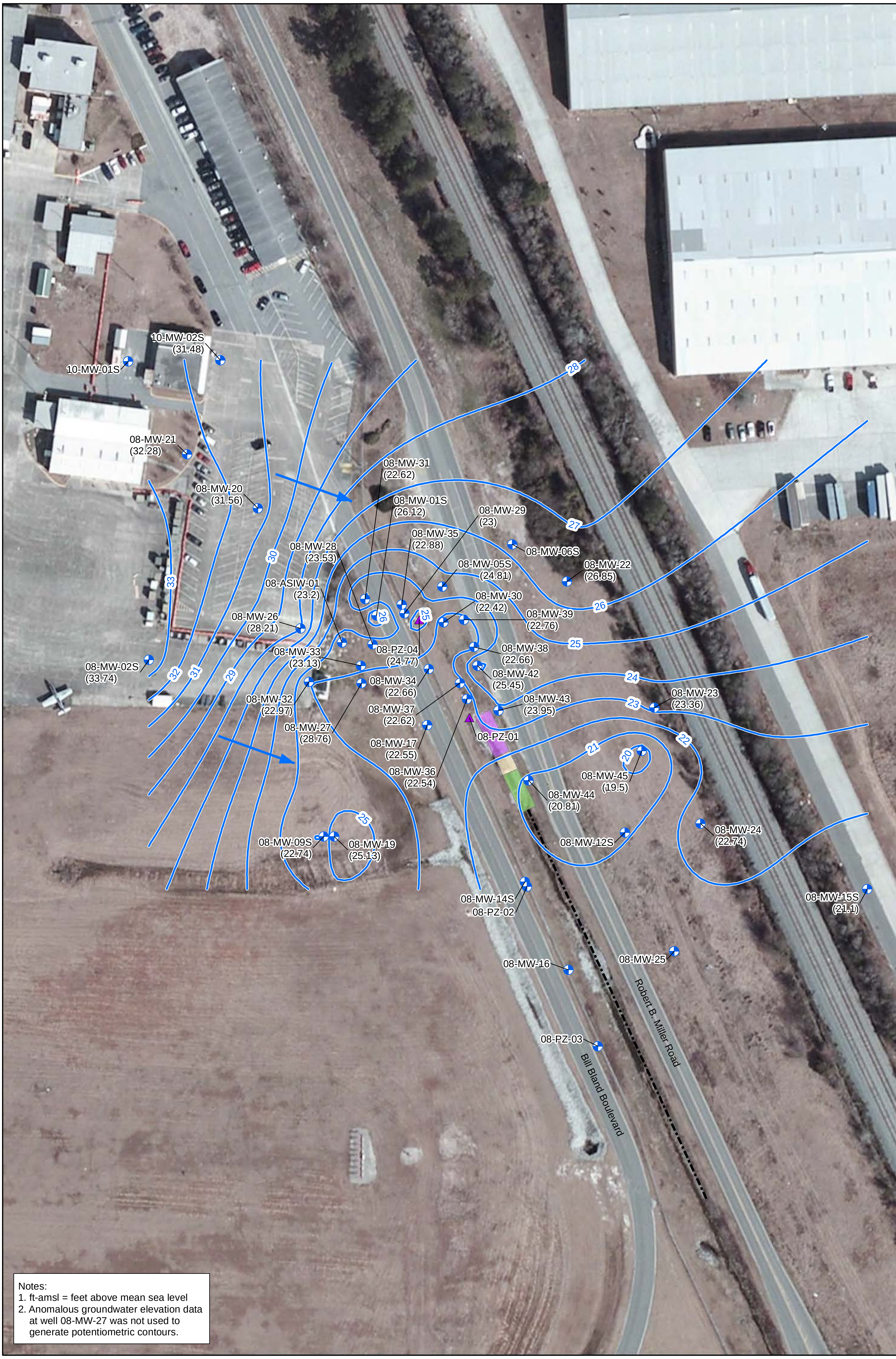


Injection Wells
Air Sparge Observation Well
Monitoring Well
Piezometer
Drainage Ditch
Aeration Basin Influent Area
Aeration Basin
Aeration Basin Effluent Area
31 Potentiometric Contour (ft-amsl)
Groundwater Flow Direction
21.72 Groundwater Elevation (ft-amsl)

N

0 50 100 200 Feet

FIGURE 1-5
August 30, 2011 Potentiometric Surface Map
3rd Annual Operation and Maintenance Performance Monitoring Report (September 2010 - September 2011)
Site 8, Savannah Air National Guard
Garden City, Georgia



Legend

- Shallow Monitoring Well
- Piezometer
- Drainage Ditch
- Potentiometric Contour (ft-amsl)
- Groundwater Flow Direction
- Contour interval = 1 foot
- Aeration Basin Effluent Area
- Aeration Basin Influent Area
- Aeration Basin

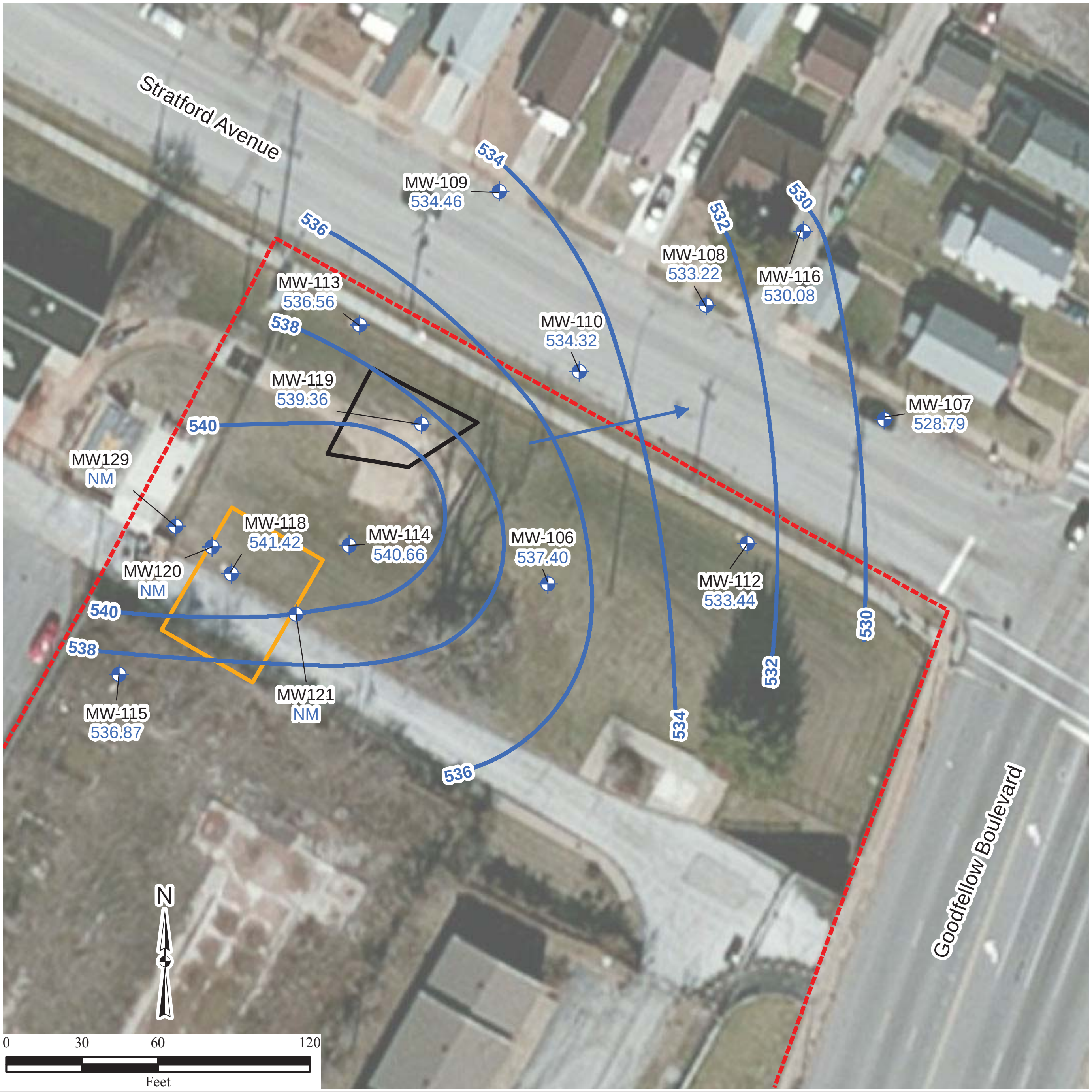
N

0 25 50 100 Feet

Figure 2
October 26, 2015, Potentiometric Surface Map
7th Annual Operation and Maintenance Performance Monitoring Report (February 2015 - January 2016)
Site 8, Savannah Air National Guard
Garden City, Georgia

ch2m:

MKE - \\Lakefront\Proj\USAirNationalGuard\SANG_Reorg\MapFiles\MW_Requests_011316\Fig02_Site8_Potentiometric_Surface_Map.mxd User Name: AESPEJO Date: 1/29/2016 Time: 1:33:22 PM



HGL, Annual Long Term Monitoring Report, OU-1 Groundwater, April 2015, The Former St. Louis Ordnance Plant, St. Louis, MO, Regional LTO/LTM

Figure 3.1
Potentiometric Surface Map
April 2015

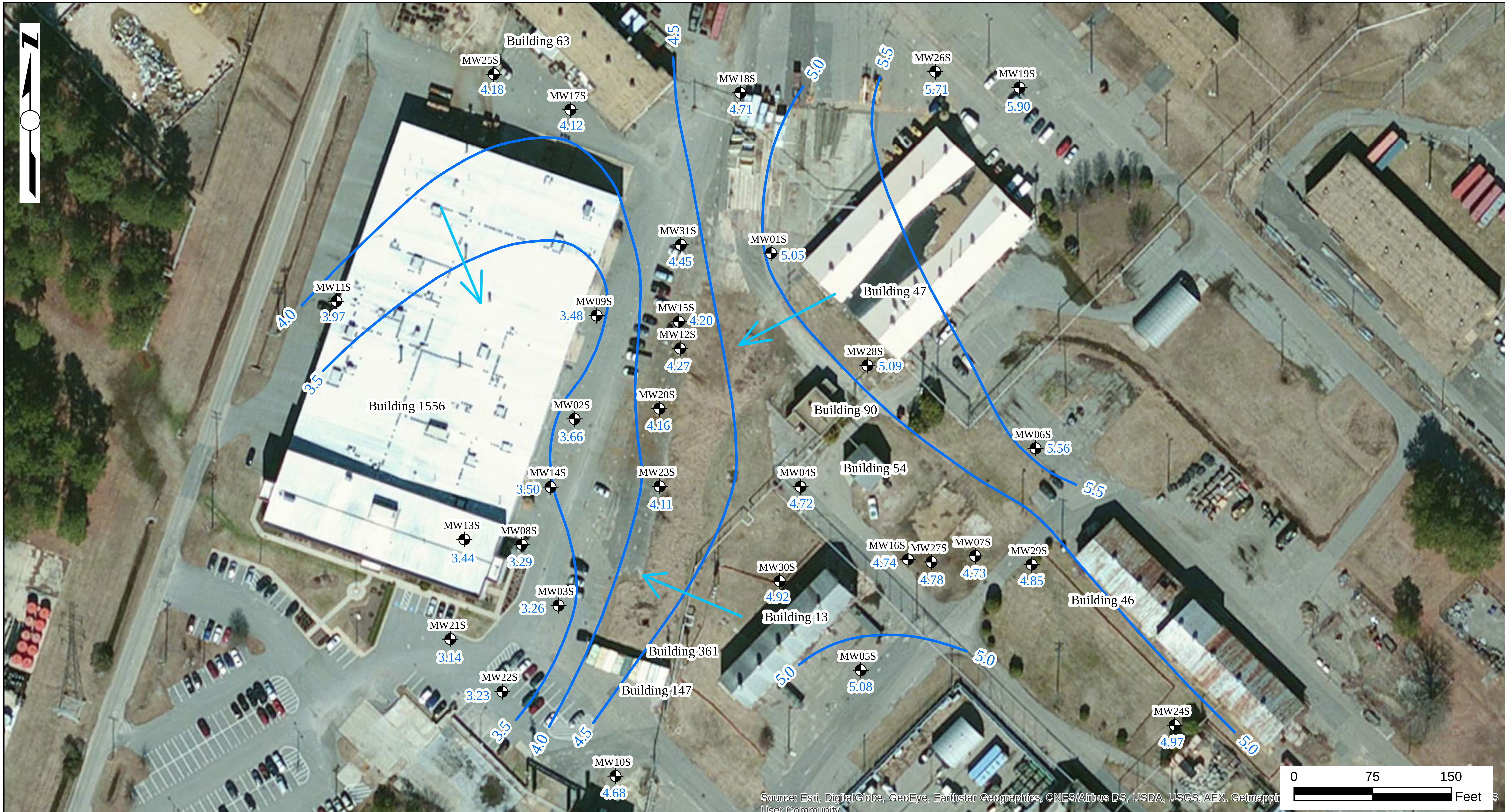
Legend

⊕	LTM Well
MW-112 533.44	Well Identification Groundwater Elevation (ft amsl)
—530—	Groundwater Elevation Contour (ft amsl)
→	Groundwater Flow Direction
- - - -	Site Boundary
☐ (black)	Soil Mixing Treatment Area
☐ (orange)	Plume C LUC

Notes:
ft amsl=feet above mean sea level
LUC=land use control
NM=not measured

\\gst-srv-01\hglgis\Army_GW\St_Louis_Ordnance_Plant\2015-04_OU1_GW_Report
(3-01)Pot_Surf_April2015.mxd
11/2/2015 JG
Source: HGL, ArcGIS Online Imagery

HGL HydroGeoLogic, Inc



Legend

Monitoring Well

3.47 Groundwater Elevation (ft.)

Groundwater Contour (ft.)

Groundwater Flow Direction

TWSC JOINT VENTURE

424 Investors Place, Suite 108
Virginia Beach, VA 23452
(757) 456-5093 (757) 456-5095 (fax)

FIGURE 2 : Groundwater Potentiometric Surface Contours November 2015

SITE 21
ST. JULIENS CREEK ANNEX
CHESAPEAKE, VIRGINIA

Date: February 15, 2016

Shaw Environmental & Infrastructure, Inc.
500 East Main Street, Suite 1630
Norfolk, Virginia 23510

REV	DATE	BY	CHD'D	APV'D	DESCRIPTION/ISSUE

REVISIONS

DESIGNED BY	B. Squire	02/10/2011
CHECKED BY	B. Squire	02/10/2011
DRAWN BY	T. ROBINSON	02/10/2011
APPROVED BY	K. LANDMAN	02/10/2011

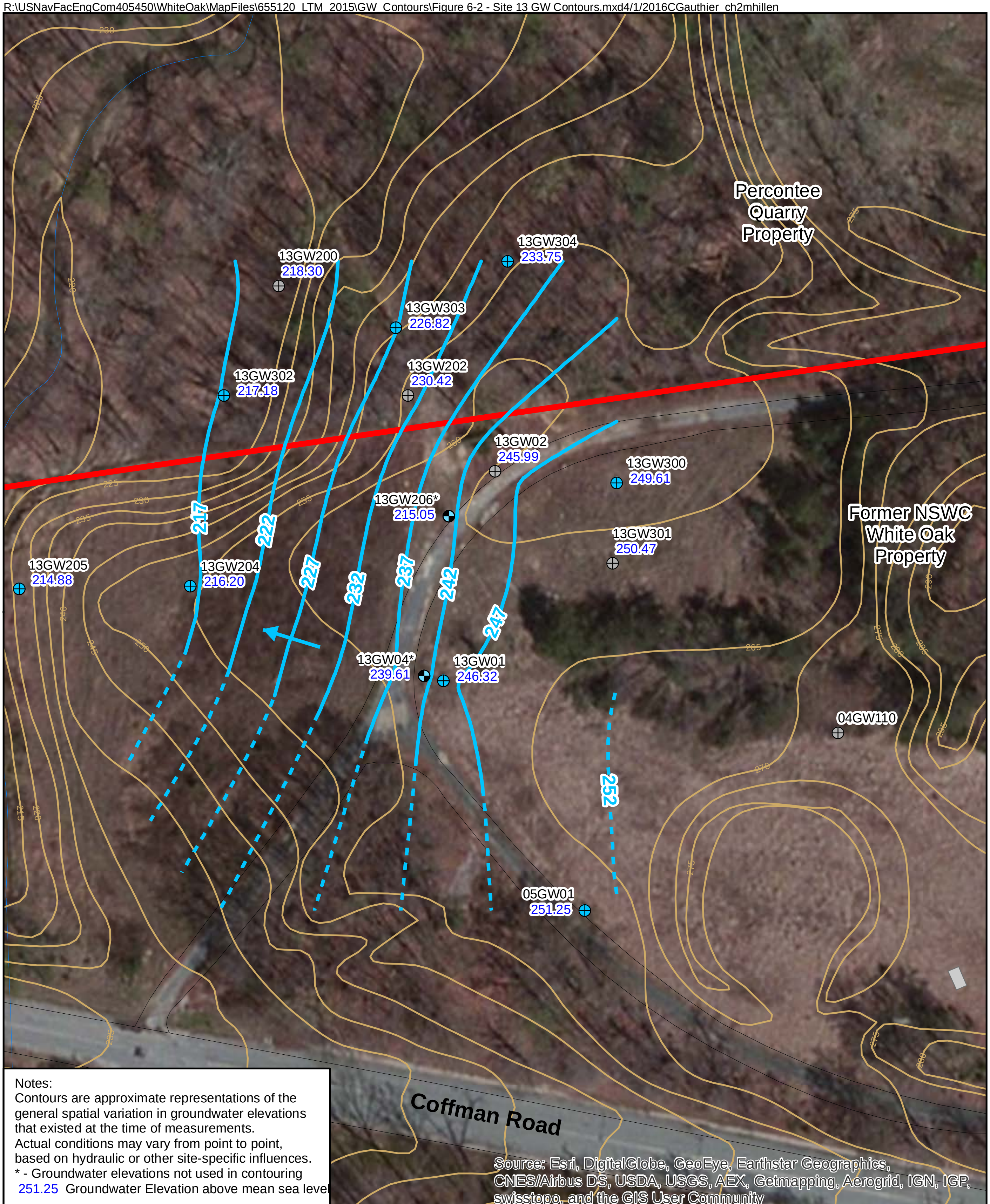
NAVFAC

NAS NORTHWEST
CHESAPEAKE, VIRGINIA
ST JULIENS
POTENTIOMETRIC SURFACE MAP - NOVEMBER 2010

SCALE: AS SHOWN
SIZE: B
TASK ORDER NO. WE 10
CONST. CONTRACT NO. N62470-08-D-1007
NAVFAC DRAWING NO.
SHEET I.D.
FIGURE 2

N:\Norfolk\GIS_Documents\Project_Maps\WE010\PSM_StJ_Nov_2010.mxd

R:\USNavFacEngCom405450\WhiteOak\MapFiles\655120_LTM_2015\GW_Contours\Figure 6-2 - Site 13 GW Contours.mxd4/1/2016CGauthier_ch2mhillen



Notes:
Contours are approximate representations of the general spatial variation in groundwater elevations that existed at the time of measurements.
Actual conditions may vary from point to point, based on hydraulic or other site-specific influences.
* - Groundwater elevations not used in contouring
251.25 Groundwater Elevation above mean sea level

Legend

- 2015 Long Term Montoring Well
- 2015 Bedrock Long Term Monitoring Well
- Montoring Well
- Topographic Contours (ft msl)
- Former NSWC - White Oak Facility Boundary
- Water Bodies
- Roads
- Groundwater Contour
- Groundwater Contour (inferred)
- Groundwater Flow Direction

N

0 40 80 Feet

Figure 6-2
Site13 Potentiometric Surface Map - November 9, 2015
Basewide Long-term Monitoring Report
Former NSWC-White Oak
Silver Spring, Maryland

ch2m:

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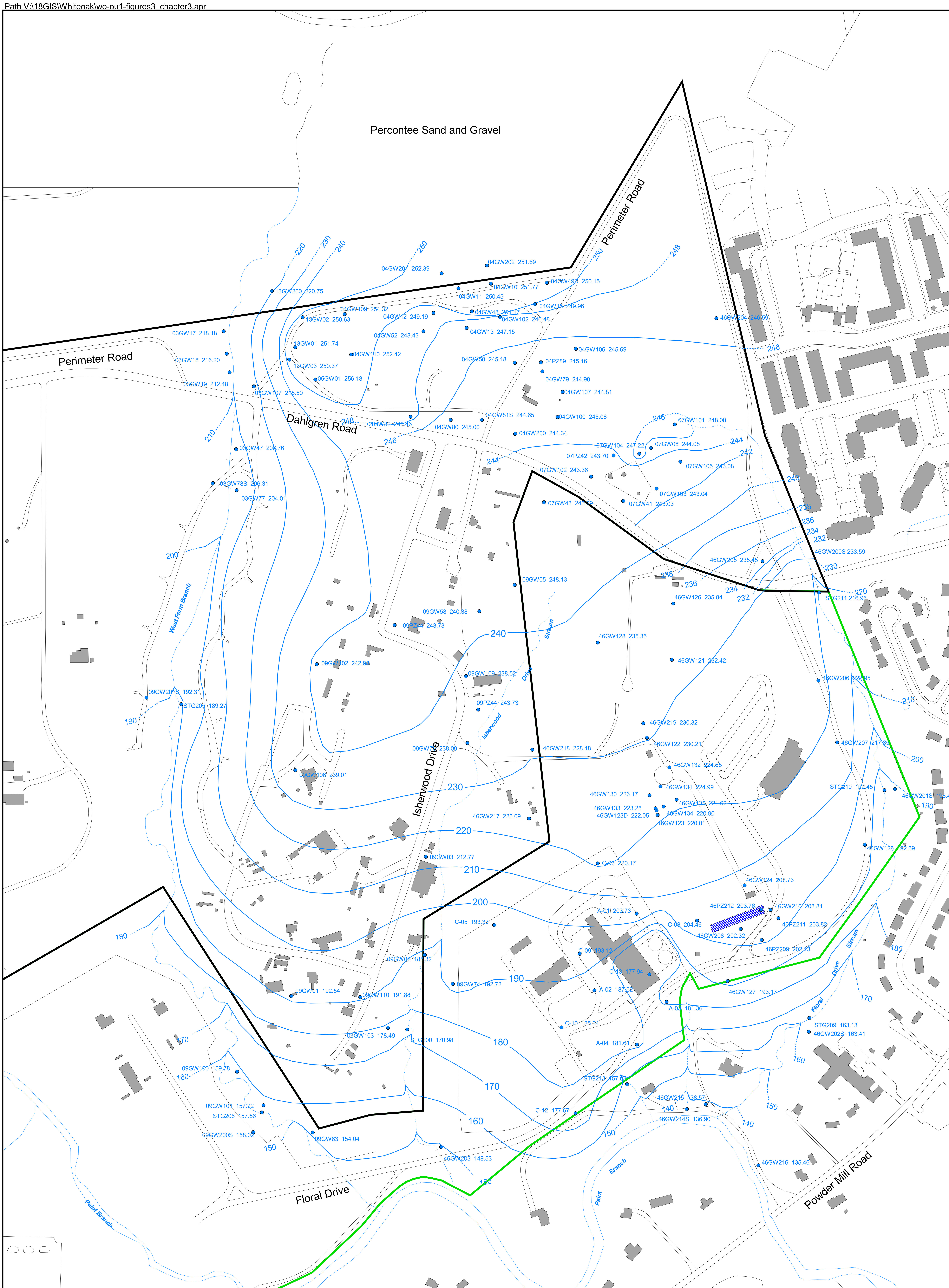


SAMPLING LOCATIONS

- 158.74 Groundwater Elevation Locations (feet above msl)
- Groundwater Contours (feet above msl)
- Estimated Groundwater Contours (feet above msl)
- Site W Swale Collection Trench

BASE MAP FEATURES

- Former NSWC White Oak Property Boundary
- Army Lab Property Boundary
- Roads and Paved Areas
- Perennial Stream
- Intermittent Stream
- Buildings and Other Structures

Note:
The contour interval between 230 feet above msl and 250 feet above msl is 2 feet north of Dahlgren Road to provide greater detail around Sites 4 and 7.

N W E S

200 0 200 400 600 800 Feet

Units = Feet

Figure 3-11
Water Table Map (April 2000)
Remedial Investigation for OU-1
NSWC - White Oak, Silver Spring, Maryland

CH2MHILL

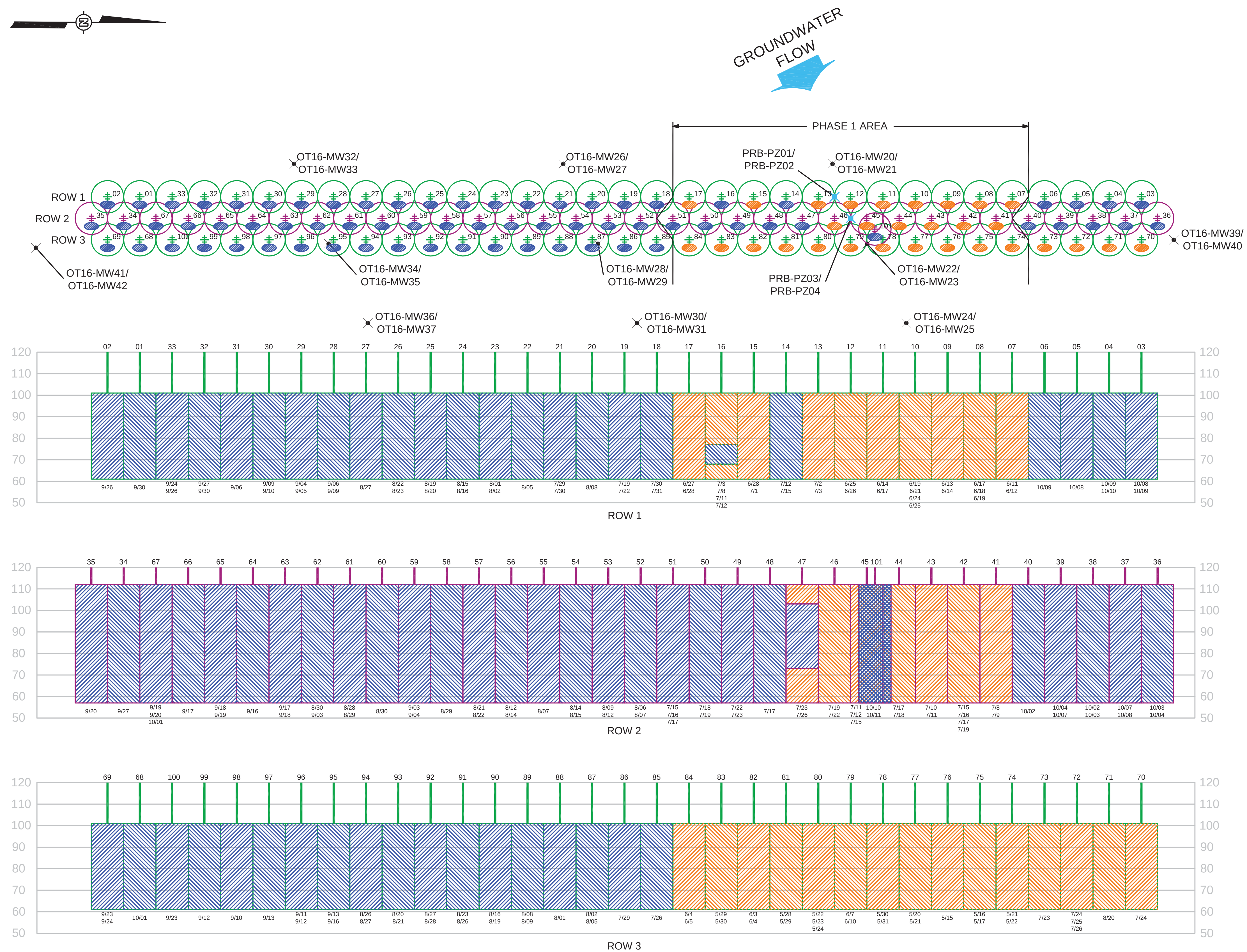
Appendix C
McGuire AFB OT-16 Well Layout

DRAWING NUMBER OT16 IRA RPT 09.DWG

APPROVED BY

CHECKED BY

DRAWN C.B. 02/04/14



LEGEND

- Injection Point (IP) 40–ft Vertical Thickness with 7.5–ft ROI
- Injection Point (IP) 55–ft Vertical Thickness with 7.5–ft ROI
- Typ. PRB Monitoring Well Locations (shallow and Intermediate)
- Typ. PRB Piezometer Locations (shallow and Intermediate)
- Crew #1 Injection Point
- Crew #2 Injection Point

Note:

1. The IP prefix for injection points (i.e., IP–01) has been removed from this figure due to spatial limitations.
2. Dates listed below each injection point indicate dates of ZVI injection in 2013.

50' 0 50'

SCALE 1"=50'

AIR FORCE CIVIL ENGINEER CENTER

ENVIRONMENTAL RESTORATION PROGRAM

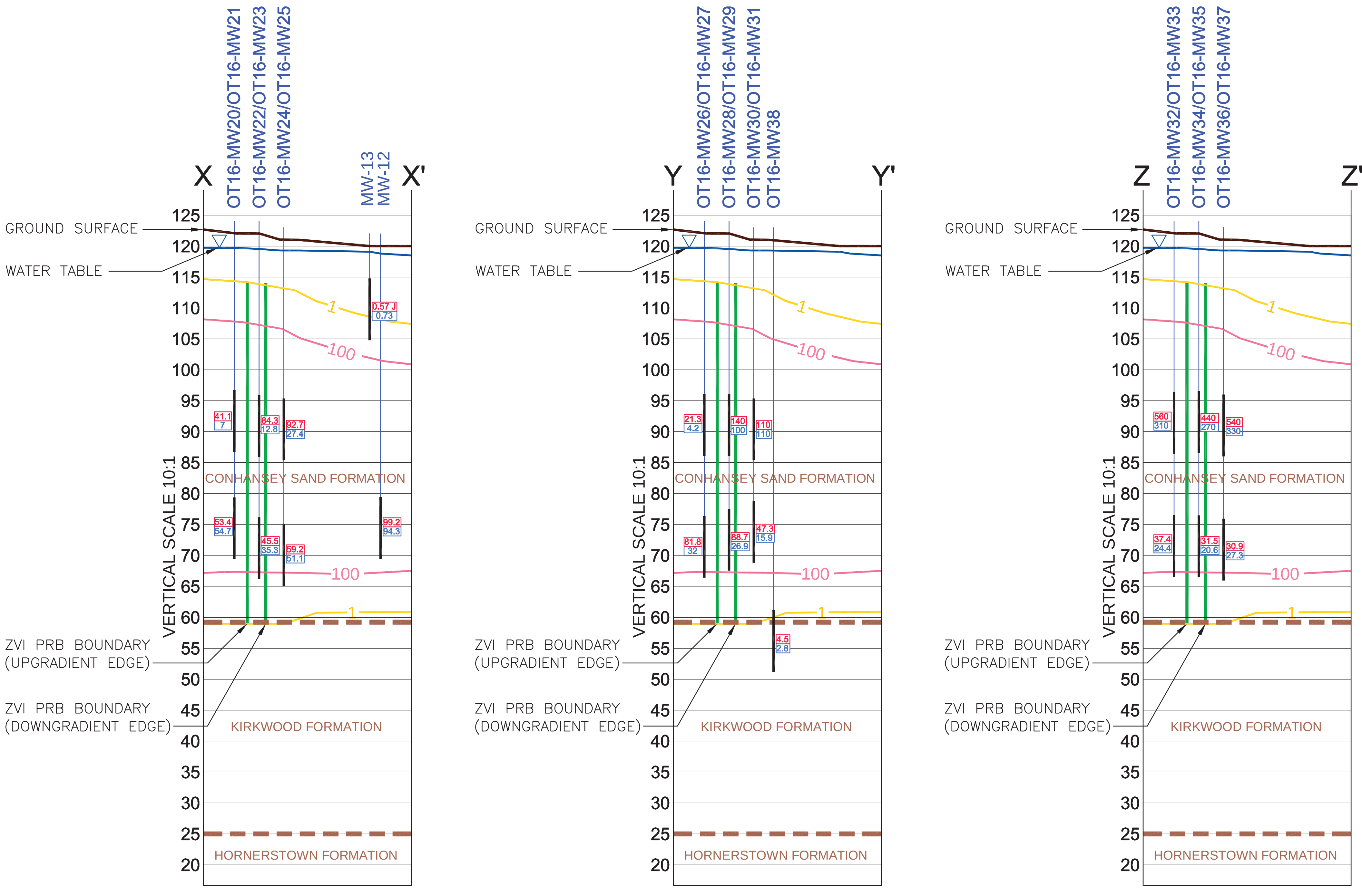
BOMARC OT-16 ZVI INJECTION POINTS WITH CROSS-SECTIONS

JOINT BASE McGUIRE-DIX-LAKEHURST NEW JERSEY

CB&I (formally Shaw Environmental, Inc.) 111 Howard Blvd., Suite 110 Mt Arlington, NJ 07856

FIGURE NO. 7-1

File: O:\Shaw Offices – CAD Files\Trenton, NJ\133485 – McGuire\Joint Base McGuire – BOMARC\OT16 IRA RPT 09_5–26–15.dwg
Plot Date/Time: Aug 19, 2015 – 2:04pm
Plotted By: bernadette.oconnor



CROSS-SECTION X-X'

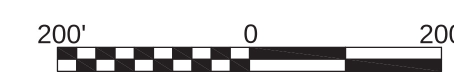
CROSS-SECTION Y-Y'

CROSS-SECTION Z-Z'

Notes:
1. The top of the clay confining layer is the Hornerstown Formation occurring at approximately 25 ft MSL (USGS, 2003).

2. Iso–concentration contours based on the maximum historical TCE concentration detected in OT–16 monitoring wells as of 2011.

LEGEND



SCALE 1"=200'

AIR FORCE
CIVIL ENGINEER CENTER
ENVIRONMENTAL RESTORATION PROGRAM

BOMARC OT-16
PRB CROSS-SECTIONS
WITH TCE GROUNDWATER RESULTS:
Q1 - MARCH 2014 AND Q3 - SEPTEMBER 2014
JOINT BASE McGUIRE-DIX-LAKEHURST
NEW JERSEY

CB&I
(formally Shaw Environmental, Inc.)
111 Howard Blvd., Suite 110
Mt Arlington, NJ 07856

FIGURE NO.
8-1

DRAWING NUMBER OT16 Y1Q1 SUM RPT 03.DWG
APPROVED BY
CHECKED BY
DRAWN C.B. 04/23/14

File: O:\Shaw Offices – CAD Files\Trenton, NJ\133485 – McGuire\Joint Base McGuire – BOMARC\OT16 Y1Q1 SUM RPT 03 Qtrs 1 and 3 5–20–15.dwg
Plot Date/Time: May 26, 2015 – 1:42pm
Plotted By: bernadette.oconnor

Appendix B
Field Notes

ABL

C-102746 calibration 1/6/17
746.5 mm Hg 18.71°C

parameter	pre-cal	post-cal	lot #	expiration
DO %	109.0	98.5		
pH 7	7.12	7.00	6GJ707	10/18
pH4	3.74	4.00	6GE220	5/18
pH10	9.89	9.98	6GE377	5/18
1.000 mS/cm	1.059	1.133	4601707	12/17
0.0 NTU	5.0	0.0	A5271/A5355	9/17 - 12/17
100 NTU	108.1	100.0	A5275	9/17
239.18 mV	242.6	239.2	16E100608	6/21

C-102746 Calibration 1/23/17 731.7 mmHg, 20.86°C

parameter	pre-cal	post-cal	lot #	expiration
DO%	0.0	probe error		
pH 7	6.85	7.00	6GJ707	10/18
pH 4	3.94	4.00	6GE220	5/18
pH 10	9.76	9.96	6GE377	5/18
Cond. (mS/cm)	1.185	1.086	4601707	12/17
0NTU	1499.6	-999.9	A5271	9/17
			A5355	12/17
100 NTU	0.3	99.7	A5275	9/17
237.5 mV	249.4	237.5	16E100608	6/21

C102009 Calibration 1/23/17 732.5 mmHg, 18.73°C

parameter	pre-cal	post-cal	lot #	expiration
DO%	89.5	96.5		
pH7	6.95	7.00	6GJ707	10/18
pH4	3.79	4.00	6GE220	5/18
pH10	9.95	10.00	6GE377	5/18
Cond (mS/cm)	1.065	1.080	4601707	12/17
0NTU	6.4	0.0	A5271/A5355	9/17 and 12/17
100NTU	109.1	100.0	A5275	9/17
237.5mV	235.2	237.6	16E100608	6/21

C102009 Calibration 1/24/17 733.9 mmHg 17.94°C

parameter	pre-cal	post-cal	lot #	expiration
DO%	104.6	96.6	—	—
pH 7	7.04	7.00	6GJ707	10/18
pH 4	3.95	4.00	6GE220	5/18
pH 10	9.79	9.96	6GE377	5/18
Cond mS/cm	spec 1.058	spec 1.114	4601707	12/17
0 NTU	1.0	0.0	A5271/A5355	9/17-12/17
100 NTU	97.2	100.0	A5275	9/17
ORP (mV)	241.6	237.5	16E100608	6/21

ABL, WV 1/4/17

Site 5 OVI investigation

Objective: clear utilities and stage supplies for drilling this week.

Weather: partly cloudy 52/44°F

Personnel: J. McCann/ATL, S. Kline/ATL

0800 Team arrived onsite, watched plant safety video

0825 Spoke with Les Mull about security clearance, cleared as escorted visitors should have contractor clearance by tomorrow morning.

0836 Spoke with A. Blow/Accumark, he does not have a crew coming. Will work on scheduling one for tomorrow morning

0840 Team received contractor badges

0844 Spoke with Saedacco, crew will be onsite this afternoon

Site 5 OVI Investigation

0849 Spoke with A. Blow, utility Locate crew will be onsite this afternoon

0855 Arrived at the groundwater treatment plant, got basic site orientation and began checking equipment

0913 Anthony/Accumark called, leaving another site and will give us an ETA once he gets back to the office

0925 Continued inspecting and staging equipment

1000 L. Mull came by to say that once utility locators or drillers arrive we should let him know so he can get the work permit started for the week

1004 S. Blaisdell showed J. McCann where shipments come in, tubing has not yet arrived

1005 Received text from A. Lunghi/Acc. ETA is 1230-1300

Site 5 OVI Investigation

1108 Completed transducer calibra[tion]

1110 Team to lunch

1228 Accumark onsite. S. Kline and J. McCann met accumar[k] at gate to drive to site

1241 Held safety Meeting

1330 Completed utility locate

1341 Accumark offsite

1405 Saedacco onsite, begin staging equipment at Site 5, safety meeting

1458 Saedacco begins delineating PRB to expedite drilling crossgradient wells

Begin on the east side to delineate PRB terminus.

1610: Eastern terminus delineated at toe of slope. ~ Marked with flag

1615: Begin Western terminus delineation

1630: Western terminus delineated

1635: Les ~~[illegible]~~ unlocks gate. SAEDACCO & CH2M leave site - sign out at security.

1645: S. Kline checks in at Wilson Supply for Dry ice - available tomorrow

1700: at Walmart Lowes for supplies.

1730: Back at Hotel

[signature] 1/4/17

ABL, WV 1/4/17

Site 5 ZVI Investigation

Pre-Task Safety Plan

Discussed: Weather, shut-off for rig, hospital route.

1/5/17

Evening of 1/4: conversation with Laura Cook (PM)

- Make sure each ~~core~~ 4-foot core has undisturbed native material for sampling (ZVI staining can creep into soil)

SICK

- ~~note ... note rate of the DPT ...~~ [illegible]
- On core - note angle of borehole so researchers can slice open lines perpendicular to ground surface; mark 'Top'

- Collect Development water during well install
- → send pictures of east side - get permission

1/5/17

0745: CH2M (S. Kline, J. McCann) at ABL

Security & sign in.

S. Kline gets wiper fluid from GWTP.

Objective: Collect ZVI cores and shipment.

Staff: CH2M: S. Kline, J. McCann; SAEDACCO: Brian, Scott, ~~Chris~~

Weather: p. cloudy cold 23°F snow expected in PM.

0800: Drive to Site 5 and begin set-up

J. McCann w/ H_2S briefing

- cold weather, rushing. working DPT rig at angled drilling (hydraulic hoses dangle)

25°F

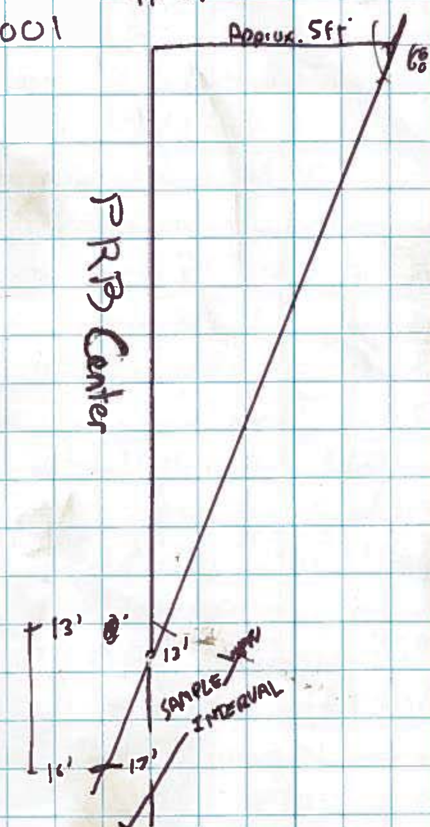
1/5/17 ABL Site 5 ESTCP

0810: Set up at DP001 location:
hand auger ~~for~~ 1-2 feet to act as a pilot hole for boring.
Setting at 66-67° angle 5ft from marked out PRB
Native soil: reddish brown SILT (ML) occasional fine gravel & sand, roots, damp.
After 4ft run, borehole has flattened out to 60°-
move rig up to increase the angle for next run.
4-8 ft section 2.9 ft recovery - SAA - damp, not saturated
8-12 ft section ZVI bottom 1 foot. approx 0.4 ft of 'bleed' into upgradient native soil (silt)
0900: Status call to L Cook.
0930: move over 2ft to the east and proceed to probe at 70° angle
(sampler tending to flatten out during drilling)
1030: collect 1st set of samples at DP001
Approx 13-17ft at a 68° angle
1125: Status call w/ Laura Cook/VBO
- Ask for labs to accept Saturday delivery
- next sample run, add another core run to see if we're collecting the middle of the ZVI
- core not oriented - let team know.
1200: collect 2nd set of DP001 samples
Core barrel stuck in heaving ZVI sands
Drillers ask if they can add water to keep ZVI down

1/5/17 ABL SITE 5 ESTCP Skline/ATL

1200: cont'd. S. Kline does not allow drillers to add water. Sampling from 20-25 ft not possible
DP001 2nd sample from 13-17' bgs. at approx. 68°

DP001



1210: Drillers taking lunch.
1240: Drillers back onsite: move to DP002 location.

1/5/17 ABL Site 5 ESTCP S.Kline/AR

1315: Test hole at DPOO2 completed at approx 70-68"
contact w/ ZVI met in the 11-15' interval
at approx. 13'
native soil downgradient of PRB - v. soft & saturated
sandy SILT. light brown coloration w/ dk. gray
stringers from ZVI wall.

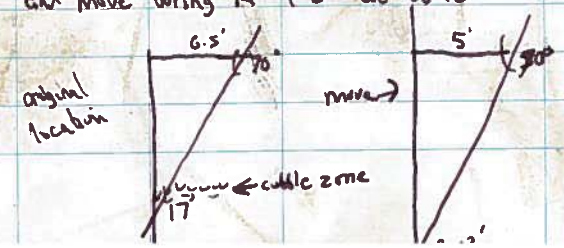
1330: set up for core collection at DPOO2
J. McCann to GWTP for sample kit prep.
- Shipping cores on Friday 6th overnight to
Olson & L. Cook's for EPA cores.

1400: Call to L. Cook
S.Kline collected 3 samples/location at DPØØ2
'halo' from ZVI more diffuse from upgradient sample
S.Kline has collected 11-13, 13-15' (interface)
and 15-17' (inside ZVI)

1445 - duplicate sample DPØØ2 - poor recovery of the
15-17' interval - approx 0.5 ft

1510: Move to DPØØ3 location
On initial run - hit the interface at 18' and
within the cobble/gravel zone - Redid Trig Calc.
and move boring is 1.5' at 68-70'

DPØØ3



1/5/17 ABL Site 5 ESTCP 25°F

1530: Mistake due to slight incorrect location of PRB by utility
locate.
- Beginning tomorrow
J. McCann back onsite. Sample kits for GW ready
will call labs to discuss TAT for RSK & if GW sampling
can occur tomorrow.

1630: Collect DPØØ3 samples
DPØØ3 collected at 11-13' (ZVI interface) and
13-15' (ZVI)
native soil a damp silty CLAY. ZVI interface &
ZVI saturated

1710: Duplicate DPØØ3 collected from 9-11' (ZVI interface)
and 11-13' (ZVI)
11-13' interval has broken through the other
side of ZVI - inferred PRB thickness
less than 2' at this location

1730: Breaking down equipment for the day

1745: Sign out at Pass office
CH2M & SAEDACCO offsite

1/5/17

1/6/17 ABL Site 5 ESTCP

0800: S. Kline onsite at base security office

Objective: complete ZVI coring, ship samples and begin groundwater sampling

Staff: S. Kline, CH2M; J. McCann; Brian Scott - SAEDACCO

Weather: cloudy 23°F staying below freezing all day

0815: waiting for Orbital ATK employee to open Site 5 gate

0830: Access through gate. conduct H&S meeting
- slips & falls, rushing, uneven ground

0845: J. McCann to collect bottleware for sampling
Driller setting up at DP004 location

0900: Native soil at DP004: reddish brown sandy SILT (ML), moist at 9'

0945: DP004 Samples Drilled to ~ 68°
9-11' - native soil
11-13' - ZVI Interface
13-15' - ZVI Interior

1110: collect all samples at DP004

1130: Call from Justine McCann - still waiting for shipment of iron filters from FedEx

1210: Driller mob. out of site
1 Drum of drill cuttings staged near building on wooden pallette

1/6/17 ABL Site 5 ESTCP

1230: SAEDACCO sign out at security - offsite.
- S. Kline to lunch

1300: Begin installing Site 1 transducers

1500: Completed installation of 3 transducers
- Meet up w/ J. McCann for sample shipment

1530: sign out of ABL security

1600 - At Wilsons' Supply - purchase approx. 100 lbs dry ice for core shipment

1630 - At Shipping office
tracking #
- 8044 6498 4740 - OHSU
8100 8997 8960 - Lewis Clark → EPA

1700: S. Kline offsite & work

1/6/17

1/6/17 ABL Site 5 ESTCP

1253 Started pumping at 5GW13. DTW = 16.85' btoc

1400 ASO5-GW13-010617 for VOCs, metals (dissolved and total), NH_3, phosphate, TOC, anions, alkalinity, sulfide, hardness, gasses and aquantarray and NGS

1405 ASO5-GW13P-010617 for VOCs and total and dissolved metals

1457 Finished collecting samples, purged about 3 gal

1600 Shipped samples MI: 810089978937 Microbac: 810089978959

1700 J. McCann offsite

Justine McCann 1/6/17

Final Parameters

DTW	Flow	pH	Temp	Cond	ORP	DO	Turb
[illegible]	200	6.57	9.58	1.486	231.4	1.71	[illegible]

1/16/17 ABL Site 5 ESTCP

Objective: mob to site, set up

Personnel: J. McCann/ATL

Weather: cloudy, 39°F

1220 Arrive onsite, sign in

1230 Head over to Site 5, note that the road around the building does not have gravel

1234 Marked the cross-gradient well locations for SAEDACCO to assess later today

1314 Finished collecting equipment

1316 Called S. Smith/SAEDACCO, they will be here around 7pm. Will meet them tomorrow at 0745 at entrance

1330 J. McCann offsite for day

Justine McCann 1/16/17

1/17/17 ABL Site 5 ESTCP

Personnel: J. McCann/CH2M
S. Smith/SAEDACCO, G. Hilgard/
Enviroprobe, B. Biddy/SAEDACCO,
S. Hunt/SAEDACCO

Objective: begin drilling and setting monitoring wells

Weather: rainy, 35-40°F

0750 J. McCann onsite
0804 SAEDACCO and enviroprobe onsite, waiting for skid steer to arrive onsite
0923 Arrived at site 5, fill out work permit and hold safety meeting
0934 Started setting up equipment
0956 Rig at 5GW27
1042 Started drilling 5GW27
1157 Hit refusal at ~20-ft bgs
1250 Finished setting well
1314 Team to lunch
1348 Returned from lunch, started set up on 5GW28
1416 Started drilling 5GW28
1515 Finished drilling 5GW28

1/17/17 ABL Site 5 ESTCP

began pulling rods and setting well
1635 Well in place, mixing grout and drumming soil
1652 Grouted 5GW27 & 5GW28 and placed monuments on wells
1659 Moved rig to make refueling easier
1720 Headed to security building to sign out
1735 Team offsite for day

Justine McCann 1/17/17

1/18/17 ABL Site 5 ESTCP
Objective: Continue installing monitoring wells
Personnel: J. McCann/CH2M, S. Smith/SAEDACCO, G. Hilgar/Enviroprobe, B. Biddy/SAEDACCO, S. Hunt/SAEDACCO, R. Chavez/SAEDACCO
Weather: Partly cloudy, 48/50°F
0740 J. McCann onsite, SAEDACCO present
0750 G. Hilgar onsite, drillers move to Site 5 while J. McCann gets YSI and ambers for development water for OHSU
0812 J. McCann moves to Site 5. Drillers getting set up at 5GW30
0832 Safety meeting: slips, trips, and falls
0844 Started drilling 5GW30
0930 Started developing 5GW27
0934 Finished drilling 5GW30, started setting well

1/18/17 ABL Site 5 ESTCP

1007 Finished installing 5GW30, Started pulling rods
1035 Finished developing 5GW27
1039 Set up to install 5GW31 and develop 5GW28
1051 Started developing 5GW28
1054 Started drilling 5GW31
1137 Finished drilling 5GW31
1148 Started installing 5GW31
1155 Finished developing 5GW28
1213 Finished installing 5GW31
1221 Moved rig to 5GW32
1232 Team to lunch
1330 Returned from lunch, went to water treatment plant to dump water
1340 S. Blaisdell says that plant can't filter drillers mud. Will work on an alternati plan for IDW. Returned to site 5. Continued setup on 5GW32.
1427 Started developing 5GW30
1441 Started drilling 5GW32

1/18/17 ABL Site 5 ESTCP

1458 Refusal in 5GW32 at 11' bgs, trying to see if L. Cook wants to set a well with 5' screen

1522 Finished developing 5GW30

1542 Started developing 5GW31

1554 Received confirmation from L. Cook to set 5GW32 with 5' screen with 2' sand above screen + 2' bentonite

1556 Began setting 5GW32

1630 Finished developing 5GW31

1634 Drillers move equipment to 5GW33

1702 Drillers cleaning up, moving drums to road

1730 Team to security office to sign out

1745 Team offsite for day

Justine McCann 1/18/17

1/19/17 ABL Site 5 ESTCP

Objective: Complete well installation, development & completion

Personnel: J. McCann/CH2M, G. Hilgar/Enviroprobe, S. Smith/SAEDACCO, S. Hunt/SAEDACCO, B. Biddy/SAEDACCO, R. Chavez/SAEDACCO

Weather: Cloudy, 43°F/50°F

0735 J. McCann & G. Hilgar onsite, SAEDACCO present

0747 SAEDACCO leaves truck that needs repair outside security gate, proceed to Site 5

0754 L. Mull on the way to unlock gate

0810 Onsite, Health and safety meeting, rushing, slipping

0810 Started drilling 5GW33

0833 Started developing 5GW32

0910 Finished drilling 5GW33 pulled rods

0923 Start installing 5GW33

0952 Finish installing 5GW33

1/19/17 ABL Site 5 ESTCP
0958 Begin setup at 5GW26
1041 Finish developing 5GW32
1052 Penske called and asked
S. Smith to come to
the truck parked at the
front gate for repair
1110 S. Smith returns to site
1114 Started drilling 5GW26
1129 Started developing 5GW33
1204 Finished drilling 5GW26,
drillers to lunch
1225 Finished developing 5GW33
1245 Drillers return to site 5
1258 Started installing 5GW26
1323 Finished installing 5GW26
1338 Rig moves to 5GW29
begin setup. Completion
crew moves to 5GW33.
Completed wells: 5GW27,
5GW28, 5GW30, 5GW31,
5GW32.
1403 Started drilling 5GW29
1442 Started developing 5GW26
1445 Finished drilling 5GW29

1/19/17 ABL Site 5 ESTCP

1510 Began installing 5GW29
1537 Finished developing 5GW26, Completion crew begins grouting and padding
1540 Finished installing 5GW29 B. Biddy begins cleaning rig and rods
1600 J. McCann and S. Smith go get pallates ~~at~~ from near Site 1 JM
1625 J. McCann and S. Smith returned to site 5, drillers working on staging drums and loading equipment JM
1645 G. Hilgar offsite
1757 Drums are staged ~~wt~~ JM on pallates near fenced in area, headed to secur office to sign out
1810 Team offsite

Justine McCann 1/19/17

1/20/17 ABL Site 5 ESTCP

Objective: develop and complete 5GW29, demob from site

Personnel: J. McCann/CH2M, S. Smith/SAEDACCO, S. Hunt/SAEDACCO, B. Biddy/SAEDACCO, R. Chavez/SAEDACCO

Weather: rainy / 35-38°F

0735 J. McCann onsite, SAEDACCO present

0738 Headed over to Site 5

0754 At site 5, begin cleaning up equipment.

0808 Safety meeting: heavy loads

0812 Continued loading equipment

0904 Started developing 5GW29

1003 Finished developing 5GW29
S. Smith finishes putting tags on wells and goes to let other drillers know that 5GW29 is ready for a pad

1023 S. Hunt and R. Chavez start 5GW29 completion
S. Smith & B. Biddy continue loading equipment

1/20/17 ABL Sites ESTCP

1125 Pad complete, loading concrete onto truck

1130 Moved up near fenced area drillers loading rig onto trailer

J. McCann completes drum inventory: 27 drums total

3 drums soil cuttings

5 drums drilling fluid

5 drums drilling/development fluid

14 drums development fluid

1208 Drillers offsite. J. McCann dropping off equipment at water treatment plant

1223 J. McCann to lunch

1300 J. McCann dropping off OHSU cooler at FedEx

1407 J. McCann drops cooler at FedEx ship center

Justine McCann 1/20/17

1/23/17 ABL Site 5 ESTCP

Objective: begin sampling select monitoring wells

Personnel: J. McCann/ATL, C. Conover/VBO

Weather: Rainy, 44-48°F

0720 J. McCann onsite, headed to groundwater treatment plant to calibrate YSIs and collect equipment

0930 Arrived at site 5, waiting for L. Mull to open gate

0956 Begin setup on 5GW33 DTW = 5.34' btoc

1012 Started pumping 5GW33

Gauged wells

well	time	PID	DTW	TD
5GW13	1415	0.0	15.16	36.06
5GW17	1420	0.0	5.61	25.92
5GW18	1351	0.0	3.40	27.08
5GW25	1356	0.0	4.09	26.98
5GW26	1345	0.0	4.61	24.22
5GW27	1350	0.9	3.82	24.73
5GW28	1353	0.1	3.64	21.15
5GW29	1408	0.0	4.75	24.63
5GW30	1405	0.0	3.11	22.16

1/23/17 ABL Site5 ESTCP

gauging continued

well	time	PID	DTW	TD
5GW31	1401	0.0	3.82	21.97
5GW32	1411	0.0	3.09	13.22
5GW33	0952	0.0	5.34	25.23

1105 AS05-GW33-012317
AS05-GW33MS-012317
AS05-GW33MSD-012317

1148 Stopped pumping 5GW33, total purge volume = 3.3 gallons

1150 C. Connover arrives onsite, J. McCann goes to security office to meet him

1220 Went to treatment plant to dump purge water

1230 Team to lunch

1312 Returned from lunch

1324 L. Mull opens site 5 gate

1345 Started water level survey

1430 Completed water level survey. Went back to groundwater treatment plant to pack coolers

1520 Left site to ship coolers

1610 Shipped coolers

Justine McCann 1/23/17

1/24/17 ABL Site 5 ESTCP

Objective: continue sampling
select wells at site 5

Personnel: J. McCann/ATL, C. Conover/VBO

Weather: cloudy, 32-42°F

0720 Team onsite

0730 Calibrating YSI C102009
see cal sheet

0800 Started loading equipment
into cars

0824 L. Mull getting keys for backgate

0843 Started pumping 5GW26
DTW=3.45' btoc

0945 A505-GW26-012417

1004 Stopped pumping 5GW26, total
purge volume=4.5gal

1014 Setup at 5GW32, DTW=1.45' btoc

1017 Started pumping 5GW32

1100 A505-GW32-012017

1120 Stopped pumping, purged 3 gal
headed to treatment plant
to dump purge water

1156 Team to lunch

1237 Returned from lunch

1246 Setup at 5GW22 DTW=2.56' btoc

1/24/17 ABL Site 5 ESTCP

1335 Started pumping 5GW27

1335 | A505-GW27-012017

1352 Stopped purging, volume = 2.8 g

1356 Setup at 5GW28 DTW = 2.44

1402 Started pumping 5GW28

1430 | A505-GW28-012017

1508 Stopped pumping, purge volume = 2.8 gal

1512 Headed to groundwater treatment plant to pack coolers & dump purge water

1535 Team offsite for day

Justine McCann 1/24/17

1/25/17 ABL Site 5 ESTCP

Objective: Continue sampling select wells at site 5

Personnel: J. McCann/ATL, C. Conover/VBO

Weather: Sunny, 41-54°F

0715 Arrived onsite

0723 Arrived at water treatment plant, started calibrating

parameter	pre-cal	post-cal	lot #	exp
DO%	97.0	97.2	—	—
pH 7	7.12	7.00	6GJ707	10/18
pH 4	3.84	4.00	6GE20	5/18
pH 10	9.73	9.95	6GE377	5/18
Cond (mS/cm)	0.627	1.118	4601707	12/17
0 NTU	1.0	0.0	A5271 A5355	9/17 12/17
100 NTU	96.8	100.1	A5225	9/17
238.1 mV	235.2	238.1	16E100168	6/21

pressure: 738.5 mmHg temp: 18.99°C

YSI #C102009

0813 Headed to site 5

0817 Setup at 5GW29 DTW=4.11' btoc

0825 Started pumping 5GW29

0905 AS05-GW29-072017

0925 Stopped pumping 5GW29, total purge volume = 3.0 gal

1/25/17 ABL Site 5 ESTCP

0927 Started setup at 5GW30
DTW = 2.46' btoc
0929 Started pumping 5GW30
1005 ASO5-GW30-012017
1027 Stopped pumping 5GW30,
purge volume = 2.2 gal
1028 Started setup on 5GW31
DTW = 2.38' btoc
1032 Started pumping 5GW31
1110 ASO5-GW31-012017
1126 Stopped purging 5GW31, total
purge volume = 3.0 gal
1131 Headed to groundwater
treatment plant to dump
purge water
1148 Team to lunch
1250 Returned from lunch, setup
at 5GW18 DTW = 2.68' btoc
1300 Started pumping 5GW18
1415 ASO5-GW18-012017
1433 Stopped pumping 5GW18, total
purge volume = 5 gal
1451 Arrived at water treatment
plant to pack coolers

1/25/17 ABL Site 5 ESTCP
1505 Left site for fedex
1531 Dropped coolers at Fedex

Justine McCann 1/25/17

1/26/17 ABL Site 5 ESTCP

Objective: complete groundwater sampling, collect waste characterization samples.

Personnel: J. McCann/ATL, C. Conover/VBO

Weather: cloudy 45-49°F

0715 Arrived onsite, headed to groundwater treatment plant to calibrate YSI

0724 Calibrated YSI C-102008
pressure: 732.2 mmHg temp: 19.67°C

parameter	pre-cal	post-cal	lot #	exp.
DO %	96.6	96.2	—	—
pH7	7.09	7.00	6GJ707	10/18
pH4	3.90	4.00	6GE220	5/18
pH 10	9.83	9.97	6GE377	5/18
Cond. (mS/cm)	1.048	1.115	4601707	12/17
0 NTU	-1.8	0.0	A5355 A5271	12/17 9/17
100 NTU	99.9	100.0	A5275	9/17
237.5 mV	234.0	237.5	16E100608	6/21

0755 Headed to Site 5

0818 Started setup at 5GW25
DTW = 3.26 btoc

0829 Started pumping 5GW25

1/26/17 ABL Site 5 ESTCP

0915 ASO5-GW25-012017

0920 ASO5-GW25P-012017

0940 Stopped pumping 5GW25
total purge volume = 2.5 gal

0943 Setup at 5GW17 DTW = 4.82' btoc

0953 Started pumping 5GW17

(0945 ASO5-FB01-012617)

1035 ASO5-GW17-012017

1046 Finished pumping 5GW17,
total purge volume = 3.0 gal

1053 Headed to treatment
plant to pick up waste
characterization cooler
& dump purge water

1117 Team to lunch

1153 Returned from lunch, went
to water treatment plant
to get bung wrench

1214 Returned to site 5, waiting
to get gate opened

1223 Setup at 5GW13 DTW = 13.32'

1229 Started pumping 5GW13

1310 ASO5-GW13-012017

1323 Stopped pumping 5GW13, total
purge ~~v~~olume = 2.2 gal

1/26/17 ABL Site 5 ESTCP

1328 Moved up to drum staging area to collect waste characterization samples

1350	AS05-IDWA-012617

1402 C.Conover goes to borrow wrench to open drum lids from water treatment plant

1414 C.Conover returns to Site 5

1430	AS05-IDWS-012617

1441 Headed to water treatment plant to pack coolers

1529 Offsite for day

Justine McCann 1/26/17

Location: ATK Date: 2/14/17

Project / Client: Water Level

Site: Landfill

0630 Arrive onsite
ML OST
26° Clear

0730 Contact Lee Mell for Access to Landfill

	~~Open~~	Time
GW 12	~~No Open~~	21.50
GW 13	14.34	0830
SGW 29	4.49	0835
SGW 30	2.35	0836
SGW 31	2.70	0837
SGW 26	3.80	0841
SGW 27	3.55	0843
SGW 28	3.40	0844
SGW 32	2.36	0840
SGW 33	4.5	0846
SGW 25	3.80	0917
SGW 18	3.01	0915
SGW 17	5.34	0924

Location Date

Project / Client

St. Louis

Location SLCP Date 1/5/17

Project / Client ZVI Perf Mon

1145 G. Roberts + Underground Detectives on site
1200 Conduct H&S checklist
1300 ~~Begin clearing~~ Review HASP + AHA.
1330 Begin clearing investigation area
1600 Completed private Utility locate No utilities identified within investigation area
1620 G. Roberts + Underground Detectives off-site

M

Location SLCP Date 1/9/17

Project / Client 2UI Perf Monitoring

0800 G. Roberts, Z. Dellbrel + Bulldog drilling onsite
Review [illegible] tasks, HSP
AHAs + sign
0830 Begin staging gear + equipment
Weather - clear + cold, 29°F
0915 Setting up on DP-005. See borings logs
0930 Spoke to Laura regarding DP-004. Sent pictures
DP-004 is location down gradient but is adjacent to Fence w/ electric above. Driller could advance w/ low clearance rig but taking tower off would add time + cost
1150 Completed DP-005. Going to set well @ 20' bgs on shale
1520 DP-005 is set @ 20' bgs on shale
1530 move + begin advancing DP-003 See borings logs
1630 Stop for day. @ 15' bgs in DP-003

[signature]

Location SLOP Date 1/10/17

Project / Client 2UJ Perf Mon

0700 6-Roberts, 2 Delbeare + Building on site
Review + sign PTSP
Weather - Cloudy + mild 50°F
chance of rain

0734 Calibrate Multirae FA01132
Multigas part # 34L-413-4F
MFG Date = Sep-16
Lot # IAQ-413-18-10
Exp Date = 9/16/2018
ISO part # 17L-248-100
MFG Date = Dec-16
Lot #: LBG-248-100-19
Exp Date = 12/12/2020

Multi O_2 = Pass Freshair = Pass
CO = Pass
H_2S = Pass
LEL = Pass
VOCs = Pass

0810 - Collect SLOP-DP003-18-20
0830 Top of shale @ 22' bgs
Set MW @ 22' bgs
0846 allowing plugs to set in DP-003
Moving to DP-006 See boring logs

Location SLUP Date 9/16/17

Project / Client 2VI Pert Munt

1115	Completed DP-w6. TD on slate @ 27' bgs. Set well @ 27' bgs
1240	Plug set. Wait 1hr to hydrate
1300	Stop due to lightning. Brad Brink w/ USACE on site
1400	Work starts back. Decon Augers
1530	Move to grout DP-w3 + w5
1645	Field team offsite

[signature]

Location SCOP Date 9/11/17

Project / Client 2UI ~~[illegible]~~ Perf Mon.

0700 G. Roberts + Bullboggs onsite
2. Dellere onsite
complete + sign PTSP
weather = clear + cold, 38°F
Rain predicted later today
H+S Topic = Rushing

0730 Calibrate Multirae FA0132
Multi O_2 = Pass Freshair = Pass
CO = Pass
H_2S = Pass
LEL = Pass
VOCs = PASS

0800 Collect SCOP-SB001-1820
+ SCOP-SB001-1618
Cap, seal + place in cooler on
dry Ice

0930 Stake @ 27' bgs in DP-001
Set well @ 27' bgs. Boring log
on separate form

1100 Plug set in DP-001
Move to DP-002
Spoke w/ L. Clark Need 2-2 foot
samples for each analysis from
16-18. So, will need to move

Location Slcf

Date 1/11/17

Project / Client 2VI Perf Monitoring

1200 ~~Collect SLCP-SB002-1618 + SLCP-SB002-1820~~
aer + drill 2nd borings to 20'
for both DP-001 + 002
will also need to go back to
DP-003 + collect a 2nd 18-20

1305 Set DP-002 @ 25' bgs
on site. B. Brink offsite

1400 Move to grout DP-001 + 002

1700 Field team offsite

Location SCOP Date 1/12/17
Project / Client 2US Pert Monto

0730 G. Alberto, Z. Dalbrecre + Bulldog
onsite.
Review + Sign PTSP
H+S Moment = Weather
Weather = Rain Potential turning to sleet
0745 Move to Decon Augers + Rod
rigs
0800 Calibrate Multiraer FA0132
Multi = O_2 = Pass Freshair = Pass
CO = Pass
H_2S = Pass
LEL = Pass
VOCs Pass
0830 Set up on DP-004 Needed
to move fences
1200 DP-004 installed @ 25' bgs
at the top of shale. Plug
set allowing to hydrate
1400 DP-004 Complete
Z. Dalbreare to office to ship
Samples. Bulldog decomming
Augers + Dumping Decon Pad
into Drum. 1

Location STL, MO Date 1/17/17

Project / Client SLOP performance monitoring

0800 All personnel on site: Z. Dolbow/CH2M, Glynn Roberts/CH2M, Cody Cline/Bulldog, John Gates/Bulldog

weather: 33/46°F, cloudy, west wind 10-15 mph, 75% humidity,

objective: well development, sample shipment, drum housekeeping 30 gal pallet

equipment: Eco Rental (YSI quatro # FA03038, Hach 2100Q # FA03014, Huron WL meter)

0815 PTSP safety briefing; topics: slopes, drums, no rushing

0830 Water levels before development

time	well ID	water level (ft bgs)
0838	DP-001	14.05
0845	DP-002	13.62
0850	DP-003	2.82
0835	DP-004	1.85
0840	DP-005	2.78
0843	DP-006	2.50

0900 Start developing at DP-005. Collect sample SLOP-SB005-1030 in (2) 1L ambers. well pumped dry.

temp	DO	SpC	pH	Orp	turb	gal purged
12.2	8.29	0.77	6.89	144.9	183	10

910 Start developing at DP-003. Collect sample SLOP-SB003-1222 in (2) 1L ambers. well pumped dry

temp	DO	SpC	pH	Orp	turb	gal purged
14.6	8.25	0.76	6.98	140.2	664	10

0925 start developing at DP-006. collect sample SLOP-SB006-1727 in (2) 1L ambers. well pumped dry.

1/17/17

Location Stl, MO Date 1/17/17

Project / Client SLOP performance monitoring

temp	DO	SpC	pH	Orp	turb	gal. purged
13.9	3.47	0.69	7.16	178.8	404	12

0945 start developing at DP-004 collect SLOP-SB004-1525 in (2) 1L ambers. well pumped dry

temp	DO	SpC	pH	Orp	turb	gal purged
14.5	8.21	0.71	7.00	153.6	297	11

0955 start developing at DP-001. collect ~~SB~~ SLOP-SB001-1727 in (2) 1L ambers. well pumped dry.

~~0955~~ ⓔ

temp	DO	SpC	pH	Orp	turb	gal purged
15.2	2.39	0.64	7.16	-103.2	>800	7

1000 start developing at DP-002 collect SLOP-SB002-1525 in (2) 1L ambers. well pumped dry.

~~1055~~ ⓔ

temp	DO	SpC	pH	Orp	turb	gal purged
~~15~~ 15.0	2.90	0.83	7.93	-190.6	830	—

1010 finished well development activities and staged all drums at gate area. Drum count: 6 aqueous, 1 decon pad, 12 soil, 2 empty drums.

1100 Glynn Roberts off site to return equipment.

1140 Zach and Ballard off site. back to ship

11/17/16

Location St. Louis, MO Date 2/15/17

Project / Client SLOP ESTCP | NAVFAC

0820 Onsite T. Swierczek | CH2M
Weather: 36°, windy & clear
Objective: Onsite to drill 1/16" hole in each riser of temp wells DPØØ1 through DPØØ6, per Kyle Kirchner | NAVFAC.
0822 Sent Frank Frazier & Tony Bridges of 88th RSC to unlock main gate.
0825 Lone worker check-in with Glynn Roberts | CH2M.
0830 Reviewed & signed PSP. Traffic Hazards.
0835 Frank onsite & unlocked gate
0840 Begin drilling 1/16" hole on east side of riser @ DPØØ1 through DPØØ6.
0844 Completed drilling holes.
Pic 1: W. view 1/16" hole @ DPØØ2.
0848 offsite

TS

Location St. Louis, MO Date 2/28/17

Project / Client SLOP ESTCP | NAVFAC

1240 Onsite T. Swierczek | CH2M

Weather: 73°, cloudy & windy

Objective: Onsite to gauge temp wells & MW-119, collect IDW samples.

1242 Called Frank Frazier | 88th RSC to unlock gate.

1248 Frank unlocked gate

Equipment

Hand tools

Heron WLI C-1Ø3274

1250 Reviewed & signed PTSP

1251 Checked in w/ Lone Worker contact, Glynn Roberts.

1255 Began opening DPØØ1 through -ØØ6 & MW-119.

1430 Collected IDW-Ø1-Ø22817

TCLP, TCLP VOCs, pH, reactivity, flashpoint

* Drum lids from all (12) soil drums removed & representative aliquots from each homogenized in baggie. Sample for TCLP VOCs collected from Drum #11.

1450 Collected IDW-Ø2-Ø22817

TCLP, TCLP VOCs, pH, reactivity, flashpoint

* Opened all (7) aqueous IDW drums &

Rite in the Rain

Location St. Louis, MO Date 2/28/17

Project / Client SLOP ESTCP / NAVFAC

collected representative aliquots of liquid for TCLP, pH, reactivity, & flashpoint. Collected TCLP VOCs from Drum # 1.

1500 Began securing all drum lids.

1530 Gauged temp wells & MW-119

MW	(ft btoc) DTW
DP001	9.68
DP002	9.87
DP003	8.52
DP004	6.65
DP005	9.01
DP006	7.92
MW-119	4.43

* Lone worker check-in completed every hour. Offsite @ 1535

1545 Shipped samples via FedEx. Tracking # 785756091612

AS

Location: STL MO Date: 3/15/17
Project / Client: SCUP ESTCP / NAVFAC

[illegible]

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	8.5 ?
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	7.13
[illegible]	4.7

1000 Begin [illegible] + abandoning
Temp well [illegible] through out
1600 Temp wells were successfully abandoned. All PVC removed + being backfilled w/ [illegible]

Location: STL MO Date: 3/15/17
Project / Client: SCUP ESTCP/NAVFAC

Cont from page 42
Area regraded w/ skid steer + smooth out ruts. Seed has been placed + covered w/ straw.
Ruts were filled w/ topsoil prior to seeding.
Also, drive has been pressure washed to remove chips + mud.
1620 Field team offsite

M

Location St. Louis, MO Date 01/23/17

Project / Client SLOP ESTCP | NAVFAC

0900 Onsite T. Swierczek | W. Conway
Weather: 44°, windy, cloudy
Objective: Onsite to complete groundwater sampling as part of ESTCP study.
0920 Reviewed & signed HSP. Discussed cold weather & walking hazards.
* Locked gates were open upon arrival.

Equipment
Peristaltic pump: C-102741
Peristaltic pump C-102654
Heron WLI C-103274
Heron WLI C-103249
Hach 2100Q C-103166
Hach 2100Q C-103269
MultiRAE C-102457
YSI 600 C-102287
YSI 600 C-102995
* All equipment calibrated @ warehouse prior to arrival.

0930 Opened temp wells DP001 - DP006 & MW-119.
1000 Began gauging wells.

TW/MW	DTW (ft btoc)*	DTB (ft btoc)*	River Height
DP001	21.80	30	2.95
DP002	19.20	27.8	2.80

* below top of casing

Location St. Louis, MD Date 01/23/17

Project / Client SLOP ESTCP / NAVFAC

TW/MW	DTW (ft btoc)	DTB (ft btoc)	Riser Height (ft)
DP003	~~14.30~~ 5.96	25.	~~3.23~~ 3.08
DP004	4.91	27.7	2.72
DP005	10.10	23.2	3.23
DP006	7.01	29.8	2.79
MW-119	1.49	29.90	—

* Will remove PDB from MW-119 before purging

1030 Setting up @ DPØØ3

* Low-flow information recorded on separate form.

1050 Began low-flow @ DPØØ3

- Excessive drawdown; use low recovery procedure

1116 Readings, except water level, stable @ DPØØ3. CHEMETS DO: .5 mg/L

1120 Collected SLOP-TWØ3-012017

1125 Collected SLOP-TWØ3P-012017 (FD)

Analyses: VOCs 8260, Total & Dissolved metals 6010/6020, Ammonia, TOC, Anions, Alkalinity, Phosphate, Sulfide, Hardness, Methane, Ethane, Ethene, Acetylene, QuantArray, NGS

* FD collected for VOC, Total & Dissolved Metals.

1300 Setup @ MW-119

Location St. Louis, MO Date 01/23/17

Project / Client SLOP ISTLP/NAVFAC

1300 Began low-flow @ MW-119
* Low-flow data recorded on separate form.
- Excessive drawdown; used low recovery procedures
1329 Readings, except water level, stable @ MW-119.
1330 Collected SLOP-MW119-012017
1330 Collected SLOP-MW119MS-012017
1330 Collected SLOP-MW119MSD-012017
Analytes same as DP003.
* MS/MSD analyzed for VOCs, Total & Dissolved Metals.
~~1430~~ 1051 Collected SLOP-TB01-01232017
Analyses: VOCs LTB Prepped 12/28/16 @ 1051
Note: Purged 250 mL @ DP003 through biofilters.
- Purged 200 mL @ MW-119 through biofilters.
1435 Packing sample coolers & completing CoCs. MGB/Quantarray biofilters going to Microbial Insights. All others going to MicroBac.
1500 Transferred <3 gallons purge water into labelled drum.
1515 Offsite to ship samples.

[signature]

Location SLOP / SFC   Date 1-24-17   15

Project / Client SLOP / USACE

0800 on site, set up

HASP - sign

Weather, cold, P. cloudy

To sample wells

Calibrate YSI 01C2257

Cond → 1.350 → 1.413 → 1.417

DO 100 → 99.3

pH 6.93 - 7 - 7.00

ORP 237 - 220 - 220

Set up on DP005

0950 Collect SLOP-TW05-012017

Same as DP05 SLOP-TD01-012017

* Following info gleaned from low flow data recorded on separate form (J. Swierczek).

0915 Began purging @ DP005

0945 Readings @ DP005 stabilized, except water level.

* Chemets DO field test @ DP005: 6 mg/L.

1050 Began purging @ DP002

1120 ORP reading fluctuating from -430 to -460 mV, collected sample because all other parameters stable.

1125 Collected SLOP-TW02-012017 DO = ~~6 mg/L~~ 7.5 mg/L

Begin purging @ DP006 @ 1415

1441 Readings, except water level, stabilized.

1445 Collected SLOP-TW06-012017 DO = 6 mg/L

Location St. Louis, MO Date 1/25/17

Project / Client SLUF ESTCP / NAVFAC

0730 Onsite T. Swierczek

0800 Onsite W. Conway

Weather: 51° & windy

Objective: Onsite to complete groundwater sampling activities

0805 Reviewed & signed HASP. Discussed inclement weather hazards & emergency contacts.

* Equipment used today same as that used on 1/23/17.

- YSI C-102995 has not been used, yet, & was calibrated @ warehouse.

Calibrate YSI C-102287

Conductance: 1.000 mS/cm → 1.000 mS/cm

DO: 100 → 99

ORP: 220 mV → 220 mV

pH: 7.00 → 7.00

Calibration solution information:

pH 7.0: LaMotte Lot # 665707 Expires: 10/2018

ORP Zobell: Lot # 16E100608 Expires: 6/1/2021

Conductance: RICCA 1000 µS/cm Lot # 4601707 Expires: 12/2017

* Transferred calibration solutions, except Zobell, to aqueous IDW drum.

Location: St Louis, MO
Date: 01/25/17
Project / Client: [illegible] | NAVFAC

0835 Setup @ DP001
• Low-flow information recorded on separate form.
1050 Setup @ DP004
• Low-flow information recorded on separate form.
0845 Began collection of ambient blank by setting sample containers filled with distilled water on retaining wall located near temp wells. Used peristaltic pump (102741) connected to car adapter because pump will not charge. Tried to use pump on 1/23/17, but would not power on. Charged on 1/24/17, but still would not power on. Notified Rob Steelnlow.

0845 Collected ambient blank SWR-FB001-01252017 Analyses: VOCs, Total & Dissolved Metals

0950 Began purging @ DP001
1000 Readings of ORP fluctuating @ DP001 & water level continuing to drop >1 foot.
1005 Made decision to collect sample because ORP was continuing to fluctuate

between -300 & -400 mV & water level was continuing to drop.

1005 Collected SLOP-TW01-012017
Analyses: See full list in notes recorded on 1/23/17.

• CHEMETS DO field test result @ DP001 is 2 mg/L.
- Purged 250 mL through biofilters for DP001.

1035 Collected SLOP-TB01-01252017
Analyses: VOCs

1100 Began purging @ DP004
1130 Readings (except water level) stabilized @ DP004.

1135 Collected SLOP-TW04-012017
Analyses: Same as those on 1/23/17.

CHEMETS DO field test result @ DP004 is 7 mg/L.
1200 Decon-ing sampling equipment with liquinox rinse & distilled water
• Purged 250 mL through each biofilter @ DP004
1200 Site clean-up
1240 W. Conway offsite

Location St. Louis, MO Date 01/25/17

Project / Client SLDF ESTCP | NAVFAC

Drum Inventory

(12) Soil

(1) Decon Pad

(7) Aqueous

(1) Empty

1300 Packing samples

1400 Shipped coolers via FedEx priority overnight.

Tracking # 785409126179 (Microbac)

Tracking # 785409156723 (MI)

JS

Location St. Louis, MO Date 01/30/17

Project / Client SLOP ESTCP / NAVFAC

0700 Onsite T. Swierczek / CH2M
Weather: 27° & partly cloudy, breezy
Objective: Onsite to oversee surveying of temp wells & conduct slug testing on the temp wells.
* Main gate to north end of site is locked, texted Tony Briches & emailed Tony B. & Frank Frazier / 88th RSC.
0705 Frank onsite to unlock main gate
0705 Reviewed HSP
Equipment
Heron WLI C-103274
In-Situ Rugged Reader C-102742
Level Troll 700 C-102694
* Per SOP, will conduct (2) valid slug tests (rising head only) on each temp well using 1.5" x 3' solid displacement device.
* Will not conduct slug test @ MW-19 because PDB device in well for April 2017 LTM sampling. Disturbing water column during slug testing may alter April 2017 results, per discussion with Army during 1/24/17 meeting. Notified Laura Cook / CH2M.

Location St. Louis, MO Date 1/30/17
Project / Client SLOP ESTCP / NAVFAC

0755 Porsgen onsite Charlie Winston
0800 Reviewed & signed HSP; discussed traffic hazards & walking hazards.
0830 Conducted site walk with Charlie to discuss surveying scope & temp well locations.
0850 Gauge wells

MW	(ft btoc) DTW	(ft btoc) DTB	(ft btoc) Level Troll Depth
MW-119	2.46	29.90	—
DPØØ1	16.66	29.98	28
DPØØ2	13.41	27.66	25.5
DPØØ3	6.88	25.32	23
DPØØ4	5.25	27.60	25.5
DPØØ5	7.92	23.15	21
DPØØ6	6.46	29.74	27.5

*Levels gauged with WLI
-Per SOP, will conduct (2) valid rising head slug tests @ each temp well.
0915 Begin setup of slug test @ DPØØ5.
-Placed slug in well & allowed to equilibrate. Slug is just below static water level. Slug installed after Level Troll set @ 21' btoc.
0940 DTW @ DPØØ5: 7.77' ~~(static)~~

Location St. Louis, MO Date 1/30/17

Project / Client SWOC ESTCP | NAVFAC

0945 Slug in DTW @ DPØØ5 : 6.80

1000 Pangea offsite

1015 DTW @ DPØØ5 : 7.50'

- Level recovered w/in 90% of static; will begin rising head @ DPØØ5.

1016 DTW: 8.55'

1030 DTW: 8.45'

* 1036 Implementing Lone Worker because Wayne Conway/CH2M did not show up.

- Texted Glynn Roberts as PQ.

1045 DTW: 8.36'

1050 DTW: 8.34'

* DPØØ5 recovered w/in 90% of original level of 7.82'. Ended Test 1.

1052 Installed slug @ DPØØ5 for Test 2.

1052 DTW w/ slug in: 7.28'

1105 DTW: 7.48'

1109 - Level w/in 90% of original DTW; begin Test 2 rising head @ DPØØ5.

1109 DTW: 8.55'

* Decomned slug

1136 Lone Worker check-in.

1145 DTW: 8.32'

* Level w/in 90%; ended Test 2.

Location St. Louis, MO Date 1/30/17

Project / Client SLOP ESTCP / NAVFAC

* Deconnect Level Troll
1155 Installed Level Troll & Slug @ DPØØ2. DTW before install: 13.13'
1157 Slug in DTW @ DPØØ2: 12.14'
1212 DTW: 12.18'
Ambient temp: 47°
1222 DTW: 12.18'
* DPØØ2 recovered w/in 90% of original level. Begin rising head Test 1.
1224 DTW @ DPØØ2: 13.30'
1236 Lone Worker check-in
1259 DTW: 13.19'
* Ended Test 1 @ DPØØ2 b/c level w/in 90% of level before Troll & slug install.
1302 Installed slug @ DPØØ2 for Test 2
1303 Slug-in DTW: 12.12'
1328 DTW: 12.14'
* Begin Test 2 b/c level w/in 90% of level before Test 1 (13.13')
* DPØØ2 recovered w/in 90% of level prior to Test 1; Begin Test 2.
1331 DTW @ DPØØ2: 13.30'
* Deconnect slug
~~1352~~ 1406 DTW: 13.17'

Location St. Louis MO Date 1/30/17

Project / Client SLUDGE ESTCP/NAVFAC

1400 Lone Worker check-in

* Ended Test 2 @ DPφφ2 b/c level w/in 90% of level before Test 1 (13.13')

* Deconned Level Troll.

1409 DTW @ DPφφ1 before install of Level Troll & slug: 16.25'

1410 Slug-in DTW: 15.14'

1435 DTW: 15.44'

* Begin Test 1 @ DPφφ1 b/c level is w/in 90% of level recorded @ 1409 before Troll & slug install.

1440 DTW @ DPφφ1: 16.58'

1515 DTW: 16.32'

1515 Lone Worker check-in

* Ended Test 1 @ DPφφ1 (w/in 90%)

1516 Installed slug @ DPφφ1 for Test 2.

Slug-in DTW: 15.20'

1541 Slug-in DTW: 15.43'

* Begin Test 2 @ DPφφ1 b/c level is w/in 90% of level recorded @ 1409.

1542 DTW @ DPφφ1: 16.52'

1617 DTW: 16.29'

1600 Lone Worker check-in

* Ended Test 2 @ DPφφ1 (w/in 90%)

Location St. Louis, MO Date 1/30/17

Project / Client SLDP ESTCP | NAVFAC

* Deconned Level Troll
Pic 1: N. view_ Drive befor entrance to N. end of site.
Pic 2: W. view_ Drive @ N. end of site
Pic 3: NW view_ Rig trucks to area of ESTCP temp wells.
Pic 4: W view_ As above
Pic 5: NW view_ As above
Pic 6: E. view_ Portable fencing along N. end of site.
Pic 7: W view_ As above
Pic 8: W. view_ Slug test @ DP005
Pic 9: W. view_ Slug test @ DP001.
1630 Offsite

QS

Location St. Louis, MO Date 1/31/17

Project / Client SLDP ESTCP / NAVFAC

0700 Onsite T. Swierczek / CH2M
0702 Lone Worker check-in with Glynn Roberts.
Weather: 47° & windy
Objective: Onsite to complete slug testing @ DPØØ3, DPØØ4, & DPØØ6.
0705 Opened slug testing wells
0710 Reviewed & Signed HSP. Reviewed emergency contacts & hospital route.

Equipment
Heron WLI C-103274
In-Situ RuggedReader C-102742
Level Troll 700 C-102694
*Per SOP, will conduct (2) valid rising head tests on each well using 3' x 1.5" dia. solid displacement slug.
0800 DTW @ DPØØ4: 3.27' btoc
0802 Installed Level Troll @ 25.5' btoc
0804 Installed slug just below water table.
0808 Slug-in DTW: 3.74'
0813 Lone Worker check-in.
0833 Slug-in DTW: 3.89'
0845 Slug-in DTW: 3.94'
0913 Lone Worker check-in

Location St. Louis, MO Date 1/31/17

Project / Client SLDP ESTCP / NAVFAC

0915 Slug-in DTW: 4.05'
* Water level @ DPØØ4 still has not recovered to w/in 90% of static level.
0920 Texted Lauren Cook / CH2M regarding slow recovery @ DPØØ4. She will contact Kyle Kirchner / NAVFAC to discuss.
0948 Slug-in DTW: 4.16'
1002 Lauren Cook has not received response from Kyle Kirchner, yet. Suggested abandoning test @ DPØØ4 & moving to another location. Will collect (1) more water level @ DPØØ4 before moving to next location.
1009 Slug-in DTW: 4.23'
* Removed slug & deconned
* Removed Level troll & deconned
1015 Setup @ DPØØ3
1015 DTW @ DPØØ3: 6.99' btoc
* Installed Level Troll @ 23' btoc
1020 Installed slug below water table
1022 Slug-in DTW: 5.42
1024 Lone Worker check-in
1030 Lauren Cook called; Kyle said we

Location St. Louis, MO Date 1/31/17

Project / Client SLOP ESTCP / NAVFAC

can run falling head test @ DPØØ4 if entire well screen & sandpack is submerged. As this is the case @ DPØØ4, will go back to DPØØ4 later to conduct falling head.

1036 Slug-in DTW @ DPØØ3: 5.54'

* Unable to do falling head test using Level Troll @ DPØØ3 because slug was installed before response received from Kyle Kirchner; slow recovery @ DPØØ3.

1058 Slug-in DTW: 5.64'

1116 DTW @ DPØØ4: 5.72'

* Based on slow recovery @ DPØØ4 & DPØØ3, will conduct falling head test @ DPØØ6. Well screen & sandpack are entirely submerged. If falling head results indicate 90% recovery to static, & time allowing, will conduct rising head @ DPØØ6.

1120 DTW @ DPØØ6: 6.55'

Equipment for DPØØ6

1.5" dia. x 5' solid displacement slug

Heron WLI C-103250

RuggedReader C-102728

Level Troll 700 C-102552

Location St. Louis, MO Date 1/31/17

Project / Client SLOF ESTCP | NAVFAC

1126 Install Level Troll @ 27.5' bgs @ DPØØ6
1127 Lone Worker check-in.
1130 Level Troll-in DTW: 6.28' @ DPØØ6
1132 DTW @ DPØØ3: 5.75' (slug-in)
1140 DTW (Level Troll-in) @ DPØØ6: 6.31'
1152 DTW (Level Troll-in) @ DPØØ6: 6.33'
* DTW @ DPØØ6 w/in 90% of static level.
1157 Begin Falling Head Test @ DPØØ6 by placing slug just beneath static level quickly.
1200 DTW @ DPØØ6: 4.48' (falling head)
1201 DTW @ DPØØ3 (slug-in): 5.84'
1204 Ambient temp: 48° & windy
1223 Lone Worker check-in.
1249 DTW @ DPØØ3 (slug-in): 5.96'
1251 DTW @ DPØØ6: 5.21'
1302 Someone is taking video of the sidewalk along Stratford Ave. He went into residence located @ 6329 Stratford. I attempted to make contact, but he left when I approached.
1309 DTW @ DPØØ6: 5.39'
1313 Texted Laura Cook about conducting only (1) falling head test @ DPØØ6, given

Location St. Louis MO Date 1/31/17

Project / Client SLDP ESTCP/NAVFAC

the time left in the day. She agreed with
this approach.
1329 Lone Worker check-in
1335 DTW @ DPØØ3 (slug-in): 6.05'
1410 DTW @ DPØØ3 (slug-in): 6.12'
1411 DTW @ DPØØ6 (falling head): 5.80'
1424 Lone Worker check-in
* Water level @ DPØØ3 has not reached
90% of static water level. Made decision
to disconnect RuggedReader from Level
Troll & leave that & slug in place to allow
water level to equilibrate overnight. Placed
J-plug on well & covered with bucket.
Will perform rising head @ DPØØ3 tomorrow.
1432 DTW @ DPØØ6 (falling head): 5.90'
1450 DTW @ DPØØ6 (falling head): 5.97'
* Water level @ DPØØ6 w/in 90% of static
level; ended Falling Head Test.
* Removed slug & Level Troll; deconned.
1500 DTW @ DPØØ4: 5.53'
1502 Installed Level Troll @ 25.5'
1505 Installed 1.5" dia. x 5' solid displacement
device below static water level.
* Similar to DPØØ3, the Level Troll & slug

Location St. Louis, MO Date 1/31/17
Project / Client SLOP ESTCP / NAVFAC

will remain in well @ DPØØ4 until level
equilibrates overnight to conduct rising
head test tomorrow morning. Secured
plug on well & placed bucket on top to
prevent potential rain from entering.
1510 DTW @ DPØØ4 (slug-in): 3.19'
1518 Lone Worker checking out
Pic 1: E. view_Slug-in @ DPØØ4
Pic 2: NE view_Slug-in @ DPØØ3
Pic 3: S view_Setting up @ DPØØ6
Pic 4: S view_Falling head @ DPØØ6
Pic 5: SE view_Secured DPØØ3 w/ Level
Troll & slug-in.
Pic 6: E. view_Secured DPØØ4 w/ Level
Troll & slug-in.
1530 Offsite

AS

Location St. Louis, MO Date 2/1/17
Project / Client SLDP ESTCP | NAVFAC

0710 Onsite T. Swierczek | CH2M
Weather: 39° & cloudy, calm
Objective: Onsite to complete rising head tests @ DPØØ3 & DPØØ4.
0715 Removed buckets & j-plugs from DPØØ3 & DPØØ4.
0720 Reviewed & signed FTSP; established contact with Glynn Roberts | Lone Worker point of contact.
0730 Static water levels on 1/31/17 @ DPØØ3 = 6.99' btoc & DPØØ4 = 5.27' btoc.

Equipment @ DPØØ4
Heron WLI C-103250
Rugged Reader C-102728
Level Troll 700 C-102552
1.5" dia. x 5' solid displacement device.

Equipment @ DPØØ3
Heron WLI C-103274
Rugged Reader C-102742
Level Troll 700 C-102694
1.5" dia. x 3' solid displacement device

0734 Wells, Level Trolls, slugs have not been tampered with (locked gate) & are still @ their proper depths.

Location St. Louis, MO Date 2/1/17

Project / Client SLOP ESTCP / NAVFAC

0740 Gauging DPØØ3 & DPØØ4

MW	DTW (ft btoc) (slug-in)
DPØØ3	7.04
DPØØ4	5.20

* Wells have recovered to w/in 90% of static levels on 1/31/17. Will proceed with rising head tests.

0742 Begin rising head test @ DPØØ3.

0743 DTW @ DPØØ3: 8.35'

0745 Begin rising head test @ DPØØ4

0747 DTW @ DPØØ4: 7.22'

0820 Lone Worker check-in

0916 DTW @ DPØØ3: 8.10'

0917 DTW @ DPØØ4: 6.80'

0920 Lone Worker check-in

*Based on my calculations, it may take 6-6.5 hours for the wells to recover to near static water levels (1345-1415).

1020 Lone Worker check-in

1109 Ambient temp: 43° & cloudy

1115 DTW @ DPØØ3: 7.90'

1116 DTW @ DPØØ4: 6.44'

1120 Lone Worker check-in

1221 Lone Worker check-in

Location St. Louis, MO Date 2/1/17

Project / Client SLOP ESTCP / NAVFAC

1316 DTW @ DPΦΦ3: 7.72'
1317 DTW @ DPΦΦ4: 6.16'
1320 Lone Worker check-in
1420 Lone Worker check-in
1422 DTW @ DPΦΦ3: 7.66'
1423 DTW @ DPΦΦ4: 6.05'
1435 Deconned both solid displacement devices.
* Water level @ DPΦΦ3 w/in 90% of static level, but will continue to run test because ~~DΦΦ~~ DPΦΦ4 level still not w/in 90% of static.
1454 Contacted Laura Cook about length of time to achieve 90% of static @ DPΦΦ4, because it will likely be well past dark before 90% of static is achieved.
1510 ~~Laura~~ Laura Cook is going to contact Kyle Kirchner / NAVFAC to discuss above issue.
1514 Laura left message w/ Kyle that test will end before dusk, to stay in compliance w/ HASP & Site Security Plan.
1517 Laura received concurrence from Kyle re: ending test before it gets dark.

Location St. Louis, MO Date 2/1/17

Project / Client SLOP ESTCP | NAVFAC

1519 Lone Worker check-in

1521 DTW @ DP003: 7.62'

1522 DTW @ DP004: 5.96'

1525 Ended rising head test @ DP003 b/c levels w/in 90% of static level.

1534 Deconned Level Troll & cable from DP003.

1600 DTW @ DP004: 5.94'

* End rising head test @ DP004 b/c the daylight is fading & the traffic on Stratford & Goodfellow is picking up (area known for errant drivers).

1605 Deconned Level Troll & cable from DP004.

1610 Lone Worker check-out

1611 Offsite

DS

Location St. Louis, MO Date 2/8/17
Project / Client SLOP ESTCP | NAVFAC

0700 Onsite T. Swierczek | CH2M
Weather: 34° cloudy & windy
Objective: Onsite to collect a round of water levels from ESTCP temp wells & MW-119.
0705 Reviewed & signed PTSP. Traffic hazards & walking hazards. Will remain aware of surroundings when driving & walking.
Equipment
Heron water level indicator C-103274
0715 Opened temp wells & MW-119
* Will return to site later in the day to gauge wells (slow recharge).
0725 Offsite
1350 Onsite T. Swierczek | CH2M
Weather: 32° & light snow (began @ 1345)

MW	DTW (ft btoc)
MW-119	3.21
DPØØ1	12.13
DPØØ2	10.25
DPØØ3	7.69
DPØØ4	5.68
DPØØ5	8.46

Location St. Louis, MO Date 2/8/17

Project / Client SLOP ESTCP / NAVFAC

MW	DTW (ft btoc)
DP046	7.20

* No pressure observed @ any of the wells when j-plugs removed @ 0715

Pic 1. & South view looking toward MW-119 & treatment zone.

1440 Offsite

Location St. Louis, MO Date 3/8/17

Project / Client SLDF ESTLP | NAVFAC

0800 Onsite T. Swierczek | CH2M
Weather: 43° & sunny
Objective: Onsite to gauge temp wells & MW-119.
0805 Reviewed & signed PTSP. Implemented Lone Worker; Glynn Roberts is check-in contact.
0810 Lone Worker check-in
0812 Began opening DPØØ1 through DPØØ6 & MW-119. Will allow wells to equilibrate before gauging.

Equipment
Hand tools
Heron WLI C-1Ø3274
0915 Began gauging wells

MW	DTW (ft. btoc)
DPØØ1	10.01
DPØØ2	11.59
DPØØ3	8.51
DPØØ4	5.47
DPØØ5	8.78
DPØØ6	7.39
MW-119	4.40

0930 Offsite

Appendix C
Boring Logs

ABL

ch2m		Location No.	5GW26
		Sheet 1 of 1	

Project No:	670338	Easting (AMG)	2152101.176	Equipment:	Rotosonic Geoprobe 8140LS
Project:	ABL	Northing (AMG)	385694.6185	Contractor:	SAEDACCO
Site:	Site 5	Elevation (ft AHD):	675.74	Logged By:	J. McCann
Date:	1/19/2017	Water Level (ft BTOC):	NM	Project Manager:	Laura Cook
Weather:	cloudy, 43° F	Final Depth (ft BGL):	22'	Checked By:	Laura Cook

Depth (ft)	Sample: Sample Interval	Sample: Recovery No./Type	Soil Description (soil type, plasticity/grain size, colour, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odour, side collapse, etc.)
5.0	0-7'	3.5' 1/sonic	0-0.9': Gravel from access road 0.9-7': sandy SILT (ML), brown, moist, med. Stiff, low plasticity, cohesive, massive	
10.0 15.0	7-17'	5.0' 2/sonic	7.0-9.6 - silty coarse SAND (SM), brown, wet, loose, massive 9.6-17: rounded COBBLES with sand and silt, wet, loose, massive	
20.0	17-22'	3.7' 3/sonic	17-19.2' - same as above 19.2-22' - weathered SHALE and silt	
			REFUSAL at 22' bgs	

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

ch2m		Location No. 5GW27
		Sheet 1 of 1

Project No:	670338	Easting (AMG)	2152104.392	Equipment:	Rotosonic Geoprobe 8140LS
Project:	ABL	Northing (AMG)	385708.9519	Contractor:	SAEDACCO
Site:	Site 5	Elevation (ft AHD):	674.82	Logged By:	J. McCann
Date:	1/17/2017	Water Level (ft BTOC):	NM	Project Manager:	Laura Cook
Weather:	rainy, 35°F	Final Depth (ft BGL):	22'	Checked By:	Laura Cook

Depth (m)	Sample Interval	Recovery No./Type	Soil Description (soil type, plasticity/grain size, colour, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odour, side collapse, etc.)
5.0	0-7'	4.2' 1/sonic	0-15.0': sandy SILT (ML), damp, brown, medium stiff, low plasticity, cohesive, massive	
10.0 15.0	7-17'	3.4' 2/sonic	15.0-16.7' - coarse SAND with silt (SM), very firm, brown, med. stiff, loose, cohesive, massive, wet 16.7-17.0' - SAA w/ cobbles, rock stuck at bottom	
20.0	17-22'	5.0' 3/sonic	17.0-19.0' - same as above, rounded cobbles growing larger and more frequent 19.0-22.0' - SHALE bedrock partially weathered, dark grey	
			REFUSAL at 22' bgs	

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

		Location No.	5GW28
ch2m		Sheet 1 of 1	

Project No:	670338	Easting (ABLCS)	2152105.249	Equipment:	Rotosonic Geoprobe 8140LS
Project:	ABL	Northing (ABLCS)	385714.4654	Contractor:	SAEDACCO
Site:	Site 5	Elevation (FT AMSL):	674.63	Logged By:	J. McCann
Date:	1/17/2017	Water Level (FT BTOC):	NM	Project Manager:	Laura Cook
Weather:	rainy, 35°F	Final Depth (FT BGL):	20'	Checked By:	Laura Cook

Depth (ft)	Sample Interval	Recovery No./Type	Soil Description (soil type, plasticity/grain size, color, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odor, side collapse, etc.)
5.0	0-7'	5.5' 1/sonic	0-7.0': Sandy SILT (ML), brown, dry to moist, stiff, low plasticity, cohesive, massive	
10.0 15.0	7-17'	6.6' 2/sonic	7.0-17.0' - Silty SAND (SW), brown, coarsening downward to cobbles at 13' bgs, med loose to loose, cohesive to noncohesive, massive	
20.0	17-22'	5.0' 3/sonic	17.0-19.0' - same as above, rounded cobbles growing larger and more frequent	
			REFUSAL at 20' bgs	

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

ch2m

Location No.	5GW29
Sheet 1 of 1	

Project No:	670338	Easting (ABLCS)	2152167.757	Equipment:	Rotosonic Geoprobe 8140LS
Project:	ABL	Northing (ABLCS)	385686.6107	Contractor:	SAEDACCO
Site:	Site 5	Elevation (FT AMSL):	677.32	Logged By:	J. McCann
Date:	1/17/2017	Water Level (FT BTOC):	NM	Project Manager:	Laura Cook
Weather:		Final Depth (FT BGL):	22'	Checked By:	Laura Cook

Depth (ft)	Sample Interval	Recovery No./Type	Soil Description (soil type, plasticity/grain size, color, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odor, side collapse, etc.)
5.0	0-7'	No Recovery 1/sonic	Some pieces of gravel from access road, no soil recovery	
10.0 15.0	7-17'	6.3' 2/sonic	7.0-14.3' - Sandy SILT (ML), brown, moist, med. stiff, low plasticity, cohesive, massive, transition 14.3-15.7' - Silty SAND (SM), brown, loose, wet, cohesive, massive 15.7-17.0' - Gravel (GW) with sand and silt, brown, wet, loose, massive	
20.0	17-22'	5.0' 3/sonic	17.0-20.6' - same as above 20.6-22' - Weathered SHALE bedrock, dark gray to black	
			REFUSAL at 22' bgs	

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

ch2m

Location No. 5GW30

Sheet 1 of 1

Project No:	670338	Easting (ABLCS)	2152169.008	Equipment:	Rotosonic Geoprobe 8140LS
Project:	ABL	Northing (ABLCS)	385700.516	Contractor:	SAEDACCO
Site:	Site 5	Elevation (FT AMSL):	674.98	Logged By:	J. McCann
Date:	1/18/2017	Water Level (FT BTOC):	NM	Project Manager:	Laura Cook
Weather:		Final Depth (FT BGL):	19'	Checked By:	Laura Cook

Depth (ft)	Sample Interval	Recovery No./Type	Soil Description (soil type, plasticity/grain size, colour, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odour, side collapse, etc.)
5.0	0-7'	3.9' 1/sonic	0-7.0' - Sandy SILT (ML), brown, moist, med stiff, low plasticity, cohesive, massive	
10.0 15.0	7-17'	4.4' 2/sonic	7.0-16.6' - Same as above, sand coarsening and becoming more abundant silty SAND (SM) 16.6-17.0' - COBBLE zone	
	17-19'	3.4' 3/sonic	17.0-18.6' - Silty GRAVEL (GM), rounded cobbles, well sorted, brown 18.6-19.0' - SHALE bedrock, weathered, dark gray	
			REFUSAL at 19' bgs	

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

ch2m		Location No.	5GW31
		Sheet 1 of 1	

Project No:	670338	Easting (ABLCS)	2152170.237	Equipment:	Rotosonic Geoprobe 8140LS
Project:	ABL	Northing (ABLCS)	385705.9236	Contractor:	SAEDACCO
Site:	Site 5	Elevation (FT AMSL):	674.82	Logged By:	J. McCann
Date:	1/18/2017	Water Level (FT BTOC):	NM	Project Manager:	Laura Cook
Weather:	Cloudy 48° F	Final Depth (FT BGL):	19'	Checked By:	Laura Cook

Depth (ft)	Sample Interval	Recovery No./Type	Soil Description (soil type, plasticity/grain size, colour, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odor, side collapse, etc.)
5.0	0-7'	4.4' 1/sonic	0-7.0' - Sandy SILT (ML), brown, moist to wet, med stiff, low plasticity, cohesive, massive	
10.0 15.0	7-17'	7.0' 2/sonic	7.0-14.0' - Same as above, transitioning to coarse silty SAND (SM) at 13' bgs 14.0-17.0' - COBBLE zone with increasing cobbles downward	
	17-19'	1.9' 3/sonic	17.0-19.0' - Same silty COBBLES as above, transitioning to weathered SHALE bedrock at 18.3' bgs	
			REFUSAL at 19' bgs	

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

ch2m		Location No. 5GW32
		Sheet 1 of 1

Project No:	670338	Easting (ABLCS)	2152233.727	Equipment:	Rotosonic Geoprobe 8140LS
Project:	ABL	Northing (ABLCS)	385688.1578	Contractor:	SAEDACCO
Site:	Site 5	Elevation (FT AMSL):	676.49	Logged By:	J. McCann
Date:	1/18/2017	Water Level (FT BTOC):	NM	Project Manager:	Laura Cook
Weather:	Cloudy 48º F	Final Depth (FT BGL):	11'	Checked By:	Laura Cook

Depth	Sample		Soil Description	Comments/Well Installation Details
(ft)	Sample Interval	Recovery No./Type	(soil type, plasticity/grain size, colour, secondary/minor components)	(fill/natural soil, visual contamination, odor, side collapse, etc.)
5.0	0-8'	4.0' 1/sonic	0-8.0' - Sandy SILT (ML) with cobbles, brown, moist to wet, med stiff to very stiff, low plasticity, cohesive, massive	
10.0	8-11'	3.7' 2/sonic	8.0-10.0' - silty GRAVEL (GW), brown, wet, loose, massive 10.0-11.0' - Weathered SHALE bedrock	
			REFUSAL at 11' bgs	

Notes
NM - not measured
FT BTOC - feet below top of casing
ABLCS - ABL coordinate system, see survey report
FT BGS - feet below ground surface

Location No.	**5GW33**		
Sheet **1** of **1**			

Project No:	670338	Easting (ABLCS)	2152049.125	Equipment:	Rotosonic Geoprobe 8140LS
Project:	ABL	Northing (ABLCS)	385700.13	Contractor:	SAEDACCO
Site:	Site 5	Elevation (ft amsl):	676.07	Logged By:	J. McCann
Date:	1/19/2017	Water Level (FT BTOC):	NM	Project Manager:	Laura Cook
Weather:	Cloudy 43 °F	Final Depth (FT BGL):	21.5'	Checked By:	Laura Cook

Depth	**Sample**		**Soil Description**	**Comments/Well Installation Details**
(ft)	**Sample Interval**	**Recovery No./Type**	(soil type, plasticity/grain size, colour, secondary/minor components)	(fill/natural soil, visual contamination, odor, side collapse, etc.)
5.0	0-7'	1.3' 1/sonic	0-7.0' - sandy SILT (ML), brown, dry to moist, med stiff, low plasticity, cohesive, massive	
10.0	8-12.3'	6.8' 2/sonic	8.0-12.3' - Same as above	
15.0	12.3-17'		12.3-17.0' - silty GRAVEL (GW), brown, wet, loose, massive	
20.0	17-21.5'	4.9' 3/sonic	17.0-18.9' - Same as above 18.9-21.5' - Weathered dark gray SHALE, massive	
			REFUSAL at 21.5' bgs	

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

St. Louis

Location No. DP-001

Sheet 1 of 1

Project No:	670338	Easting (SPCS)	886653.23	Equipment:	HSA 4" ID; CME SSO Truck
Project:	ESTCP Long Term ZVI Performance	Northing (SPCS)	1042976.9	Contractor:	Bulldog Drilling
Site:	St. Louis Ordnance Depot OU1	Elevation (ft amsl):	548.81	Logged By:	G. Roberts
Date:	1/11/2017	Water Level (ft BTOC):	NM	Project Manager:	Laura Cook
Weather:	Clear and cold 38˚ F	Final Depth (ft BGL):	30.0'	Checked By:	Laura Cook

Depth (ft)	Sample Interval	Sample Recovery No./Type	PID (ppm)	Soil Description (soil type, plasticity/grain size, colour, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odour, side collapse, etc.)
5.0	0-5'	4.0' No. 1	0 ppm	0-1.0' - Dark Brown lean CLAY (CL) with silt, moist, soft 1.0-4.0' - Brown lean CLAY (CL) with silt, moist, firm, iron flakes, mixed, iron staining	
10.0	5-10'	4.5' No. 2	0 ppm	4.0-16.0' - Gray lean CLAY (CL) with silt, moist, firm, iron flakes, mixed, iron staining	
15.0	10-15'	1' No. 3	0 ppm		10-15' - tree material in shoe
20.0	15-20'	5' No. 4	0 ppm		Sample collected from 16-18' and 18-20'
25.0	20-25'	5' No. 5	0 ppm	16.0-24.0' - same as above, less iron staining 24.0-26.0' - Light brown lean CLAY (CL), less silt, more moisture, more firm	
30.0	25-30'	5' No. 6	0 ppm	26.0-27.0' - same as above, yellow/gray 27.0-30.0' - Yellow/gray SHALE	
				REFUSAL at 30' bgs	Well set from 17-23'

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

		Location No.	**DP-002**
		Sheet **1** of **1**	

Project No:	**670338**	Easting (SPCS)	886632.75	Equipment:	HSA 4" ID; CME SSO Truck
Project:	**ESTCP Long Term ZVI Performance**	Northing (SPCS)	1042958.69	Contractor:	Bulldog Drilling
Site:	**St. Louis Ordnance Depot**	Elevation (ft amsl):	546.7	Logged By:	G. Roberts
Date:	1/11/2017	Water Level (ft BTOC):		Project Manager:	Laura Cook
Weather:	Clear and cold 38˚ F	Final Depth (ft BGL):	26.0'	Checked By:	Laura Cook

Depth (ft)	Sample Interval	Recovery No./Type	PID (ppm)	Soil Description (soil type, plasticity/grain size, colour, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odour, side collapse, etc.)
5.0	0-5'	4.0' No. 1	0 ppm	0-0.5' - (CL) dark brown lean CLAY with silt, moist, soft 0.5-4.0' - Brown lean CLAY (CL) with silt, moist, firm, mixed, iron staining, abundant iron shavings from soil mixing	
10.0	5-10'	1.0' No. 2	0 ppm	4.0-10.0' - same as above, gray	
15.0	10-15'	1' No. 3	0 ppm		Pushed twice with little recovery; possibly woody make
20.0	15-20'	2.5' No. 4	0 ppm	10.0-20.0' - same as above, less silt, more staining	Sample collected from 16-18' and 18-20'
25.0	20-25'	1.5' No. 5	0 ppm	20.0-25.0' - same as above, increasing brown component	Augers to 25'
26.0	25-26'	1' No. 6	0 ppm	25.0-26.0' - Brown SHALE	
				REFUSAL at 26'	Well set at 25'

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

ch2m

Location No.	DP-003
Sheet 1 of 1	

Project No:	670338	Easting (SPCS)	886611.11	Equipment:	HSA 4" ID; CME SSO Truck
Project:	ESTCP Long Term ZVI Performance	Northing (SPCS)	1042954.56	Contractor:	Bulldog Drilling
Site:	St. Louis Ordnance Depot	Elevation (ft amsl):	546.09	Logged By:	G. Roberts
Date:	1/9/2017	Water Level (ft BTOC):	NM	Project Manager:	Laura Cook
Weather:	Clear and Cold 29˚ F	Final Depth (ft BGL):	25.0'	Checked By:	Laura Cook

Depth (ft)	Sample Interval	Recovery No./Type	PID (ppm)	Soil Description (soil type, plasticity/grain size, colour, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odour, side collapse, etc.)
5.0	0-5'	4.0' No. 1	0 ppm	0-1.0' - (ML) Dark Brown SILT, moist, firm 1.0-2.0' - Brown SILT (ML), moist, firm, moderate iron staining 4.0-6.0' - same as above, less iron staining	
10.0	5-10'	5.0' No. 2	0 ppm	6.0-8.0' - Grey/yellow SILT (ML), moist, firm, abundant iron staining 8.0-9.0' - same as above, less iron staining (minimal)	
15.0	10-15'	5' No. 3	0 ppm	9.0-12.5' - same as above, iron staining 12.5-14.0' - same as above, less iron staining	
20.0	15-20'	5' No. 4	0 ppm	14.0-20.0' - Brown SILT (ML), moist, firm, iron staining	Sample collected from 18-20'
25.0	20-25'	5' No. 4	0 ppm	20.0-22.0' - Brown lean CLAY (CL) with abundant silt, moist, firm 22.0-25.0' - brown SHALE	
				REFUSAL at 25'	Well screen from 12-22' bgs

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

ch2m		**Location No.** DP-004
		Sheet **1** of **1**

Project No:	670338	Easting (SPCS)	886670.26	Equipment:	HSA 4" ID; CME SSO Truck
Project:	ESTCP Long Term ZVI Performance	Northing (SPCS)	1942981.91	Contractor:	Bulldog Drilling
Site:	St. Louis Ordnance Depot	Elevation (ft amsl):	540.63	Logged By:	G. Roberts
Date:	1/11/2017	Water Level (ft BTOC):	NM	Project Manager:	Laura Cook
Weather:	Clear and cold 38˚ F	Final Depth (ft BGL):	25.0'	Checked By:	Laura Cook

Depth (ft)	Sample Interval	Recovery No./Type	PID (ppm)	Soil Description (soil type, plasticity/grain size, color, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odor, side collapse, etc.)
5.0	0-5'	3.5' No. 1	0 ppm	0-0.5' - Dark Brown lean CLAY (CL) with silt, moist, soft 0.5-3.5' - Brown SILT (ML), moist, soft, iron staining 3.5-6.0' - Gray/yellow SILT (ML), moist, firm, iron staining	0.5' at top of mixing tube
10.0	5-10'	5' No. 2	0 ppm	6.0-8.0' - same as above, less iron staining 8.0-10.0' - same as above, more iron staining	
15.0	10-15'	5' No. 3	0 ppm		
20.0	15-20'	5' No. 4	0 ppm	10.0-23.0' - Brown SILT (ML) with clay, moist, firm, moderate iron staining	Sample collected from 18-20'
25.0	20-25'	5' No. 5	0 ppm	23.0-25.0' - Gray/yellow lean CLAY (CL) with silt, moist, stiff, brown shale at 25'	hard drilling at 23'

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

ch2m		Location No. DP-005
		Sheet 1 of 1

Project No:	670338	Easting (SPCS)	886614.64	Equipment:	HSA 4" ID; CME SSO Truck
Project:	ESTCP Long Term ZVI Performance	Northing (SPCS)	1042974.66	Contractor:	Bulldog Drilling
Site:	St. Louis Ordnance Depot	Elevation (FT AMSL):	545.87	Logged By:	G. Roberts
Date:	1/9/2017	Water Level (ft BTOC):	NM	Project Manager:	Laura Cook
Weather:	Clear and Cold 29˚ F	Final Depth (FT BGL):	30.0'	Checked By:	

Depth (ft)	Sample Interval	Recovery No./Type	PID (ppm)	Soil Description (soil type, plasticity/grain size, color, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odor, side collapse, etc.)
5.0	0-5'	5' No. 1	0 ppm	0-0.5' - Hard concrete (3") with approximately 3" of coarse gravel underneath 0.5-2.0' - Brown lean CLAY (CL), moist, firm 2.0-3.0' - White gravelly fill	0.5' at top of mixing tube
10.0	5-10'	5' No. 2	0 ppm	3.0-4.0' - Dark brown lean CLAY (CL), moist, firm 4.0-9.0' - Brown lean CLAY (CL), moist, stiff, iron staining	
15.0	10-15'	5' No. 3	0 ppm	9.0-13.0' - yellow/gray SILT (ML), moist, firm 13.0-14.0' - same as above, less iron staining	
20.0	15-20'	5' No. 4	0 ppm	14.0-18.0' - same as above, more iron staining 18.0-20.0' - Brown lean CLAY (CL), moist, stiff, iron staining	Sample collected from 18-20'
25.0	20-25'	5' No. 5	0 ppm	20.0-24.0' - redish SHALE, moist	hard drilling around 20' (1000psi)
30.0	25-30'	5' No. 6	0 ppm	24.0-30.0' - yellow/brown SHALE, moist	

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

ch2m

				Location No.	**DP-006**
				Sheet **1** of	**1**
Project No:	670338	Easting (SPCS)	886662.02	Equipment:	HSA 4" ID; CME SSO Truck
Project:	ESTCP Long Term ZVI Performance	Northing (SPCS)	1092942.28	Contractor:	Bulldog Drilling
Site:	St. Louis Ordnance Depot	Elevation (FT AMSL):	543.81	Logged By:	G. Roberts
Date:	1/10/2017	Water Level (ft BTOC):	NM	Project Manager:	Laura Cook
Weather:	Cloudy and Mild 50˚ F	Final Depth (ft BGL):	28.3'	Checked By:	Laura Cook

Depth (ft)	Sample: Sample Interval	Sample: Recovery No./Type	PID (ppm)	Soil Description (soil type, plasticity/grain size, color, secondary/minor components)	Comments/Well Installation Details (fill/natural soil, visual contamination, odor, side collapse, etc.)
	0-5'	4' No. 1	0 ppm	0.0-0.5' - 6 inches of concrete 0.5-1.0' - Brown lean CLAY (CL) with iron staining, moist, firm 1.0-1.5' - Coarse gravel fill	
5.0	5-10'	5' No. 2	0 ppm	1.5-6.0' - Gray SILT (ML) with clay, moist, firm, no iron staining 6.0-9.0' - Same as above, abundant iron staining	
10.0	10-15'	5' No. 3	0 ppm	9.0-12.0' - Same as above, iron staining, less clay, moist 12.0-13.0' - Same as above, moderate iron staining	
15.0	15-20'	5' No. 4	0 ppm	13.0-24.0' - Brown SILT (ML), moist, firm, iron staining	
20.0	20-25'	5' No. 5	0 ppm		
25.0	25-28.3'	3.3' No. 6	0 ppm	24.0-27.0' - Brown lean CLAY (CL), moist, very stiff 27.0-28.0' - Brown SHALE 28.0-28.3' - Yellow/brown SHALE	Well screen at 17-27' hard drilling around 27'

Notes

NM - not measured

FT BTOC - feet below top of casing

ABLCS - ABL coordinate system, see survey report

FT BGS - feet below ground surface

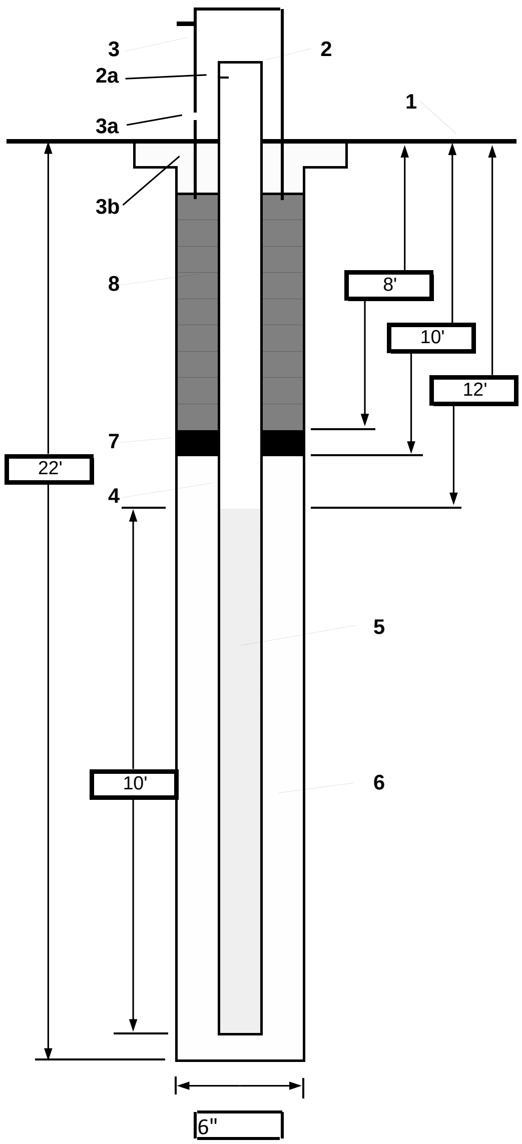
Appendix D
Well Construction Diagrams

ABL

PROJECT NUMBER	WELL NUMBER
670338	5GW26 SHEET 1 OF 1

WELL COMPLETION DIAGRAM

PROJECT : ABL Site 5 LOCATION : Rocket Center, WV
DRILLING CONTRACTOR : SAEDACCO
DRILLING METHOD AND EQUIPMENT USED : Rotosonic Geoprobe 8140LS
WATER LEVELS : START : 1258 1/19/17 END : 1323 1/19/17 LOGGER : J. McCann



1- Ground elevation at well: ####

2- Top of casing elevation: ####
a) vent hole?: No

3- Wellhead protection cover type: Stickup
a) weep hole?: No
b) concrete pad dimensions: 2' x 2'

4- Dia./type of well casing: 2" Schedule 40 PVC

5- Type/slot size of screen: 0.010" PVC

6- Type screen filter: Filter Media #2 Sand
a) Quantity used: 5 - 0.5 cubic ft bags

7- Type of seal: Pel-plug Bentonite
a) Quantity used: 1 Bucket

8- Grout
a) Grout mix used: Dry Bag Type I Portland
b) Method of placement: Poured from Top
c) Vol. of well casing grout: N/A

Development method: Pump until stable with Hurrican Pump

Development time: 55 minutes

Estimated purge volume: 110 gallons

Comments: Final Field Parameters during well development:

Turbidity	36.1
pH	6.62
Conductivity	0.77
Temperature	NM

PROJECT NUMBER	WELL NUMBER
670338	5GW27 SHEET 1 OF 1

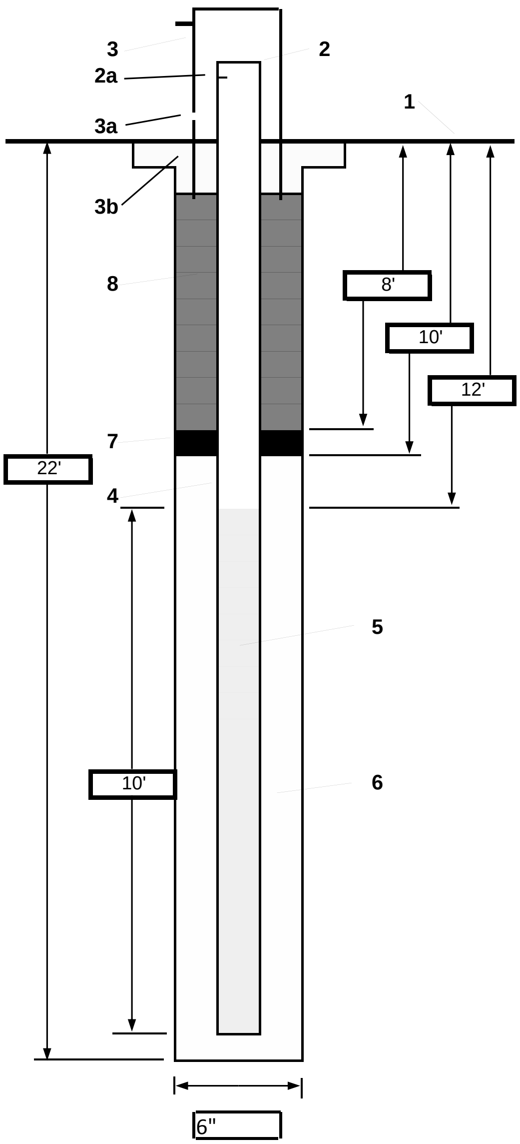
WELL COMPLETION DIAGRAM

PROJECT : ABL Site 5 LOCATION : Rocket Center, WV

DRILLING CONTRACTOR : SAEDACCO

DRILLING METHOD AND EQUIPMENT USED : Rotosonic Geoprobe 8140LS

WATER LEVELS : START : 1228 1/17/17 END : 1250 1/17/17 LOGGER : J. McCann



1- Ground elevation at well: ####

2- Top of casing elevation: ####
a) vent hole? No

3- Wellhead protection cover type: Stickup
a) weep hole? No
b) concrete pad dimensions: 2' x 2'

4- Dia./type of well casing: 2" Schedule 40 PVC

5- Type/slot size of screen: 0.010" PVC

6- Type screen filter: Filter Media #2 Sand
a) Quantity used: 5 - 0.5 cubic ft bags

7- Type of seal: Pel-plug Bentonite
a) Quantity used: 1 Bucket

8- Grout
a) Grout mix used: 1.5 - 94lb. Dry Bag Type I Portland, 4.25 gal water, ~40 gal
b) Method of placement: Tremie
c) Vol. of well casing grout: 20 gal

Development method: Pump until stable with Hurrican Pump

Development time: 57 minutes

Estimated purge volume: 115 gal

Comments: Final Field Parameters during well development:

Turbidity	9
pH	7.17
Conductivity	0.53
Temperature	12.9

PROJECT NUMBER	WELL NUMBER
670338	5GW28 SHEET 1 OF 1

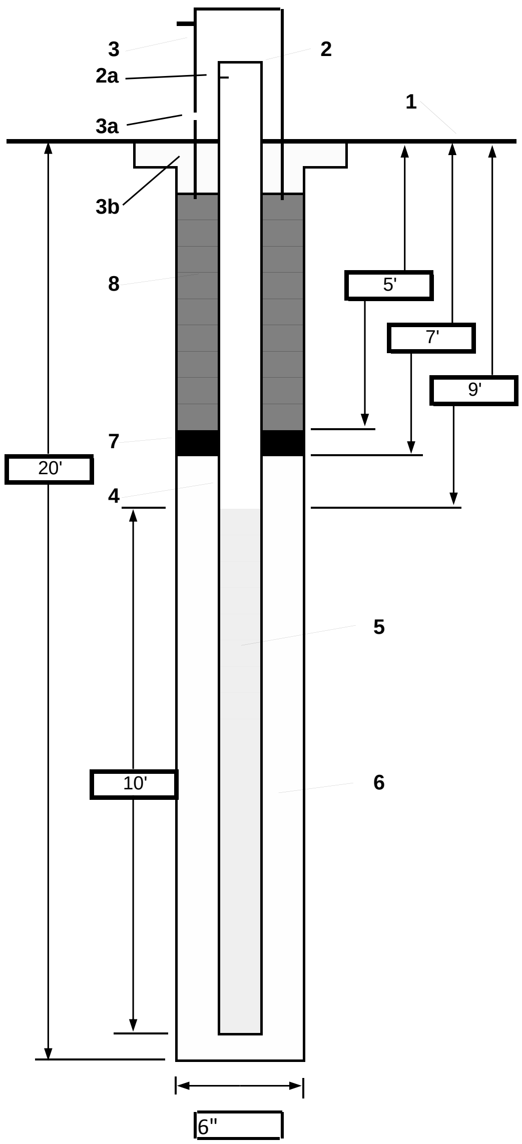
WELL COMPLETION DIAGRAM

PROJECT : ABL Site 5 LOCATION : Rocket Center, WV

DRILLING CONTRACTOR : SAEDACCO

DRILLING METHOD AND EQUIPMENT USED : Rotosonic Geoprobe 8140LS

WATER LEVELS : START : 1600 1/17/17 END : 1635 1/17/17 LOGGER : J. McCann



1- Ground elevation at well	####
2- Top of casing elevation	####
a) vent hole?	No
3- Wellhead protection cover type	Stickup
a) weep hole?	No
b) concrete pad dimensions	2' x 2'
4- Dia./type of well casing	2" Schedule 40 PVC
5- Type/slot size of screen	0.010" PVC
6- Type screen filter	Filter Media #2 Sand
a) Quantity used	6.5 - 0.5 cubic ft bags
7- Type of seal	Pel-plug Bentonite
a) Quantity used	3/4 Bucket
8- Grout	
a) Grout mix used	1.5 - 94lb. Dry Bag Type I Portland, 4.25 gal water, ~40 gal
b) Method of placement	Tremie
c) Vol. of well casing grout	10 gal
Development method	Pump until stable with Hurrican Pump
Development time	54 minutes
Estimated purge volume	125 gal

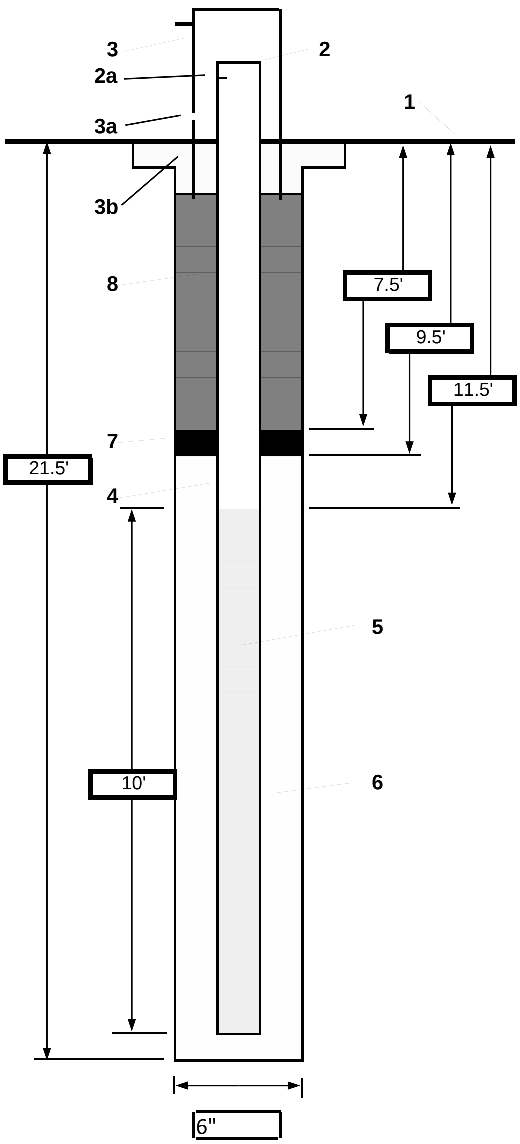
Comments Final Field Parameters during well development:

Turbidity	3.4
pH	7.16
Conductivity	0.54
Temperature	NM

PROJECT NUMBER	WELL NUMBER
670338	5GW29 SHEET 1 OF 1

WELL COMPLETION DIAGRAM

PROJECT : ABL Site 5 LOCATION : Rocket Center, WV
DRILLING CONTRACTOR : SAEDACCO
DRILLING METHOD AND EQUIPMENT USED : Rotosonic Geoprobe 8140LS
WATER LEVELS : START : 1508 1/19/17 END : 1540 1/19/17 LOGGER : J. McCann



1- Ground elevation at well ####

2- Top of casing elevation ####
a) vent hole? No

3- Wellhead protection cover type Stickup
a) weep hole? No
b) concrete pad dimensions 2' x 2'

4- Dia./type of well casing 2" Schedule 40 PVC

5- Type/slot size of screen 0.010" PVC

6- Type screen filter Filter Media #2 Sand
a) Quantity used 5 - 0.5 cubic ft bags

7- Type of seal Pel-plug Bentonite
a) Quantity used 1 Bucket

8- Grout
a) Grout mix used 0.5 - 94lb. Dry Bag Type I Portland Cement
b) Method of placement Poured from top
c) Vol. of well casing grout N/A

Development method Pump until stable with Hurrican Pump

Development time 59 minutes

Estimated purge volume 110 gal

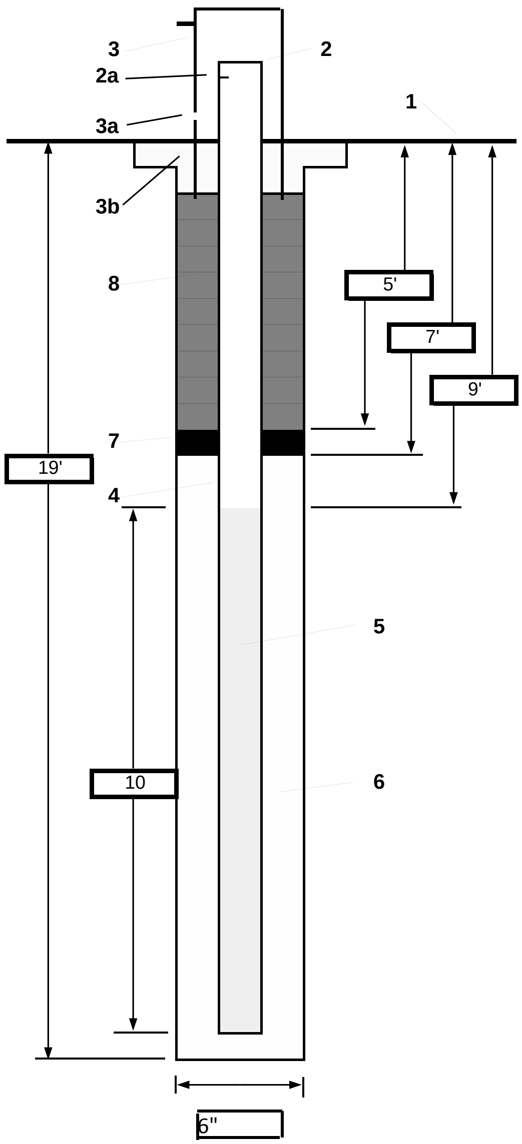
Comments Final Field Parameters during well development:

Turbidity	294
pH	6.35
Conductivity	1.08
Temperature	NM

PROJECT NUMBER	WELL NUMBER
670338	5GW30 SHEET 1 OF 1

WELL COMPLETION DIAGRAM

PROJECT : ABL Site 5 LOCATION : Rocket Center, WV
DRILLING CONTRACTOR : SAEDACCO
DRILLING METHOD AND EQUIPMENT USED : Rotosonic Geoprobe 8140LS
WATER LEVELS : START : 0934 1/18/17 END : 1007 1/18/17 LOGGER : J. McCann



1- Ground elevation at well: ####

2- Top of casing elevation: ####
a) vent hole? No

3- Wellhead protection cover type: Stickup
a) weep hole? No
b) concrete pad dimensions: 2' x 2'

4- Dia./type of well casing: 2" Schedule 40 PVC

5- Type/slot size of screen: 0.010" PVC

6- Type screen filter: Filter Media #2 Sand
a) Quantity used: 5 - 0.5 cubic ft bags

7- Type of seal: Pel-plug Bentonite
a) Quantity used: 1 Bucket

8- Grout
a) Grout mix used: 0.5 - 94lb. Dry Bag Type I Portland mixed w/ GW
b) Method of placement: Poured from top
c) Vol. of well casing grout: N/A

Development method: Pump until stable with Hurrican Pump

Development time: 55 minutes

Estimated purge volume: 110 gal

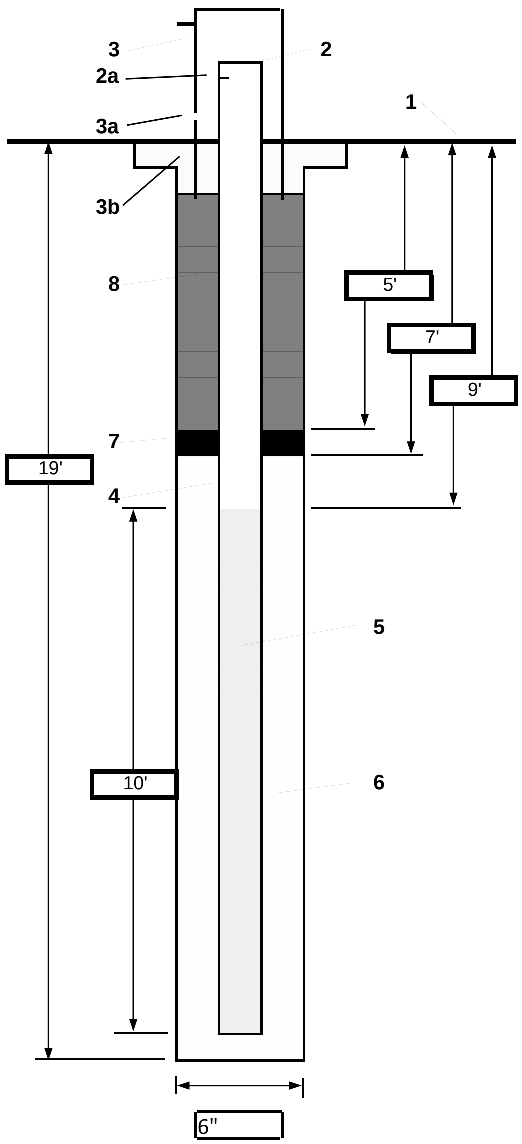
Comments: Final Field Parameters during well development:

Turbidity	9.4
pH	6.73
Conductivity	0.69
Temperature	NM

PROJECT NUMBER	WELL NUMBER
670338	5GW31 SHEET 1 OF 1

WELL COMPLETION DIAGRAM

PROJECT : ABL Site 5 LOCATION : Rocket Center, WV
DRILLING CONTRACTOR : SAEDACCO
DRILLING METHOD AND EQUIPMENT USED : Rotosonic Geoprobe 8140LS
WATER LEVELS : START : 1148 1/18/17 END : 1213 1/18/17 LOGGER : J. McCann



1- Ground elevation at well	####
2- Top of casing elevation	####
a) vent hole?	No
3- Wellhead protection cover type	Stickup
a) weep hole?	No
b) concrete pad dimensions	2' x 2'
4- Dia./type of well casing	2" Schedule 40 PVC
5- Type/slot size of screen	0.010" PVC
6- Type screen filter	Filter Media #2 Sand
a) Quantity used	5 - 0.5 cubic ft bags
7- Type of seal	Pel-plug Bentonite
a) Quantity used	1 Bucket
8- Grout	
a) Grout mix used	0.5 - 94lb. Dry Bag Type I Portland mixed w/ GW
b) Method of placement	Poured from top
c) Vol. of well casing grout	N/A
Development method	Pump until stable with Hurrican Pump
Development time	52 minutes
Estimated purge volume	110 gal

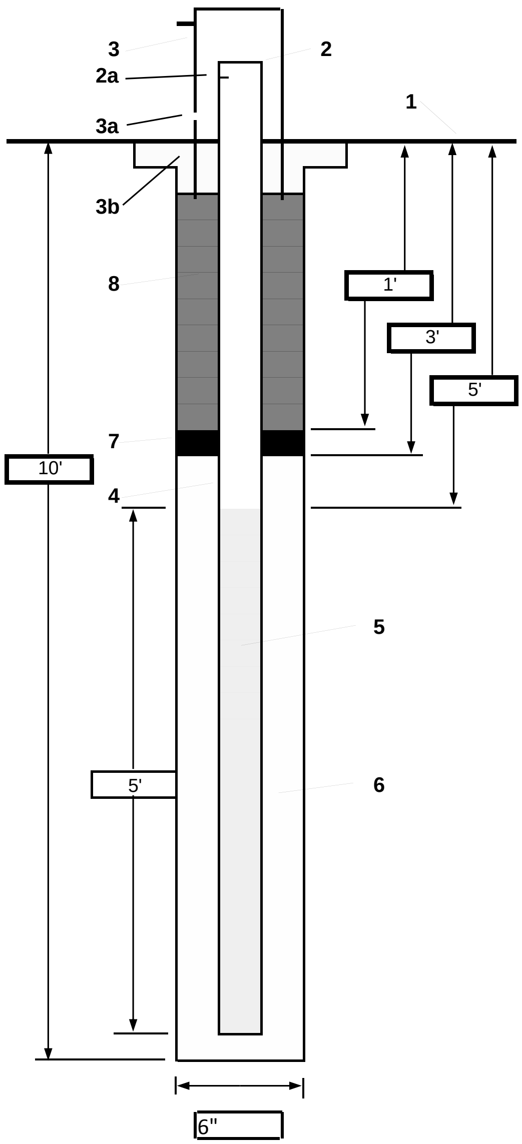
Comments Final Field Parameters during well development:

Turbidity	25.6
pH	6.67
Conductivity	0.68
Temperature	NM

PROJECT NUMBER	WELL NUMBER
670338	5GW32 SHEET 1 OF 1

WELL COMPLETION DIAGRAM

PROJECT : ABL Site 5 LOCATION : Rocket Center, WV
DRILLING CONTRACTOR : SAEDACCO
DRILLING METHOD AND EQUIPMENT USED : Rotosonic Geoprobe 8140LS
WATER LEVELS : START : 1556 1/18/17 END : 1622 1/18/17 LOGGER : J. McCann



1- Ground elevation at well: ####

2- Top of casing elevation: ####
a) vent hole?: No

3- Wellhead protection cover type: Stickup
a) weep hole?: No
b) concrete pad dimensions: 2' x 2'

4- Dia./type of well casing: 2" Schedule 40 PVC

5- Type/slot size of screen: 0.010" PVC

6- Type screen filter: Filter Media #2 Sand
a) Quantity used: 2.5 - 0.5 cubic ft bags

7- Type of seal: Pel-plug Bentonite
a) Quantity used: 1 Bucket

8- Grout
a) Grout mix used: Quikrete Concrete Mix from pad
b) Method of placement: Poured from top
c) Vol. of well casing grout: N/A

Development method: Pump until stable with Hurrican Pump

Development time: 2 hours 8 minutes

Estimated purge volume: 108 gal

Comments: Final Field Parameters during well development:

Turbidity	28.7
pH	6.73
Conductivity	0.92
Temperature	NM

PROJECT NUMBER	WELL NUMBER
670338	5GW33 SHEET 1 OF 1

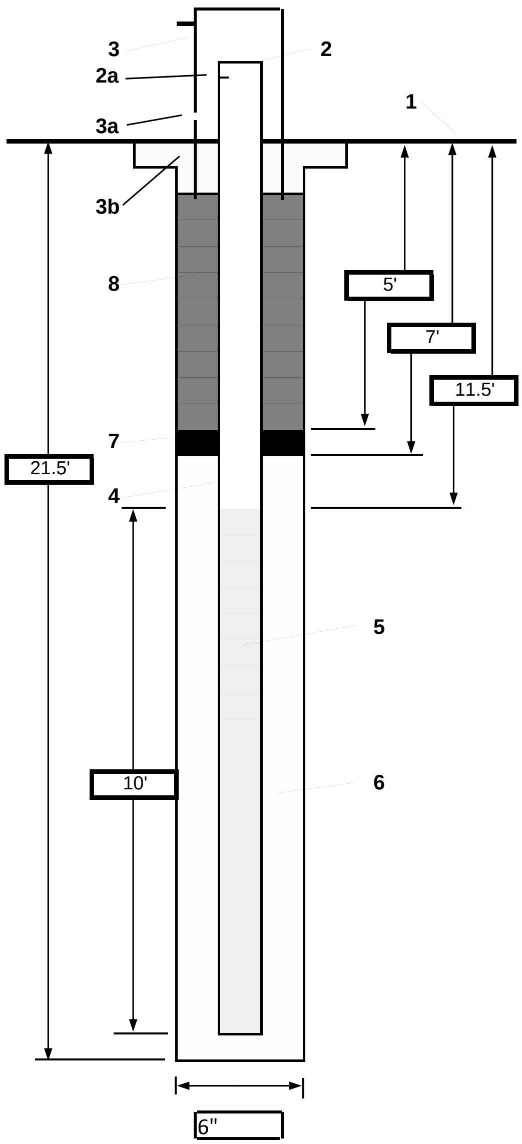
WELL COMPLETION DIAGRAM

PROJECT : ABL Site 5 LOCATION : Rocket Center, WV

DRILLING CONTRACTOR : SAEDACCO

DRILLING METHOD AND EQUIPMENT USED : Rotosonic Geoprobe 8140LS

WATER LEVELS : START : 0923 1/19/17 END : 0952 1/19/17 LOGGER : J. McCann



1- Ground elevation at well	####
2- Top of casing elevation	####
a) vent hole?	No
3- Wellhead protection cover type	Stickup
a) weep hole?	No
b) concrete pad dimensions	2' x 2'
4- Dia./type of well casing	2" Schedule 40 PVC
5- Type/slot size of screen	0.010" PVC
6- Type screen filter	Filter Media #2 Sand
a) Quantity used	5.5 - 0.5 cubic ft bags
7- Type of seal	Pel-plug Bentonite
a) Quantity used	1 Bucket
8- Grout	
a) Grout mix used	0.5 bags dry portland mixed w/ GW
b) Method of placement	Poured from top
c) Vol. of well casing grout	N/A
Development method	Pump until stable with Hurrican Pump
Development time	56 minutes
Estimated purge volume	115 gal

Comments Final Field Parameters during well development:

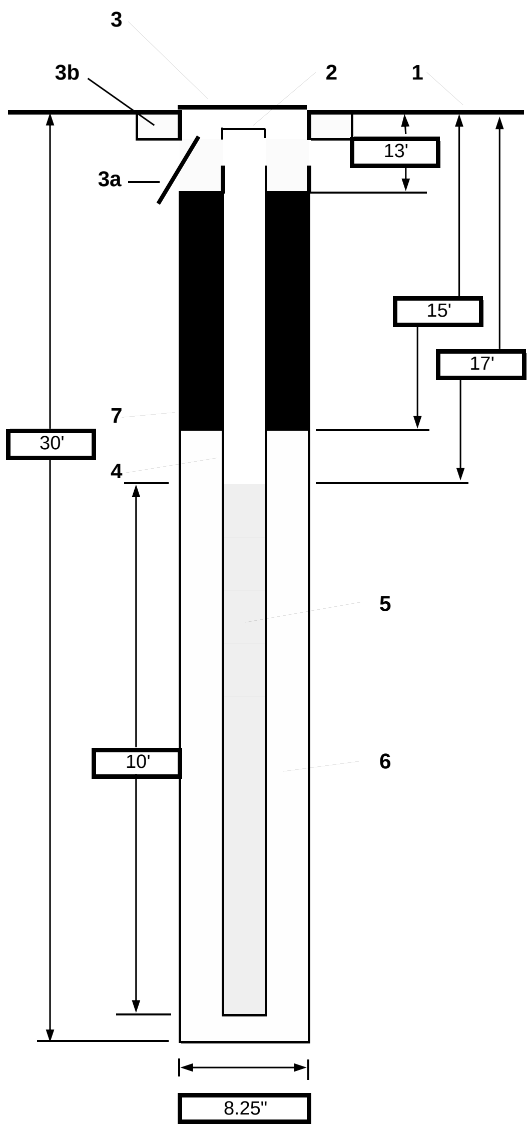
Turbidity	41.8
pH	6.25
Conductivity	0.61
Temperature	NM

St. Louis

PROJECT NUMBER	WELL NUMBER
680338	DP-001 SHEET 1 OF 1

WELL COMPLETION DIAGRAM

PROJECT : St. Louis Ordnance Depot OU1 LOCATION : St. Louis, MO
DRILLING CONTRACTOR : Bulldog Drilling
DRILLING METHOD AND EQUIPMENT USED : HAS 4" ID; CME SSO
WATER LEVELS : 14.05' bgs START : 1/11/17 END : 1/11/17 LOGGER : Z. Dolbeare/G. Roberts



1-	Ground elevation at well	540.59
2-	Top of casing elevation	543.81
3-	Wellhead protection cover type	N/A
	a) drain tube?	N/A
	b) concrete pad dimensions	N/A
4-	Dia./type of well casing	2" PVC Stickup
5-	Type/slot size of screen	0.010" slot
6-	Type screen filter	#2 Quartz filter sand
	a) Quantity used	6 - 50 lb bags
7-	Type of seal	3/8" sodium bentonite chips
	a) Quantity used	2 - 50 lb bags, 10 gallons water

Development method Surge and Purge

Development time 1/17/17 0955

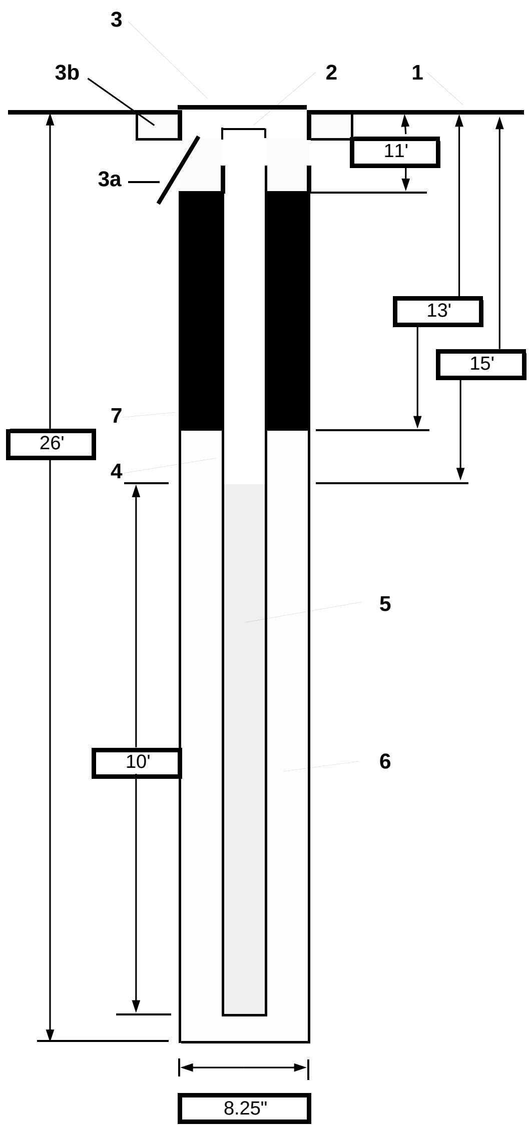
Estimated purge volume 7 gallons

Comments High solids, bentonite grains above seal to surface

PROJECT NUMBER	WELL NUMBER
680338	DP-002 SHEET 1 OF 1

WELL COMPLETION DIAGRAM

PROJECT : St. Louis Ordnance Depot OU1 LOCATION : St. Louis, MO
DRILLING CONTRACTOR : Bulldog Drilling
DRILLING METHOD AND EQUIPMENT USED : HAS 4" ID; CME SSO
WATER LEVELS : 18.62' bgs START : 1/11/17 END :1410 1/11/17 LOGGER : Z. Dolbeare/G. Roberts



1- Ground elevation at well	543.8
2- Top of casing elevation	546.7
3- Wellhead protection cover type	N/A
a) drain tube?	N/A
b) concrete pad dimensions	N/A
4- Dia./type of well casing	2" PVC Stickup
5- Type/slot size of screen	0.010" slot
6- Type screen filter	#2 Quartz filter sand
a) Quantity used	6 - 50 lb bags
7- Type of seal	3/8" sodium bentonite chips
a) Quantity used	2 - 50 lb bags, 10 gallons water
Development method	Surge and Purge
Development time	1/17/17 0955
Estimated purge volume	

Comments High solids, bentonite grout above seal to surface

PROJECT NUMBER	WELL NUMBER
680338	DP-003 SHEET 1 OF 1

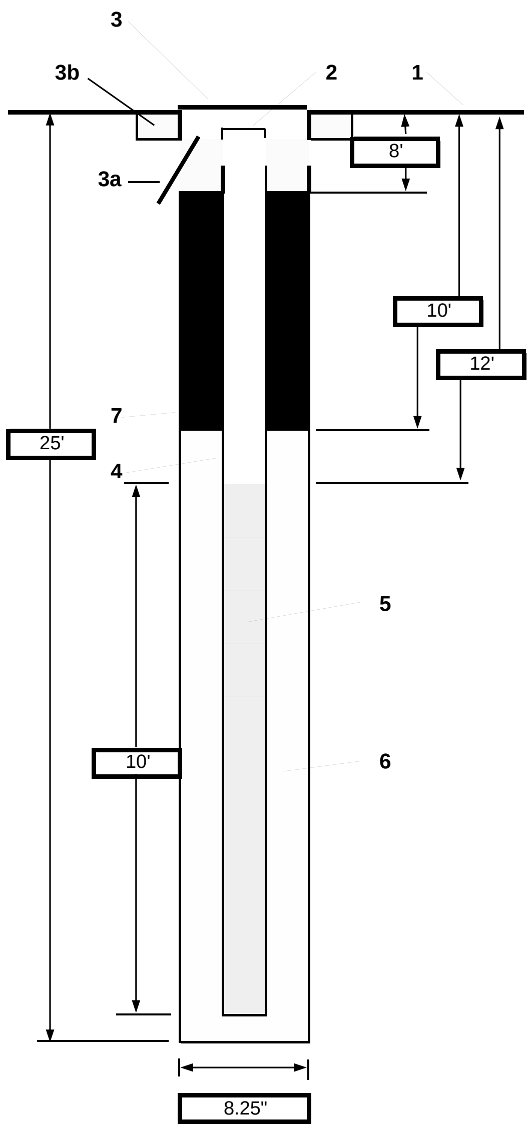
WELL COMPLETION DIAGRAM

PROJECT : St. Louis Ordnance Depot OU1 LOCATION : St. Louis, MO

DRILLING CONTRACTOR : Bulldog Drilling

DRILLING METHOD AND EQUIPMENT USED : HAS 4" ID; CME SSO

WATER LEVELS : 2.82' bgs START : 1/9/17 END :1410 1/9/17 LOGGER : Z. Dolbeare/G. Roberts



1- Ground elevation at well: 543.13

2- Top of casing elevation: 546.09

3- Wellhead protection cover type: N/A
- a) drain tube?: N/A
- b) concrete pad dimensions: N/A

4- Dia./type of well casing: 2" PVC Stickup

5- Type/slot size of screen: 0.010" slot

6- Type screen filter: #2 Quartz filter sand
- a) Quantity used: 7 - 50 lb bags

7- Type of seal: 3/8" sodium bentonite chips
- a) Quantity used: 1 - 50 lb bag, 10 gallons water

Development method: Surge and Purge

Development time: 1/17/17 1000

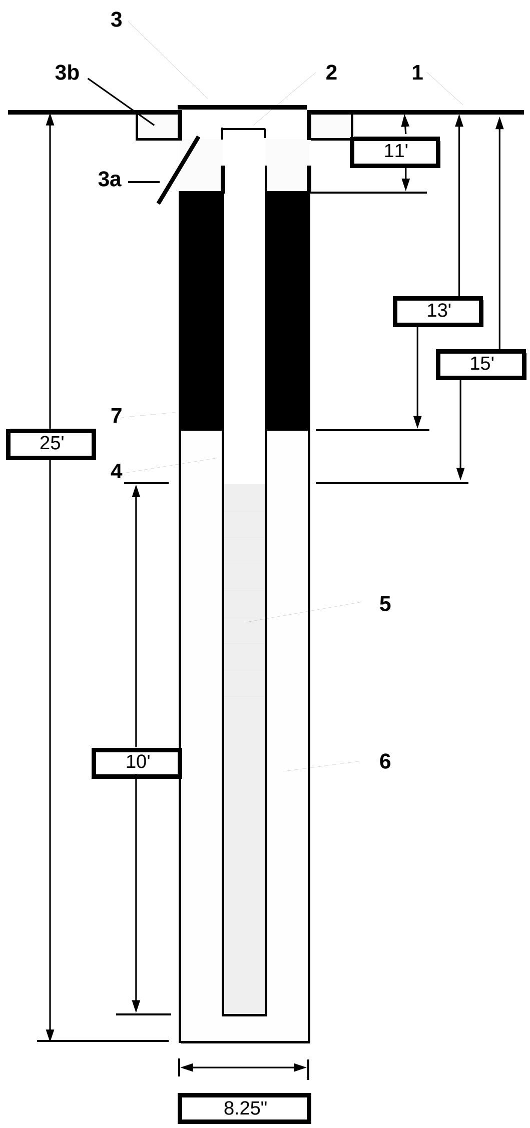
Estimated purge volume: 12 gallons

Comments: High solids, bentonite grout above seal to surface

PROJECT NUMBER	WELL NUMBER
680338	DP-004 SHEET 1 OF 1

WELL COMPLETION DIAGRAM

PROJECT : St. Louis Ordnance Depot OU1 LOCATION : St. Louis, MO
DRILLING CONTRACTOR : Bulldog Drilling
DRILLING METHOD AND EQUIPMENT USED : HAS 4" ID; CME SSO
WATER LEVELS : 1.85' bgs START : 1200 1/12/17 END :1400 1/12/17 LOGGER : Z. Dolbeare/G. Roberts



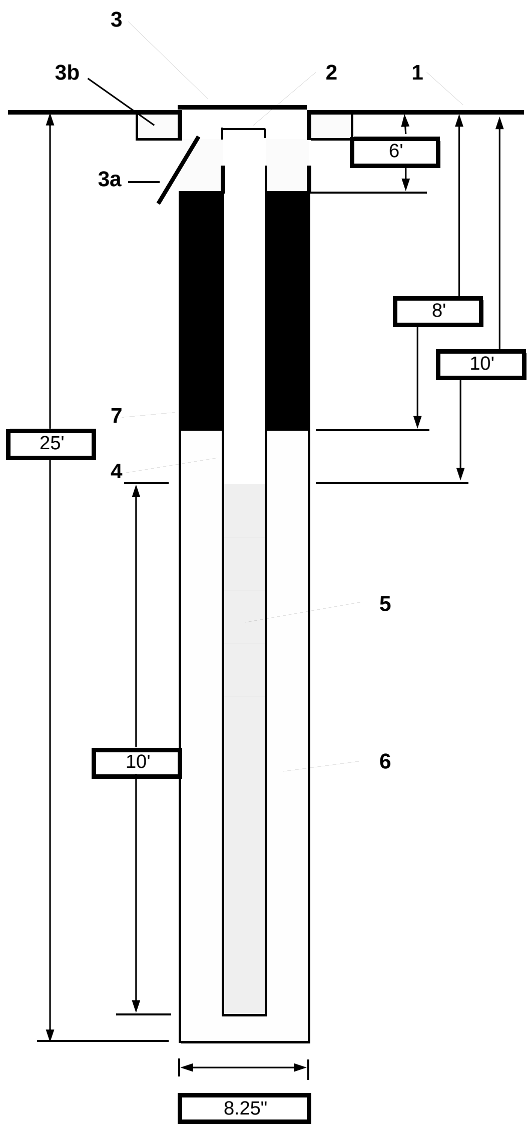
1- Ground elevation at well: 537.69
2- Top of casing elevation: 540.63
3- Wellhead protection cover type: N/A
a) drain tube?: N/A
b) concrete pad dimensions: N/A
4- Dia./type of well casing: 2" PVC Stickup
5- Type/slot size of screen: 0.010" slot
6- Type screen filter: #2 Quartz filter sand
a) Quantity used: 6 - 50 lb bags
7- Type of seal: 3/8" sodium bentonite chips
a) Quantity used: 1 - 50 lb bag, 10 gallons water

Development method: Surge and Purge
Development time: 1/17/17 0945
Estimated purge volume: 11 gallons
Comments: High solids, bentonite grout above seal to surface

PROJECT NUMBER	WELL NUMBER
680338	DP-005 SHEET 1 OF 1

WELL COMPLETION DIAGRAM

PROJECT : St. Louis Ordnance Depot OU1 LOCATION : St. Louis, MO
DRILLING CONTRACTOR : Bulldog Drilling
DRILLING METHOD AND EQUIPMENT USED : HAS 4" ID; CME SSO
WATER LEVELS : 2.78' bgs START : 1/9/17 END :1520 1/9/17 LOGGER : Z. Dolbeare/G. Roberts



1- Ground elevation at well: 542.52

2- Top of casing elevation: 545.87

3- Wellhead protection cover type: N/A
a) drain tube?: N/A
b) concrete pad dimensions: N/A

4- Dia./type of well casing: 2" PVC Stickup

5- Type/slot size of screen: 0.010" slot

6- Type screen filter: #2 Quartz filter sand
a) Quantity used: 9 - 50 lb bags

7- Type of seal: 3/8" sodium bentonite chips
a) Quantity used: 1 - 50 lb bag, 10 gallons water

Development method: Surge and Purge

Development time: 1/17/17 0900

Estimated purge volume: 10 gallons

Comments: High solids, bentonite grout above seal to surface

PROJECT NUMBER	WELL NUMBER
680338	DP-006 SHEET 1 OF 1

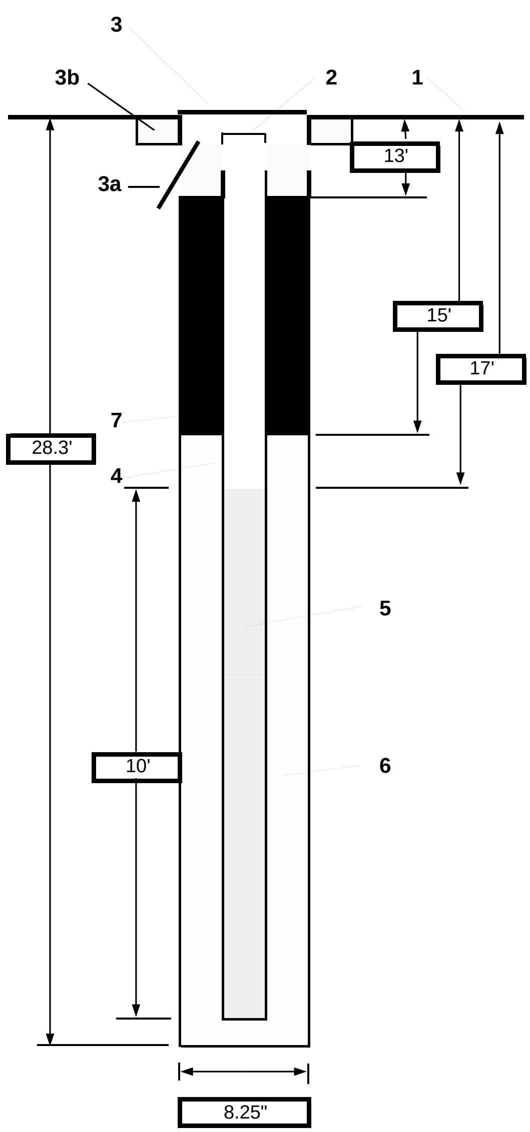
WELL COMPLETION DIAGRAM

PROJECT : St. Louis Ordnance Depot OU1 LOCATION : St. Louis, MO

DRILLING CONTRACTOR : Bulldog Drilling

DRILLING METHOD AND EQUIPMENT USED : HAS 4" ID; CME SSO

WATER LEVELS : 2.50' bgs START : 1/10/17 END 1240 1/10/17 LOGGER : Z. Dolbeare/G. Roberts



1- Ground elevation at well: 540.99

2- Top of casing elevation: 543.81

3- Wellhead protection cover type: N/A
- a) drain tube?: N/A
- b) concrete pad dimensions: N/A

4- Dia./type of well casing: 2" PVC Stickup

5- Type/slot size of screen: 0.010" slot

6- Type screen filter: #2 Quartz filter sand
- a) Quantity used: 7 - 50 lb bags

7- Type of seal: 3/8" sodium bentonite chips
- a) Quantity used: 2 - 50 lb bags

Development method: Surge and Purge

Development time: 1/17/17 0925

Estimated purge volume: 12 gallons

Comments: High solids, bentonite grout above seal to surface

Appendix E
IDW Disposal Paperwork

ABL

Clearfield MMG
Post Office Box 1444
Chesapeake, VA 23327
(757) 549-8448
FAX: (757) 549-6668

NON-HAZARDOUS SHIPPING MANIFEST

MANIFEST NO. ____________

GENERATOR

NAME	Dept. of the Navy - Allegany Ballistics Lab	TELEPHONE	304-726-5218		
ADDRESS	210 State Route 956	CITY	Rocket Center	STATE	WV
SHIPMENT ORIGIN	ABL, Site 5	CITY	Rocket Center	STATE	WV
AUTHORIZED AGENT	c/o CH2M Hill, Inc.	FIRM			
ADDRESS		OTHER	PO# 10006-7-107053		

MATERIAL CHARACTERIZATION

ACTIVITY GENERATING THIS MATERIAL: UST/AST REMOVAL ________ OTHER Investigation Derived Waste

PETROLEUM TYPE (S): None VIRGIN PRODUCT ________ NON-VIRGIN PRODUCT ________

PHYSICAL STATE: STOCKPILED ________ EXCAVATING ________ DRUMS 24 OTHER ________ (Dev,Purge,&Decon Water)

HANDLING INSTRUCTIONS: **Transport To Facility Designated Below**

FIRE OR SPILL INSTRCUTIONS: **Non-Flammable / Non-Hazardous**

DESTINATION: Chesapeake Facility, 416 Dominion Blvd. North

I hereby certify, to the best of my knowledge, the material characterized above is non-hazardous as defined by the Virginia Hazardous Waste Management Regulations, Federal Regulations under Subtitle C - RCRA, U.S. Department of Transportation, or local / state of origin regulations.

[signature] for US Dept. of the Navy
Signature of Generator / Agent

Leslie H. Mull II / 3/23/17
Printed Name / Date

TRANSPORTER

TRANSPORTER NAME Clearfield MMG, Inc. TELEPHONE 757-549-8448 TRUCK NO. 14

I certify that the materials described above were received by me for shipment and delivered to the designated facility.

[signature] 3-23-17
Transporter Signature / Date

FACILTIY

I certify that the materials described above were delivered to the facility and received by me.

ACCEPTED BY ________________ DATE ________

REASONS FOR REJECTION ________________

Gross Weight	
Tare Weight	
Net Weight	
Tons	

GENERATOR

Clearfield MMG
Post Office Box 1444
Chesapeake, VA 23327
(757) 549-8448
FAX: (757) 549-6668

NON-HAZARDOUS SHIPPING MANIFEST

MANIFEST NO.________

GENERATOR

NAME: Dept. of the Navy - Allegany Ballistics Lab | TELEPHONE: 304-726-5218

ADDRESS: 210 State Route 956 | CITY: Rocket Center | STATE: WV

SHIPMENT ORIGIN: ABL, Site 5 | CITY: Rocket Center | STATE: WV

AUTHORIZED AGENT: c/o CH2M Hill, Inc. | FIRM:

ADDRESS: | OTHER: PO# 10006-7-107053

MATERIAL CHARACTERIZATION

ACTIVITY GENERATING THIS MATERIAL: UST/AST REMOVAL ____ OTHER: Investigation Derived Waste

PETROLEUM TYPE (S): None VIRGIN PRODUCT ____ NON-VIRGIN PRODUCT ____

PHYSICAL STATE: STOCKPILED ____ EXCAVATING ____ DRUMS 3 *(Soil Cuttings)* OTHER ____

HANDLING INSTRUCTIONS: **Transport To Facility Designated Below**

FIRE OR SPILL INSTRCUTIONS: **Non-Flammable / Non-Hazardous**

DESTINATION: Chesapeake Facility, 416 Dominion Blvd. North

I hereby certify, to the best of my knowledge, the material characterized above is non-hazardous as defined by the Virginia Hazardous Waste Management Regulations, Federal Regulations under Subtitle C - RCRA, U.S. Department of Transportation, or local / state of origin regulations.

[signature] II
Signature of Generator / Agent
for US Dept of Navy

Leslie H. Mull II / 3/23/17
Printed Name / Date

TRANSPORTER

TRANSPORTER NAME: Clearfield MMG, Inc. | TELEPHONE: 757-549-8448 | TRUCK NO. 14

I certify that the materials described above were received by me for shipment and delivered to the designated facility.

[signature] 3-23-17
Transporter Signature / Date

FACILTIY

I certify that the materials described above were delivered to the facility and received by me.

ACCEPTED BY ________ DATE ______

REASONS FOR REJECTION ________

Gross Weight	
Tare Weight	
Net Weight	
Tons	

GENERATOR

St. Louis

WASTE MATERIAL PROFILE SHEET

Clean Harbors Profile No. CH1413235

A. GENERAL INFORMATION

GENERATOR EPA ID #/REGISTRATION # ***MO8 210 490 084 MO ID# 002823***

GENERATOR NAME: ***St Louis Ordanance Plant***

GENERATOR CODE (Assigned by Clean Harbors) ***ST41755***

CITY ***St. Louis*** STATE/PROVINCE ***MO*** ZIP/POSTAL CODE ***63137***

ADDRESS ***4301 Goodfellow Blvd***

PHONE: **(703) 376-5304**

CUSTOMER CODE (Assigned by Clean Harbors) ***CH20618***

CUSTOMER NAME: ***CH2M Hill***

ADDRESS ***6600 Peachtree Dunwoody Road Embassy Row - Building 400 Suite 600***

CITY ***Atlanta*** STATE/PROVINCE ***GA*** ZIP/POSTAL CODE ***30328***

B. WASTE DESCRIPTION

WASTE DESCRIPTION: ***Nonhazardous soil*** Investigation Derived Waste

PROCESS GENERATING WASTE: **Drill cuttings from investigation of organic contamination. Source unknown, waste is not listed haz.**

IS THIS WASTE CONTAINED IN SMALL PACKAGING CONTAINED WITHIN A LARGER SHIPPING CONTAINER ? **No**

C. PHYSICAL PROPERTIES (at 25C or 77F)

PHYSICAL STATE
- [x] SOLID WITHOUT FREE LIQUID
- [ ] POWDER
- [ ] MONOLITHIC SOLID
- [ ] LIQUID WITH NO SOLIDS
- [ ] LIQUID/SOLID MIXTURE
- % FREE LIQUID
- % SETTLED SOLID
- % TOTAL SUSPENDED SOLID
- [ ] SLUDGE
- [ ] GAS/AEROSOL

NUMBER OF PHASES/LAYERS

1 2 3

% BY VOLUME (Approx.)

TOP ***0.00***
MIDDLE ***0.00***
BOTTOM ***0.00***

VISCOSITY (If liquid present)
- [ ] 1 - 100 (e.g. Water)
- [ ] 101 - 500 (e.g. Motor Oil)
- [ ] 501 - 10,000 (e.g. Molasses)
- [ ] > 10,000

COLOR

brown

ODOR
- [x] NONE
- [ ] MILD
- [ ] STRONG

Describe:

BOILING POINT ºF (ºC)
- [ ] <= 95 (<=35)
- [ ] 95 - 100 (35-38)
- [ ] 101 - 129 (38-54)
- [ ] >= 130 (>54)

MELTING POINT ºF (ºC)
- [ ] < 140 (<60)
- [ ] 140-200 (60-93)
- [x] > 200 (>93)

TOTAL ORGANIC CARBON
- [x] <= 1%
- [ ] 1-9%
- [ ] >= 10%

FLASH POINT ºF (ºC)
- [ ] < 73 (<23)
- [ ] 73 - 100 (23-38)
- [ ] 101 -140 (38-60)
- [ ] 141 -200 (60-93)
- [ ] > 200 (>93)

pH
- [ ] <= 2
- [ ] 2.1 - 6.9
- [ ] 7 (Neutral)
- [x] 7.1 - 12.4
- [ ] >= 12.5

SPECIFIC GRAVITY
- [ ] < 0.8 (e.g. Gasoline)
- [ ] 0.8-1.0 (e.g. Ethanol)
- [x] 1.0 (e.g. Water)
- [ ] 1.0-1.2 (e.g. Antifreeze)
- [ ] > 1.2 (e.g. Methylene Chloride)

ASH
- [ ] < 0.1
- [ ] 0.1 - 1.0
- [ ] 1.1 - 5.0
- [ ] 5.1 - 20.0
- [ ] > 20
- [x] Unknown

BTU/LB (MJ/kg)
- [x] < 2,000 (<4.6)
- [ ] 2,000-5,000 (4.6-11.6)
- [ ] 5,000-10,000 (11.6-23.2)
- [ ] > 10,000 (>23.2)

Actual:

D. COMPOSITION (List the complete composition of the waste, include any inert components and/or debris. Ranges for individual components are acceptable. If a trade name is used, please supply an MSDS. Please do not use abbreviations.)

CHEMICAL	MIN	--	MAX	UOM
BARIUM	0.3710000	--	0.3710000	PPM
CHLOROFORM	3.0000000	--	3.0000000	PPB
DEBRIS (PPE, LINER, SAMPLE EQUIPMENT)	0.0000000	--	2.0000000	%
SOIL	98.0000000	--	100.0000000	%

DOES THIS WASTE CONTAIN ANY HEAVY GAUGE METAL DEBRIS OR OTHER LARGE OBJECTS (EX., METAL PLATE OR PIPING >1/4" THICK OR >12" LONG, METAL REINFORCED HOSE >12" LONG, METAL WIRE >12" LONG, METAL VALVES, PIPE FITTINGS, CONCRETE REINFORCING BAR OR PIECES OF CONCRETE >3")? YES [ ] NO [x]

If yes, describe, including dimensions:

DOES THIS WASTE CONTAIN ANY METALS IN POWDERED OR OTHER FINELY DIVIDED FORM? YES [ ] NO [x]

DOES THIS WASTE CONTAIN OR HAS IT CONTACTED ANY OF THE FOLLOWING; ANIMAL WASTES, HUMAN BLOOD, BLOOD PRODUCTS, BODY FLUIDS, MICROBIOLOGICAL WASTE, PATHOLOGICAL WASTE, HUMAN OR ANIMAL DERIVED SERUMS OR PROTEINS OR ANY OTHER POTENTIALLY INFECTIOUS MATERIAL? YES [ ] NO [x]

I acknowledge that this waste material is neither infectious nor does it contain any organism known to be a threat to human health. This certification is based on my knowledge of the material. Select the answer below that applies:

The waste was never exposed to potentially infectious material. YES NO

Chemical disinfection or some other form of sterilization has been applied to the waste. YES NO

I ACKNOWLEDGE THAT THIS PROFILE MEETS THE CLEAN HARBORS BATTERY PACKAGING REQUIREMENTS. YES NO

I ACKNOWLEDGE THAT MY FRIABLE ASBESTOS WASTE IS DOUBLE BAGGED AND WETTED. YES NO

SPECIFY THE SOURCE CODE ASSOCIATED WITH THE WASTE. ***G49***

SPECIFY THE FORM CODE ASSOCIATED WITH THE WASTE. ***W301***

E. CONSTITUENTS

Are these values based on testing or knowledge? Knowledge ☑ Testing

If constituent concentrations are based on analytical testing, analysis must be provided. Please attach document(s) using the link on the Submit tab.

Please indicate which constituents below apply. Concentrations must be entered when applicable to assist in accurate review and expedited approval of your waste profile. Please note that the total regulated metals and other constituents sections require answers.

RCRA	REGULATED METALS	REGULATORY LEVEL (mg/l)	TCLP mg/l	TOTAL	UOM	NOT APPLICABLE
D004	ARSENIC	5.0				☑
D005	BARIUM	100.0				☑
D006	CADMIUM	1.0				☑
D007	CHROMIUM	5.0				☑
D008	LEAD	5.0				☑
D009	MERCURY	0.2				☑
D010	SELENIUM	1.0				☑
D011	SILVER	5.0				☑

RCRA	VOLATILE COMPOUNDS	REGULATORY LEVEL (mg/l)
D018	BENZENE	0.5
D019	CARBON TETRACHLORIDE	0.5
D021	CHLOROBENZENE	100.0
D022	CHLOROFORM	6.0
D028	1,2-DICHLOROETHANE	0.5
D029	1,1-DICHLOROETHYLENE	0.7
D035	METHYL ETHYL KETONE	200.0
D039	TETRACHLOROETHYLENE	0.7
D040	TRICHLOROETHYLENE	0.5
D043	VINYL CHLORIDE	0.2

RCRA	SEMI-VOLATILE COMPOUNDS	REGULATORY LEVEL (mg/l)
D023	o-CRESOL	200.0
D024	m-CRESOL	200.0
D025	p-CRESOL	200.0
D026	CRESOL (TOTAL)	200.0
D027	1,4-DICHLOROBENZENE	7.5
D030	2,4-DINITROTOLUENE	0.13
D032	HEXACHLOROBENZENE	0.13
D033	HEXACHLOROBUTADIENE	0.5
D034	HEXACHLOROETHANE	3.0
D036	NITROBENZENE	2.0
D037	PENTACHLOROPHENOL	100.0
D038	PYRIDINE	5.0
D041	2,4,5-TRICHLOROPHENOL	400.0
D042	2,4,6-TRICHLOROPHENOL	2.0

RCRA	PESTICIDES AND HERBICIDES	REGULATORY LEVEL (mg/l)
D012	ENDRIN	0.02
D013	LINDANE	0.4
D014	METHOXYCHLOR	10.0
D015	TOXAPHENE	0.5
D016	2,4-D	10.0
D017	2,4,5-TP (SILVEX)	1.0
D020	CHLORDANE	0.03
D031	HEPTACHLOR (AND ITS EPOXIDE)	0.008

OTHER CONSTITUENTS	MAX	UOM	NOT APPLICABLE
BROMINE			☑
CHLORINE			☑
FLUORINE			☑
IODINE			☑
SULFUR			☑
POTASSIUM			☑
SODIUM			☑
AMMONIA			☑
CYANIDE AMENABLE			☑
CYANIDE REACTIVE			☑
CYANIDE TOTAL			☑
SULFIDE REACTIVE			☑

HOCs

☑ NONE
< 1000 PPM
>= 1000 PPM

PCBs

☑ NONE
< 50 PPM
>=50 PPM

IF PCBS ARE PRESENT, IS THE WASTE REGULATED BY TSCA 40 CFR 761?

YES ☑ NO

ADDITIONAL HAZARDS

DOES THIS WASTE HAVE ANY UNDISCLOSED HAZARDS OR PRIOR INCIDENTS ASSOCIATED WITH IT, WHICH COULD AFFECT THE WAY IT SHOULD BE HANDLED?

YES ☑ NO (If yes, explain)

CHOOSE ALL THAT APPLY

DEA REGULATED SUBSTANCES	EXPLOSIVE	FUMING	OSHA REGULATED CARCINOGENS
POLYMERIZABLE	RADIOACTIVE	REACTIVE MATERIAL	☑ NONE OF THE ABOVE

F. REGULATORY STATUS

YES ☑ NO USEPA HAZARDOUS WASTE?

YES ☑ NO DO ANY STATE WASTE CODES APPLY?

Texas Waste Code

YES ☑ NO DO ANY CANADIAN PROVINCIAL WASTE CODES APPLY?

YES ☑ NO IS THIS WASTE PROHIBITED FROM LAND DISPOSAL WITHOUT FURTHER TREATMENT PER 40 CFR PART 268?

LDR CATEGORY: ***Not subject to LDR***
VARIANCE INFO:

YES ☑ NO IS THIS A UNIVERSAL WASTE?

YES ☑ NO IS THE GENERATOR OF THE WASTE CLASSIFIED AS CONDITIONALLY EXEMPT SMALL QUANTITY GENERATOR (CESQG)?

YES NO IS THIS MATERIAL GOING TO BE MANAGED AS A RCRA EXEMPT COMMERCIAL PRODUCT, WHICH IS FUEL (40 CFR 261.2 (C)(2)(II))?

YES ☑ NO DOES TREATMENT OF THIS WASTE GENERATE A F006 OR F019 SLUDGE?

YES NO IS THIS WASTE STREAM SUBJECT TO THE INORGANIC METAL BEARING WASTE PROHIBITION FOUND AT 40 CFR 268.3(C)?

YES ☑ NO DOES THIS WASTE CONTAIN VOC'S IN CONCENTRATIONS >=500 PPM?

YES NO DOES THE WASTE CONTAIN GREATER THAN 20% OF ORGANIC CONSTITUENTS WITH A VAPOR PRESSURE >= .3KPA (.044 PSIA)?

YES ☑ NO DOES THIS WASTE CONTAIN AN ORGANIC CONSTITUENT WHICH IN ITS PURE FORM HAS A VAPOR PRESSURE > 77 KPA (11.2 PSIA)?

YES ☑ NO IS THIS CERCLA REGULATED (SUPERFUND) WASTE ?

YES ☑ NO IS THE WASTE SUBJECT TO ONE OF THE FOLLOWING NESHAP RULES?

Hazardous Organic NESHAP (HON) rule (subpart G) Pharmaceuticals production (subpart GGG)

YES NO IF THIS IS A US EPA HAZARDOUS WASTE, DOES THIS WASTE STREAM CONTAIN BENZENE?

YES NO Does the waste stream come from a facility with one of the SIC codes listed under benzene NESHAP or is this waste regulated under the benzene NESHAP rules because the original source of the waste is from a chemical manufacturing, coke by-product recovery, or petroleum refinery process?

YES NO Is the generating source of this waste stream a facility with Total Annual Benzene (TAB) >10 Mg/year?

What is the TAB quantity for your facility? Megagram/year (1 Mg = 2,200 lbs)

The basis for this determination is: Knowledge of the Waste Or Test Data Knowledge X Testing

Describe the knowledge : Microbac Lab Report # L17030114, 13 Mar 2017 confirms waste is non-hazardous.:

G. DOT/TDG INFORMATION

DOT/TDG PROPER SHIPPING NAME:

NON HAZARDOUS, NON D.O.T. REGULATED, (SOIL)

H. TRANSPORTATION REQUIREMENTS

ESTIMATED SHIPMENT FREQUENCY ONE TIME WEEKLY MONTHLY QUARTERLY YEARLY ☑ OTHER ***as needed***

☑ **CONTAINERIZED**

1-25 CONTAINERS/SHIPMENT

STORAGE CAPACITY:
CONTAINER TYPE:

PORTABLE TOTE TANK BOX|CARTON|CASE
CUBIC YARD BOX ☑ DRUM
OTHER:
DRUM SIZE: ***55***

BULK LIQUID

GALLONS/SHIPMENT: ***0 Min -0 Max*** GAL.

BULK SOLID

SHIPMENT UOM: TON YARD

TONS/YARDS/SHIPMENT: ***0 Min - 0 Max***

I. SPECIAL REQUEST

COMMENTS OR REQUESTS:

GENERATOR'S CERTIFICATION

I certify that I am authorized to execute this document as an authorized agent. I hereby certify that all information submitted in this and attached documents is correct to the best of my knowledge.I also certify that any samples submitted are representative of the actual waste.If Clean Harbors discovers a discrepancy during the approval process, Generator grants Clean Harbors the authority to amend the profile, as Clean Harbors deems necessary, to reflect the discrepancy.

"On Behalf of the 88th RSC"

AUTHORIZED SIGNATURE	NAME (PRINT)	TITLE	DATE
	Tony L. Bridges	Env Prot Specialist	7 April 2017

WASTE MATERIAL PROFILE SHEET

Clean Harbors Profile No. CH1414492

A. GENERAL INFORMATION

GENERATOR EPA ID #/REGISTRATION # *MO8 210 490 084 MO ID# 002823*

GENERATOR NAME: *St Louis Ordanance Plant*

GENERATOR CODE (Assigned by Clean Harbors) *ST41755*

CITY *St. Louis* STATE/PROVINCE *MO* ZIP/POSTAL CODE *63137*

ADDRESS *4301 Goodfellow Blvd*

PHONE: **(703) 376-5304**

CUSTOMER CODE (Assigned by Clean Harbors) *CH20618*

CUSTOMER NAME: *CH2M Hill*

ADDRESS *6600 Peachtree Dunwoody Road Embassy Row - Building 400 Suite 600*

CITY *Atlanta* STATE/PROVINCE *GA* ZIP/POSTAL CODE *30328*

B. WASTE DESCRIPTION

WASTE DESCRIPTION: *Nonhazardous debris*

PROCESS GENERATING WASTE: **Debris from decontamination/investigation of organic contamination. Source unknown, waste is not listed haz.**

IS THIS WASTE CONTAINED IN SMALL PACKAGING CONTAINED WITHIN A LARGER SHIPPING CONTAINER ? **No**

C. PHYSICAL PROPERTIES (at 25C or 77F)

PHYSICAL STATE
- ☑ SOLID WITHOUT FREE LIQUID
- POWDER
- MONOLITHIC SOLID
- LIQUID WITH NO SOLIDS
- LIQUID/SOLID MIXTURE
- % FREE LIQUID
- % SETTLED SOLID
- % TOTAL SUSPENDED SOLID
- SLUDGE
- GAS/AEROSOL

NUMBER OF PHASES/LAYERS

1 2 3

% BY VOLUME (Approx.) TOP *0.00* MIDDLE *0.00* BOTTOM *0.00*

VISCOSITY (If liquid present)
- 1 - 100 (e.g. Water)
- 101 - 500 (e.g. Motor Oil)
- 501 - 10,000 (e.g. Molasses)
- > 10,000

COLOR

varies

ODOR
- ☑ NONE
- MILD
- STRONG

Describe:

BOILING POINT °F (°C)
- <= 95 (<=35)
- 95 - 100 (35-38)
- 101 - 129 (38-54)
- >= 130 (>54)

MELTING POINT °F (°C)
- < 140 (<60)
- 140-200 (60-93)
- ☑ > 200 (>93)

TOTAL ORGANIC CARBON
- ☑ <= 1%
- 1-9%
- >= 10%

FLASH POINT °F (°C)
- < 73 (<23)
- 73 - 100 (23-38)
- 101 -140 (38-60)
- 141 -200 (60-93)
- > 200 (>93)

pH
- <= 2
- 2.1 - 6.9
- 7 (Neutral)
- ☑ 7.1 - 12.4
- >= 12.5

SPECIFIC GRAVITY
- < 0.8 (e.g. Gasoline)
- 0.8-1.0 (e.g. Ethanol)
- ☑ 1.0 (e.g. Water)
- 1.0-1.2 (e.g. Antifreeze)
- > 1.2 (e.g. Methylene Chloride)

ASH
- < 0.1
- 0.1 - 1.0
- 1.1 - 5.0
- 5.1 - 20.0
- > 20
- ☑ Unknown

BTU/LB (MJ/kg)
- ☑ < 2,000 (<4.6)
- 2,000-5,000 (4.6-11.6)
- 5,000-10,000 (11.6-23.2)
- > 10,000 (>23.2)

Actual:

D. COMPOSITION

(List the complete composition of the waste, include any inert components and/or debris. Ranges for individual components are acceptable. If a trade name is used, please supply an MSDS. Please do not use abbreviations.)

CHEMICAL	MIN	--	MAX	UOM
BARIUM	0.3710000	--	0.3710000	PPM
CHLOROFORM	3.0000000	--	3.0000000	PPB
DEBRIS (PPE, LINER, SAMPLE EQUIPMENT)	98.0000000	--	100.0000000	%
SOIL	0.0000000	--	2.0000000	%

DOES THIS WASTE CONTAIN ANY HEAVY GAUGE METAL DEBRIS OR OTHER LARGE OBJECTS (EX., METAL PLATE OR PIPING >1/4" THICK OR >12" LONG, METAL REINFORCED HOSE >12" LONG, METAL WIRE >12" LONG, METAL VALVES, PIPE FITTINGS, CONCRETE REINFORCING BAR OR PIECES OF CONCRETE >3")? YES ☑ NO

If yes, describe, including dimensions:

DOES THIS WASTE CONTAIN ANY METALS IN POWDERED OR OTHER FINELY DIVIDED FORM? YES ☑ NO

DOES THIS WASTE CONTAIN OR HAS IT CONTACTED ANY OF THE FOLLOWING; ANIMAL WASTES, HUMAN BLOOD, BLOOD PRODUCTS, BODY FLUIDS, MICROBIOLOGICAL WASTE, PATHOLOGICAL WASTE, HUMAN OR ANIMAL DERIVED SERUMS OR PROTEINS OR ANY OTHER POTENTIALLY INFECTIOUS MATERIAL? YES ☑ NO

I acknowledge that this waste material is neither infectious nor does it contain any organism known to be a threat to human health. This certification is based on my knowledge of the material. Select the answer below that applies:

The waste was never exposed to potentially infectious material. YES NO

Chemical disinfection or some other form of sterilization has been applied to the waste. YES NO

I ACKNOWLEDGE THAT THIS PROFILE MEETS THE CLEAN HARBORS BATTERY PACKAGING REQUIREMENTS. YES NO

I ACKNOWLEDGE THAT MY FRIABLE ASBESTOS WASTE IS DOUBLE BAGGED AND WETTED. YES NO

SPECIFY THE SOURCE CODE ASSOCIATED WITH THE WASTE. *G49*

SPECIFY THE FORM CODE ASSOCIATED WITH THE WASTE. *W002*

E. CONSTITUENTS

Are these values based on testing or knowledge? Knowledge ☑ Testing

If constituent concentrations are based on analytical testing, analysis must be provided. Please attach document(s) using the link on the Submit tab.

Please indicate which constituents below apply. Concentrations must be entered when applicable to assist in accurate review and expedited approval of your waste profile. Please note that the total regulated metals and other constituents sections require answers.

RCRA	REGULATED METALS	REGULATORY LEVEL (mg/l)	TCLP mg/l	TOTAL	UOM	NOT APPLICABLE
D004	ARSENIC	5.0				☑
D005	BARIUM	100.0				☑
D006	CADMIUM	1.0				☑
D007	CHROMIUM	5.0				☑
D008	LEAD	5.0				☑
D009	MERCURY	0.2				☑
D010	SELENIUM	1.0				☑
D011	SILVER	5.0				☑

VOLATILE COMPOUNDS

D018	BENZENE	0.5
D019	CARBON TETRACHLORIDE	0.5
D021	CHLOROBENZENE	100.0
D022	CHLOROFORM	6.0
D028	1,2-DICHLOROETHANE	0.5
D029	1,1-DICHLOROETHYLENE	0.7
D035	METHYL ETHYL KETONE	200.0
D039	TETRACHLOROETHYLENE	0.7
D040	TRICHLOROETHYLENE	0.5
D043	VINYL CHLORIDE	0.2

SEMI-VOLATILE COMPOUNDS

D023	o-CRESOL	200.0
D024	m-CRESOL	200.0
D025	p-CRESOL	200.0
D026	CRESOL (TOTAL)	200.0
D027	1,4-DICHLOROBENZENE	7.5
D030	2,4-DINITROTOLUENE	0.13
D032	HEXACHLOROBENZENE	0.13
D033	HEXACHLOROBUTADIENE	0.5
D034	HEXACHLOROETHANE	3.0
D036	NITROBENZENE	2.0
D037	PENTACHLOROPHENOL	100.0
D038	PYRIDINE	5.0
D041	2,4,5-TRICHLOROPHENOL	400.0
D042	2,4,6-TRICHLOROPHENOL	2.0

PESTICIDES AND HERBICIDES

D012	ENDRIN	0.02
D013	LINDANE	0.4
D014	METHOXYCHLOR	10.0
D015	TOXAPHENE	0.5
D016	2,4-D	10.0
D017	2,4,5-TP (SILVEX)	1.0
D020	CHLORDANE	0.03
D031	HEPTACHLOR (AND ITS EPOXIDE)	0.008

OTHER CONSTITUENTS	MAX	UOM	NOT APPLICABLE
BROMINE			☑
CHLORINE			☑
FLUORINE			☑
IODINE			☑
SULFUR			☑
POTASSIUM			☑
SODIUM			☑
AMMONIA			☑
CYANIDE AMENABLE			☑
CYANIDE REACTIVE			☑
CYANIDE TOTAL			☑
SULFIDE REACTIVE			☑

HOCs

☑ NONE

< 1000 PPM

>= 1000 PPM

PCBs

☑ NONE

< 50 PPM

>=50 PPM

IF PCBS ARE PRESENT, IS THE WASTE REGULATED BY TSCA 40 CFR 761?

YES ☑ NO

ADDITIONAL HAZARDS

DOES THIS WASTE HAVE ANY UNDISCLOSED HAZARDS OR PRIOR INCIDENTS ASSOCIATED WITH IT, WHICH COULD AFFECT THE WAY IT SHOULD BE HANDLED?

YES ☑ NO (If yes, explain)

CHOOSE ALL THAT APPLY

DEA REGULATED SUBSTANCES	EXPLOSIVE	FUMING	OSHA REGULATED CARCINOGENS
POLYMERIZABLE	RADIOACTIVE	REACTIVE MATERIAL	☑ NONE OF THE ABOVE

F. REGULATORY STATUS

YES ☑ NO USEPA HAZARDOUS WASTE?

YES ☑ NO DO ANY STATE WASTE CODES APPLY?

Texas Waste Code

YES ☑ NO DO ANY CANADIAN PROVINCIAL WASTE CODES APPLY?

YES ☑ NO IS THIS WASTE PROHIBITED FROM LAND DISPOSAL WITHOUT FURTHER TREATMENT PER 40 CFR PART 268?

LDR CATEGORY: ***Not subject to LDR***
VARIANCE INFO:

YES ☑ NO IS THIS A UNIVERSAL WASTE?

YES ☑ NO IS THE GENERATOR OF THE WASTE CLASSIFIED AS CONDITIONALLY EXEMPT SMALL QUANTITY GENERATOR (CESQG)?

YES NO IS THIS MATERIAL GOING TO BE MANAGED AS A RCRA EXEMPT COMMERCIAL PRODUCT, WHICH IS FUEL (40 CFR 261.2 (C)(2)(II))?

YES ☑ NO DOES TREATMENT OF THIS WASTE GENERATE A F006 OR F019 SLUDGE?

YES NO IS THIS WASTE STREAM SUBJECT TO THE INORGANIC METAL BEARING WASTE PROHIBITION FOUND AT 40 CFR 268.3(C)?

YES ☑ NO DOES THIS WASTE CONTAIN VOC'S IN CONCENTRATIONS >=500 PPM?

YES NO DOES THE WASTE CONTAIN GREATER THAN 20% OF ORGANIC CONSTITUENTS WITH A VAPOR PRESSURE >= .3KPA (.044 PSIA)?

YES ☑ NO DOES THIS WASTE CONTAIN AN ORGANIC CONSTITUENT WHICH IN ITS PURE FORM HAS A VAPOR PRESSURE > 77 KPA (11.2 PSIA)?

YES ☑ NO IS THIS CERCLA REGULATED (SUPERFUND) WASTE ?

YES ☑ NO IS THE WASTE SUBJECT TO ONE OF THE FOLLOWING NESHAP RULES?

Hazardous Organic NESHAP (HON) rule (subpart G) Pharmaceuticals production (subpart GGG)

YES NO IF THIS IS A US EPA HAZARDOUS WASTE, DOES THIS WASTE STREAM CONTAIN BENZENE?

YES NO Does the waste stream come from a facility with one of the SIC codes listed under benzene NESHAP or is this waste regulated under the benzene NESHAP rules because the original source of the waste is from a chemical manufacturing, coke by-product recovery, or petroleum refinery process?

YES NO Is the generating source of this waste stream a facility with Total Annual Benzene (TAB) >10 Mg/year?

What is the TAB quantity for your facility? ______ Megagram/year (1 Mg = 2,200 lbs)

The basis for this determination is: Knowledge of the Waste Or Test Data Knowledge X Testing

Describe the knowledge : Microbac Lab Report # L17030114, 13 Mar 2017 confirms waste is non-hazardous.:

G. DOT/TDG INFORMATION

DOT/TDG PROPER SHIPPING NAME:

NON HAZARDOUS, NON D.O.T. REGULATED, (DEBRIS)

H. TRANSPORTATION REQUIREMENTS

ESTIMATED SHIPMENT FREQUENCY ONE TIME WEEKLY MONTHLY QUARTERLY YEARLY ☑ OTHER ***as needed***

☑ **CONTAINERIZED**	**BULK LIQUID**	**BULK SOLID**
1-25 CONTAINERS/SHIPMENT	GALLONS/SHIPMENT: ***0 Min -0 Max*** GAL.	SHIPMENT UOM: TON YARD
STORAGE CAPACITY:		TONS/YARDS/SHIPMENT: ***0 Min - 0 Max***
CONTAINER TYPE: PORTABLE TOTE TANK; BOX|CARTON|CASE; CUBIC YARD BOX; ☑ DRUM; OTHER:; DRUM SIZE: ***55***		

I. SPECIAL REQUEST

COMMENTS OR REQUESTS:

GENERATOR'S CERTIFICATION

I certify that I am authorized to execute this document as an authorized agent. I hereby certify that all information submitted in this and attached documents is correct to the best of my knowledge.I also certify that any samples submitted are representative of the actual waste.If Clean Harbors discovers a discrepancy during the approval process, Generator grants Clean Harbors the authority to amend the profile, as Clean Harbors deems necessary, to reflect the discrepancy.

"On Behalf of the 88th RSC"

AUTHORIZED SIGNATURE	NAME (PRINT)	TITLE	DATE
	Tony L. Bridges	Env Prot Specialist	7 April 2017

WASTE MATERIAL PROFILE SHEET

Clean Harbors Profile No. CH1414499

A. GENERAL INFORMATION

GENERATOR EPA ID #/REGISTRATION #: *MO8 210 490 084* / *MO ID# 002823*

GENERATOR NAME: *St Louis Ordanance Plant*

GENERATOR CODE (Assigned by Clean Harbors): *ST41755*

CITY: *St. Louis* STATE/PROVINCE: *MO* ZIP/POSTAL CODE: *63137*

ADDRESS: *4301 Goodfellow Blvd*

PHONE: **(703) 376-5304**

CUSTOMER CODE (Assigned by Clean Harbors): *CH20618*

CUSTOMER NAME: *CH2M Hill*

ADDRESS: *6600 Peachtree Dunwoody Road Embassy Row - Building 400 Suite 600*

CITY: *Atlanta* STATE/PROVINCE: *GA* ZIP/POSTAL CODE: *30328*

B. WASTE DESCRIPTION

WASTE DESCRIPTION: *Nonhazardous water*

PROCESS GENERATING WASTE: **Development and sampling of monitoring wells from organic contaminated area; source unknown, waste not listed hazardous**

IS THIS WASTE CONTAINED IN SMALL PACKAGING CONTAINED WITHIN A LARGER SHIPPING CONTAINER ? **No**

C. PHYSICAL PROPERTIES (at 25C or 77F)

PHYSICAL STATE
- SOLID WITHOUT FREE LIQUID
- POWDER
- MONOLITHIC SOLID
- [x] LIQUID WITH NO SOLIDS
- LIQUID/SOLID MIXTURE
- % FREE LIQUID
- % SETTLED SOLID
- % TOTAL SUSPENDED SOLID
- SLUDGE
- GAS/AEROSOL

NUMBER OF PHASES/LAYERS
- [x] 1 2 3
- % BY VOLUME (Approx.): TOP *100.00*; MIDDLE *0.00*; BOTTOM *0.00*

VISCOSITY (If liquid present)
- [x] 1 - 100 (e.g. Water)
- 101 - 500 (e.g. Motor Oil)
- 501 - 10,000 (e.g. Molasses)
- > 10,000

COLOR: *clear*

ODOR
- [x] NONE
- MILD
- STRONG
- Describe:

BOILING POINT °F (°C)
- <= 95 (<=35)
- 95 - 100 (35-38)
- 101 - 129 (38-54)
- [x] >= 130 (>54)

MELTING POINT °F (°C)
- < 140 (<60)
- 140-200 (60-93)
- > 200 (>93)

TOTAL ORGANIC CARBON
- [x] <= 1%
- 1-9%
- >= 10%

FLASH POINT °F (°C)
- < 73 (<23)
- 73 - 100 (23-38)
- 101 -140 (38-60)
- 141 -200 (60-93)
- [x] > 200 (>93)

pH
- <= 2
- 2.1 - 6.9
- 7 (Neutral)
- [x] 7.1 - 12.4
- >= 12.5

SPECIFIC GRAVITY
- < 0.8 (e.g. Gasoline)
- 0.8-1.0 (e.g. Ethanol)
- [x] 1.0 (e.g. Water)
- 1.0-1.2 (e.g. Antifreeze)
- > 1.2 (e.g. Methylene Chloride)

ASH
- < 0.1
- 0.1 - 1.0
- 1.1 - 5.0
- 5.1 - 20.0
- > 20
- [x] Unknown

BTU/LB (MJ/kg)
- [x] < 2,000 (<4.6)
- 2,000-5,000 (4.6-11.6)
- 5,000-10,000 (11.6-23.2)
- > 10,000 (>23.2)
- Actual:

D. COMPOSITION (List the complete composition of the waste, include any inert components and/or debris. Ranges for individual components are acceptable. If a trade name is used, please supply an MSDS. Please do not use abbreviations.)

CHEMICAL	MIN	--	MAX	UOM
WATER	100.0000000	--	100.0000000	%

DOES THIS WASTE CONTAIN ANY HEAVY GAUGE METAL DEBRIS OR OTHER LARGE OBJECTS (EX., METAL PLATE OR PIPING >1/4" THICK OR >12" LONG, METAL REINFORCED HOSE >12" LONG, METAL WIRE >12" LONG, METAL VALVES, PIPE FITTINGS, CONCRETE REINFORCING BAR OR PIECES OF CONCRETE >3")? YES NO

If yes, describe, including dimensions:

DOES THIS WASTE CONTAIN ANY METALS IN POWDERED OR OTHER FINELY DIVIDED FORM? YES [x] NO

DOES THIS WASTE CONTAIN OR HAS IT CONTACTED ANY OF THE FOLLOWING; ANIMAL WASTES, HUMAN BLOOD, BLOOD PRODUCTS, BODY FLUIDS, MICROBIOLOGICAL WASTE, PATHOLOGICAL WASTE, HUMAN OR ANIMAL DERIVED SERUMS OR PROTEINS OR ANY OTHER POTENTIALLY INFECTIOUS MATERIAL? YES [x] NO

I acknowledge that this waste material is neither infectious nor does it contain any organism known to be a threat to human health. This certification is based on my knowledge of the material. Select the answer below that applies:

The waste was never exposed to potentially infectious material. YES NO

Chemical disinfection or some other form of sterilization has been applied to the waste. YES NO

I ACKNOWLEDGE THAT THIS PROFILE MEETS THE CLEAN HARBORS BATTERY PACKAGING REQUIREMENTS. YES NO

I ACKNOWLEDGE THAT MY FRIABLE ASBESTOS WASTE IS DOUBLE BAGGED AND WETTED. YES NO

SPECIFY THE SOURCE CODE ASSOCIATED WITH THE WASTE. *G49*

SPECIFY THE FORM CODE ASSOCIATED WITH THE WASTE. *W101*

E. CONSTITUENTS

Are these values based on testing or knowledge? Knowledge ☑ Testing

If constituent concentrations are based on analytical testing, analysis must be provided. Please attach document(s) using the link on the Submit tab.

Please indicate which constituents below apply. Concentrations must be entered when applicable to assist in accurate review and expedited approval of your waste profile. Please note that the total regulated metals and other constituents sections require answers.

RCRA	REGULATED METALS	REGULATORY LEVEL (mg/l)	TCLP mg/l	TOTAL	UOM	NOT APPLICABLE
D004	ARSENIC	5.0				☑
D005	BARIUM	100.0				☑
D006	CADMIUM	1.0				☑
D007	CHROMIUM	5.0				☑
D008	LEAD	5.0				☑
D009	MERCURY	0.2				☑
D010	SELENIUM	1.0				☑
D011	SILVER	5.0				☑

VOLATILE COMPOUNDS

D018	BENZENE	0.5
D019	CARBON TETRACHLORIDE	0.5
D021	CHLOROBENZENE	100.0
D022	CHLOROFORM	6.0
D028	1,2-DICHLOROETHANE	0.5
D029	1,1-DICHLOROETHYLENE	0.7
D035	METHYL ETHYL KETONE	200.0
D039	TETRACHLOROETHYLENE	0.7
D040	TRICHLOROETHYLENE	0.5
D043	VINYL CHLORIDE	0.2

SEMI-VOLATILE COMPOUNDS

D023	o-CRESOL	200.0
D024	m-CRESOL	200.0
D025	p-CRESOL	200.0
D026	CRESOL (TOTAL)	200.0
D027	1,4-DICHLOROBENZENE	7.5
D030	2,4-DINITROTOLUENE	0.13
D032	HEXACHLOROBENZENE	0.13
D033	HEXACHLOROBUTADIENE	0.5
D034	HEXACHLOROETHANE	3.0
D036	NITROBENZENE	2.0
D037	PENTACHLOROPHENOL	100.0
D038	PYRIDINE	5.0
D041	2,4,5-TRICHLOROPHENOL	400.0
D042	2,4,6-TRICHLOROPHENOL	2.0

PESTICIDES AND HERBICIDES

D012	ENDRIN	0.02
D013	LINDANE	0.4
D014	METHOXYCHLOR	10.0
D015	TOXAPHENE	0.5
D016	2,4-D	10.0
D017	2,4,5-TP (SILVEX)	1.0
D020	CHLORDANE	0.03
D031	HEPTACHLOR (AND ITS EPOXIDE)	0.008

OTHER CONSTITUENTS	MAX	UOM	NOT APPLICABLE
BROMINE			☑
CHLORINE			☑
FLUORINE			☑
IODINE			☑
SULFUR			☑
POTASSIUM			☑
SODIUM			☑
AMMONIA			☑
CYANIDE AMENABLE			☑
CYANIDE REACTIVE			☑
CYANIDE TOTAL			☑
SULFIDE REACTIVE			☑

HOCs

☑ NONE

< 1000 PPM

>= 1000 PPM

PCBs

☑ NONE

< 50 PPM

>=50 PPM

IF PCBS ARE PRESENT, IS THE WASTE REGULATED BY TSCA 40 CFR 761?

YES ☑ NO

ADDITIONAL HAZARDS

DOES THIS WASTE HAVE ANY UNDISCLOSED HAZARDS OR PRIOR INCIDENTS ASSOCIATED WITH IT, WHICH COULD AFFECT THE WAY IT SHOULD BE HANDLED?

YES ☑ NO (If yes, explain)

CHOOSE ALL THAT APPLY

DEA REGULATED SUBSTANCES	EXPLOSIVE	FUMING	OSHA REGULATED CARCINOGENS
POLYMERIZABLE	RADIOACTIVE	REACTIVE MATERIAL	☑ NONE OF THE ABOVE

F. REGULATORY STATUS

YES ☑ NO USEPA HAZARDOUS WASTE?

YES ☑ NO DO ANY STATE WASTE CODES APPLY?

Texas Waste Code

YES ☑ NO DO ANY CANADIAN PROVINCIAL WASTE CODES APPLY?

YES ☑ NO IS THIS WASTE PROHIBITED FROM LAND DISPOSAL WITHOUT FURTHER TREATMENT PER 40 CFR PART 268?

LDR CATEGORY: ***Not subject to LDR***
VARIANCE INFO:

YES ☑ NO IS THIS A UNIVERSAL WASTE?

YES ☑ NO IS THE GENERATOR OF THE WASTE CLASSIFIED AS CONDITIONALLY EXEMPT SMALL QUANTITY GENERATOR (CESQG)?

YES NO IS THIS MATERIAL GOING TO BE MANAGED AS A RCRA EXEMPT COMMERCIAL PRODUCT, WHICH IS FUEL (40 CFR 261.2 (C)(2)(II))?

YES ☑ NO DOES TREATMENT OF THIS WASTE GENERATE A F006 OR F019 SLUDGE?

YES NO IS THIS WASTE STREAM SUBJECT TO THE INORGANIC METAL BEARING WASTE PROHIBITION FOUND AT 40 CFR 268.3(C)?

YES ☑ NO DOES THIS WASTE CONTAIN VOC'S IN CONCENTRATIONS >=500 PPM?

YES NO DOES THE WASTE CONTAIN GREATER THAN 20% OF ORGANIC CONSTITUENTS WITH A VAPOR PRESSURE >= .3KPA (.044 PSIA)?

YES ☑ NO DOES THIS WASTE CONTAIN AN ORGANIC CONSTITUENT WHICH IN ITS PURE FORM HAS A VAPOR PRESSURE > 77 KPA (11.2 PSIA)?

YES ☑ NO IS THIS CERCLA REGULATED (SUPERFUND) WASTE ?

YES ☑ NO IS THE WASTE SUBJECT TO ONE OF THE FOLLOWING NESHAP RULES?

Hazardous Organic NESHAP (HON) rule (subpart G) Pharmaceuticals production (subpart GGG)

YES NO IF THIS IS A US EPA HAZARDOUS WASTE, DOES THIS WASTE STREAM CONTAIN BENZENE?

YES NO Does the waste stream come from a facility with one of the SIC codes listed under benzene NESHAP or is this waste regulated under the benzene NESHAP rules because the original source of the waste is from a chemical manufacturing, coke by-product recovery, or petroleum refinery process?

YES NO Is the generating source of this waste stream a facility with Total Annual Benzene (TAB) >10 Mg/year?

What is the TAB quantity for your facility? Megagram/year (1 Mg = 2,200 lbs)

The basis for this determination is: Knowledge of the Waste Or Test Data Knowledge X Testing

Describe the knowledge : Microbac Lab Report # L17030114, 13 Mar 2017 confirms waste is non-hazardous.:

G. DOT/TDG INFORMATION

DOT/TDG PROPER SHIPPING NAME:

NON HAZARDOUS, NON D.O.T. REGULATED, (WATER)

H. TRANSPORTATION REQUIREMENTS

ESTIMATED SHIPMENT FREQUENCY ONE TIME WEEKLY MONTHLY QUARTERLY YEARLY ☑ OTHER ***as needed***

☑ CONTAINERIZED	BULK LIQUID	BULK SOLID
1-25 CONTAINERS/SHIPMENT	GALLONS/SHIPMENT: ***0 Min -0 Max*** GAL.	SHIPMENT UOM: TON YARD
STORAGE CAPACITY:		TONS/YARDS/SHIPMENT: ***0 Min - 0 Max***
CONTAINER TYPE: PORTABLE TOTE TANK; BOX|CARTON|CASE; CUBIC YARD BOX; ☑ DRUM; OTHER:; DRUM SIZE: ***55***		

I. SPECIAL REQUEST

COMMENTS OR REQUESTS:

GENERATOR'S CERTIFICATION

I certify that I am authorized to execute this document as an authorized agent. I hereby certify that all information submitted in this and attached documents is correct to the best of my knowledge.I also certify that any samples submitted are representative of the actual waste.If Clean Harbors discovers a discrepancy during the approval process, Generator grants Clean Harbors the authority to amend the profile, as Clean Harbors deems necessary, to reflect the discrepancy.

"On Behalf of the 88th RSC:

AUTHORIZED SIGNATURE	NAME (PRINT)	TITLE	DATE
	Tony L. Bridges	Env Prot Spec	7 April 2017

TS1701941377 SC PPW 1/4/2017

Please print or type. (Form designed for use on elite (12-pitch) typewriter.)

Form Approved. OMB No. 2050-0039

UNIFORM HAZARDOUS WASTE MANIFEST

1. Generator ID Number: NONEREQUIRED
2. Page 1 of: 1
3. Emergency Response Phone: (800) 483-3718
4. Manifest Tracking Number: 010490238 FLE

GENERATOR

5. Generator's Name and Mailing Address:
St Louis Ordnance Plant
4301 Goodfellow Blvd
St Louis MO 63137
Generator's Phone: (703) 376-5304

Generator's Site Address (if different than mailing address): SAME

6. Transporter 1 Company Name: Clean Harbors Environmental Service, Inc.
U.S. EPA ID Number: MAD039322250

7. Transporter 2 Company Name:
U.S. EPA ID Number:

8. Designated Facility Name and Site Address:
Spring Grove Resource Recovery Inc.
4879 Spring Grove Avenue
Cincinnati, OH 45232
Facility's Phone: (513) 681-6738
U.S. EPA ID Number: OHD000816629

9a. HM	9b. U.S. DOT Description (including Proper Shipping Name, Hazard Class, ID Number, and Packing Group (if any))	10. Containers No.	10. Containers Type	11. Total Quantity	12. Unit Wt./Vol.	13. Waste Codes
	1. NON HAZARDOUS, NON D.O.T. REGULATED, (DEBRIS)	001	DM	00250	P	
	2. NON HAZARDOUS, NON D.O.T. REGULATED, (SOIL)	012	DM	08400	P	
	3. NON HAZARDOUS, NON D.O.T. REGULATED, (WATER)	007	DM	03325	P	
	4.					

14. Special Handling Instructions and Additional Information
1. CH1414498 1x55
2. CH1419233 12x55
3. CH1414499 7x55
Investigation Derived Waste   Weight Estimated

15. **GENERATOR'S/OFFEROR'S CERTIFICATION:** I hereby declare that the contents of this consignment are fully and accurately described above by the proper shipping name, and are classified, packaged, marked and labeled/placarded, and are in all respects in proper condition for transport according to applicable international and national governmental regulations. If export shipment and I am the Primary Exporter, I certify that the contents of this consignment conform to the terms of the attached EPA Acknowledgment of Consent.
I certify that the waste minimization statement identified in 40 CFR 262.27(a) (if I am a large quantity generator) or (b) (if I am a small quantity generator) is true.

Generator's/Offeror's Printed/Typed Name: On Behalf of 88th RSC Troy Bridges — Signature: [signature] — Month 05 Day 05 Year 17

INT'L

16. International Shipments ☐ Import to U.S. ☐ Export from U.S. Port of entry/exit:
Transporter signature (for exports only): Date leaving U.S.:

TRANSPORTER

17. Transporter Acknowledgment of Receipt of Materials
Transporter 1 Printed/Typed Name: Matt [illegible] — Signature: [signature] — Month 05 Day 05 Year 17
Transporter 2 Printed/Typed Name: — Signature: — Month Day Year

DESIGNATED FACILITY

18. Discrepancy
18a. Discrepancy Indication Space ☐ Quantity ☐ Type ☐ Residue ☐ Partial Rejection ☐ Full Rejection
Manifest Reference Number:
18b. Alternate Facility (or Generator) U.S. EPA ID Number
Facility's Phone:
18c. Signature of Alternate Facility (or Generator) Month Day Year

19. Hazardous Waste Report Management Method Codes (i.e., codes for hazardous waste treatment, disposal, and recycling systems)
1. H141 2. H141 3. H141 4.

20. Designated Facility Owner or Operator: Certification of receipt of hazardous materials covered by the manifest except as noted in Item 18a
Printed/Typed Name — Signature — Month Day Year

EPA Form 8700-22 (Rev. 3-05) Previous editions are obsolete.

GENERATOR'S INITIAL COPY

Appendix F
Reactivity SOP

Handling Frozen Samples from SERDP ER2621

This procedure is used for handling cryogenic core samples, or otherwise frozen-preserved soil samples. The preparation stages should be performed quickly to avoid thawing samples. Batches of 3 to 6 samples at a time worked well for handling and transfer into an Anoxic Chamber, wherein most of the analysis occurred.

Sites processed to date:

- SLOP (4 wells 6 samples per well, although select analysis performed for some sample only)

1. Sample preparation.

    a. Cut 1 (1" think) puck from each frozen core (cylinder)
    b. Re-label cylinders and consolidate into bags (2 to a bag), sealed for long term storage I foodsaver bags, frozen in chest freezer.
        i. Leave 2 inches extra per bag for 2nd access
    c. Pucks are labeled on foil covering, bagged, sealed (5,6 or 7 per bag) for short term storage
        i. Leave 2-3 inches extra per bag for 2nd and 3rd access
    d. When sampling from a bag of pucks
        i. Prepare new labels on foil,
        ii. Cut into one bag at a time, minimizing exposure and melting time.
        iii. Chisel used to section puck
        iv. Re-foil, bag and seal pucks asap after sampling.

2. ZVI Content analysis by acidification
    a. Pre-weight and label 40 mL VOA vials
    b. Weight ~2.5 g of puck materials in VOA vials.
    c. Transfer to glove box (O_2 < 1.0 mg/L, No H_2)
    d. Acidify using 10 mL of 1M HCl.
    e. Vortex mix samples twice daily
    f. After 24 hrs of digestion
        i. Measure pressure,
        ii. Pre-load 2 mL in syringe,
        iii. Puncture septa, inject 2mL of gas
        iv. Flush syringe 3 times, withdraw 2 mL sample on 4th
        v. Transfer syringe out of glove box.
        vi. Hydrogen analysis on GC (SRI 8610C, equipped with a carboxen 1010 plot column, injector, oven isothermal at 30 degrees C, and TCD at 170 C, Nitrogen carrier gas with elution peak at ~1.3 mins.
        vii. GC externally calibrated using hydrogen and foil coated Tedlar bags (SKC Flexfoil).

g. Cap removed from 40 mL VOA vial to relieve pressure and purge headspace (about 10 mins), mix open sample gentle and re-seal (same Teflon coated silicon septa)
h. Repeat sampling at 48 hrs, or until Hydrogen is no longer produced (reaction in vial considered complete if <5% of hydrogen is added to total, or sample peak at detection limit).
i. Transfer vial to oven at 100 deg C for 24 hrs
j. Weight 40 mL VOA vials – calculate water content

3. pH – ORP
   a. Pre-weight and Label 40 VOA vials
   b. Weight ~ 5 g of puck material in VOA vials
   c. Transfer to glove box (O_2 < 1mg/L, No H_2)
   d. Add 10 mL deoxygenated deionized water
   e. Rotate on test tube mixer for 30 mins to thaw and mix
   f. Measure pH and ORP using needle probes (ORP - Microelectrodes MI800-411B, pH – Vernier pH)
   g. Transfer vial to oven at 80 deg C for 24 hrs
   h. Weight sample Gravimetric analysis

4. Magnetic and Gravimetric Analysis
   a. Follows from Sample in Step 3
   b. Sample pulverized using mortar & pestle
   c. Pour sample onto weighing dish 1 (thin plastic), weighed
   d. Magnet placed in another weighing dish 2, stacked on top of sample in dish 1
   e. Dish 3 pre-weighed,
   f. Magnet and dish 2 transferred to top of dish 3, magnet removed allowing magnetic particles to fall into dish 3
   g. Sample in dish 1 mixed before magnet and dish 2 stacked on top of sample again.
   h. Repeat d and e (10-15x) or until no more particles are removed
   i. Magnet placed under dish 3
   j. Dish 3 rinsed with DI water until silt and clay removed (carefully separating magnetic fraction)
   k. Sonication bath used to remove clay
   l. Dish 3 dried overnight and reweighed for gravimetric determination of Magnetically separable fraction.

5. Chemical Reactive Dyes – Resazurin (Rzn)
   a. Prepare Stainless Steel column with 1” Swage-Lok fittings and custom end caps. Seal $1/8^{th}$ ” union end of column
   b. Weight Column with all fittings and labels
   c. Place ½ Puck (for SLOP cores) into SS Column, Weigh
   d. Seal $1/16^{th}$ ” union end of column, leaving the plug un-sealed

e. Pass unsealed column into anoxic chamber (glove box < 1ppm O_2), Vacuum purging and replacing transfer chamber with ultra-high purity nitrogen 3x to remove oxygen.
f. Un-plug both ends, attach Luer to 1/8th and 1/16th swage-lok fittings on respective ends of the column.
g. Flush column bottom-upwards with 6.4 mM bicarbonate buffer solution adjusted to pH 7.2. Leaving no headspace, seal plugs on both ends
h. Pass column out of anoxic chamber
i. Weight and place on rotary mixer for 1 hour to thaw and mix.
j. Inject 1mM Resazurin Dye into bottom of the column, Volume = 1/20th of the liquid volume that was added in "g" (determined gravimetrically from "i" and "c") allowing excess to flow out of the top of the column, maintaining zero headspace.
k. Place column on roller for 1 hour
l. Place column upright on retort stand for 5 mins, allowing sediment to settle. Attach Luer to 1/8th and 1/16th swage-lok fittings on respective ends of the column.
m. Deliver 2.5 mL of deionized water into the bottom of the column (1/16th" fitting) while collecting the same volume "sample from the top of the column (via 1/16th " fitting)
n. Filter sample, wasting first 10 drops (less for turbid samples) before collecting 1 mL in a micro-cuvette. 0.45 µm Fisherbrand PVDA syringe filters.
o. Analysis using UV/Vis Spectrophotometer Resazurin peak = 604nm (blue, Oxidized form of dye), Resorufin peak = 560 nm (pink, reduced for of dye)

Appendix G
Complete Analytical Results

10515 Research Drive
Knoxville, TN 37932
Phone: 865.573.8188
Fax: 865.573.8133
Web:www.microbe.com

SITE LOGIC Report

Next Generation Sequencing (NGS) Report

Contact: Anita Dodson

Phone:

Address: CH2M HILL
5701 Cleveland Street
Suite 200
Virginia Beach, VA 23462

Email: anita.dodson@ch2m.com

MI Identifier: 052OA

Report Date: 03/01/2017

Project: SLOP ESTCP Study
Comments:

Sample Overview

Table 1: Sample information for 052OA.

MI Identifier	Sample Name	Sample Date	Reads Passing Quality Filtering	% Reads Classified to Genus
052OA-1	SLOP-TW03-012017	01/23/2017	478,745	94.0%
052OA-2	SLOP-MW119-012017	01/23/2017	389,203	91.9%
052OA-3	SLOP-TW05-012017	01/24/2017	1,713	53.0%
052OA-4	SLOP-TW06-012017	01/24/2017	477,859	96.4%
052OA-5	SLOP-TW02-012017	01/24/2017	338,337	95.3%
052OA-6	SLOP-TW01-012017	01/25/2017	583,516	90.8%
052OA-7	SLOP-TW04-012017	01/25/2017	530,469	98.0%

Table 2: Genus diversity indices for 052OA. Please refer to the Interpretation section for more information on what these diversity indices mean.

MI Identifier	Sample Name	Shannon	Simpson	Chao1 Predicted Genera	Total Genera Observed	Total Eubacteria (cells/mL)
052OA-1	SLOP-TW03-012017	2.1	0.63	480	459	1.19e+04
052OA-2	SLOP-MW119-012017	2.5	0.67	700	592	7.25e+06
052OA-3	SLOP-TW05-012017	3.8	0.92	280	148	3.56e+03
052OA-4	SLOP-TW06-012017	2.3	0.84	480	411	1.46e+04
052OA-5	SLOP-TW02-012017	2	0.73	530	433	7.76e+05
052OA-6	SLOP-TW01-012017	3	0.86	630	548	6.56e+05
052OA-7	SLOP-TW04-012017	1.1	0.41	540	467	1.60e+05

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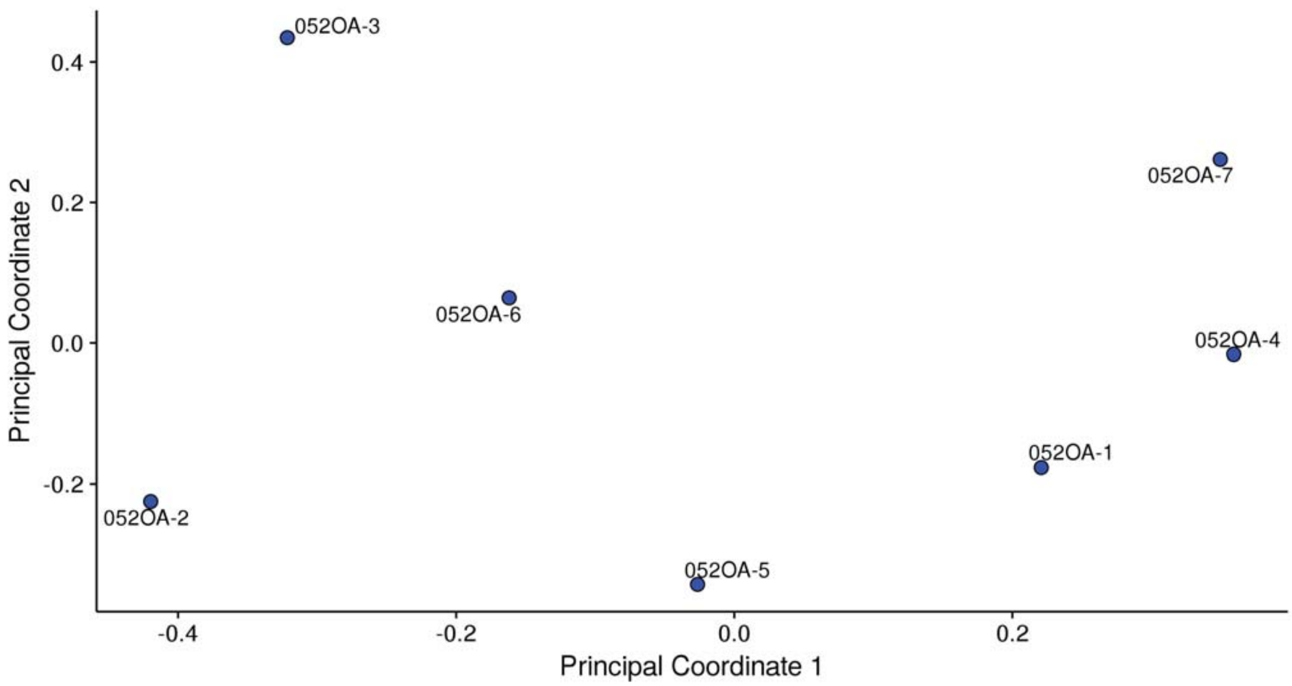

Figure 1: Principal Coordinate Analysis. This scatterplot shows a Principal Coordinate Analysis (PCoA) of the normalized relative abundance of all samples at the genus-level classifications. Increasing distance between sample points on this plot indicate increasing dissimilarity between bacterial populations in the samples.

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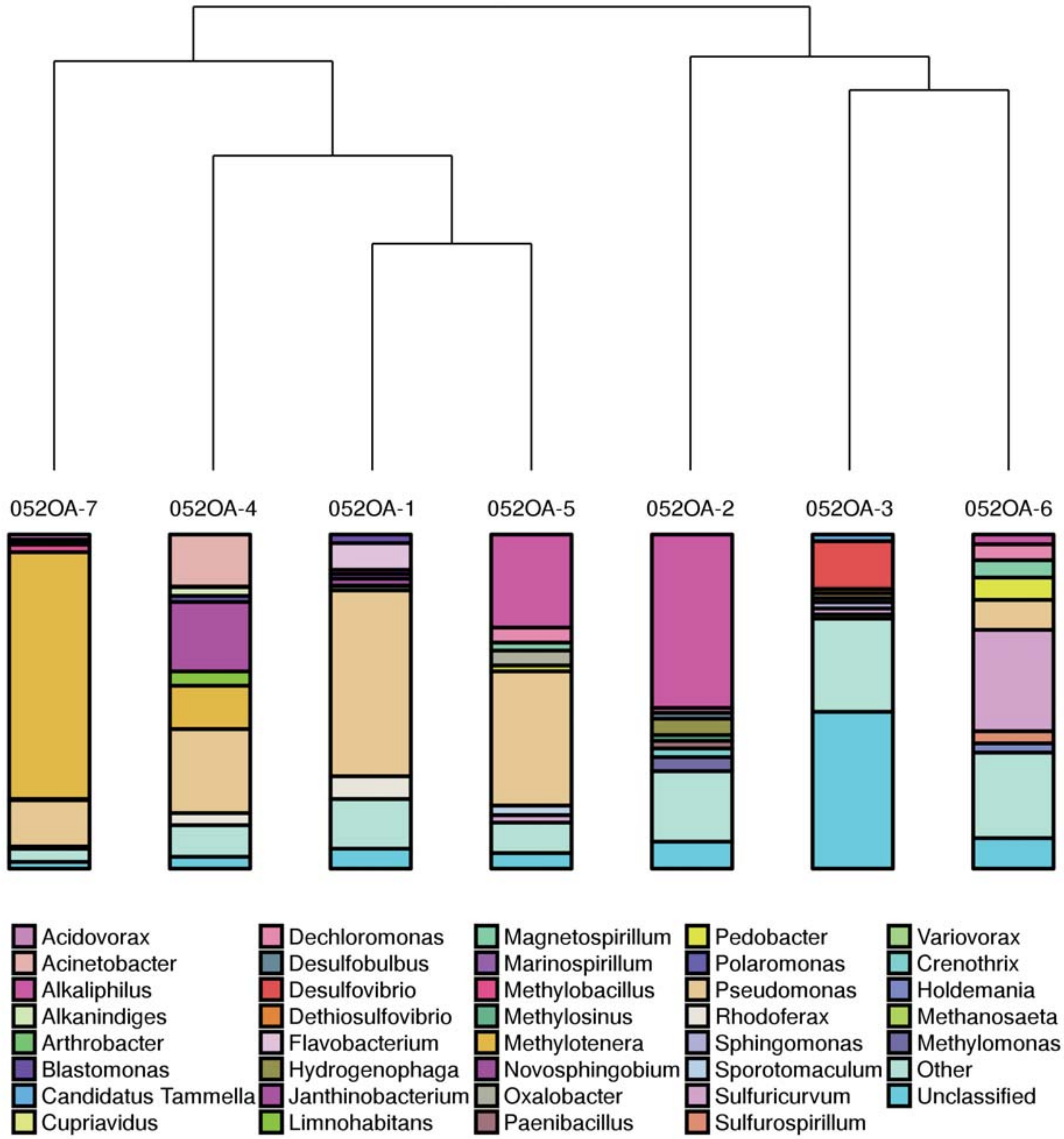

Figure 2: Hierachical Clustering Dendrogram. This dendrogram shows a hierarchical clustering of samples based on genus-level classifications. Branch length is representative of relatedness between samples. The barchart beneath each sample show the relative abundance of the top 8 genus-level classifications, along with all other classified and unclassifed genera. See the following detailed analysis by sample to identify the dominant genera in each sample.

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Table 3: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
478,745	438,178	91.5%

Table 4: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	430,354	98.2%
Phylum	428,628	97.8%
Class	426,659	97.4%
Order	423,146	96.6%
Family	421,110	96.1%
Genus	411,980	94.0%
Species	242,549	55.4%

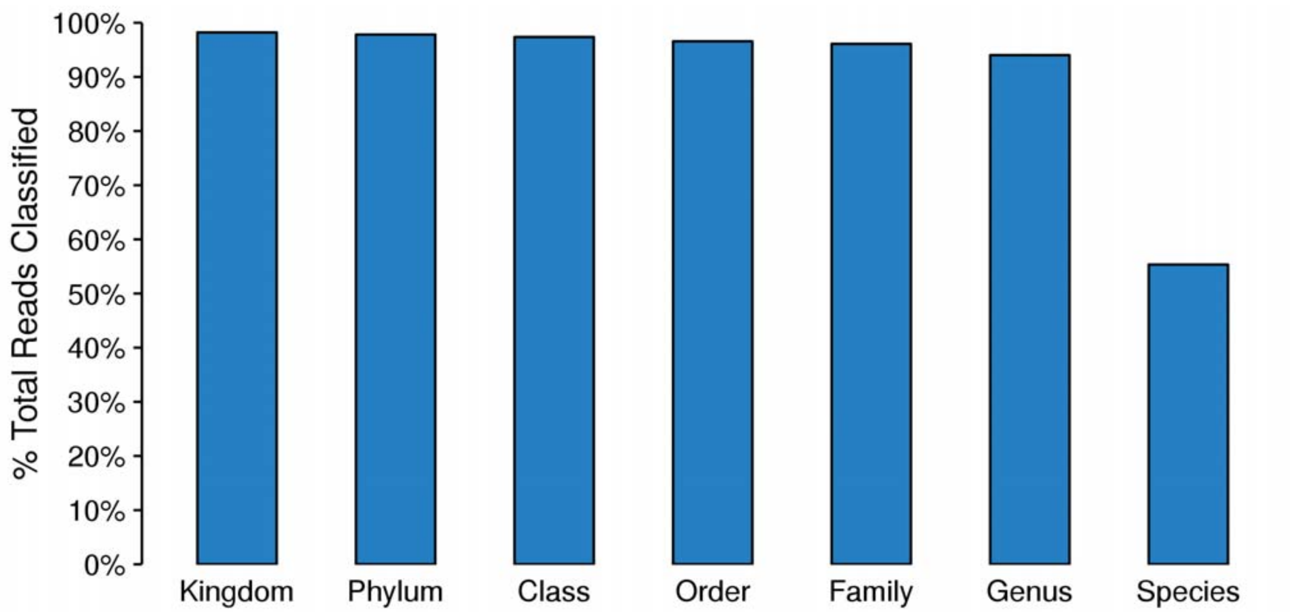

Figure 3: Classification Rate by Taxonomic Level

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SLOP-TW03-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 5: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	375,539	85.7%
Bacteroidetes	43,936	10.0%
Unclassified at Phylum level	9,550	2.2%
Firmicutes	5,059	1.1%
Actinobacteria	878	0.2%
Caldithrix	820	0.2%
Cyanobacteria	347	0.1%
Verrucomicrobia	253	0.1%

Total Phylum-level Taxonomic Categories Identified: 25. This table shows the top 8 of 25 classifications. The 8 phyla shown in this table account for 99.6% of all observed classifications.

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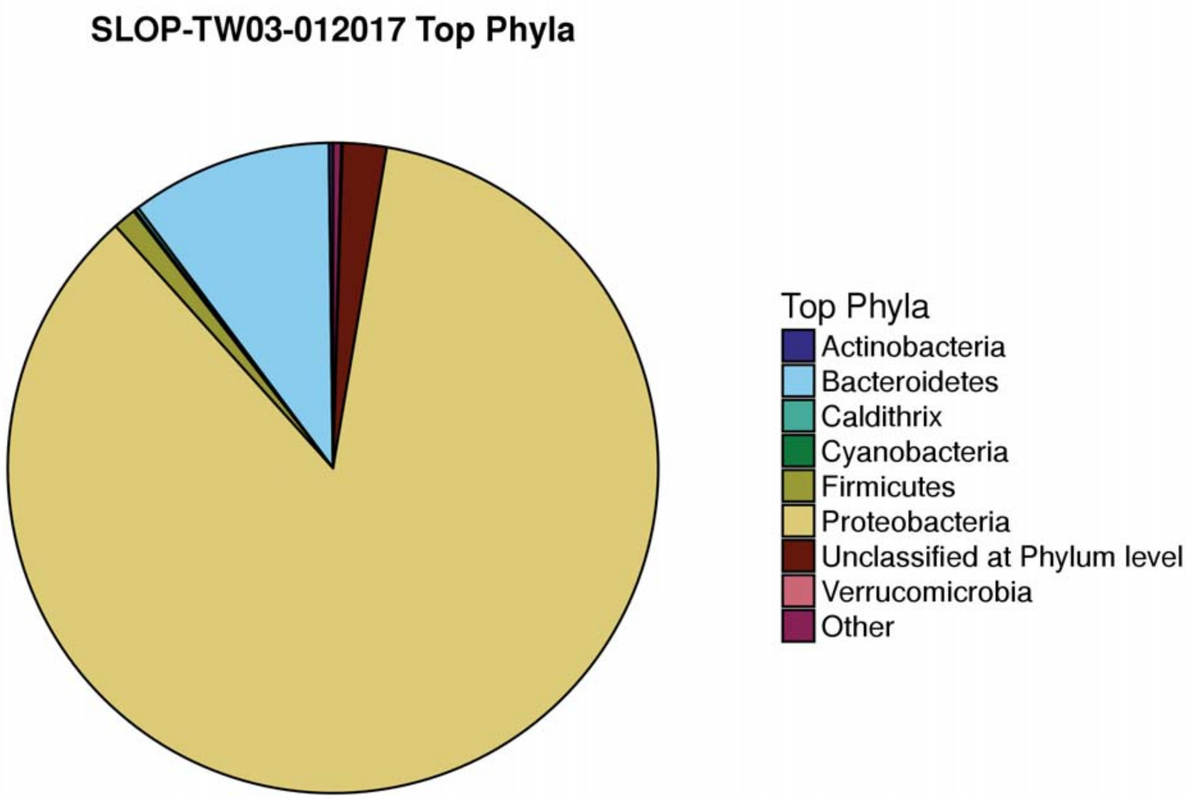

Figure 4: Top Phylum Classification Results

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Table 6: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Blastomonas	11,289	2.6%	This genus includes strictly aerobic, photosynthetic bacteria. Organisms are chemoorganotrophic and facultatively photoorganoheterotrophic.
Flavobacterium	35,007	8.0%	Flavobacterium degrades biopolymers such as chitin and cellulose. This genus is aerobic and is widely distributed in soil and water.
Marinospirillum	6,000	1.4%	This genus of halophilic, Gram-negative, hetertrophic bacteria are aerobic and can live in saline conditions.
Novosphingobium	9,043	2.1%	This is a genus that can degrade aromatic compounds such as phenol, aniline, nitrobenzene, and phenanthrene.
Oxalobacter	5,728	1.3%	These anaerobic bacteria are found in the gastrointestinal tracts of vertebrates and can degrade oxalic acid.
Pseudomonas	244,068	55.7%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Rhodoferax	29,855	6.8%	This genus is typically found in well-lit stagnant water and can thrive in aerobic or anaerobic environments using many substrates as carbon sources.
Unclassified at Genus level	26,198	6.0%	

Total Genus-level Taxonomic Categories Identified: 460. This table shows the top 8 of 460 classifications. The 8 genera shown in this table account for 83.8% of all observed classifications.

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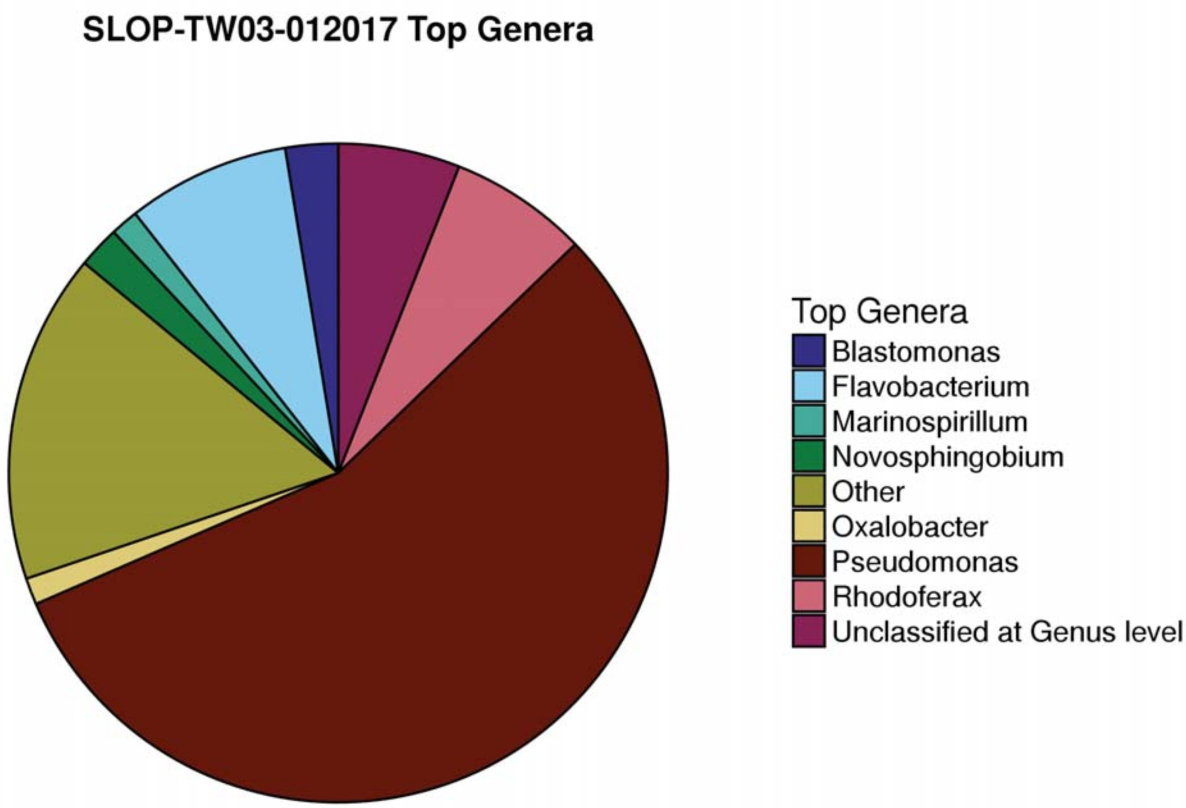

Figure 5: Top Genus Classification Results

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Results for SLOP-MW119-012017

Table 7: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
389,203	359,178	92.3%

Table 8: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	358,962	99.9%
Phylum	352,749	98.2%
Class	348,366	97.0%
Order	345,388	96.2%
Family	339,723	94.6%
Genus	330,107	91.9%
Species	242,543	67.5%

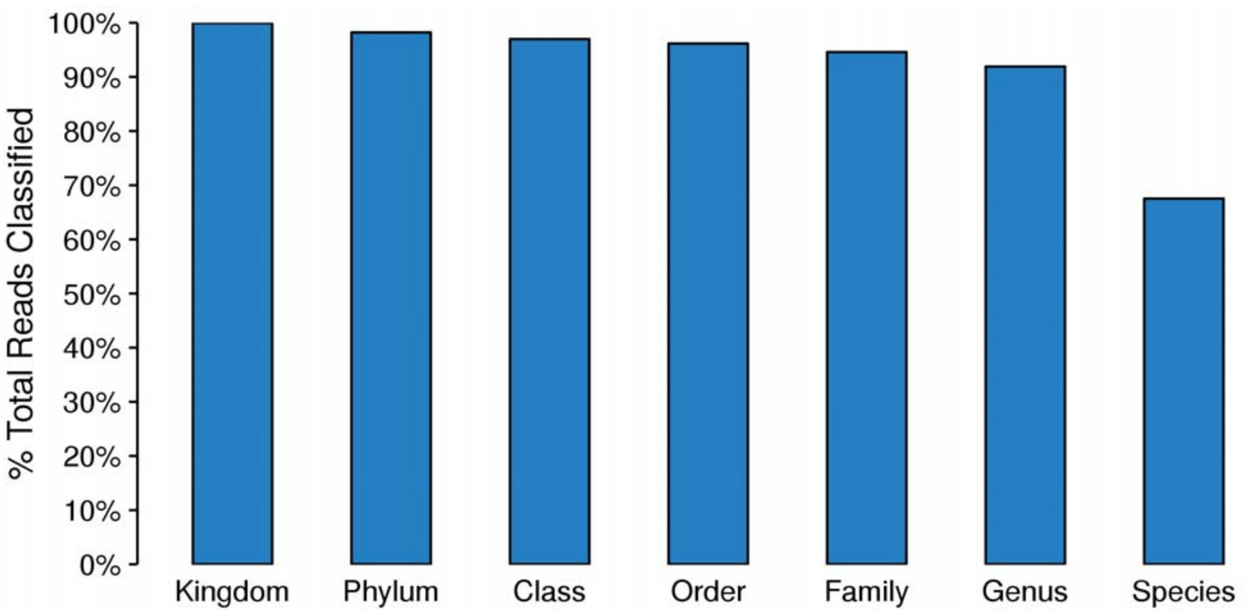

Figure 6: Classification Rate by Taxonomic Level

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SLOP-MW119-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 9: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Firmicutes	215,516	60.0%
Proteobacteria	104,184	29.0%
Bacteroidetes	8,323	2.3%
Euryarchaeota	6,618	1.8%
Unclassified at Phylum level	6,429	1.8%
Actinobacteria	5,294	1.5%
Tenericutes	3,796	1.1%
Cyanobacteria	2,209	0.6%

Total Phylum-level Taxonomic Categories Identified: 30. This table shows the top 8 of 30 classifications. The 8 phyla shown in this table account for 98.1% of all observed classifications.

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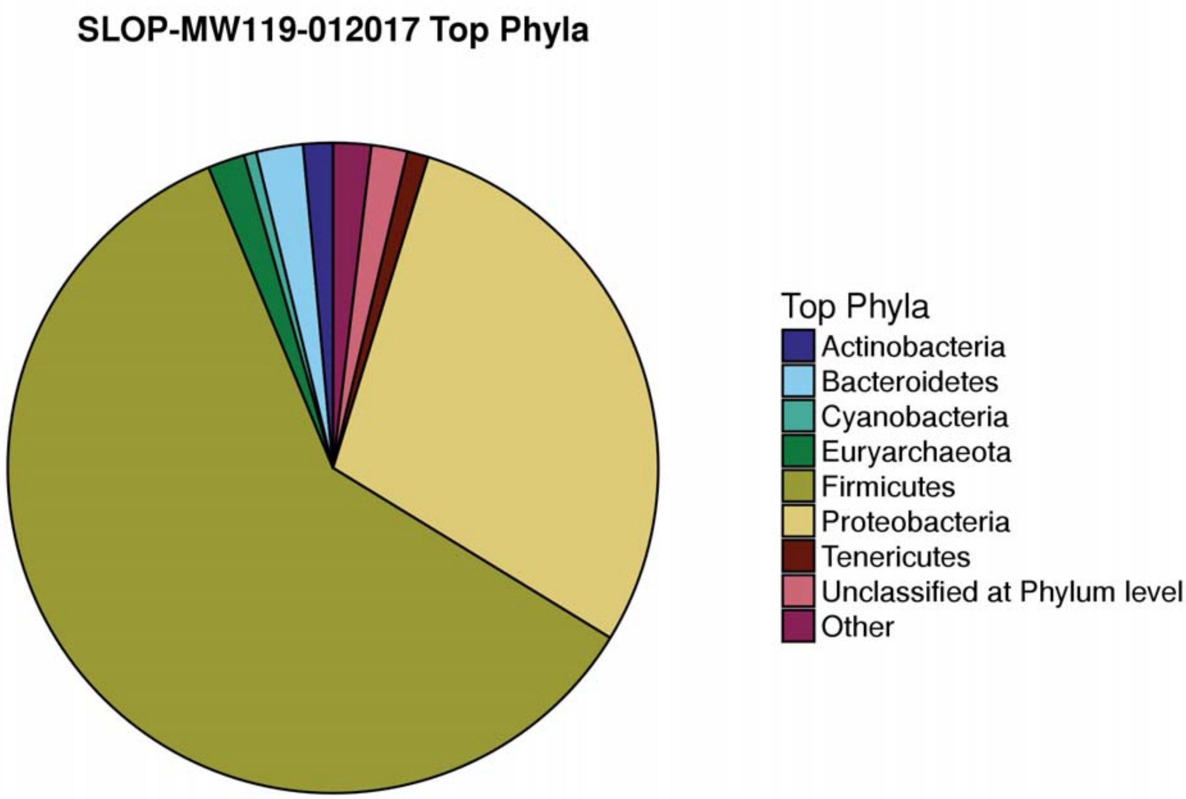

Figure 7: Top Phylum Classification Results

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Table 10: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Alkaliphilus	186,025	51.8%	These alkaliphilic fermenters can be found in soil. Alkaliphilus metalliredigens is capable of reducing Fe (III).
Crenothrix	9,397	2.6%	Crenothrix is a filamentous methane oxidizer.
Desulfobulbus	6,423	1.8%	This genus contains strictly anaerobic sulfate reducers commonly isolated in anaerobic parts of freshwater, brackish water, marine habitats, rumen contents, animal dung, and sewage sludge.
Hydrogenophaga	17,581	4.9%	Some species can degrade methyl-tert-butyl ether, and some can oxidize carbon monoxide.
Methylomonas	15,037	4.2%	Methane, methanol and formaldehyde are the only known sources of energy and carbon for this organism.
Methylosinus	6,235	1.7%	Methylosinus is a methanotroph which oxidatively degrades chlorinated ethenes.
Paenibacillus	8,146	2.3%	This is a genus of facultative anaerobic, endospore-forming bacteria commonly isolated from a variety of environments, such as soil, water, rhizosphere, insect larvae, and clinical samples.
Unclassified at Genus level	29,071	8.1%	

Total Genus-level Taxonomic Categories Identified: 593. This table shows the top 8 of 593 classifications. The 8 genera shown in this table account for 77.4% of all observed classifications.

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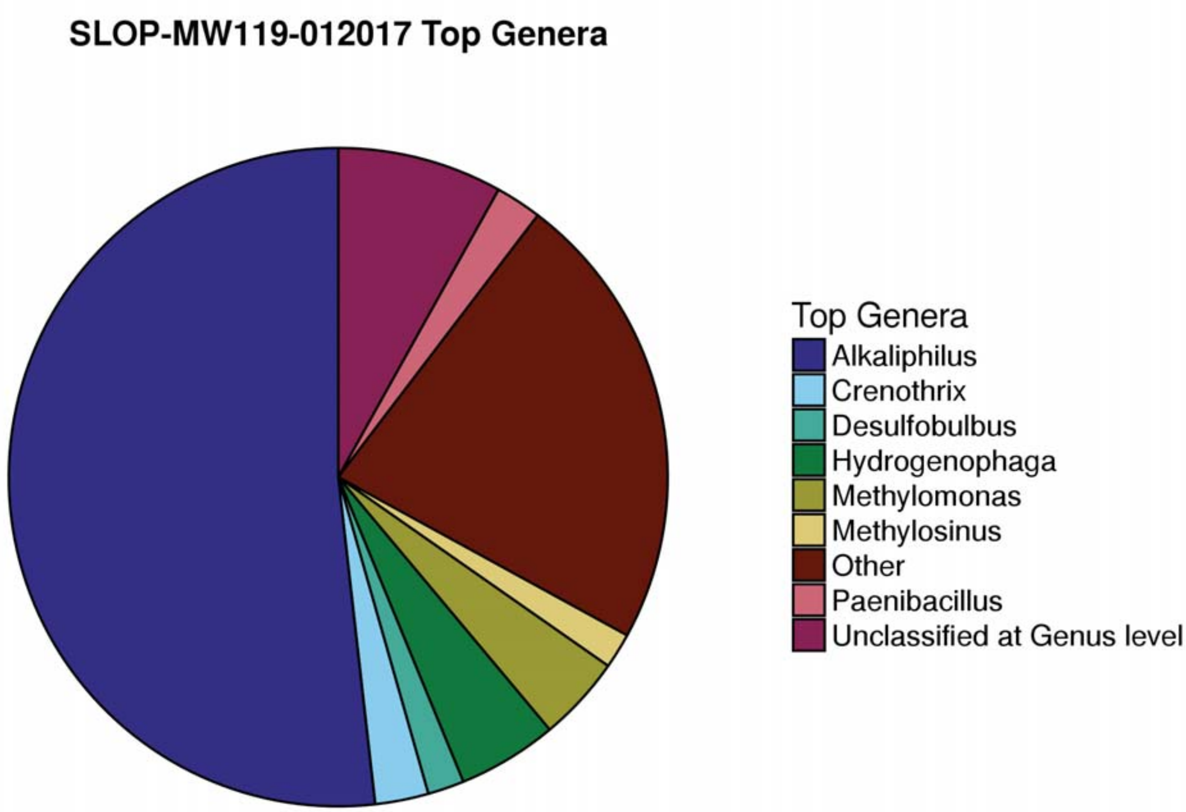

Figure 8: Top Genus Classification Results

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Results for SLOP-TW05-012017

Table 11: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
1,713	1,059	61.8%

Table 12: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	654	61.8%
Phylum	636	60.1%
Class	617	58.3%
Order	610	57.6%
Family	590	55.7%
Genus	561	53.0%
Species	352	33.2%

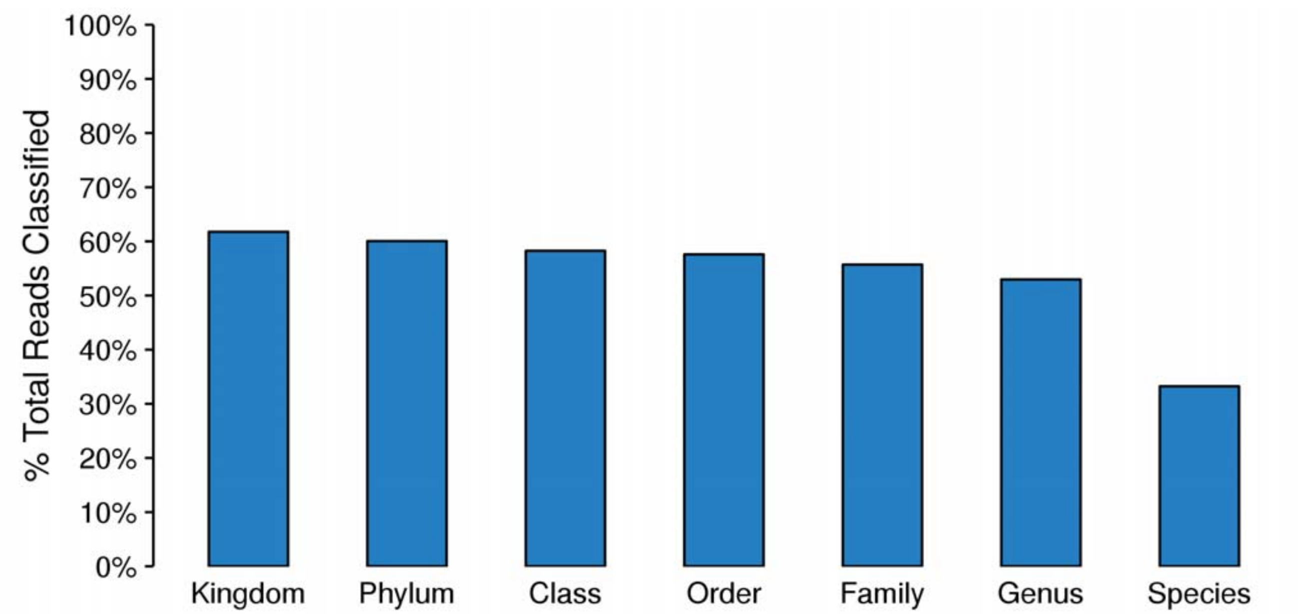

Figure 9: Classification Rate by Taxonomic Level

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SLOP-TW05-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 13: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Unclassified at Phylum level	423	39.9%
Proteobacteria	422	39.9%
Firmicutes	57	5.4%
Synergistetes	42	4.0%
Bacteroidetes	31	2.9%
Actinobacteria	28	2.6%
Euryarchaeota	16	1.5%
Thermotogae	11	1.0%

Total Phylum-level Taxonomic Categories Identified: 22. This table shows the top 8 of 22 classifications. The 8 phyla shown in this table account for 97.3% of all observed classifications.

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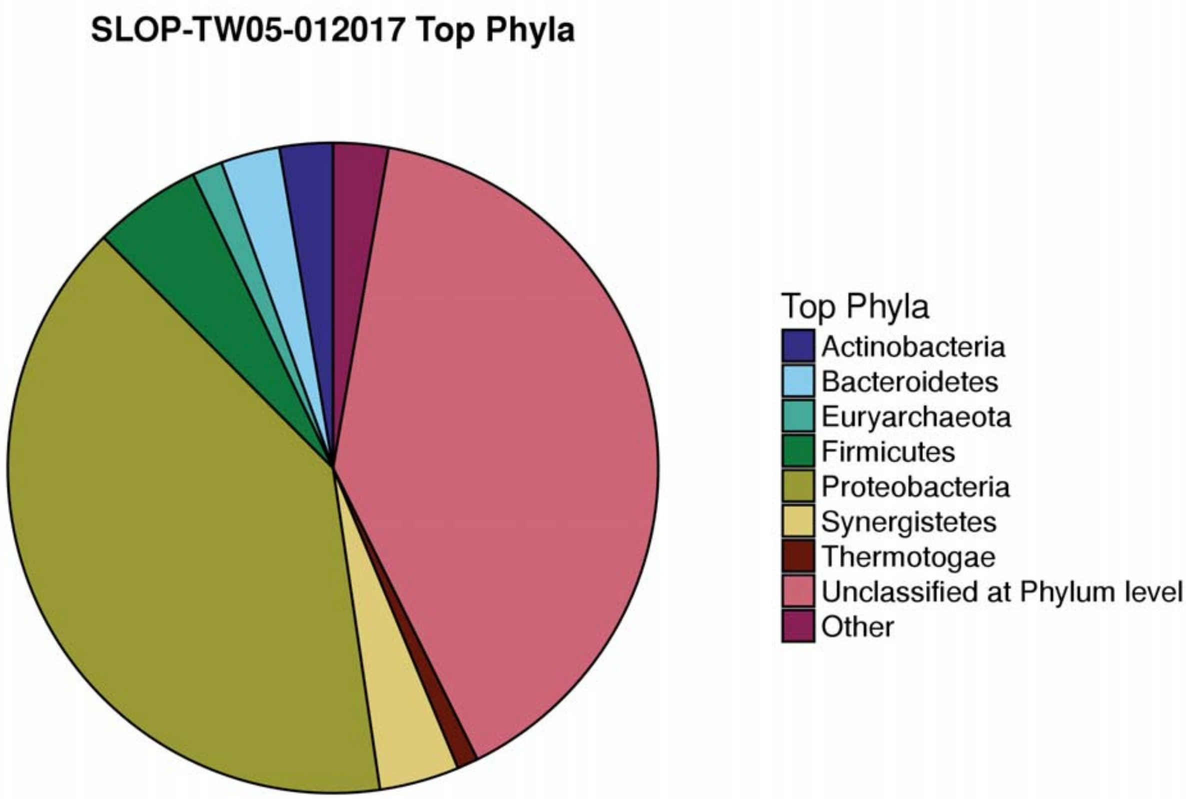

Figure 10: Top Phylum Classification Results

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Table 14: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Candidatus Tammella	21	2.0%	These rod-shaped ectosymbionts has been isolated from termite guts.
Desulfovibrio	150	14.2%	These halophilic sulfate-reducers are found in sediment of lakes, brackish water and marine environments. Desulfovibrio is also commonly found in industrial water systems resulting in biofouling biocorrosion. Desulfovibrio has been implicated in the corrosion of various metals, including carbon steel, stainless steel, galvanized steel, and copper alloys.
Dethiosulfovibrio	14	1.3%	Members of this genus are anaerobic, slightly halophilic, and capable of reducing sulfur and thiosulfate.
Methanosaeta	13	1.2%	These organisms are thermophilic, obligately-aceticlastic, methane-producing archaea.
Pseudomonas	15	1.4%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Sphingomonas	20	1.9%	These aerobic chemoorganotrophs have been shown to degrade toluene, naphthalene, and other aromatic compounds. This non-spore forming, chemoheterotrophic genus is found in many different environments.
Sulfuricurvum	19	1.8%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Unclassified at Genus level	498	47.0%	

Total Genus-level Taxonomic Categories Identified: 149. This table shows the top 8 of 149 classifications. The 8 genera shown in this table account for 70.8% of all observed classifications.

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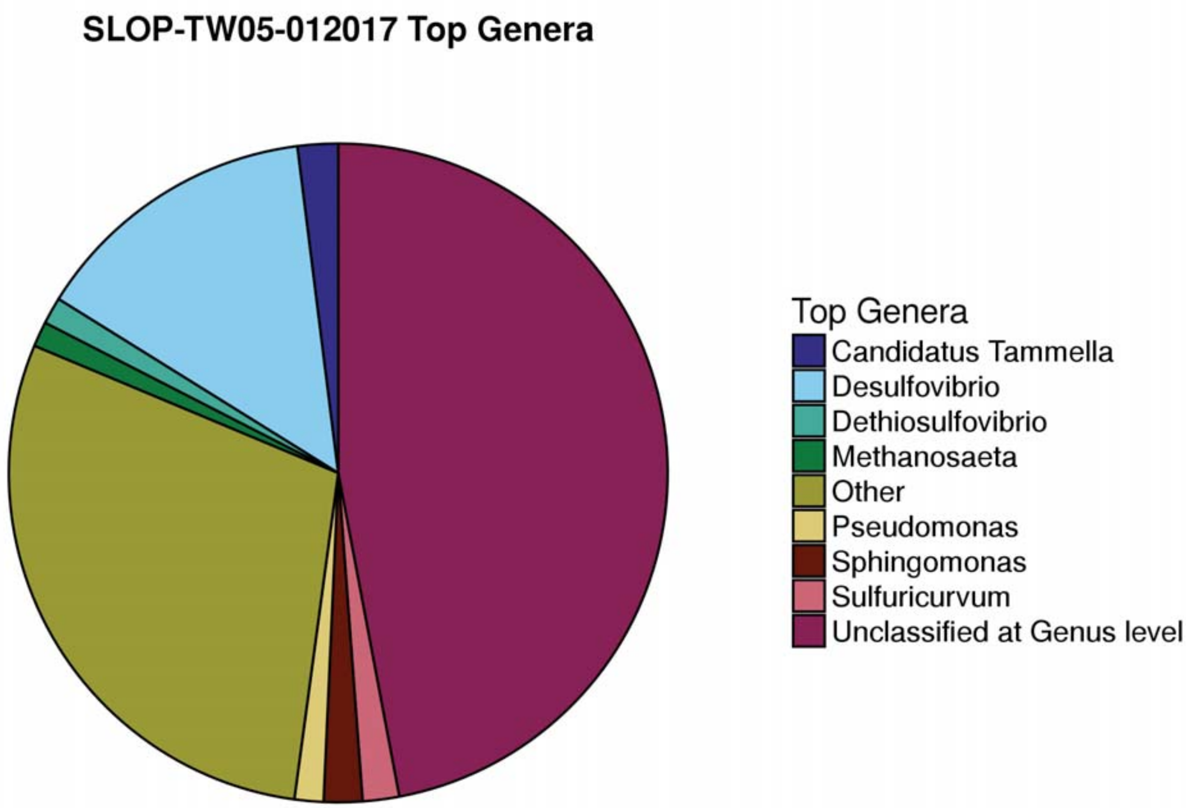

Figure 11: Top Genus Classification Results

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Results for SLOP-TW06-012017

Table 15: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
477,859	438,413	91.8%

Table 16: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	435,979	99.4%
Phylum	434,591	99.1%
Class	433,714	98.9%
Order	431,643	98.5%
Family	430,602	98.2%
Genus	422,771	96.4%
Species	235,356	53.7%

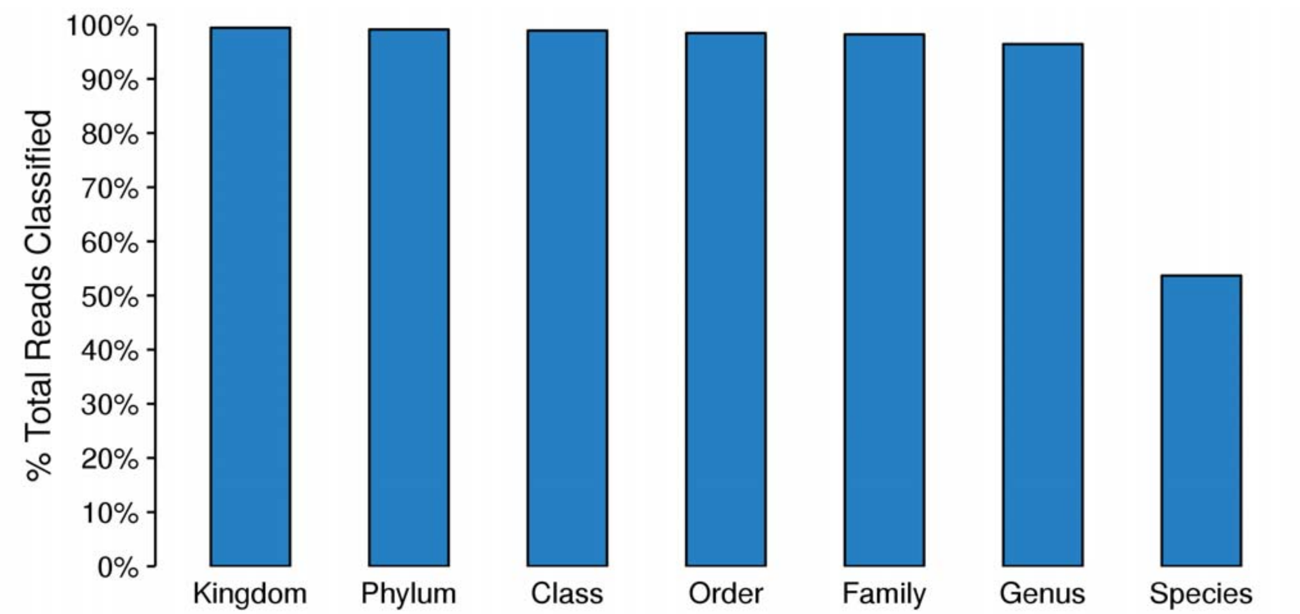

Figure 12: Classification Rate by Taxonomic Level

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SLOP-TW06-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 17: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	421,459	96.1%
Bacteroidetes	6,812	1.6%
Unclassified at Phylum level	3,822	0.9%
Firmicutes	3,037	0.7%
Actinobacteria	1,020	0.2%
Chloroflexi	325	0.1%
Fusobacteria	284	0.1%
Thermodesulfobacteria	182	0.0%

Total Phylum-level Taxonomic Categories Identified: 26. This table shows the top 8 of 26 classifications. The 8 phyla shown in this table account for 99.6% of all observed classifications.

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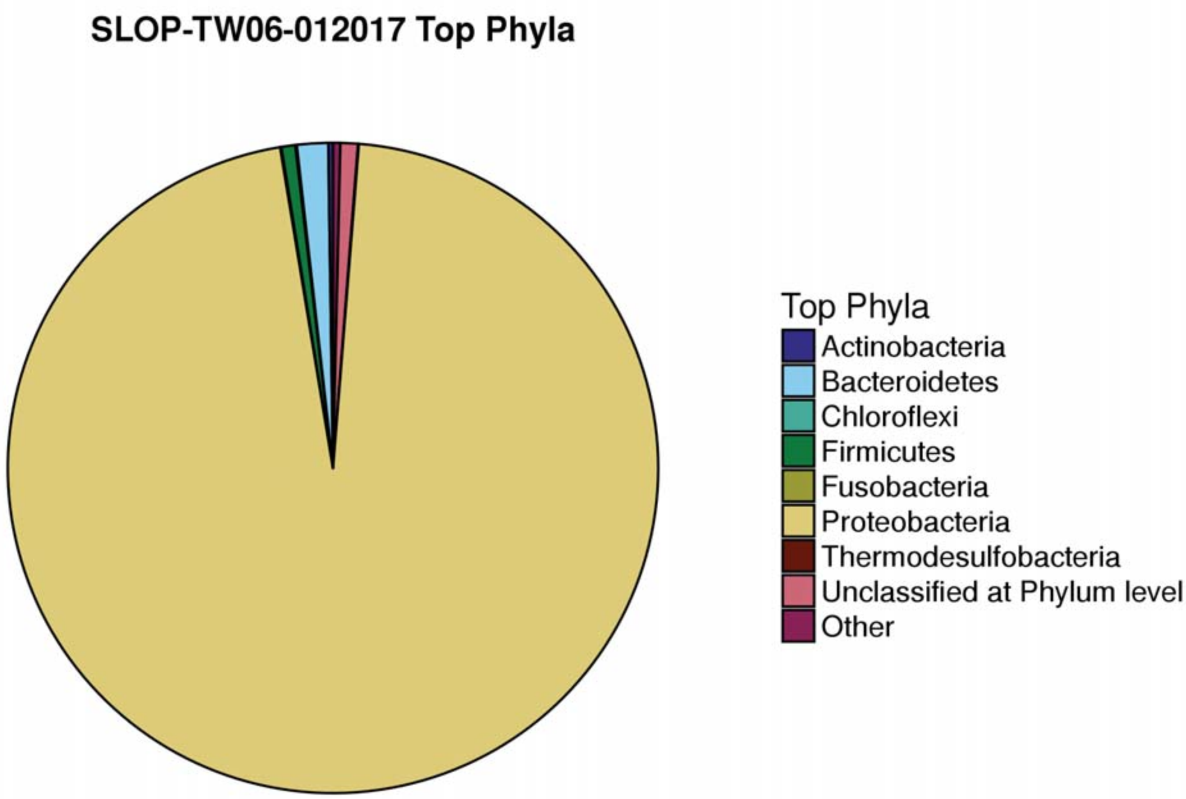

Figure 13: Top Phylum Classification Results

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Table 18: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Acinetobacter	68,322	15.6%	These strictly aerobic microorganisms are strictly aerobic, and contibute to mineralization of multiple compounds, including aromatics.
Alkanindiges	11,566	2.6%	This genus includes aerobic, alkane-degrading microorganisms isolated from oilfield soils.
Janthinobacterium	91,160	20.8%	This genus of bacteria can tolerate a variety of environmental stressors and demonstrates diverse metabolic abilities.
Limnohabitans	18,775	4.3%	These freshwater bacteria are free-living, globally distributed, and have an important role in carbon flow to higher trophic levels. Members are generally Gram-negative, aerobic, and catalase- and oxidase-positive.
Methylotenera	57,005	13.0%	Members of this genus can utilize methylamine as a single source of energy, carbon, and nitrogen.
Pseudomonas	110,423	25.2%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Rhodoferax	15,880	3.6%	This genus is typically found in well-lit stagnant water and can thrive in aerobic or anaerobic environments using many substrates as carbon sources.
Unclassified at Genus level	15,642	3.6%	

Total Genus-level Taxonomic Categories Identified: 412. This table shows the top 8 of 412 classifications. The 8 genera shown in this table account for 88.7% of all observed classifications.

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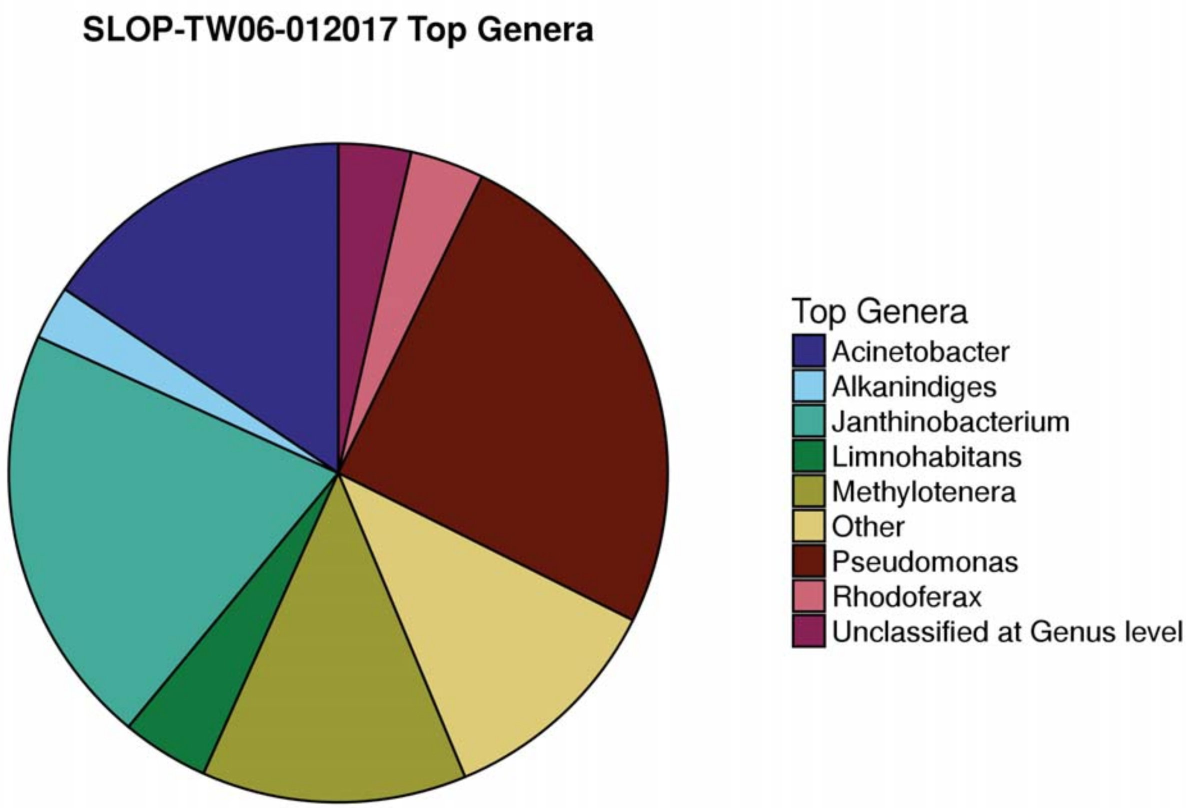

Figure 14: Top Genus Classification Results

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Results for SLOP-TW02-012017

Table 19: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
338,337	311,924	92.2%

Table 20: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	311,765	100.0%
Phylum	310,154	99.4%
Class	308,641	99.0%
Order	306,547	98.3%
Family	301,272	96.6%
Genus	297,341	95.3%
Species	215,847	69.2%

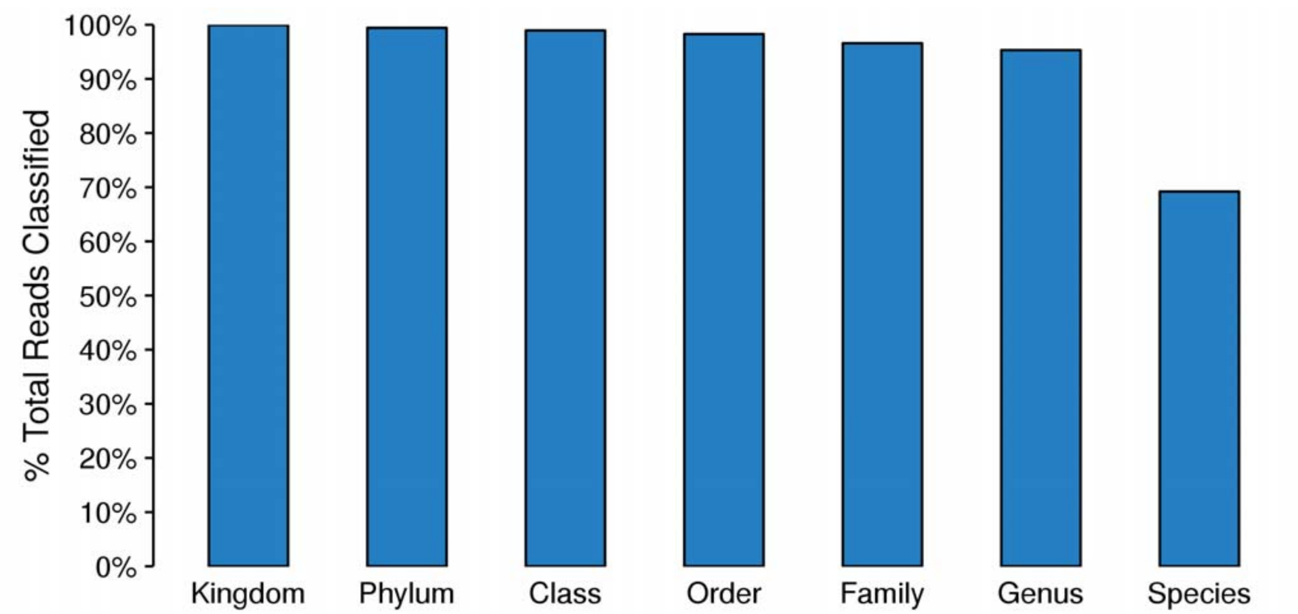

Figure 15: Classification Rate by Taxonomic Level

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SLOP-TW02-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 21: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	193,495	62.0%
Firmicutes	108,086	34.6%
Bacteroidetes	6,508	2.1%
Unclassified at Phylum level	1,770	0.6%
Actinobacteria	750	0.2%
Acidobacteria	424	0.1%
Spirochaetes	218	0.1%
Euryarchaeota	168	0.0%

Total Phylum-level Taxonomic Categories Identified: 25. This table shows the top 8 of 25 classifications. The 8 phyla shown in this table account for 99.8% of all observed classifications.

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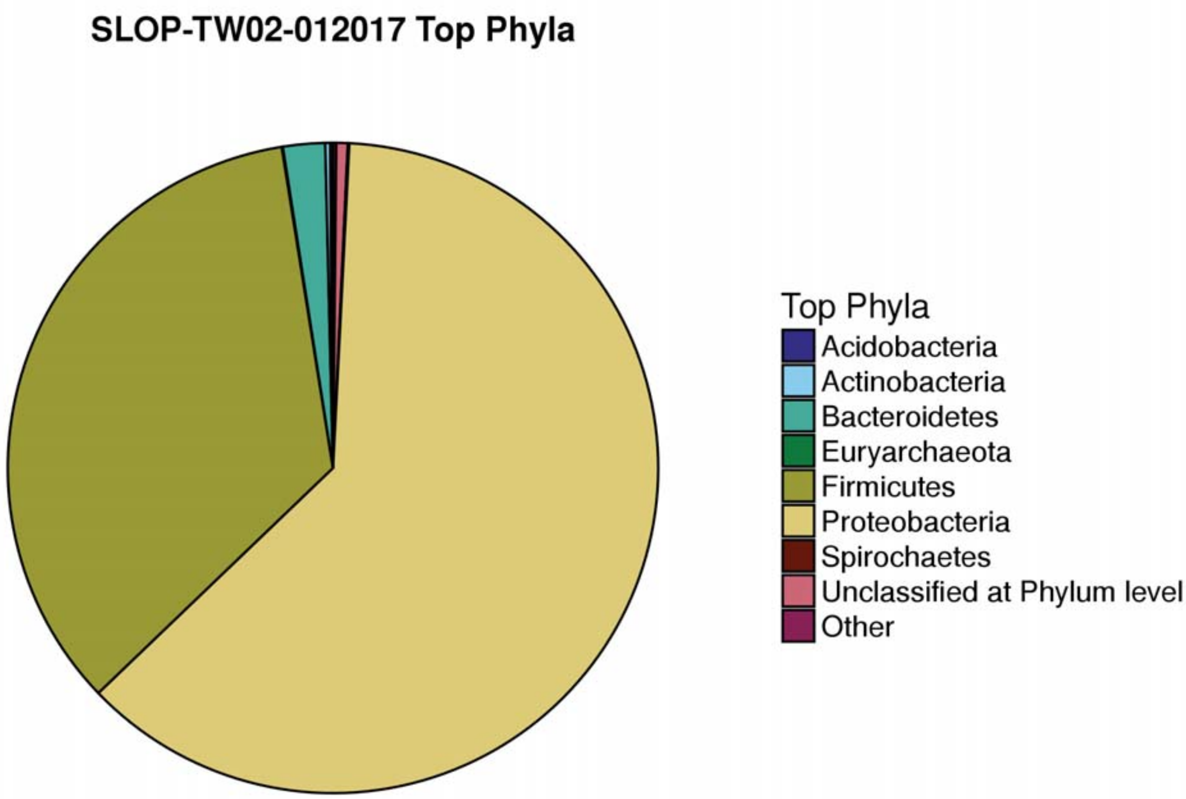

Figure 16: Top Phylum Classification Results

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Table 22: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Alkaliphilus	86,410	27.7%	These alkaliphilic fermenters can be found in soil. Alkaliphilus metalliredigens is capable of reducing Fe (III).
Dechloromonas	14,025	4.5%	Some species, present in aquatic and sediment habitats, can oxidize aromatic compounds such as toluene, benzoate, and chlorobenzoate. They can also reduce perchlorate and oxidize iron and H2S.
Magnetospirillum	7,527	2.4%	This gram-negative, microaerophilic genus of magnetotactic bacteria grow in the oxic-anoxic interface.
Oxalobacter	13,916	4.5%	These anaerobic bacteria are found in the gastrointestinal tracts of vertebrates and can degrade oxalic acid.
Pseudomonas	125,535	40.2%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Sporotomaculum	8,995	2.9%	These strict anaerobes possess fermentative metabolism without using inorganic electron acceptors.
Sulfuricurvum	6,990	2.2%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Unclassified at Genus level	14,583	4.7%	

Total Genus-level Taxonomic Categories Identified: 434. This table shows the top 8 of 434 classifications. The 8 genera shown in this table account for 89.1% of all observed classifications.

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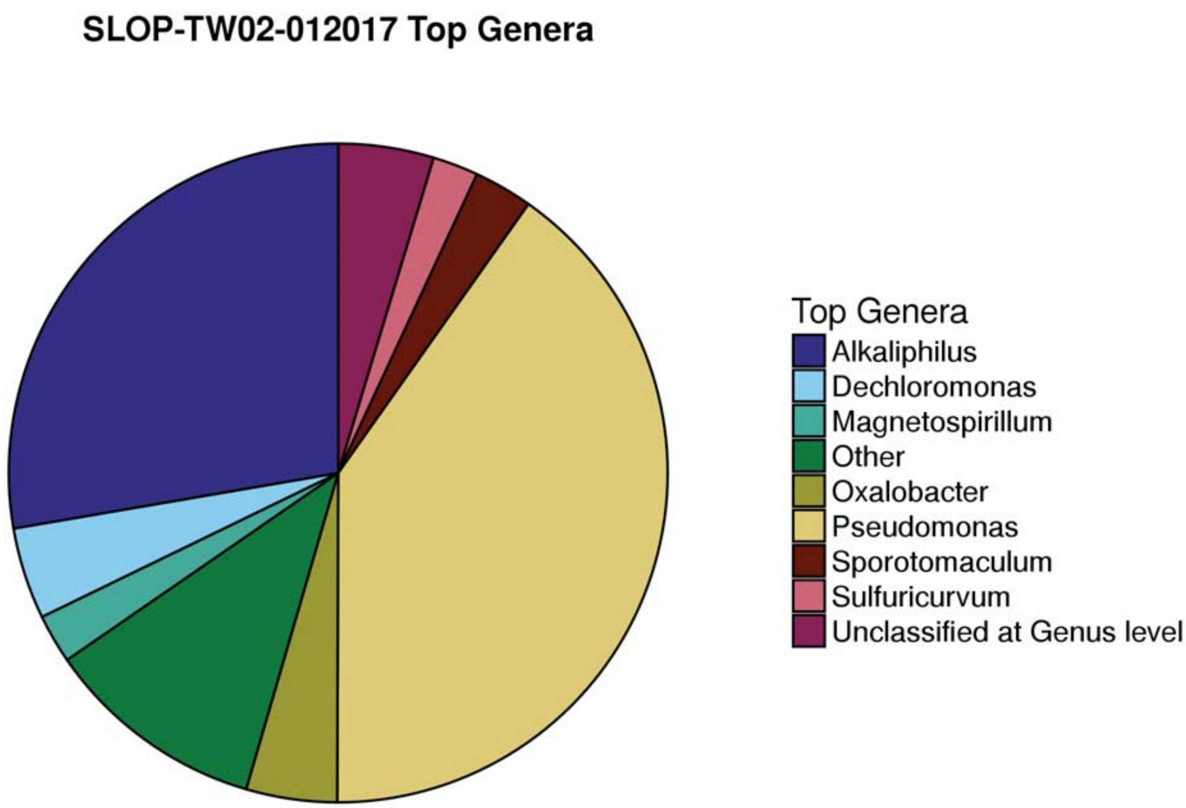

Figure 17: Top Genus Classification Results

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Results for SLOP-TW01-012017

Table 23: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
583,516	536,873	92.0%

Table 24: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	536,653	100.0%
Phylum	525,767	97.9%
Class	514,293	95.8%
Order	508,096	94.6%
Family	504,105	93.9%
Genus	487,736	90.8%
Species	325,236	60.6%

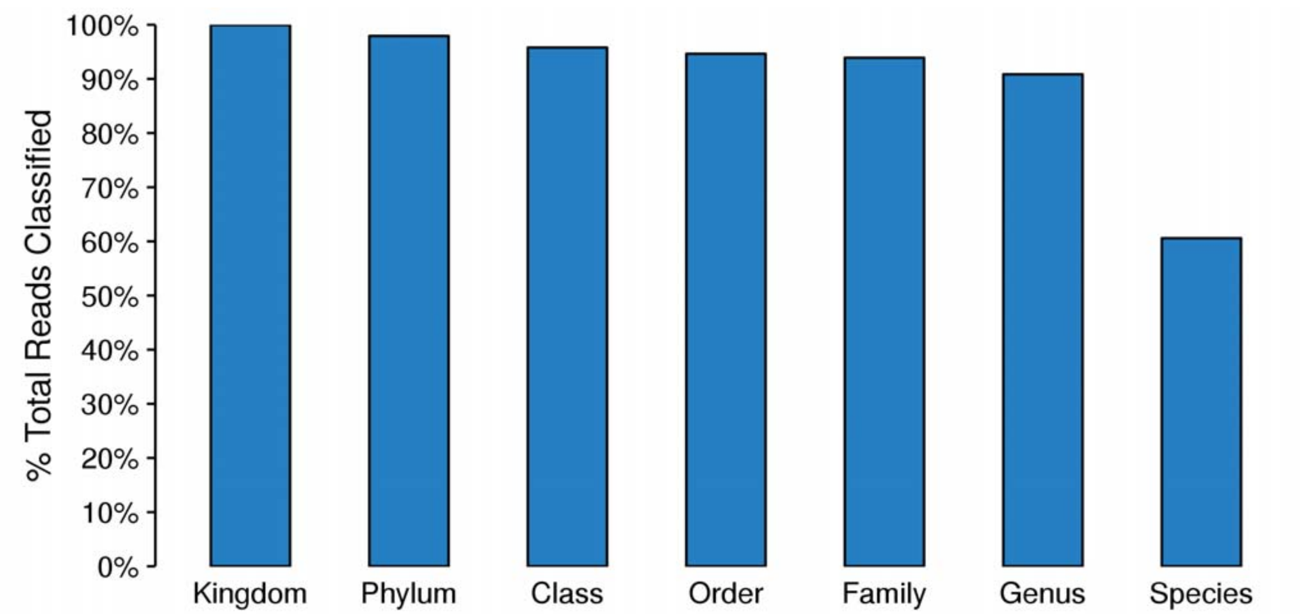

Figure 18: Classification Rate by Taxonomic Level

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SLOP-TW01-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 25: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	412,295	76.8%
Firmicutes	68,816	12.8%
Bacteroidetes	39,517	7.4%
Unclassified at Phylum level	11,106	2.1%
Actinobacteria	1,187	0.2%
Acidobacteria	1,176	0.2%
Tenericutes	914	0.2%
Verrucomicrobia	298	0.1%

Total Phylum-level Taxonomic Categories Identified: 28. This table shows the top 8 of 28 classifications. The 8 phyla shown in this table account for 99.7% of all observed classifications.

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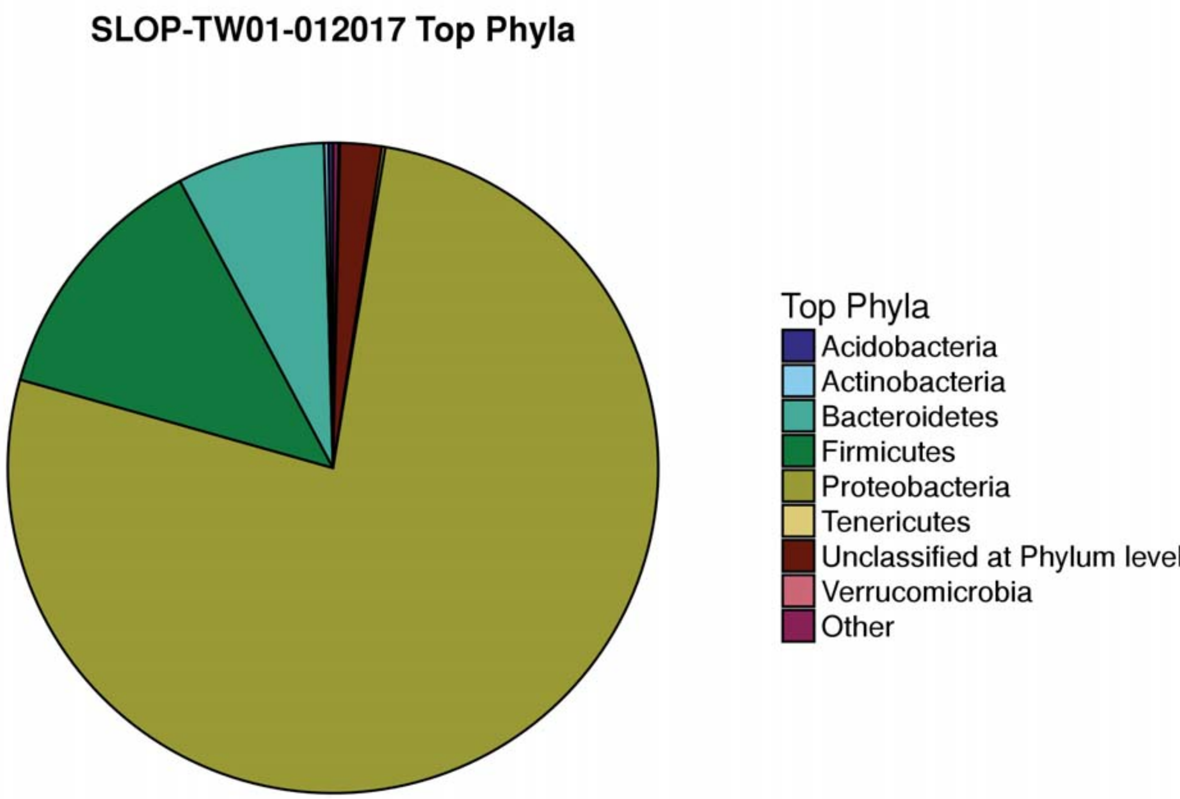

Figure 19: Top Phylum Classification Results

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Table 26: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Alkaliphilus	15,653	2.9%	These alkaliphilic fermenters can be found in soil. Alkaliphilus metalliredigens is capable of reducing Fe (III).
Dechloromonas	25,626	4.8%	Some species, present in aquatic and sediment habitats, can oxidize aromatic compounds such as toluene, benzoate, and chlorobenzoate. They can also reduce perchlorate and oxidize iron and H2S.
Magnetospirillum	27,874	5.2%	This gram-negative, microaerophilic genus of magnetotactic bacteria grow in the oxic-anoxic interface.
Pedobacter	35,115	6.5%	Pedobacter is a facultative psychrophile isolated from a variety of environments.
Pseudomonas	48,259	9.0%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Sulfuricurvum	163,126	30.4%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Sulfurospirillum	19,456	3.6%	These microaerophilic sulfur-reducing bacteria can respire PCE to cis-1,2-DCE.
Unclassified at Genus level	49,137	9.2%	

Total Genus-level Taxonomic Categories Identified: 549. This table shows the top 8 of 549 classifications. The 8 genera shown in this table account for 71.6% of all observed classifications.

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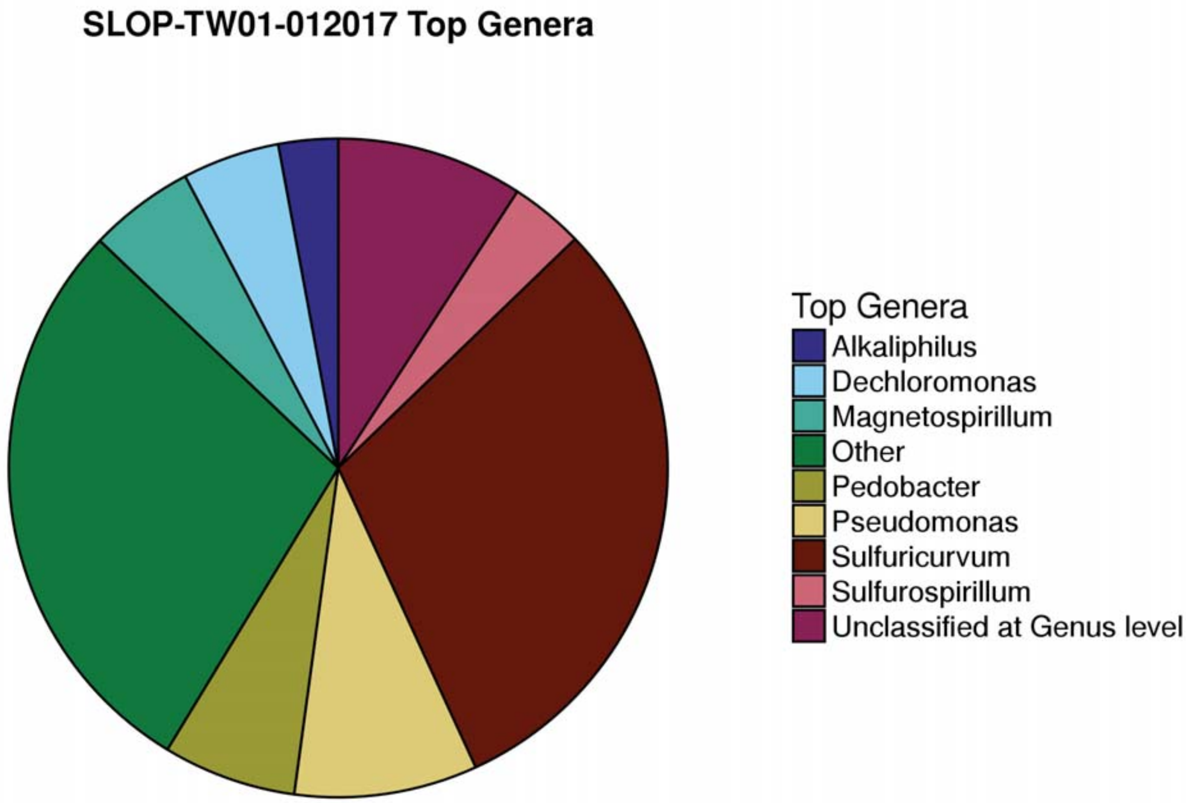

Figure 20: Top Genus Classification Results

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Results for SLOP-TW04-012017

Table 27: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
530,469	483,273	91.1%

Table 28: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	483,145	100.0%
Phylum	482,386	99.8%
Class	481,208	99.6%
Order	477,824	98.9%
Family	477,232	98.8%
Genus	473,569	98.0%
Species	131,357	27.2%

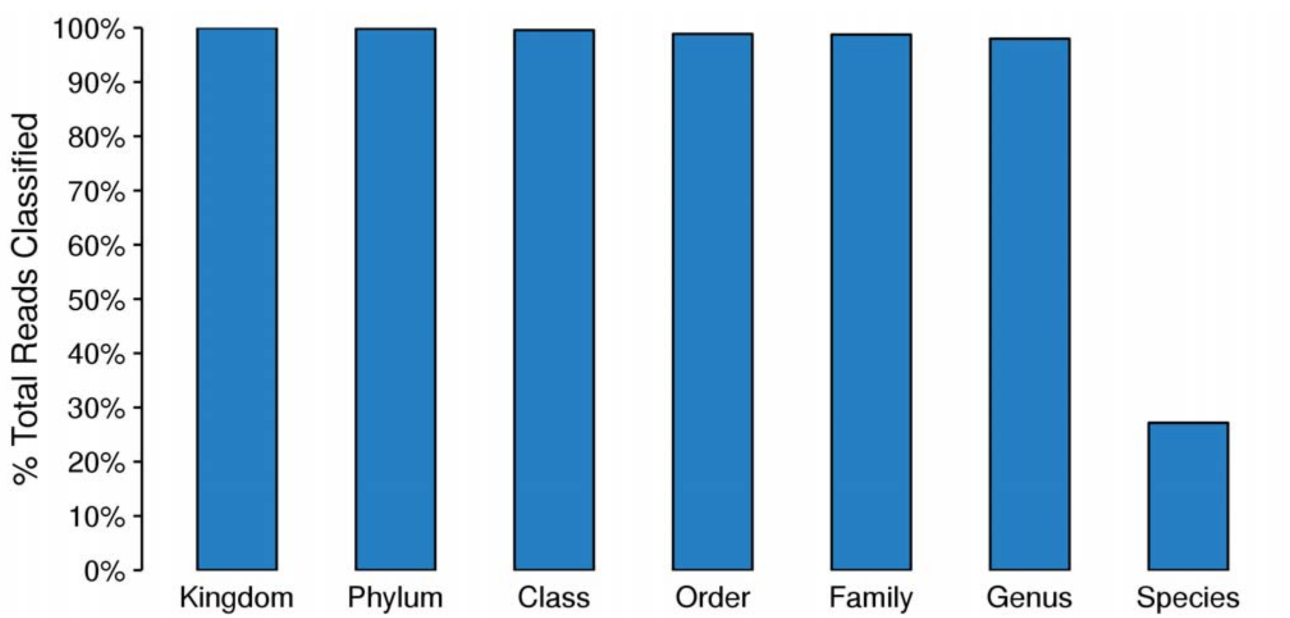

Figure 21: Classification Rate by Taxonomic Level

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SLOP-TW04-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 29: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	474,061	98.1%
Actinobacteria	4,793	1.0%
Firmicutes	1,255	0.3%
Bacteroidetes	997	0.2%
Unclassified at Phylum level	887	0.2%
Thermi	305	0.1%
Acidobacteria	229	0.0%
Nitrospirae	220	0.0%

Total Phylum-level Taxonomic Categories Identified: 27. This table shows the top 8 of 27 classifications. The 8 phyla shown in this table account for 99.9% of all observed classifications.

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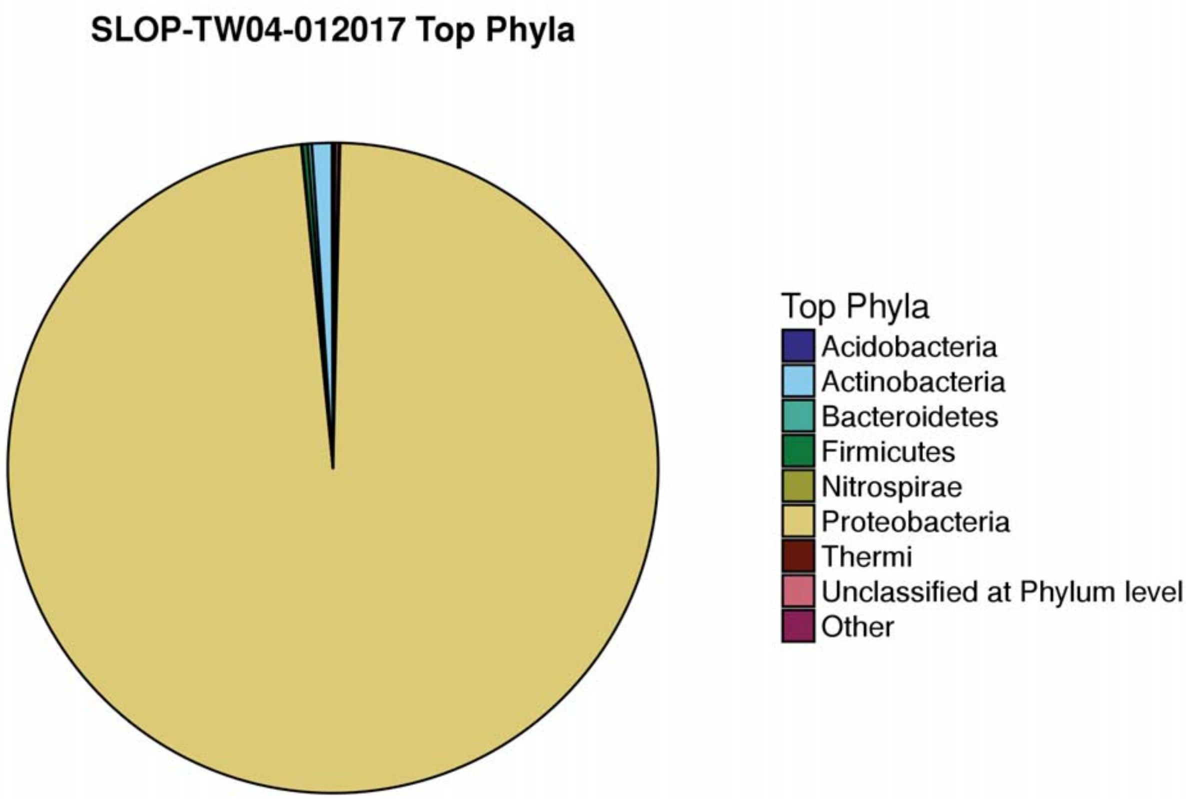

Figure 22: Top Phylum Classification Results

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Table 30: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Acidovorax	7,241	1.5%	There is evidence that Acidovorax can anaerobically degrade both benzene and nitrobenzene.
Arthrobacter	3,423	0.7%	Arthrobacter species are obligately aerobic, chemoorganotrophic soil bacteria that have been found to reduce hexavalent chromium in contaminated soil and to degrade agricultural pesticides. Their metabolism is strictly respiratory, never fermentative.
Cupriavidus	3,851	0.8%	These aerobic chemolithoautotrophs often inhabit oxic-anoxic interfaces in nature to take advantage of the hydrogen produced by anaerobic organisms while still maintaining a supply of oxygen.
Methylobacillus	11,065	2.3%	This is a methylotrophic genus of obligate methanol- and methylamine-utilizers.
Methylotenera	356,711	73.8%	Members of this genus can utilize methylamine as a single source of energy, carbon, and nitrogen.
Pseudomonas	67,149	13.9%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Unclassified at Genus level	9,704	2.0%	
Variovorax	3,230	0.7%	Members of this genus are 2, 4-dichlorophenoxyacetic acid-degrading bacteria.

Total Genus-level Taxonomic Categories Identified: 468. This table shows the top 8 of 468 classifications. The 8 genera shown in this table account for 95.7% of all observed classifications.

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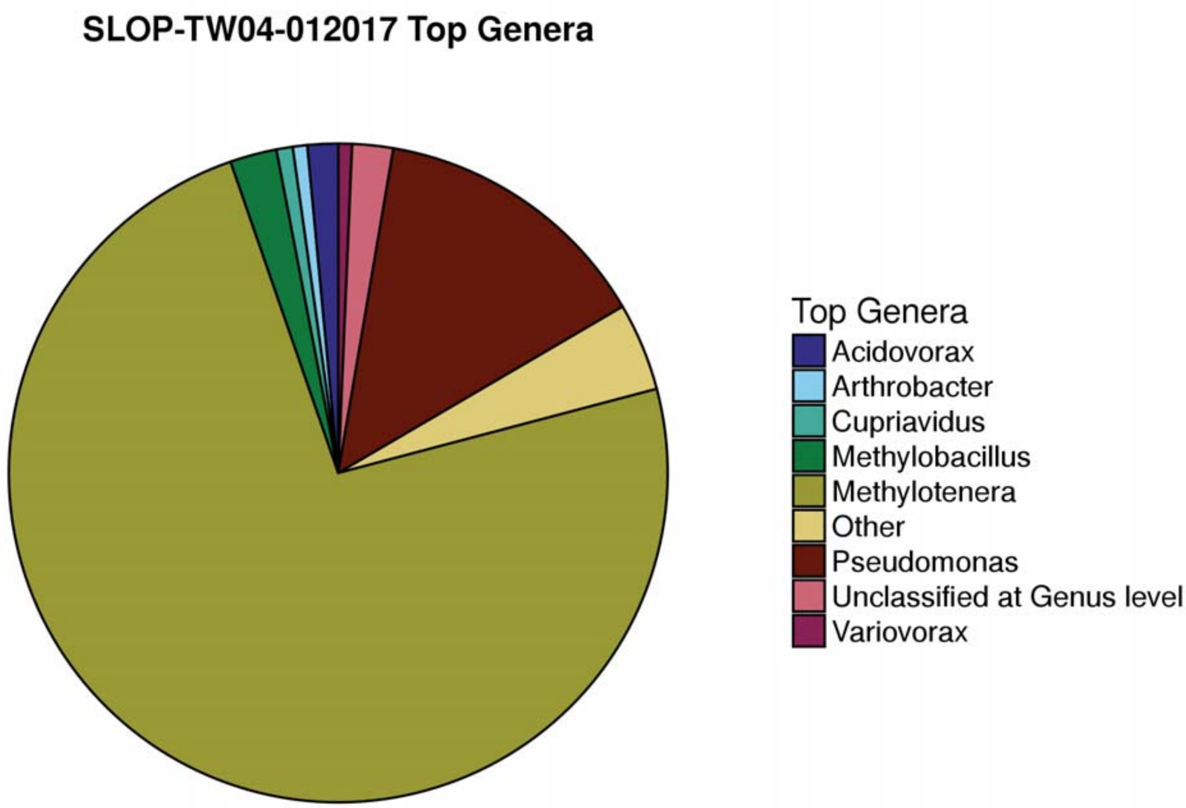

Figure 23: Top Genus Classification Results

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Interpretation

Diversity Indices

The Shannon diversity index is a quantitative measurement that characterizes how many different genera are present in the sample and takes into account the distribution of the number of organisms classified to each genus present in the sample (commonly referred to as species eveness) [1, 2]. Shannon's diversity index increases in value as the number of genera increases and as the number of organisms present per genera becomes even. Simpson's index measures the probability that two individuals selected randomly from the sample would belong to different genera: the greater the value, the greater the sample diversity. The Chao1 index is an excellent indicator of species richness and is based on the number of reads when one (singleton) or two (doubleton) operational taxonomic units (OTUs) are observed. This value is the predicted number of genera based on the number of singletons and doubletons. The total genera observed is presented here, but does not include reads unclassified at genus species.

Principal Coordinate Analysis

Principal coordinate analysis (PCoA) is an excellent tool for visualizing differences in microbial communities between samples [3]. Unlike more traditional methods such as principal component analysis (PCA), PCoA calculates complex functions for the axes rather than dimensional scaling used in PCA. Therefore, PCoA is able to better demonstrate dissimilarities that may be nuanced in PCA tests. PCoA accomplishes this by using a dissimilarity matrix to assign each sample a location in dimensional space, then changes the coordinate system to display the data in two dimensions.

Hierarchical Clustering Dendrogram

Hierarchical clustering is accomplished by comparing dissimilarities between the samples using complete agglomeration of the Bray-Curtis dissimilarity. This groups samples which are the least dissimilar together. The length of the branches indicate the amount of dissimilarity between samples. Therefore, shorter branches are more similar. The stacked bar chart below each leaf of the tree represents the relative abundance of genus-level classifications.

References

1. Gotelli, N. J. & Colwell, R. K. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology letters* **4,** 379–391 (2001).
2. Hill, M. O. Diversity and evenness: a unifying notation and its consequences. *Ecology* **54,** 427–432 (1973).
3. Buttigieg, P. L. & Ramette, A. A guide to statistical analysis in microbial ecology: a community-focused, living review of multivariate data analyses. *FEMS Microbiology Ecology* **90,** 543–550. ISSN: 1574-6941 (2014).

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SITE LOGIC Report

Next Generation Sequencing (NGS) Report

Contact: Anita Dodson

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Suite 200
Virginia Beach, VA 23462

Email: anita.dodson@ch2m.com

MI Identifier: 008OA

Report Date: 03/01/2017

Project: ABL Site 5 ESTCP
Comments:

Sample Overview

Table 1: Sample information for 008OA.

MI Identifier	Sample Name	Sample Date	Reads Passing Quality Filtering	% Reads Classified to Genus
008OA-1	AS05-GW13-010617	01/06/2017	462,774	66.3%
008OA-3	AS05-GW26-012017	01/24/2017	466,244	94.5%
008OA-5	AS05-GW27-012017	01/24/2017	290,096	94.5%
008OA-6	AS05-GW28-012017	01/24/2017	392,175	92.9%
008OA-7	AS05-GW29-012017	01/25/2017	453,995	82.1%
008OA-8	AS05-GW30-012017	01/25/2017	264,956	90.7%
008OA-9	AS05-GW31-012017	01/25/2017	326,277	89.1%
008OA-10	AS05-GW18-012017	01/25/2017	541,388	88.9%
008OA-11	AS05-GW25-012017	01/26/2017	505,716	82.9%

Table 2: Genus diversity indices for 008OA. Please refer to the Interpretation section for more information on what these diversity indices mean.

MI Identifier	Sample Name	Shannon	Simpson	Chao1 Predicted Genera	Total Genera Observed	Total Eubacteria (cells/mL)
008OA-1	AS05-GW13-010617	4.7	0.98	680	623	7.99e+04
008OA-3	AS05-GW26-012017	2.5	0.82	650	563	3.07e+05
008OA-5	AS05-GW27-012017	2.5	0.8	560	488	9.04e+04
008OA-6	AS05-GW28-012017	2.5	0.78	620	540	6.53e+05
008OA-7	AS05-GW29-012017	4	0.95	700	640	3.12e+05
008OA-8	AS05-GW30-012017	2.8	0.78	630	542	1.91e+05
008OA-9	AS05-GW31-012017	3	0.78	610	544	4.84e+04
008OA-10	AS05-GW18-012017	2.7	0.8	680	625	3.09e+05
008OA-11	AS05-GW25-012017	3.3	0.9	670	573	1.34e+06

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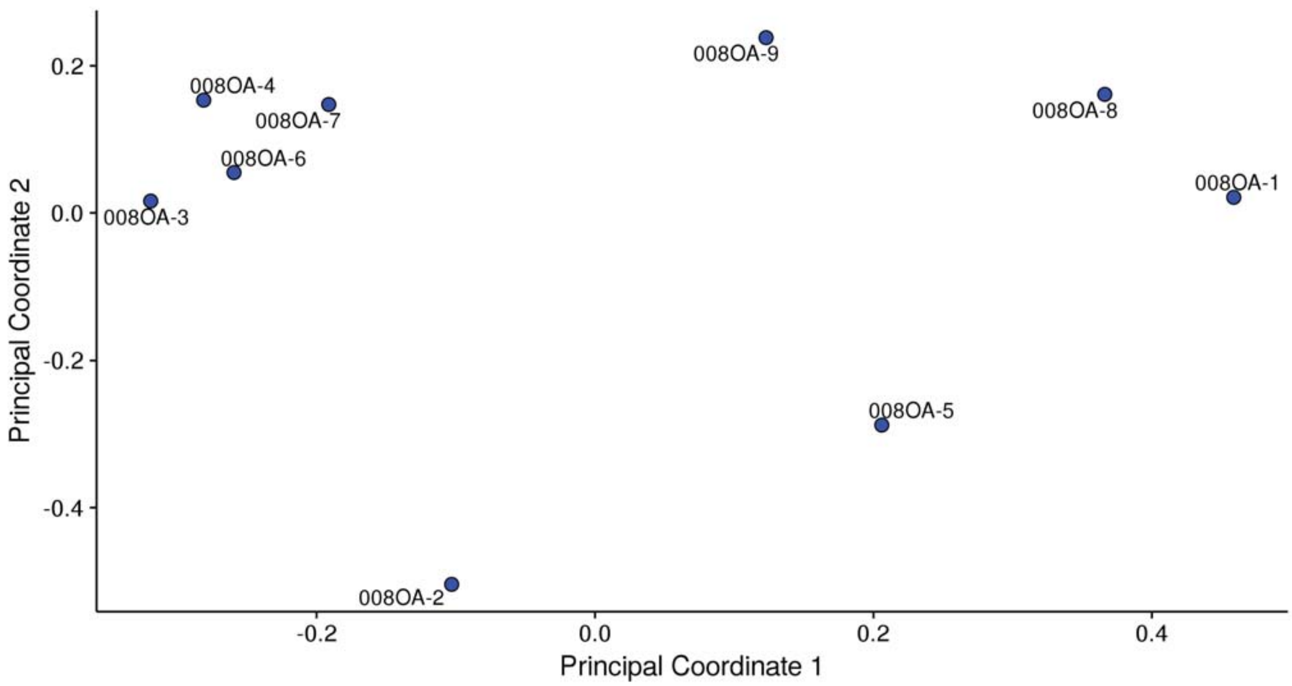

Figure 1: Principal Coordinate Analysis. This scatterplot shows a Principal Coordinate Analysis (PCoA) of the normalized relative abundance of all samples at the genus-level classifications. Increasing distance between sample points on this plot indicate increasing dissimilarity between bacterial populations in the samples.

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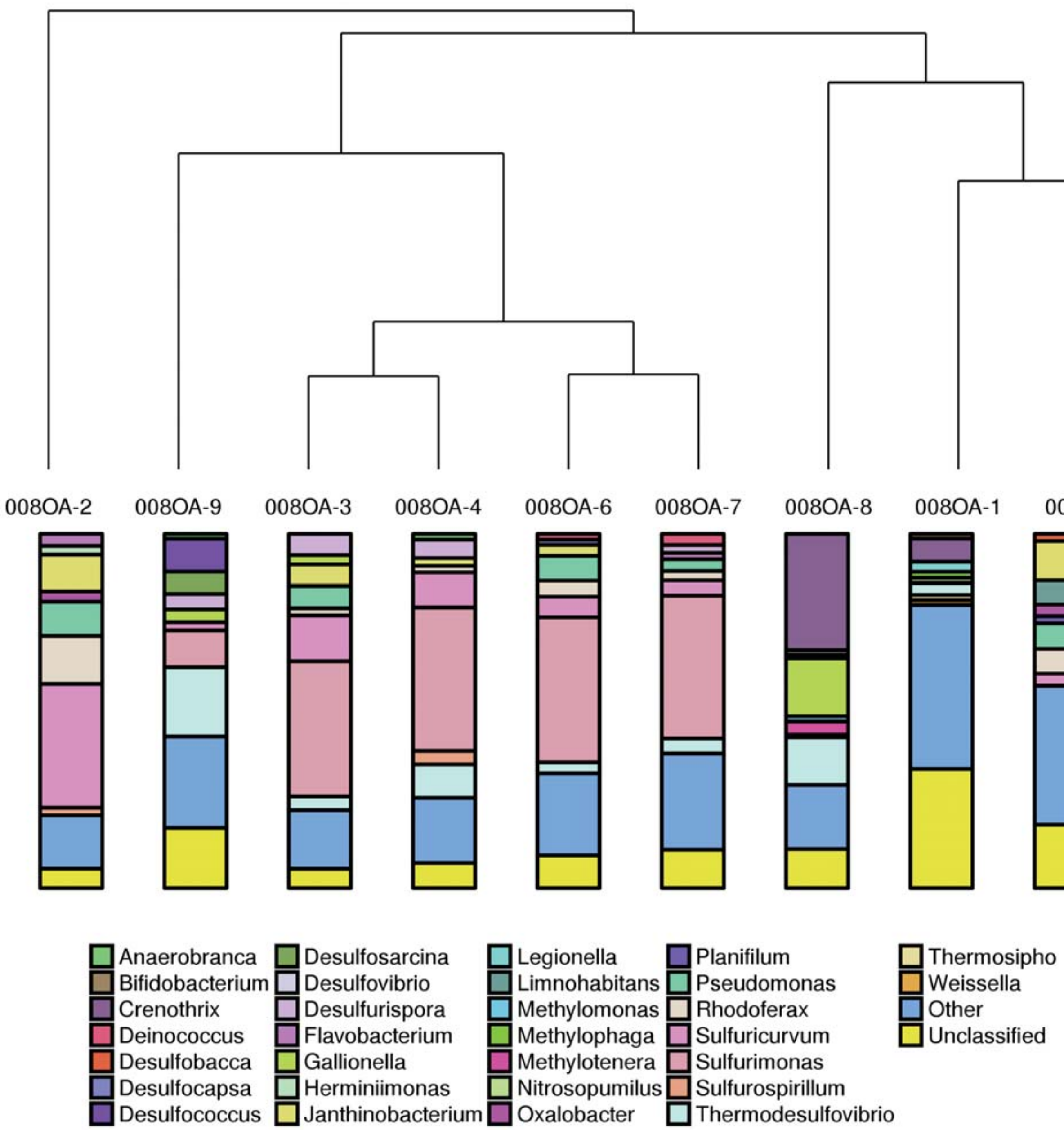

Figure 2: Hierachical Clustering Dendrogram. This dendrogram shows a hierarchical clustering of samples based on genus-level classifications. Branch length is representative of relatedness between samples. The barchart beneath each sample show the relative abundance of the top 8 genus-level classifications, along with all other classified and unclassifed genera. See the following detailed analysis by sample to identify the dominant genera in each sample.

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Results for AS05-GW13-010617

Table 3: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
462,774	426,219	92.1%

Table 4: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	418,260	98.1%
Phylum	372,006	87.3%
Class	353,443	82.9%
Order	334,853	78.6%
Family	315,630	74.0%
Genus	282,546	66.3%
Species	148,299	34.8%

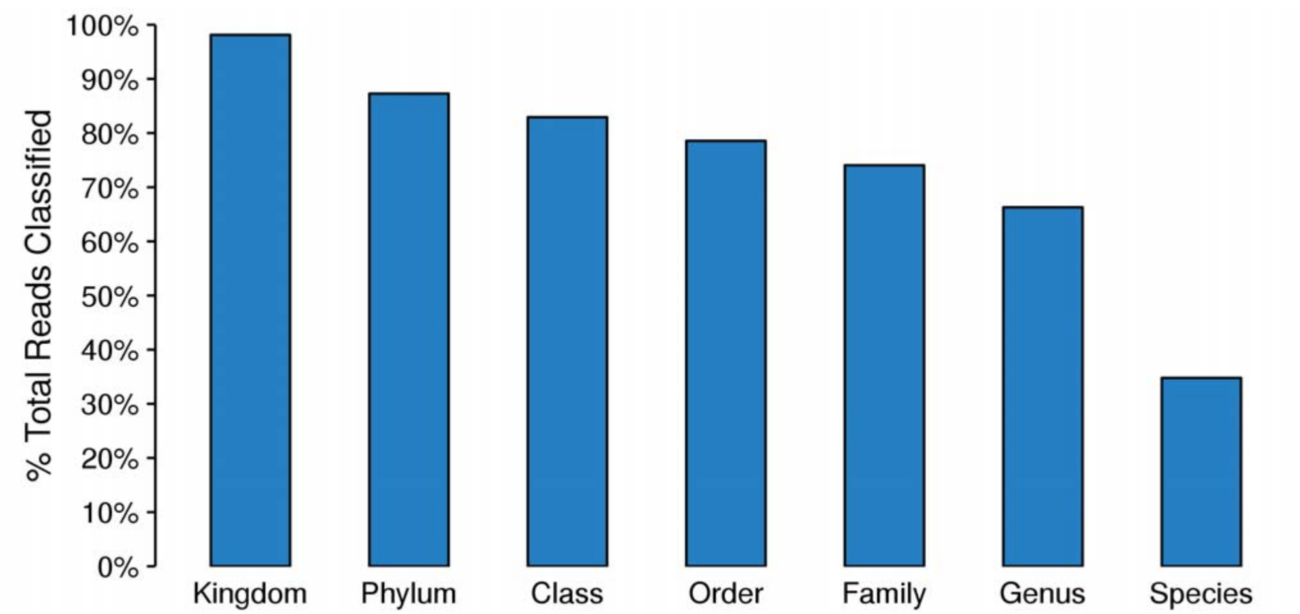

Figure 3: Classification Rate by Taxonomic Level

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AS05-GW13-010617 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 5: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	209,853	49.2%
Unclassified at Phylum level	54,213	12.7%
Firmicutes	43,620	10.2%
Actinobacteria	21,660	5.1%
Bacteroidetes	19,680	4.6%
Nitrospirae	15,202	3.6%
Thermotogae	11,974	2.8%
Crenarchaeota	6,136	1.4%

Total Phylum-level Taxonomic Categories Identified: 31. This table shows the top 8 of 31 classifications. The 8 phyla shown in this table account for 89.7% of all observed classifications.

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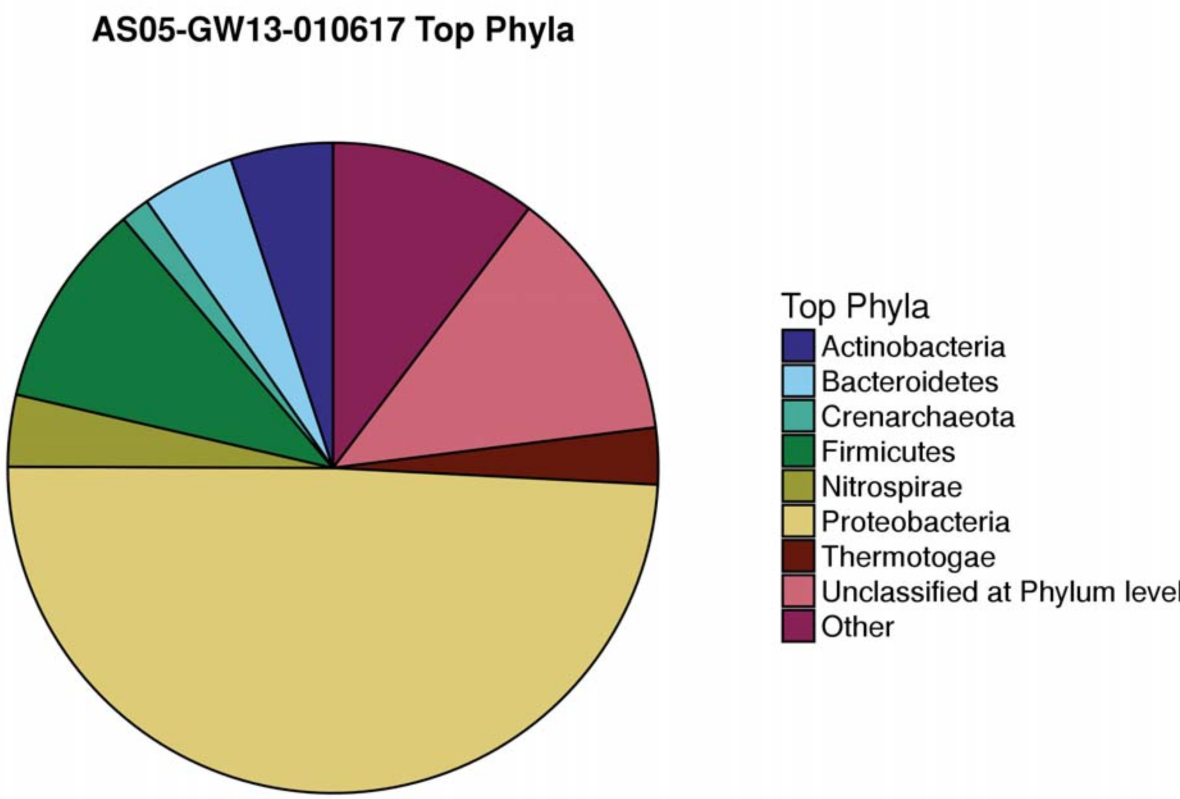

Figure 4: Top Phylum Classification Results

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Table 6: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Crenothrix	27,831	6.5%	Crenothrix is a filamentous methane oxidizer.
Legionella	11,954	2.8%	The genus Legionella is composed of pathogenic bacteria which are found mainly in water sources, such as cooling towers, where they can be protected by growing intracellularly in protozoa within biofilms.
Methylophaga	7,253	1.7%	Methylophaga species are part of a consortium of bacteria effective in the degradation of high-molecular-weight PAHs.
Nitrosopumilus	6,029	1.4%	This common archaeon lives in sea water, where it oxidizes ammonia to nitrite.
Thermodesulfovibrio	14,147	3.3%	Members of this genus are thermophilic anaerobic sulfate-reducers.
Thermosipho	6,255	1.5%	These thermophilic anaerobic bacteria have been isolated from deep-sea hydrothermal vents.
Unclassified at Genus level	143,673	33.7%	
Weissella	5,780	1.4%	Members of this genus are chemoorganotrophic, heterofermentative, lactic acid bacteria.

Total Genus-level Taxonomic Categories Identified: 624. This table shows the top 8 of 624 classifications. The 8 genera shown in this table account for 52.3% of all observed classifications.

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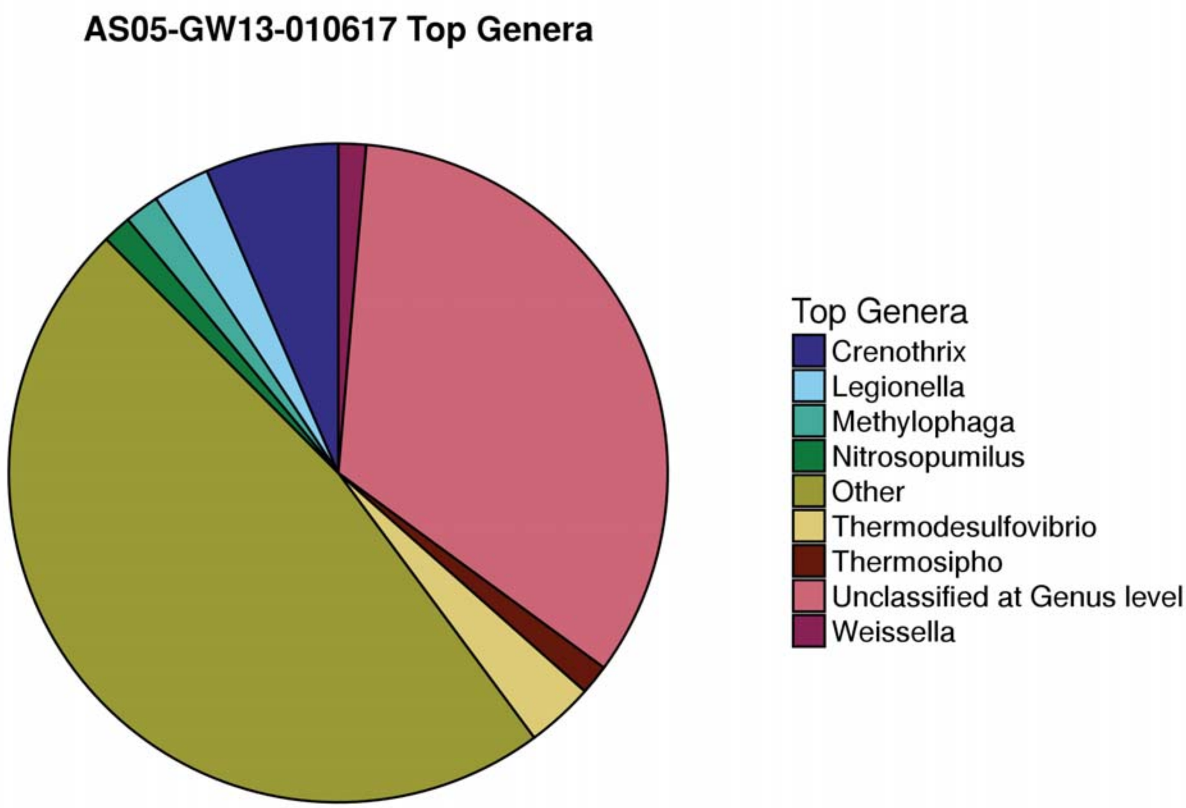

Figure 5: Top Genus Classification Results

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Results for AS05-GW26-012017

Table 7: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
466,244	430,780	92.4%

Table 8: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	430,577	100.0%
Phylum	427,588	99.3%
Class	425,264	98.7%
Order	422,271	98.0%
Family	419,158	97.3%
Genus	407,127	94.5%
Species	269,444	62.5%

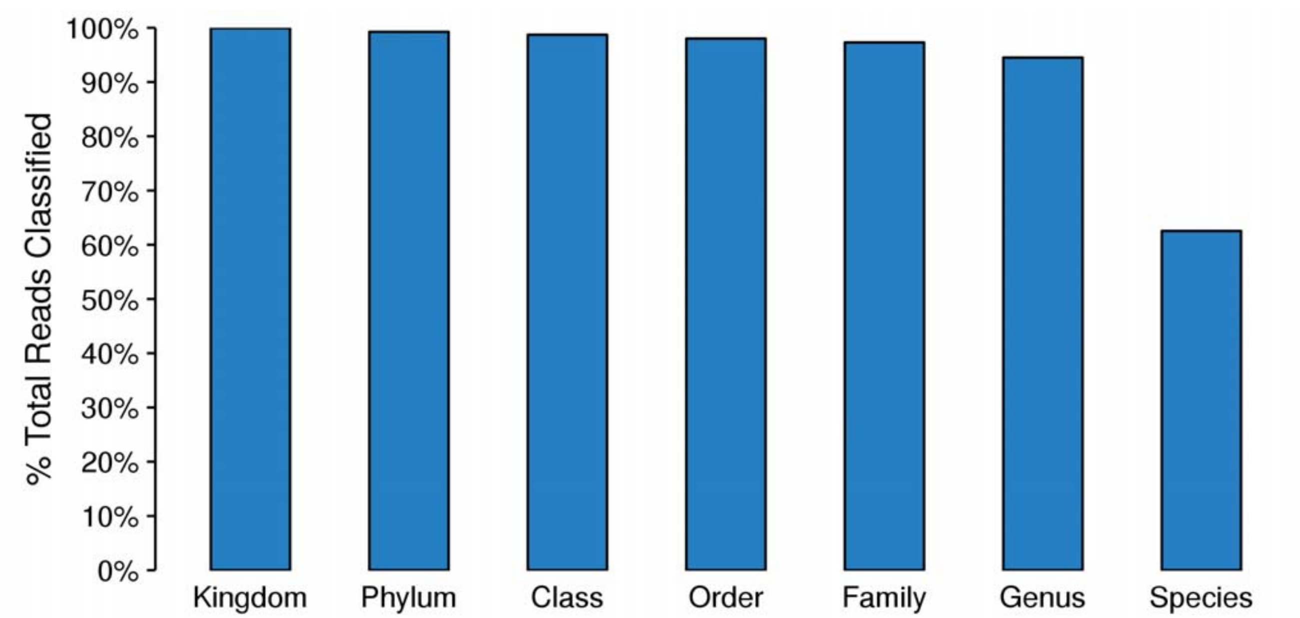

Figure 6: Classification Rate by Taxonomic Level

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AS05-GW26-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 9: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	399,673	92.8%
Bacteroidetes	18,179	4.2%
Firmicutes	3,317	0.8%
Unclassified at Phylum level	3,192	0.7%
Actinobacteria	1,732	0.4%
Spirochaetes	1,330	0.3%
Chloroflexi	544	0.1%
Thermotogae	443	0.1%

Total Phylum-level Taxonomic Categories Identified: 27. This table shows the top 8 of 27 classifications. The 8 phyla shown in this table account for 99.4% of all observed classifications.

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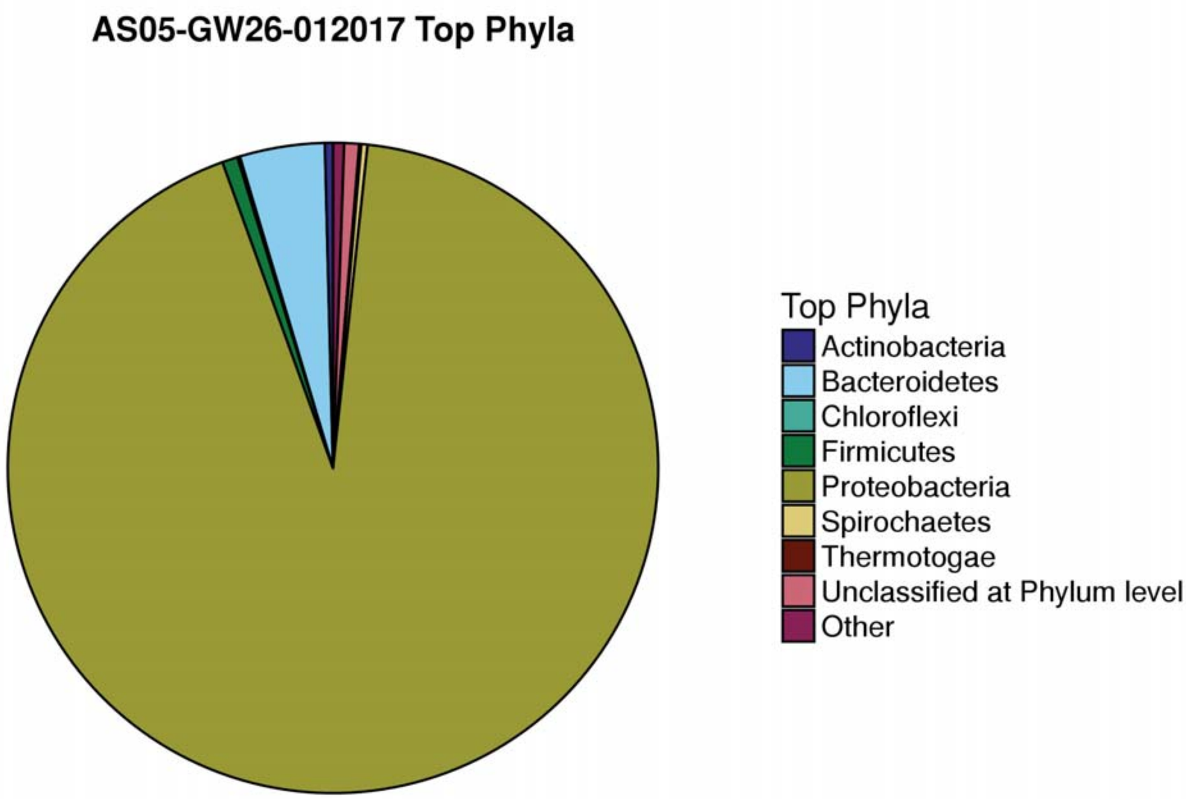

Figure 7: Top Phylum Classification Results

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Table 10: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Flavobacterium	14,537	3.4%	Flavobacterium degrades biopolymers such as chitin and cellulose. This genus is aerobic and is widely distributed in soil and water.
Herminiimonas	10,656	2.5%	Some species belonging to this aerobic genus have been isolated from drinking water and mineral water. At least one species is capable of oxidizing arsenite and reducing nitrogen.
Janthinobacterium	44,246	10.3%	This genus of bacteria can tolerate a variety of environmental stressors and demonstrates diverse metabolic abilities.
Oxalobacter	12,531	2.9%	These anaerobic bacteria are found in the gastrointestinal tracts of vertebrates and can degrade oxalic acid.
Pseudomonas	41,498	9.6%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Rhodoferax	58,529	13.6%	This genus is typically found in well-lit stagnant water and can thrive in aerobic or anaerobic environments using many substrates as carbon sources.
Sulfuricurvum	150,811	35.0%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Unclassified at Genus level	23,653	5.5%	

Total Genus-level Taxonomic Categories Identified: 564. This table shows the top 8 of 564 classifications. The 8 genera shown in this table account for 82.7% of all observed classifications.

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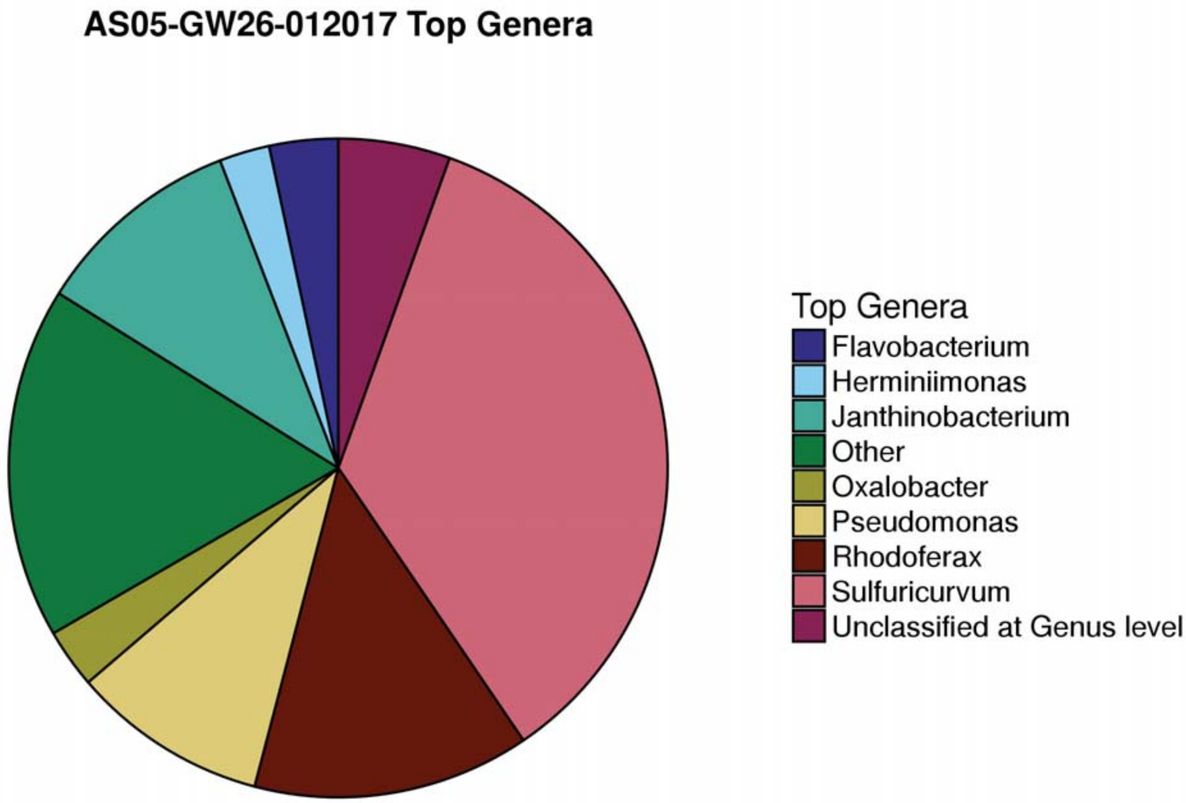

Figure 8: Top Genus Classification Results

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Results for AS05-GW27-012017

Table 11: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
290,096	268,181	92.5%

Table 12: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	267,927	99.9%
Phylum	266,152	99.2%
Class	265,217	98.9%
Order	257,905	96.2%
Family	256,596	95.7%
Genus	253,526	94.5%
Species	101,639	37.9%

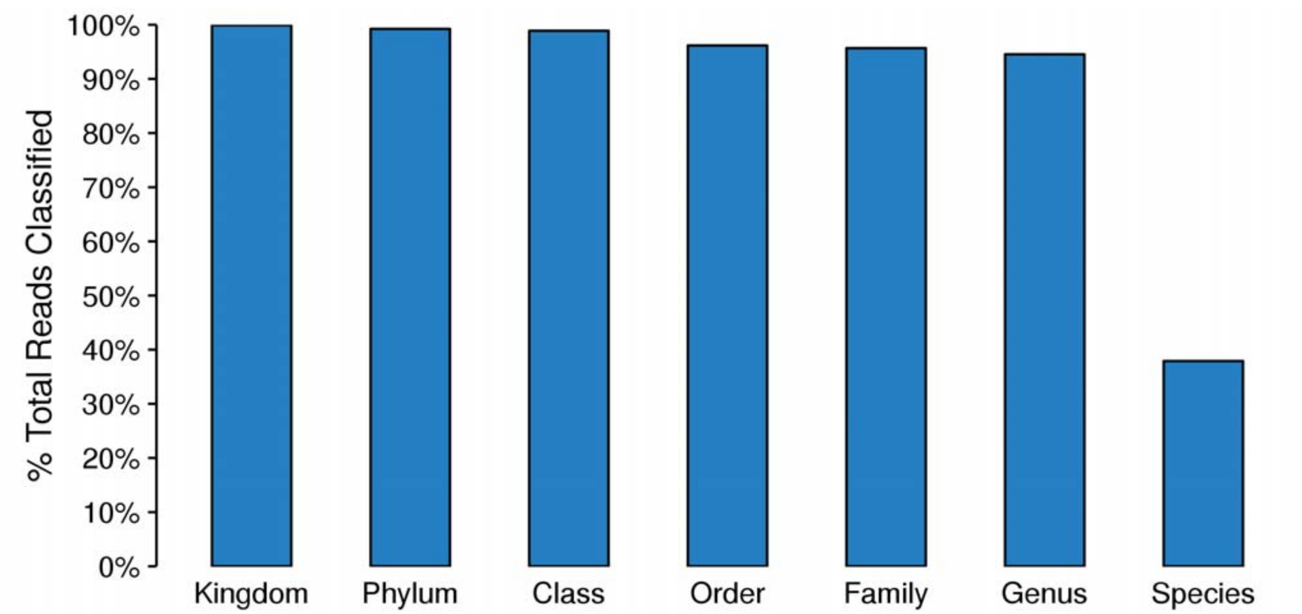

Figure 9: Classification Rate by Taxonomic Level

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AS05-GW27-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 13: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	218,319	81.4%
Firmicutes	29,661	11.1%
Nitrospirae	10,535	3.9%
Bacteroidetes	2,905	1.1%
Unclassified at Phylum level	2,029	0.8%
Actinobacteria	1,152	0.4%
Chlorobi	716	0.3%
Spirochaetes	618	0.2%

Total Phylum-level Taxonomic Categories Identified: 28. This table shows the top 8 of 28 classifications. The 8 phyla shown in this table account for 99.2% of all observed classifications.

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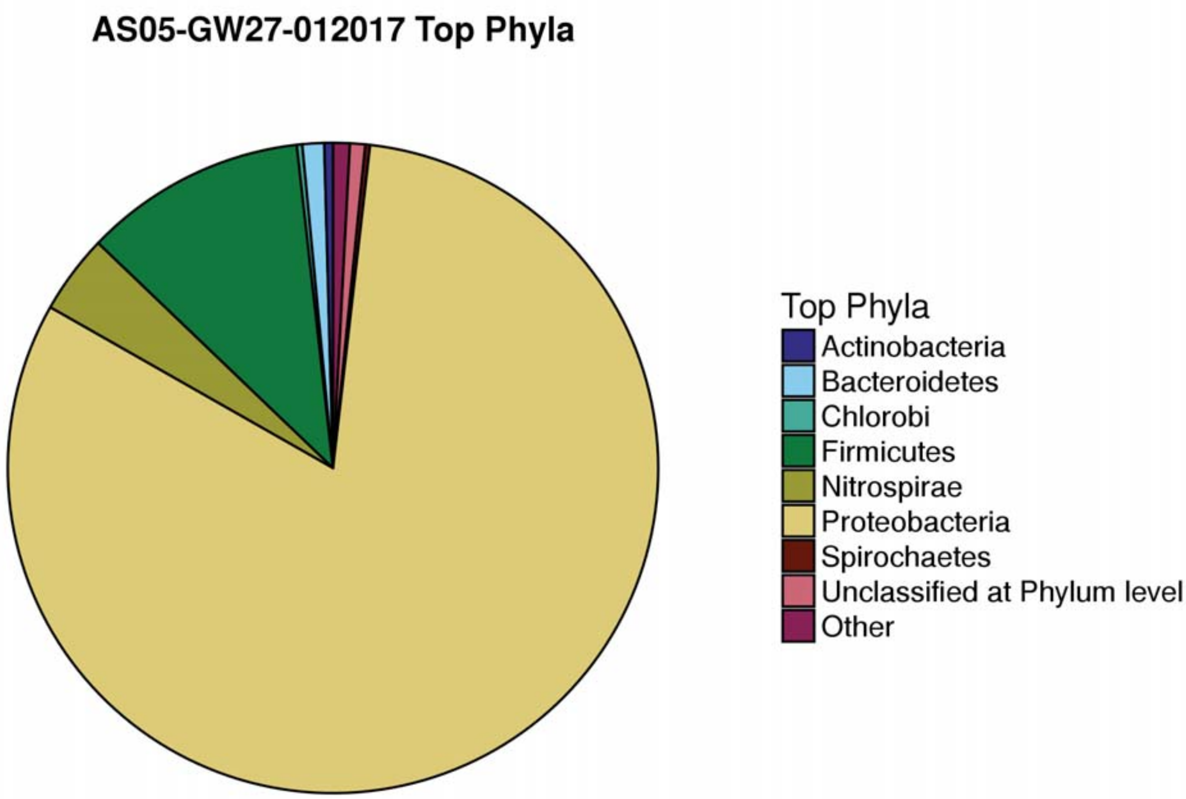

Figure 10: Top Phylum Classification Results

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Table 14: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Desulfurispora	16,033	6.0%	This genus is comprised of thermophilic sulfate reducers.
Gallionella	7,053	2.6%	This genus comprises iron-oxidizing, chemolithotrophic bacteria that have been found in a variety of different aquatic habitats.
Janthinobacterium	16,071	6.0%	This genus of bacteria can tolerate a variety of environmental stressors and demonstrates diverse metabolic abilities.
Pseudomonas	16,832	6.3%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Sulfuricurvum	34,642	12.9%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Sulfurimonas	102,481	38.2%	This is a genus of sulfur- and thiosulfate-oxidizing bacteria found in deep sea sediments.
Thermodesulfovibrio	10,493	3.9%	Members of this genus are thermophilic anaerobic sulfate-reducers.
Unclassified at Genus level	14,655	5.5%	

Total Genus-level Taxonomic Categories Identified: 489. This table shows the top 8 of 489 classifications. The 8 genera shown in this table account for 81.4% of all observed classifications.

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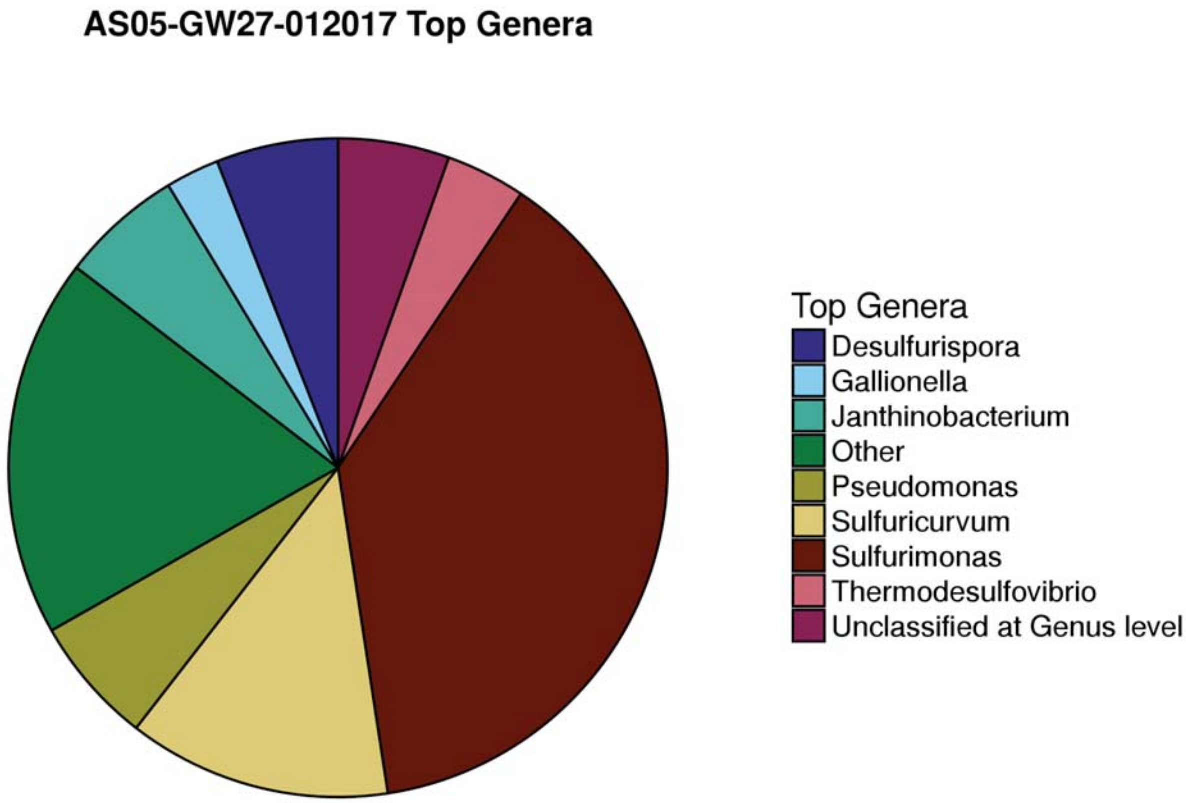

Figure 11: Top Genus Classification Results

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Results for AS05-GW28-012017

Table 15: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
392,175	362,475	92.4%

Table 16: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	362,254	99.9%
Phylum	357,368	98.6%
Class	355,620	98.1%
Order	347,545	95.9%
Family	343,438	94.8%
Genus	336,596	92.9%
Species	150,868	41.6%

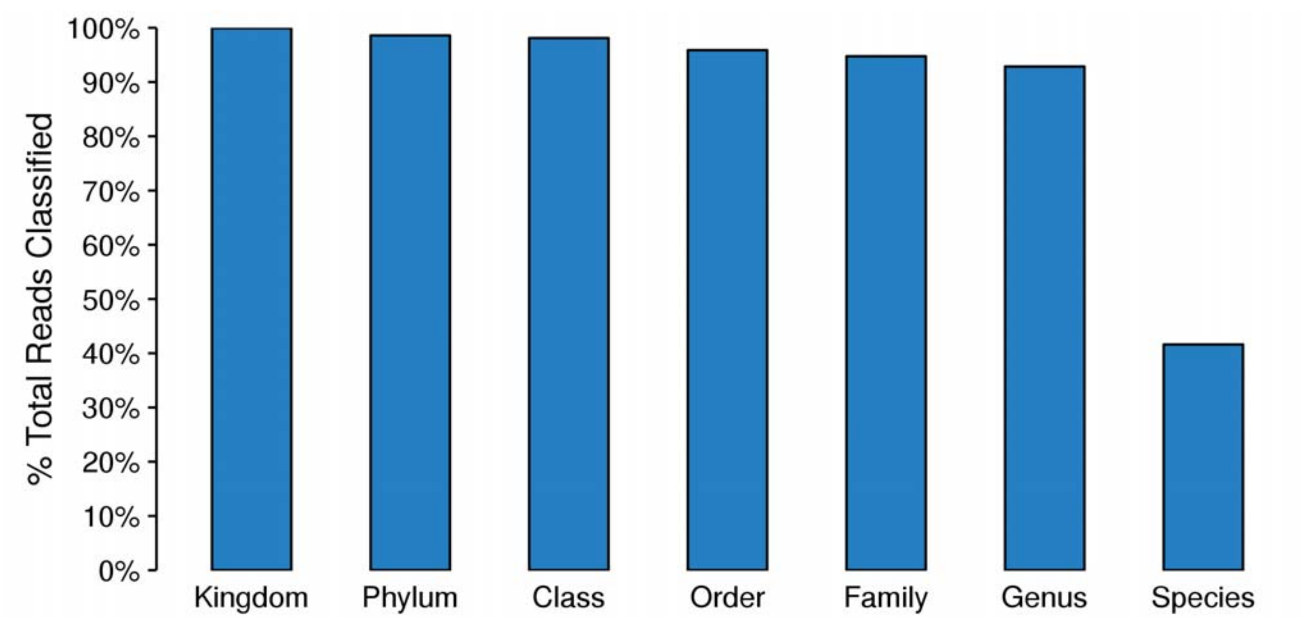

Figure 12: Classification Rate by Taxonomic Level

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AS05-GW28-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 17: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	268,748	74.1%
Firmicutes	41,948	11.6%
Nitrospirae	34,430	9.5%
Unclassified at Phylum level	5,107	1.4%
Bacteroidetes	2,329	0.6%
Verrucomicrobia	1,582	0.4%
Actinobacteria	1,481	0.4%
Thermi	1,219	0.3%

Total Phylum-level Taxonomic Categories Identified: 31. This table shows the top 8 of 31 classifications. The 8 phyla shown in this table account for 98.5% of all observed classifications.

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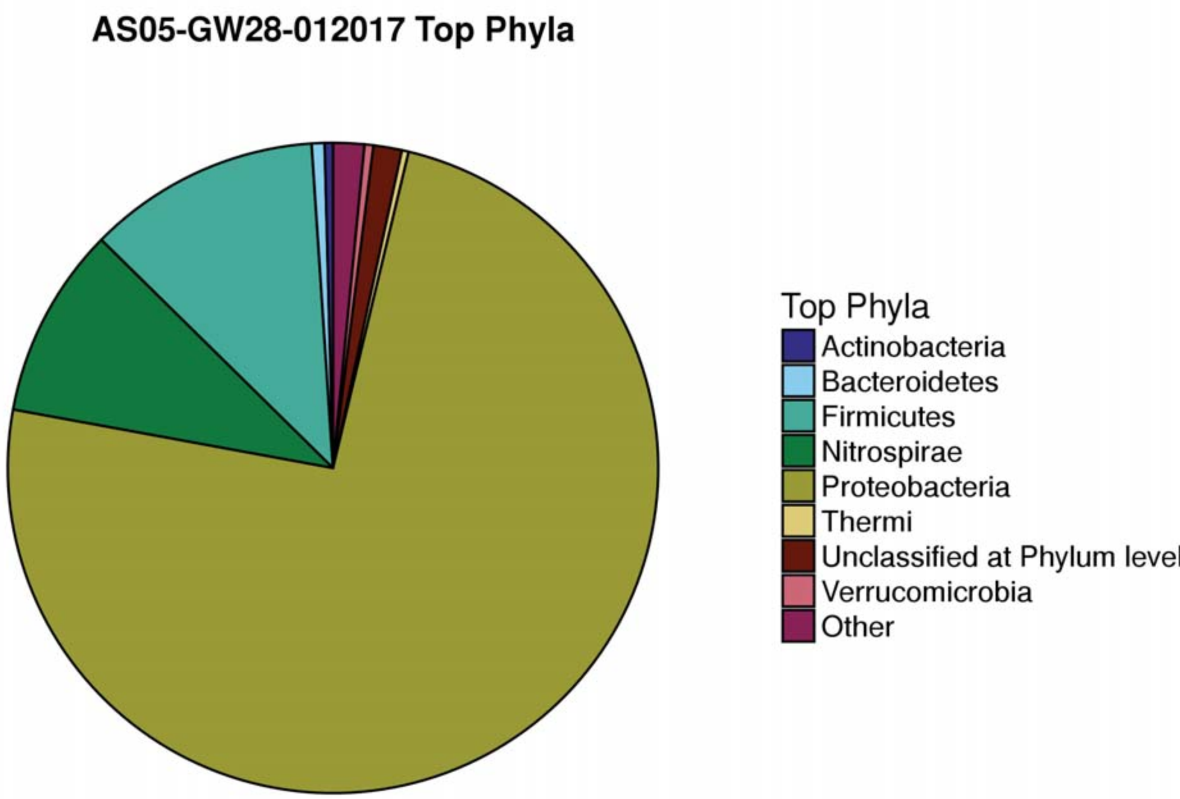

Figure 13: Top Phylum Classification Results

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Table 18: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Desulfurispora	18,966	5.2%	This genus is comprised of thermophilic sulfate reducers.
Janthinobacterium	7,974	2.2%	This genus of bacteria can tolerate a variety of environmental stressors and demonstrates diverse metabolic abilities.
Rhodoferax	6,561	1.8%	This genus is typically found in well-lit stagnant water and can thrive in aerobic or anaerobic environments using many substrates as carbon sources.
Sulfuricurvum	35,499	9.8%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Sulfurimonas	146,916	40.5%	This is a genus of sulfur- and thiosulfate-oxidizing bacteria found in deep sea sediments.
Sulfurospirillum	13,838	3.8%	These microaerophilic sulfur-reducing bacteria can respire PCE to cis-1,2-DCE.
Thermodesulfovibrio	34,418	9.5%	Members of this genus are thermophilic anaerobic sulfate-reducers.
Unclassified at Genus level	25,879	7.1%	

Total Genus-level Taxonomic Categories Identified: 541. This table shows the top 8 of 541 classifications. The 8 genera shown in this table account for 80% of all observed classifications.

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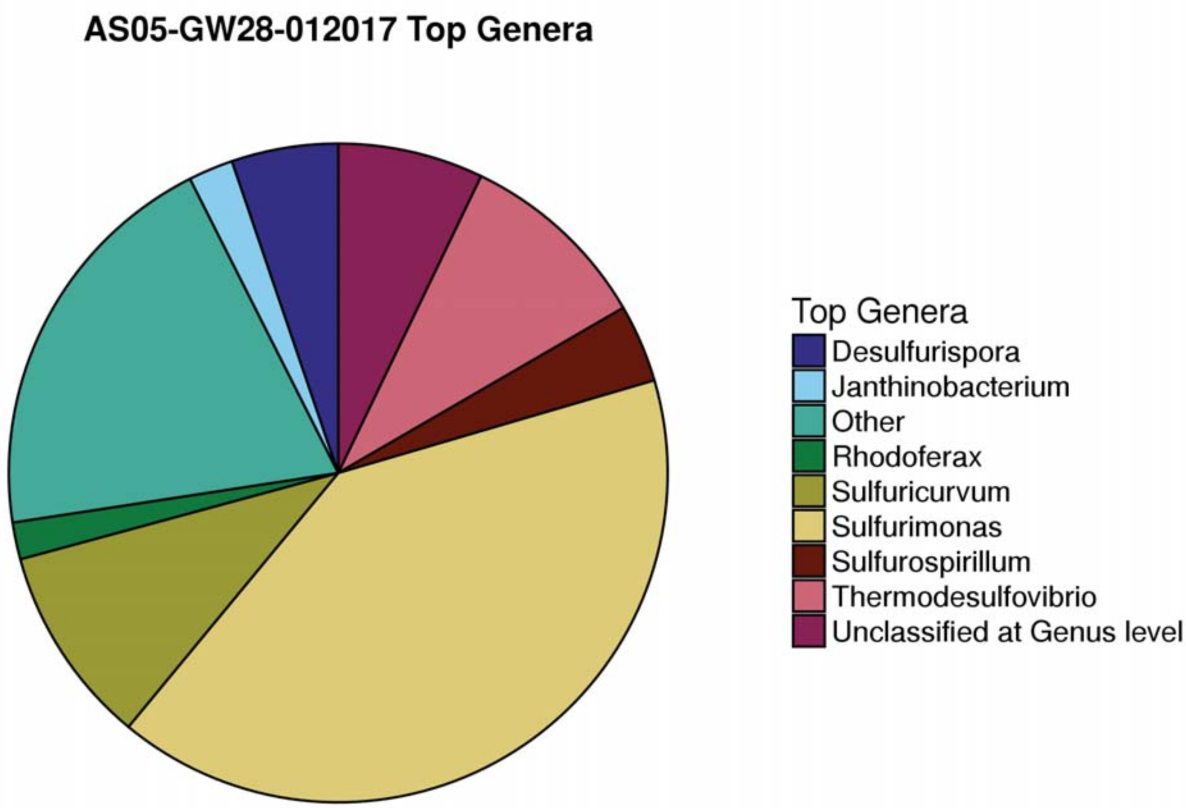

Figure 14: Top Genus Classification Results

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Results for AS05-GW29-012017

Table 19: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
453,995	412,397	90.8%

Table 20: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	409,637	99.3%
Phylum	388,622	94.2%
Class	381,720	92.6%
Order	371,378	90.0%
Family	356,374	86.4%
Genus	338,434	82.1%
Species	157,428	38.2%

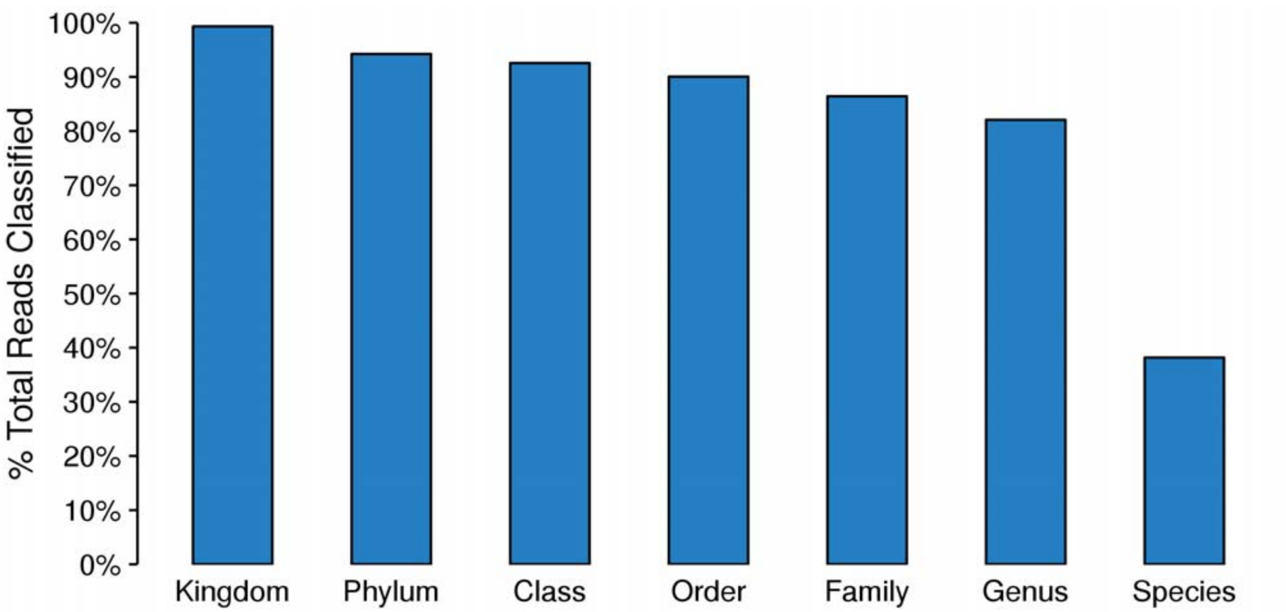

Figure 15: Classification Rate by Taxonomic Level

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AS05-GW29-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 21: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	292,543	70.9%
Firmicutes	41,971	10.2%
Unclassified at Phylum level	23,775	5.8%
Actinobacteria	12,779	3.1%
Bacteroidetes	7,058	1.7%
Nitrospirae	6,777	1.6%
Chloroflexi	5,957	1.4%
Thermotogae	3,112	0.8%

Total Phylum-level Taxonomic Categories Identified: 31. This table shows the top 8 of 31 classifications. The 8 phyla shown in this table account for 95.5% of all observed classifications.

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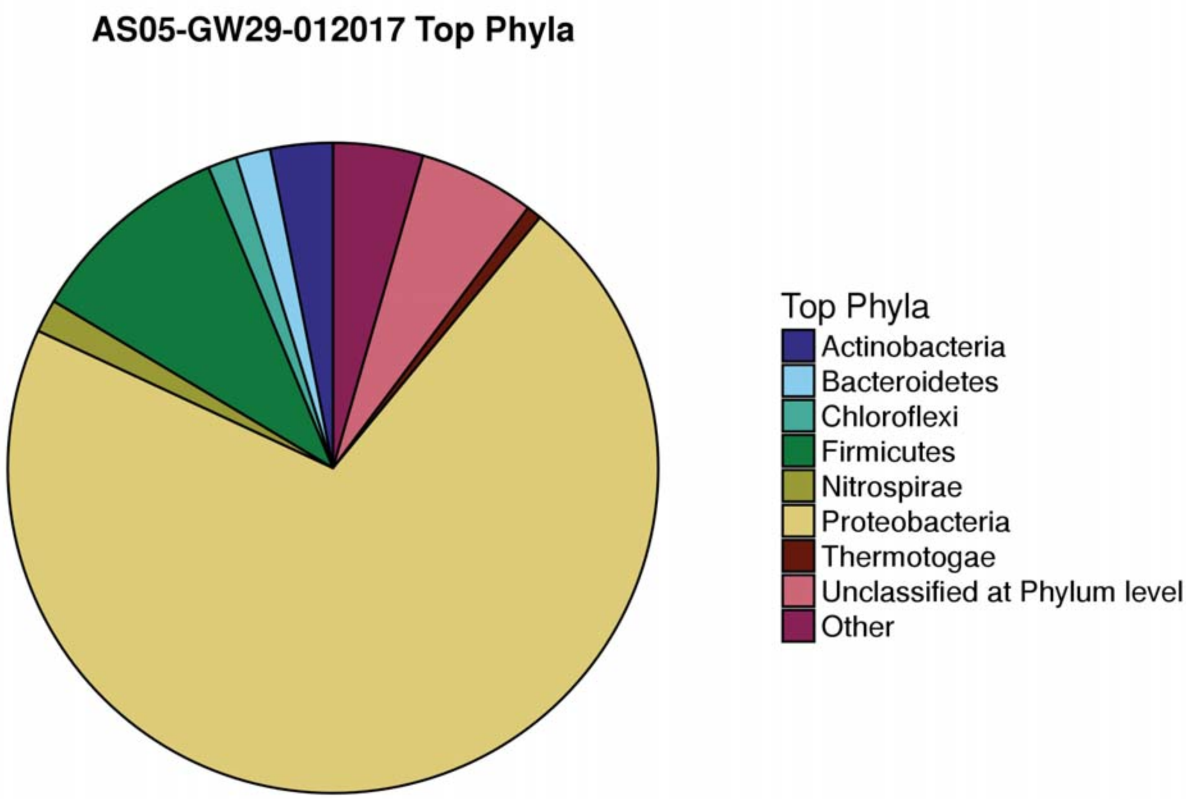

Figure 16: Top Phylum Classification Results

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Table 22: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Desulfobacca	8,424	2.0%	These mesophilic sulfate reducers can degrade acetate and utilize sulfite and thiosulfate as electron acceptors.
Janthinobacterium	45,633	11.1%	This genus of bacteria can tolerate a variety of environmental stressors and demonstrates diverse metabolic abilities.
Limnohabitans	27,718	6.7%	These freshwater bacteria are free-living, globally distributed, and have an important role in carbon flow to higher trophic levels. Members are generally Gram-negative, aerobic, and catalase- and oxidase-positive.
Oxalobacter	13,500	3.3%	These anaerobic bacteria are found in the gastrointestinal tracts of vertebrates and can degrade oxalic acid.
Pseudomonas	29,771	7.2%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Rhodoferax	29,054	7.0%	This genus is typically found in well-lit stagnant water and can thrive in aerobic or anaerobic environments using many substrates as carbon sources.
Sulfuricurvum	14,026	3.4%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Unclassified at Genus level	73,963	17.9%	

Total Genus-level Taxonomic Categories Identified: 641. This table shows the top 8 of 641 classifications. The 8 genera shown in this table account for 58.7% of all observed classifications.

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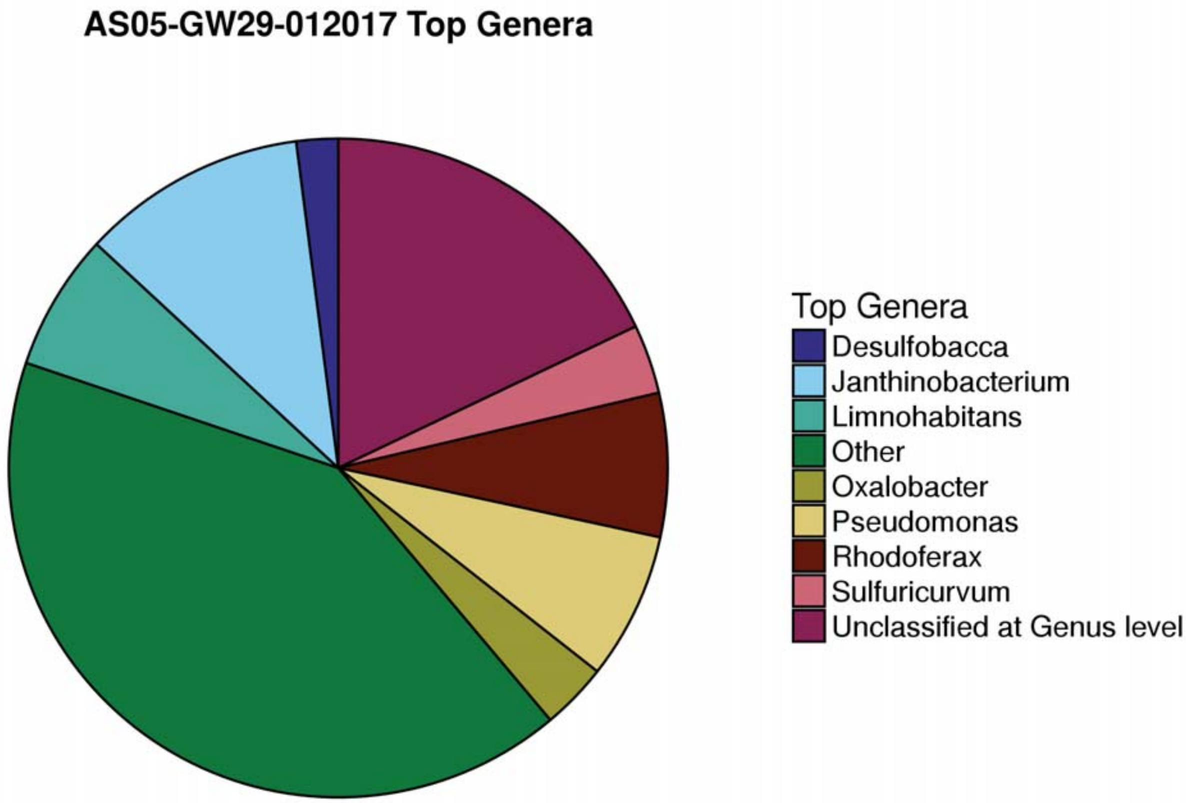

Figure 17: Top Genus Classification Results

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Results for AS05-GW30-012017

Table 23: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
264,956	245,413	92.6%

Table 24: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	244,460	99.6%
Phylum	239,919	97.8%
Class	237,661	96.8%
Order	231,609	94.4%
Family	228,009	92.9%
Genus	222,662	90.7%
Species	74,227	30.2%

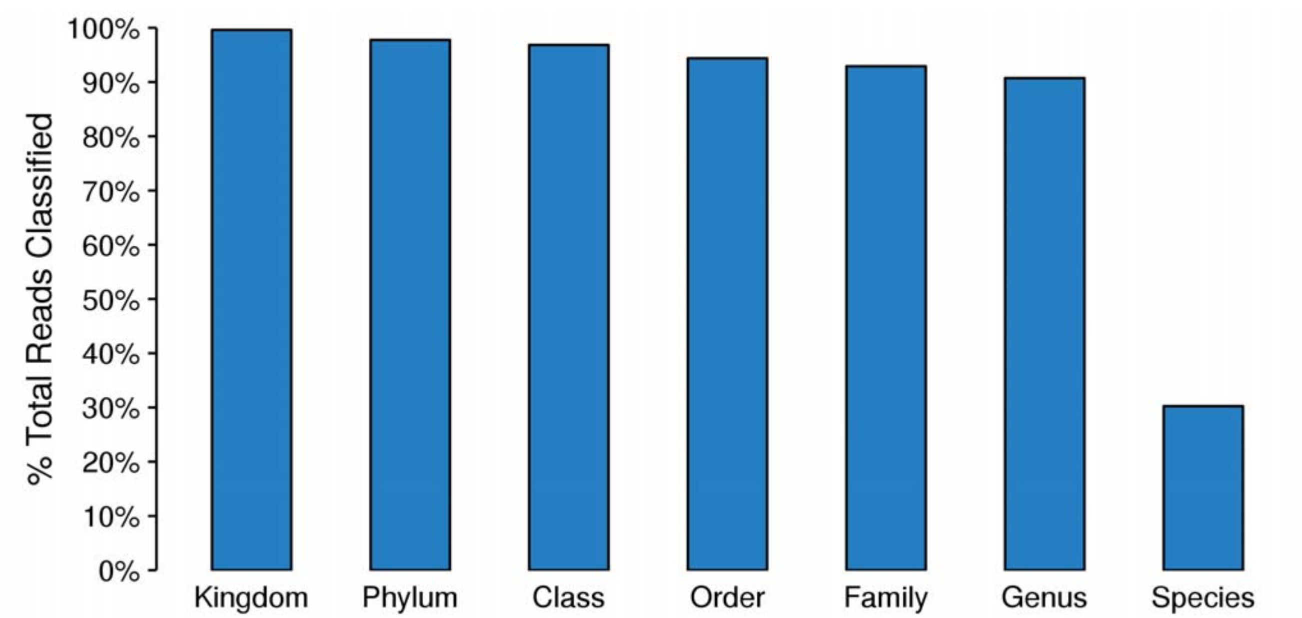

Figure 18: Classification Rate by Taxonomic Level

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AS05-GW30-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 25: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	204,435	83.3%
Firmicutes	11,777	4.8%
Nitrospirae	7,581	3.1%
Unclassified at Phylum level	5,494	2.2%
Thermi	4,067	1.7%
Bacteroidetes	2,325	1.0%
Actinobacteria	2,281	0.9%
Chlorobi	1,065	0.4%

Total Phylum-level Taxonomic Categories Identified: 31. This table shows the top 8 of 31 classifications. The 8 phyla shown in this table account for 97.4% of all observed classifications.

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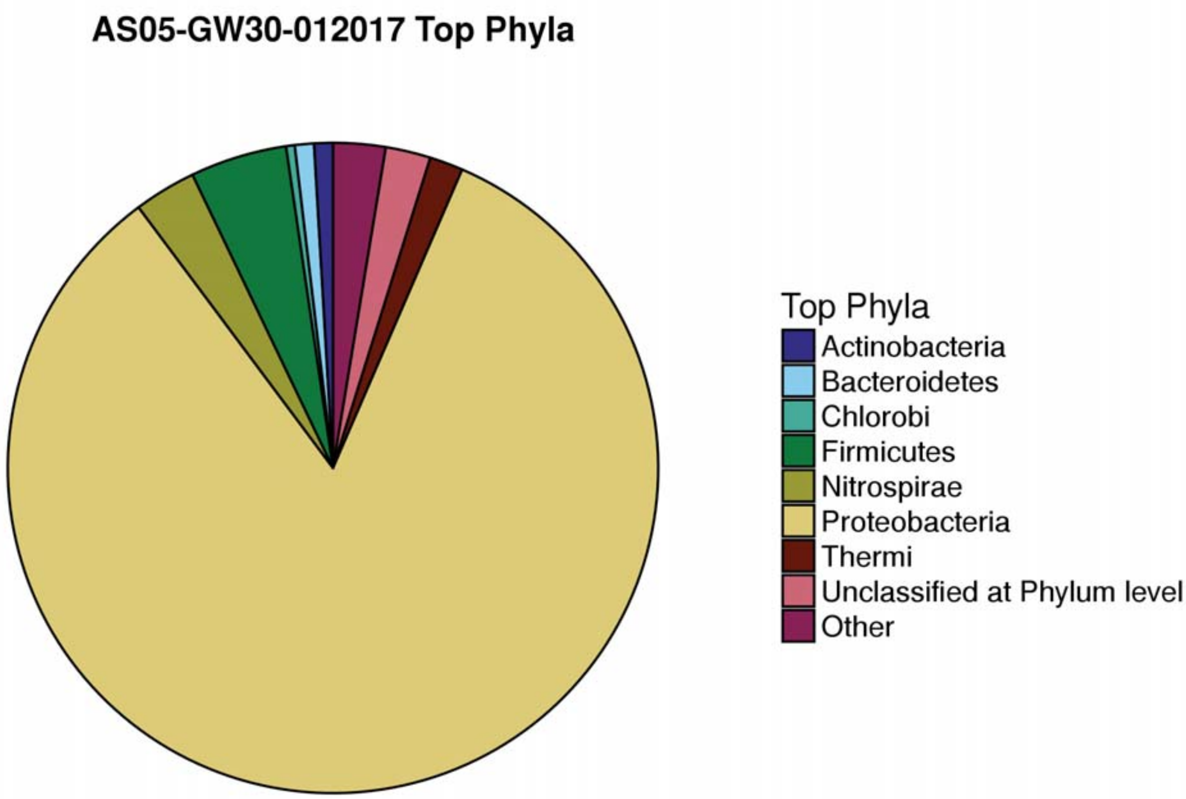

Figure 19: Top Phylum Classification Results

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Table 26: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Deinococcus	4,048	1.7%	This genus is highly resistant to environmental stressors.
Janthinobacterium	7,641	3.1%	This genus of bacteria can tolerate a variety of environmental stressors and demonstrates diverse metabolic abilities.
Pseudomonas	17,172	7.0%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Rhodoferax	10,844	4.4%	This genus is typically found in well-lit stagnant water and can thrive in aerobic or anaerobic environments using many substrates as carbon sources.
Sulfuricurvum	14,226	5.8%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Sulfurimonas	100,664	41.0%	This is a genus of sulfur- and thiosulfate-oxidizing bacteria found in deep sea sediments.
Thermodesulfovibrio	7,550	3.1%	Members of this genus are thermophilic anaerobic sulfate-reducers.
Unclassified at Genus level	22,751	9.3%	

Total Genus-level Taxonomic Categories Identified: 543. This table shows the top 8 of 543 classifications. The 8 genera shown in this table account for 75.3% of all observed classifications.

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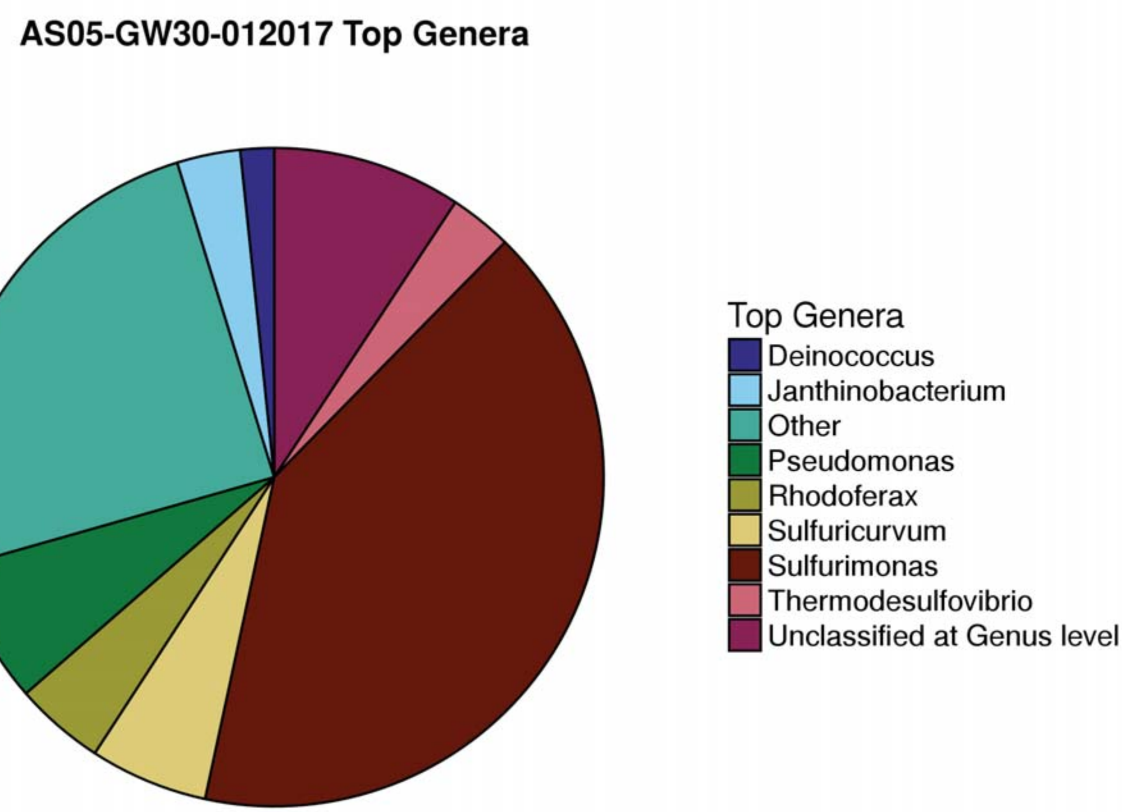

Figure 20: Top Genus Classification Results

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Results for AS05-GW31-012017

Table 27: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
326,277	302,190	92.6%

Table 28: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	298,356	98.7%
Phylum	291,410	96.4%
Class	287,553	95.2%
Order	281,491	93.2%
Family	277,461	91.8%
Genus	269,303	89.1%
Species	88,446	29.3%

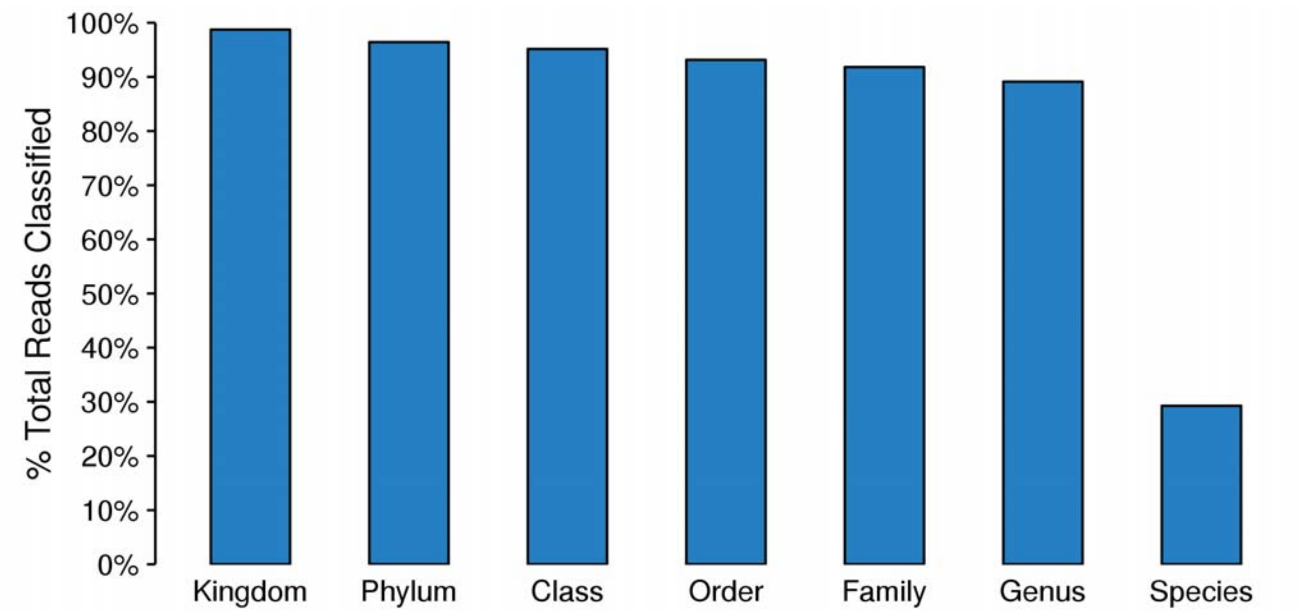

Figure 21: Classification Rate by Taxonomic Level

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AS05-GW31-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 29: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	216,066	71.5%
Firmicutes	22,801	7.5%
Bacteroidetes	14,882	4.9%
Nitrospirae	12,990	4.3%
Unclassified at Phylum level	10,780	3.6%
Thermi	9,508	3.1%
Actinobacteria	2,754	0.9%
Chlorobi	2,173	0.7%

Total Phylum-level Taxonomic Categories Identified: 30. This table shows the top 8 of 30 classifications. The 8 phyla shown in this table account for 96.6% of all observed classifications.

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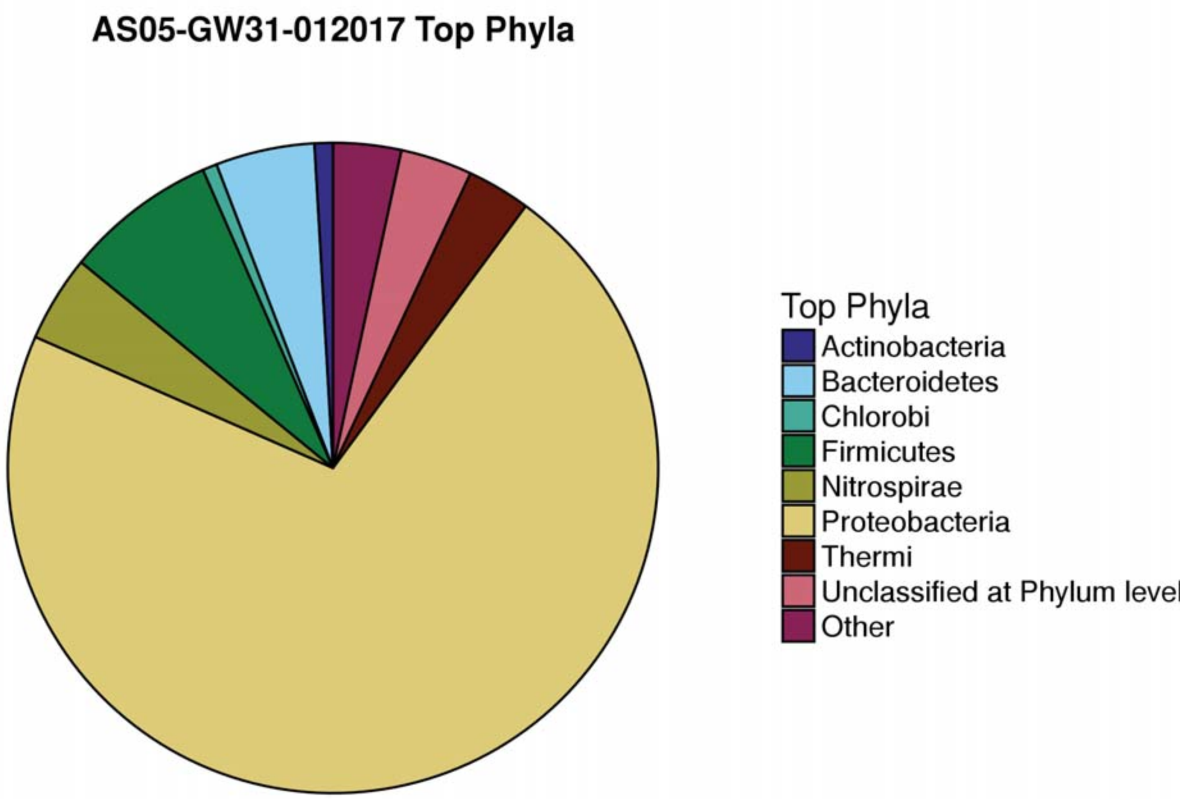

Figure 22: Top Phylum Classification Results

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Table 30: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Deinococcus	9,463	3.1%	This genus is highly resistant to environmental stressors.
Desulfurispora	6,821	2.3%	This genus is comprised of thermophilic sulfate reducers.
Pseudomonas	10,103	3.3%	Pseudomonas species can grow very rapidly to take advantage of carbon and oxygen availability. Members of this genus are gram-negative, chemoorganotrophic, and aerobic. Pseudomonas are frequently involved in the early stages of biofilm formation. Biofilms can be detrimental to the underlying surface, leading to biodeterioration of the metal surface.
Rhodoferax	7,902	2.6%	This genus is typically found in well-lit stagnant water and can thrive in aerobic or anaerobic environments using many substrates as carbon sources.
Sulfuricurvum	12,660	4.2%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Sulfurimonas	122,011	40.4%	This is a genus of sulfur- and thiosulfate-oxidizing bacteria found in deep sea sediments.
Thermodesulfovibrio	12,871	4.3%	Members of this genus are thermophilic anaerobic sulfate-reducers.
Unclassified at Genus level	32,887	10.9%	

Total Genus-level Taxonomic Categories Identified: 545. This table shows the top 8 of 545 classifications. The 8 genera shown in this table account for 71% of all observed classifications.

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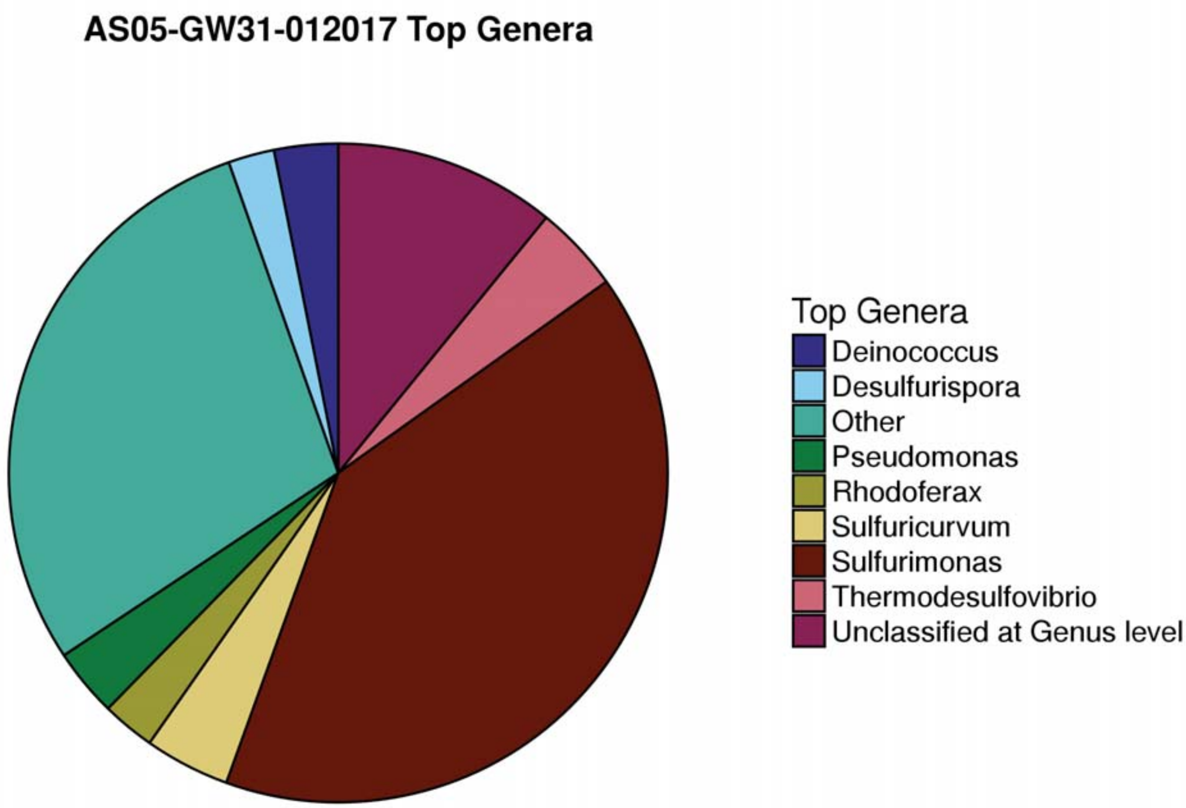

Figure 23: Top Genus Classification Results

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Results for AS05-GW18-012017

Table 31: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
541,388	498,345	92.0%

Table 32: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	497,346	99.8%
Phylum	482,337	96.8%
Class	476,701	95.7%
Order	466,011	93.5%
Family	457,705	91.8%
Genus	443,231	88.9%
Species	212,128	42.6%

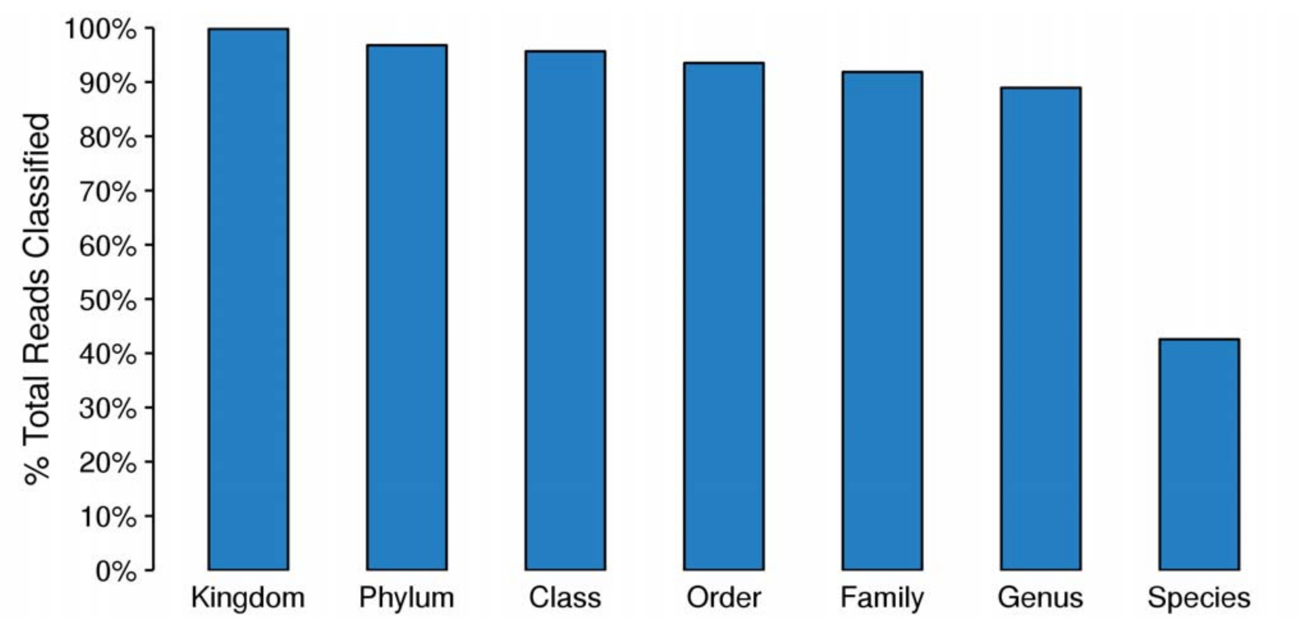

Figure 24: Classification Rate by Taxonomic Level

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AS05-GW18-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 33: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	367,395	73.7%
Nitrospirae	67,656	13.6%
Unclassified at Phylum level	16,008	3.2%
Firmicutes	11,420	2.3%
Bacteroidetes	10,511	2.1%
Actinobacteria	7,959	1.6%
Acidobacteria	2,319	0.5%
Tenericutes	2,168	0.4%

Total Phylum-level Taxonomic Categories Identified: 30. This table shows the top 8 of 30 classifications. The 8 phyla shown in this table account for 97.4% of all observed classifications.

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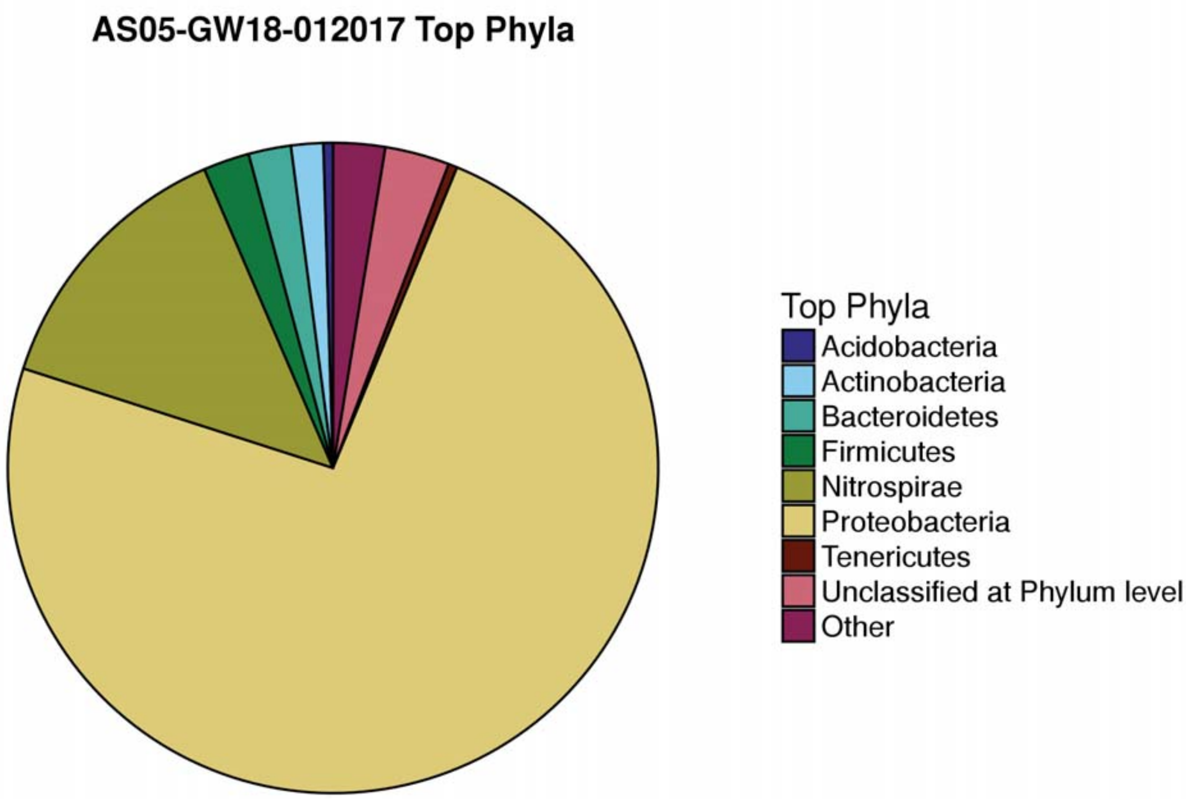

Figure 25: Top Phylum Classification Results

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Table 34: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Crenothrix	163,076	32.7%	Crenothrix is a filamentous methane oxidizer.
Desulfovibrio	6,413	1.3%	These halophilic sulfate-reducers are found in sediment of lakes, brackish water and marine environments. Desulfovibrio is also commonly found in industrial water systems resulting in biofouling biocorrosion. Desulfovibrio has been implicated in the corrosion of various metals, including carbon steel, stainless steel, galvanized steel, and copper alloys.
Flavobacterium	4,959	1.0%	Flavobacterium degrades biopolymers such as chitin and cellulose. This genus is aerobic and is widely distributed in soil and water.
Gallionella	81,473	16.4%	This genus comprises iron-oxidizing, chemolithotrophic bacteria that have been found in a variety of different aquatic habitats.
Methylomonas	7,621	1.5%	Methane, methanol and formaldehyde are the only known sources of energy and carbon for this organism.
Methylotenera	18,697	3.8%	Members of this genus can utilize methylamine as a single source of energy, carbon, and nitrogen.
Thermodesulfovibrio	67,281	13.5%	Members of this genus are thermophilic anaerobic sulfate-reducers.
Unclassified at Genus level	55,114	11.1%	

Total Genus-level Taxonomic Categories Identified: 626. This table shows the top 8 of 626 classifications. The 8 genera shown in this table account for 81.2% of all observed classifications.

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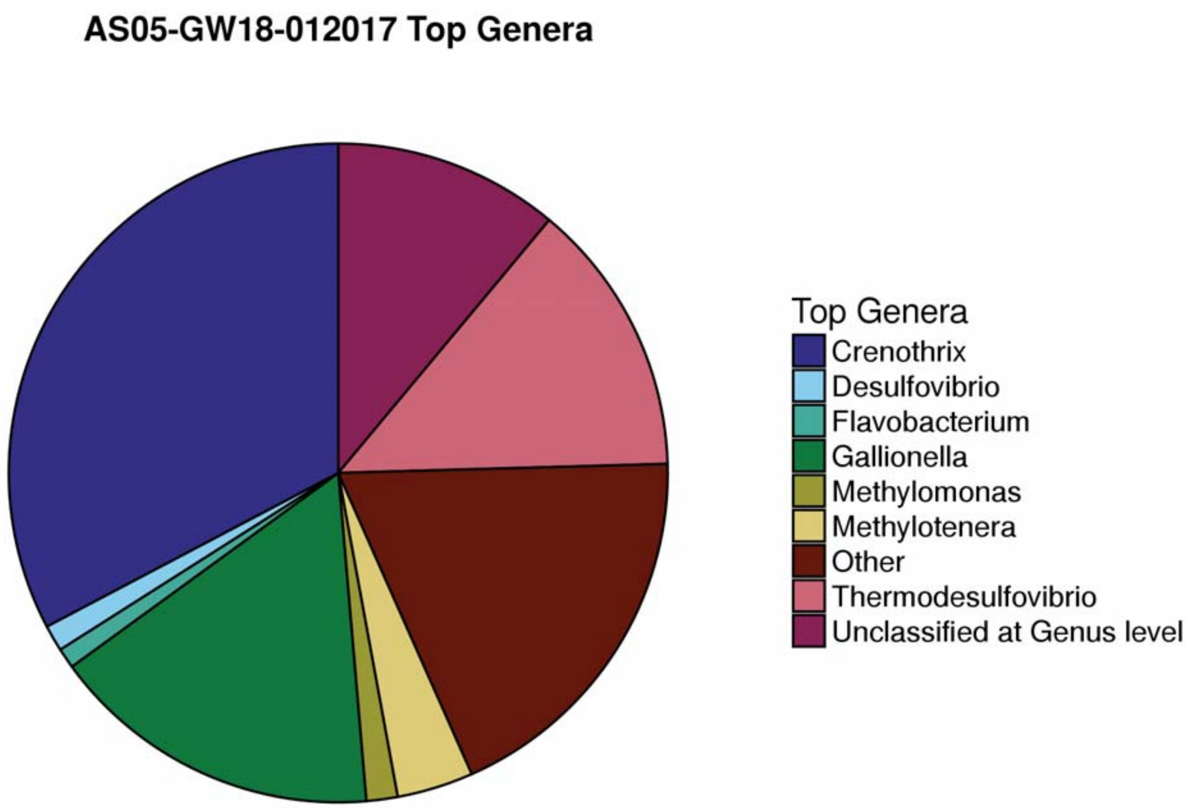

Figure 26: Top Genus Classification Results

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Results for AS05-GW25-012017

Table 35: Sequencing Statistics

Total Reads	Reads Passing Quality Filtering	% Reads Passing Quality Filtering
505,716	468,704	92.7%

Table 36: Classification Rate Summary

Taxonomic Level	Reads Classified to Taxonomic Level	% Total Reads Classified to Taxonomic Level
Kingdom	467,919	99.8%
Phylum	448,825	95.8%
Class	443,499	94.6%
Order	431,078	92.0%
Family	423,835	90.4%
Genus	388,763	82.9%
Species	223,348	47.6%

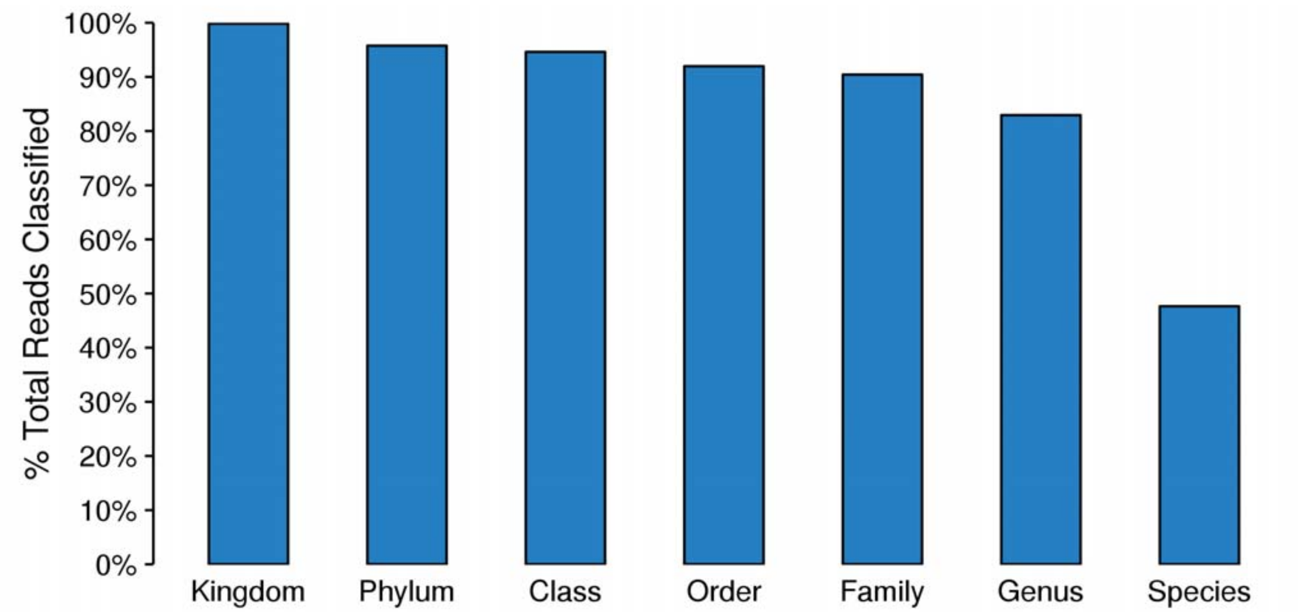

Figure 27: Classification Rate by Taxonomic Level

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AS05-GW25-012017 Classification Results by Taxonomic Level

Tables and pie charts show the highest 8 taxonomic classifications at each level.

Table 37: Top Phylum Classification Results

Classification	Number of Reads	% Total Reads
Proteobacteria	265,913	56.7%
Nitrospirae	91,923	19.6%
Firmicutes	56,231	12.0%
Unclassified at Phylum level	19,879	4.2%
Cyanobacteria	5,618	1.2%
Bacteroidetes	5,485	1.2%
Verrucomicrobia	5,011	1.1%
Actinobacteria	3,860	0.8%

Total Phylum-level Taxonomic Categories Identified: 30. This table shows the top 8 of 30 classifications. The 8 phyla shown in this table account for 96.8% of all observed classifications.

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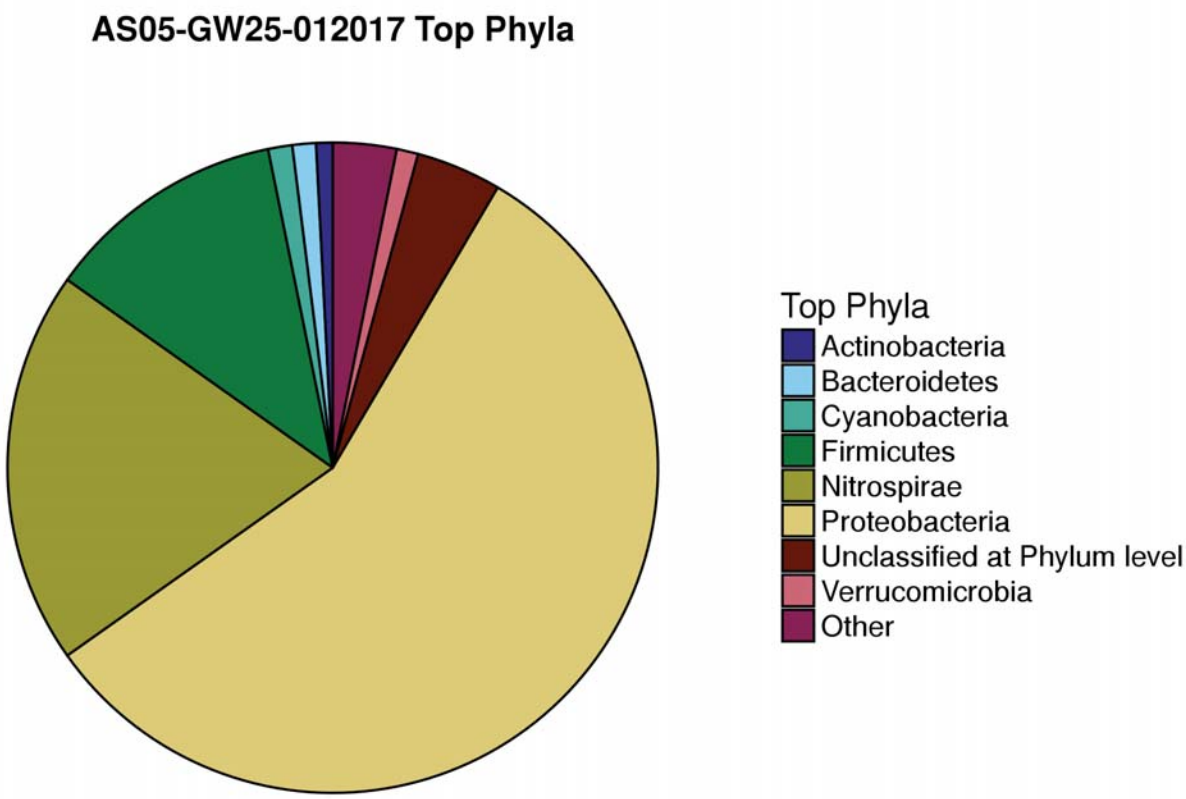

Figure 28: Top Phylum Classification Results

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Table 38: Top Genus Classification Results

Classification	Number of Reads	% Total Reads	Description
Desulfococcus	43,381	9.3%	These strictly anaerobic, sulfate-reducing bacteria have been isolated from anaerobic mud from freshwater, brackish water and marine habitats. They also occur in sludge from anaerobic sewage digestors.
Desulfosarcina	29,208	6.2%	Members of this sulfate-reducing genus have been shown to degrade 3-methoxybenzoate in co-culture with an Acetobacterium sp. These organisms are characterized as Group II sulfate reducers because they can utilize acetate and other fatty acids, oxidizing them completely.
Desulfurispora	20,389	4.3%	This genus is comprised of thermophilic sulfate reducers.
Gallionella	16,843	3.6%	This genus comprises iron-oxidizing, chemolithotrophic bacteria that have been found in a variety of different aquatic habitats.
Sulfuricurvum	10,749	2.3%	The only described species of this genus is a motile, anaerobic, sulfur-oxidizing bacterium.
Sulfurimonas	48,852	10.4%	This is a genus of sulfur- and thiosulfate-oxidizing bacteria found in deep sea sediments.
Thermodesulfovibrio	91,892	19.6%	Members of this genus are thermophilic anaerobic sulfate-reducers.
Unclassified at Genus level	79,941	17.1%	

Total Genus-level Taxonomic Categories Identified: 574. This table shows the top 8 of 574 classifications. The 8 genera shown in this table account for 72.8% of all observed classifications.

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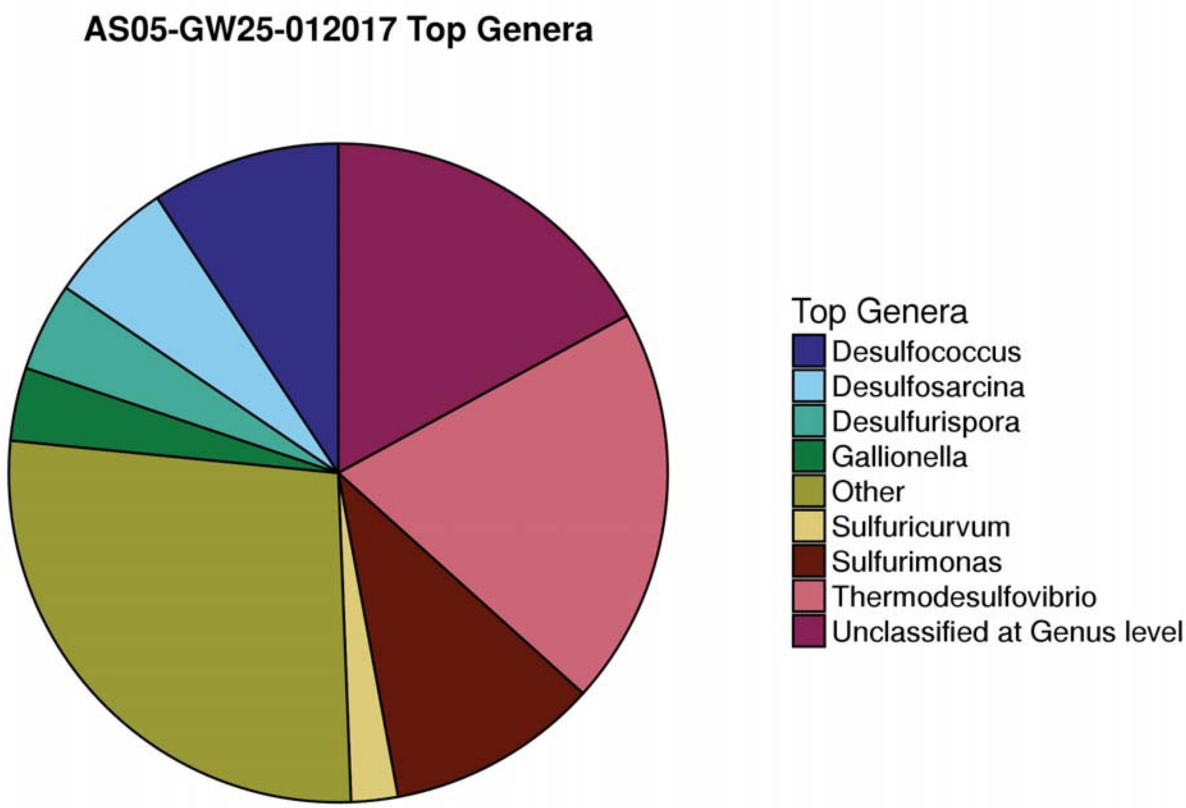

Figure 29: Top Genus Classification Results

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Interpretation

Diversity Indices

The Shannon diversity index is a quantitative measurement that characterizes how many different genera are present in the sample and takes into account the distribution of the number of organisms classified to each genus present in the sample (commonly referred to as species eveness) [1, 2]. Shannon's diversity index increases in value as the number of genera increases and as the number of organisms present per genera becomes even. Simpson's index measures the probability that two individuals selected randomly from the sample would belong to different genera: the greater the value, the greater the sample diversity. The Chao1 index is an excellent indicator of species richness and is based on the number of reads when one (singleton) or two (doubleton) operational taxonomic units (OTUs) are observed. This value is the predicted number of genera based on the number of singletons and doubletons. The total genera observed is presented here, but does not include reads unclassified at genus species.

Principal Coordinate Analysis

Principal coordinate analysis (PCoA) is an excellent tool for visualizing differences in microbial communities between samples [3]. Unlike more traditional methods such as principal component analysis (PCA), PCoA calculates complex functions for the axes rather than dimensional scaling used in PCA. Therefore, PCoA is able to better demonstrate dissimilarities that may be nuanced in PCA tests. PCoA accomplishes this by using a dissimilarity matrix to assign each sample a location in dimensional space, then changes the coordinate system to display the data in two dimensions.

Hierarchical Clustering Dendrogram

Hierarchical clustering is accomplished by comparing dissimilarities between the samples using complete agglomeration of the Bray-Curtis dissimilarity. This groups samples which are the least dissimilar together. The length of the branches indicate the amount of dissimilarity between samples. Therefore, shorter branches are more similar. The stacked bar chart below each leaf of the tree represents the relative abundance of genus-level classifications.

References

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2. Hill, M. O. Diversity and evenness: a unifying notation and its consequences. *Ecology* **54,** 427–432 (1973).
3. Buttigieg, P. L. & Ramette, A. A guide to statistical analysis in microbial ecology: a community-focused, living review of multivariate data analyses. *FEMS Microbiology Ecology* **90,** 543–550. ISSN: 1574-6941 (2014).

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Sample ID	AS05-GW13-012017	AS05-GW13P-010617	AS05-GW17-012017	AS05-GW18-012017	AS05-GW25-012017	AS05-GW25P-012017	AS05-GW26-012017	AS05-GW27-012017	AS05-GW28-012017	AS05-GW29-012017	AS05-GW30-012017	AS05-GW31-012017	AS05-GW32-012017	AS05-GW33-012317
Sample Date	1/26/17	1/6/17	1/26/17	1/25/17	1/26/17	1/26/17	1/24/17	1/24/17	1/24/17	1/25/17	1/25/17	1/25/17	1/24/17	1/23/17
Chemical Name														
Volatile Organic Compounds (UG/L)														
1,1,1-Trichloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1,2,2-Tetrachloroethane	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon-113)	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
1,1,2-Trichloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1-Dichloroethane	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
1,1-Dichloroethene	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
1,2,3-Trichlorobenzene	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U
1,2,4-Trichlorobenzene	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U
1,2-Dibromo-3-chloropropane	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-Dibromoethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,2-Dichlorobenzene	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
1,2-Dichloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,2-Dichloropropane	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U
1,3-Dichlorobenzene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,4-Dichlorobenzene	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
2-Butanone	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2-Hexanone	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
4-Methyl-2-pentanone	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Acetone	5 UQ	5 U	5 UQ	5 UQ	5 UQ	5 UQ	5 UQ	5 UQ	5 UQ	5 UQ	5 UQ	5 UQ	5 UQ	5 UQ
Acetylene	5 U	NS	5 U	5 U	5 U	NS	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Benzene	0.25 U	0.25 U	0.25 U	0.25 U	0.532 J	0.541 J	0.25 U	0.293 J	0.576 J	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
Bromochloromethane	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U
Bromodichloromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Bromoform	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Bromomethane	1 UQ	1 UQ	1 UQ	1 UQ	1 UQ	1 UQ	1 UQ	1 UQ	1 UQ	1 UQ	1 UQ	1 UQ	1 UQ	1 U
Carbon dioxide	78,200	NS	217,000	60,300	21,700	NS	98,000	72,000	39,200	123,000	94,600	77,600	76,500	188,000
Carbon disulfide	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Carbon tetrachloride	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Chlorobenzene	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
Chloroethane	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Chloroform	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
Chloromethane	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
cis-1,2-Dichloroethene	0.889 J	0.697 J	5.43	2.38	4.1	4.07	0.5 U	2.87	5.28	15.4	0.5 U	0.5 U	0.422 J	2.75
cis-1,3-Dichloropropene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Cyclohexane	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
Dibromochloromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Dichlorodifluoromethane (Freon-12)	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Ethane	2 U	NS	2 U	2 U	5.75	NS	2 U	3.85 J	6.9	2 U	3.21 J	3.37 J	2 U	2 U
Ethene	2 U	NS	2 U	2 U	2 U	NS	2 U	1.08 J	1.74 J	2 U	2 U	2 U	2 U	2 U
Ethylbenzene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Isopropylbenzene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
m- and p-Xylene	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Methane	2 U	NS	1.27 J	3,090	NS	NS	36.7	1,500	2,110	219	1,420	2,170	8.07	12.5
Methyl acetate	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
Methylcyclohexane	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
Methylene chloride	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Methyl-tert-butyl ether (MTBE)	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
o-Xylene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Styrene	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
Tetrachloroethene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Toluene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
trans-1,2-Dichloroethene	0.5 U	0.5 U	0.5 U	1.74	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.278 J	0.5 U	0.5 U	0.5 U	0.5 U
trans-1,3-Dichloropropene	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Trichloroethene	6.54	8.53	6.23	9.95	0.5 U	0.5 U	0.338 J	0.5 U	0.5 U	16.7	0.5 U	0.331 J	7.77	4.03
Trichlorofluoromethane (Freon-11)	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Vinyl chloride	0.5 U	0.5 U	0.5 U	0.592 J	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 J	0.5 U	0.5 U	0.5 U	0.5 U
Total Metals (MG/L)														
Aluminum	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.19 J	0.101 J	0.2 U	0.2 U	0.2 U	0.2 U	0.218 J
Antimony	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Arsenic	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Barium	0.0224	0.0122 J	0.0341	0.194	0.186	0.182	0.0532	0.109	0.188	0.0515	0.591	0.555	0.0399	0.0406
Beryllium	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Boron	0.202	0.2	0.1 U	0.0526 J	0.0613 J	0.0587 J	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.0536 J	0.1 U	0.1 U
Cadmium	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Calcium	184	191	81.9	71.8	63.1	63.2	152	107	72.5	151	129	98.7	109	86.4
Chromium	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Cobalt	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.0127 J
Copper	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Iron	0.22	0.1 U	0.796	9.45	4.85	4.6	1.61	5.78	5.67	4.14	22.2	21.5	0.1 U	0.268
Lead	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Lithium	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Magnesium	44	45.9	23	11.1	39	40.1	32.3	29	30.6	35	21.8	17.2	20	28.5
Manganese	0.332	0.199	0.196	0.395	0.782	0.773	0.63	1.03	1.1	9.49	0.6	0.484	0.0181 J	1.28
Mercury	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U
Molybdenum	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Nickel	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U
Potassium	4.26	3.23	0.551 J	0.679 J	1.37 J	1.22 J	1.7 J	1.31 J	1.21 J	1.21 J	1.12 J	1.19 J	0.689 J	1.24 J

Sample ID	AS05-GW13-012017	AS05-GW13P-010617	AS05-GW17-012017	AS05-GW18-012017	AS05-GW25-012017	AS05-GW25P-012017	AS05-GW26-012017	AS05-GW27-012017	AS05-GW28-012017	AS05-GW29-012017	AS05-GW30-012017	AS05-GW31-012017	AS05-GW32-012017	AS05-GW33-012317
Sample Date	1/26/17	1/6/17	1/26/17	1/25/17	1/26/17	1/26/17	1/24/17	1/24/17	1/24/17	1/25/17	1/25/17	1/25/17	1/24/17	1/23/17
Chemical Name														
Selenium	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U
Silicon	2.46	2.23	3.7	7.69	4.12	4.02	3.6	5.09	3.71	3.67	6.3	5.48	3.93	3.16
Silver	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Sodium	40.8	40.5	9.13	16.3	15.4	15.2	10.7	14.6	13.5	11.2	12.3	14.2	14.2	10.6
Strontium	3.65	3.93	0.715	0.137	1.03	1.01	8.63	2.86	1.93	2.98	0.365	0.45	0.307	0.279
Thallium	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Titanium	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
URANIUM	0.00717	0.00733	0.001 U	0.000643 J	0.001 U	0.001 U	0.00289	0.000774 J	0.001 U	0.00513	0.001 U	0.001 U	0.000991 J	0.001 U
Vanadium	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Zinc	0.02 U	0.02 U	0.0113 J	0.02 U	0.02 U	0.02 U	0.02 U	0.0243 J	0.0211 J	0.02 U	0.02 U	0.02 U	0.02 U	0.0813
Dissolved Metals (MG/L)														
Aluminum	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Antimony	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Arsenic	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Barium	0.00883 J	0.0106 J	0.0335	0.197	0.182	0.176	0.0532	0.1	0.195	0.0526	0.59	0.577	0.0384	0.0374
Beryllium	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Boron	0.205	0.199 J	0.1 U	0.0542 J	0.0556 J	0.061 J	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.0507 J	0.1 U	0.1 U
Cadmium	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Calcium	181	195	81.1	76.7	62.7	63.1	145	99.8	75.3	154	131	107	108	85.9
Chromium	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Cobalt	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.0114 J
Copper	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Iron	0.1 U	0.1 U	0.275	8.49	4.55	4.61	1.78	5.15	6.05	4.08	22.8	23.2	0.1 U	0.1 U
Lead	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Lithium	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Magnesium	43.9	46.4	23.4	11.7	38.5	38.5	32.4	27.4	30.3	35.2	21.9	18.2	19.8	27.8
Manganese	0.0343	0.167	0.192	0.392	0.767	0.775	0.639	0.978	1.04	9.61	0.605	0.497	0.0151 J	1.16
Mercury	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U
Molybdenum	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Nickel	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.0212 J
Potassium	4.27	2.97	0.548 J	0.815 J	1.29 J	1.15 J	1.68 J	1.22 J	1.35 J	1.32 J	1.04 J	1.22 J	0.653 J	1.63 J
Selenium	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U
Silicon	2.49	2.19	3.76	7.79	3.98	4.04	3.65	4.62	3.7	3.71	6.16	5.76	3.93	2.8
Silver	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Sodium	41.5	40	9.03	16.8	15.1	15	10.9	13.8	13.6	11.4	12.2	14.3	14.1	10.2
Strontium	3.59	4.04	0.703	0.142	1	0.989	8.12	2.67	2.03	3.02	0.362	0.492	0.305	0.268
Thallium	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Titanium	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
URANIUM	0.00737	0.00704	0.001 U	6.45E-04 J	0.001 U	0.001 U	0.0028	8.12E-04 J	0.001 U	0.00484	0.001 U	0.001 U	9.26E-04 J	0.001 U
Vanadium	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Zinc	0.02 U	0.02 U	0.0124 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.0157 J
Wet Chemistry (MG/L)														
Alkalinity	320	NS	166	186	224	NS	295	226	188	332	259	212	149	99.4
Ammonia	0.167 J	NS	0.0753 J	0.587	0.253	NS	0.205	0.226	0.187 J	0.68	0.677	0.675	0.135 J	0.176 J
Chloride	52.9	NS	22.7	22.1	26.4	NS	18.5	30.5	27	18.4	21.2	22.3	19.7	19.5
Fluoride	0.4 U	NS	0.118 J	0.158 J	0.133 J	NS	0.228 J	0.161 J	0.151 J	0.204 J	0.137 J	0.143 J	0.4 U	0.4 U
Hardness	680	NS	308	260	320	NS	570	392	304	610	416	352	344	340
Nitrate	0.362 J	NS	0.33 J	0.2 U	0.2 U	NS	0.622 J	0.2 U	0.2 U	0.664 J	0.2 U	0.2 U	2.81	0.4 U
Nitrite	0.4 U	NS	0.2 U	0.2 U	0.2 U	NS	0.4 U	0.2 U	0.2 U	0.4 U	0.2 U	0.2 U	0.4 U	0.4 U
Phosphate	0.05 U	NS	0.05 U	0.05 U	0.05 U	NS	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U
Sulfate	326	NS	127	58.5	95.6	NS	192	147	96.5	212	159	118	196	233
Sulfide	1 U	NS	1 U	1 U	1 U	NS	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Total organic carbon (TOC)	7.69	NS	8.71	3.66	5.1	NS	7.81	4.74	4.13	6.83	5.39	2.74	5.74	7.62

Notes:

J - The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outisde the quantitation range).

Q - One or more quality control criteria failed (e.g., LCS recovery, surrogate spike recoery or CCV recovery).

U - The material was analyzed for, but not detected

UQ - The material was analyzed for, but not detected. One or more quality control criteria failed.

UG/L - Micrograms per liter

MG/L - Milligrams per liter

NS - Not sampled

Sample ID	AS05-GW13-010617	AS05-GW18-012017	AS05-GW25-012017	AS05-GW26-012017	AS05-GW27-012017	AS05-GW28-012017	AS05-GW29-012017	AS05-GW30-012017	AS05-GW31-012017
Sample Date	1/6/17	1/20/17	1/20/17	1/20/17	1/20/17	1/20/17	1/20/17	1/20/17	1/20/17
Analyte (Cells/mL)									
APS	1.29E+04	2.13E+05	7.64E+05	7.29E+04	2.46E+04	1.10E+05	1.06E+05	7.22E+04	1.58E+04
BAV1 R-Dase	1.00E+00 U	1.00E+00 U	1.00E+00 U	1.00E+00 U	1.00E+00 U	1.00E+00 U	1.00E+00 U	1.00E+00 U	1.00E+00 U
CFR	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U
DCA	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U
DCAR	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U
DCM	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U
DCMA	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U
DECO	4.28E+01	4.45E+01	1.08E+02	4.41E+01	6.00E-01 J	4.40E+01	1.70E+02	6.36E+01	1.00E+01 U
Dehalobacter	1.68E+01	2.36E+02	2.63E+02	8.19E+01	9.40E+00 J	5.44E+02	1.00E+01 U	1.70E+02	9.60E+00 J
Dehalococcoides	1.00E+00 U	3.40E+02	4.68E+01	1.01E+01	1.00E+00 U	7.80E+00	2.94E+02	3.34E+01	9.00E+00
DHG	7.53E+01	1.00E+01 U	3.88E+02	3.25E+02	1.00E+01 U	1.00E+01 U	8.33E+02	1.00E+01 U	1.00E+01 U
Desulfitobacterium	1.00E+01 U	1.00E+01 U	4.20E+01	1.00E+01 U	1.00E+01 U	3.34E+02	1.61E+02	1.07E+02	1.00E+01 U
Desulfuromonas	1.00E+01 U	1.38E+03	9.75E+03	1.00E+01 U	1.00E+01 U	1.64E+04	1.34E+04	2.59E+03	1.46E+03
Total Bacteria	7.99E+04	3.09E+05	1.34E+06	3.07E+05	9.04E+04	6.53E+05	3.12E+05	1.91E+05	4.84E+04
EtnC	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U
EtnE	1.00E+01 U	1.10E+02	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U
Methanogens	3.30E+00 J	2.08E+02	4.62E+02	1.81E+01	8.30E+00 J	1.41E+03	1.01E+02	9.08E+01	1.72E+01
PHE	6.70E+00 J	7.30E+00 J	7.30E+01	6.65E+02	8.83E+01	2.58E+02	1.82E+02	2.88E+02	9.80E+00 J
PMMO	3.15E+01	2.60E+02	1.20E+02	2.07E+02	8.46E+02	4.64E+01	6.86E+01	2.63E+01	9.10E+00 J
RDEG	1.00E+01 U	2.96E+01	1.00E+01 U	7.12E+02	1.00E+01 U	3.80E+02	3.20E+00 J	9.74E+01	1.00E+01 U
RMO	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	2.72E+01	1.00E+01 U	1.00E+01 U	5.07E+01	1.00E+01 U
SMMO	4.87E+02	2.21E+03	1.12E+03	5.93E+02	5.51E+01	2.14E+02	2.89E+02	1.66E+02	4.56E+01
TCBO	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.00E+01 U	1.40E+00 J	1.00E+01 U	1.00E+01 U	1.00E+01 U
TCE R-Dase	1.00E+00 U	7.00E-01 J	1.00E+00 U	1.00E+00 U	1.00E+00 U	1.00E+00 U	7.00E-01 J	1.00E+00 U	1.00E+00 U
Toluene Dioxygenase	7.00E+00 J	1.05E+01	2.14E+01	2.83E+01	7.40E+00 J	1.76E+01	1.93E+01	1.51E+01	2.00E+00 J
VC R-Dase	1.00E+00 U	2.00E-01 J	1.00E+00 U	1.00E+00 U	1.00E+00 U	1.00E+00 U	3.20E+00	1.00E+00 U	1.00E+00 U

Notes:
J - The reported result is an estimated value
U - TAnalyzed for, but not detected
control criteria failed.
Shading indicates detection
Cells/mL - cells per milliliter

Sample ID	SLOP-MW119-012017	SLOP-TW01-012017	SLOP-TW02-012017	SLOP-TW03-012017	SLOP-TW03P-012017	SLOP-TW04-012017	SLOP-TW05-012017	SLOP-TW06-012017
Sample Date	1/23/17	1/25/17	1/24/17	1/23/17	1/23/17	1/25/17	1/24/17	1/24/17
Chemical Name								
Volatile Organic Compounds (UG/L)								
1,1,1-Trichloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,1,2,2-Tetrachloroethane	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon-113)	4 U	4 U	4 U	4 U	4 U	4 U	4 U	4 U
1,1,2-Trichloroethane	4.43	3.32	0.5 U	0.5 U	0.5 U	4.69	0.5 U	0.5 U
1,1-Dichloroethane	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
1,1-Dichloroethene	1 U	2.73	1.09 J	1 U	1 U	2.49	1 U	1 U
1,2,3-Trichlorobenzene	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U	0.3 U
1,2,4-Trichlorobenzene	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U
1,2-Dibromo-3-chloropropane	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
1,2-Dibromoethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,2-Dichlorobenzene	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
1,2-Dichloroethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,2-Dichloropropane	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U
1,3-Dichlorobenzene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
1,4-Dichlorobenzene	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
2-Butanone	4.02 J	3.72 J	21.6	5 U	5 U	5 U	5 U	5 U
2-Hexanone	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
4-Methyl-2-pentanone	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Acetone	6.89 J	9.87 Q	36.1 Q	5 U	5 U	3.26 Q	5 UQ	5 UQ
Acetylene	5 U	5 U	5 U	5 U	NS	5 U	5 U	5 U
Benzene	3.13	0.794 J	7.92	0.25 U	0.25 U	0.441 J	0.25 U	0.25 U
Bromochloromethane	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U	0.4 U
Bromodichloromethane	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Bromoform	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Bromomethane	1 U	1 UQ	1 UQ	1 U	1 U	1 UQ	1 UQ	1 UQ
Carbon disulfide	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Carbon tetrachloride	0.5 U	1.45	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Chlorobenzene	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
Chloroethane	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Chloroform	0.25 U	5.5	0.417 J	0.161 J	0.177 J	9.27	0.194 J	0.178 J
Chloromethane	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
cis-1,2-Dichloroethene	7.17	197	1,970	0.5 U	0.5 U	754	0.5 U	144
cis-1,3-Dichloropropene	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Cyclohexane	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
Dibromochloromethane	0.5 U	0.5 U	0.342 J	0.5 U	0.5 U	0.636 J	0.5 U	0.5 U
Dichlorodifluoromethane (Freon-12)	0.5 UQ	0.5 U	0.5 U	0.5 UQ	0.5 UQ	0.5 U	0.5 U	0.5 U
Ethane	140	22	270	2 U	NS	8.4	2 U	2 U
Ethene	4.1 J	11	4.5 J	2 U	NS	2 U	2 U	2 U
Ethylbenzene	1.52	0.291 J	9.57	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Isopropylbenzene	0.5 U	0.5 U	0.256 J	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
m- and p-Xylene	1.2 J	1 U	18.1	1 U	1 U	1 U	1 U	1 U
Methane	14,000	120	3,200	2 U	NS	13	2 U	2 U
Methyl acetate	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
Methylcyclohexane	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U
Methylene chloride	0.5 U	0.406 J	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Methyl-tert-butyl ether (MTBE)	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
o-Xylene	0.763 J	0.277 J	2.86	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Styrene	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U	0.25 U
Tetrachloroethene	0.5 U	9,570	269	1.21	1.13	12,000	1.14	677

Sample ID	SLOP-MW119-012017	SLOP-TW01-012017	SLOP-TW02-012017	SLOP-TW03-012017	SLOP-TW03P-012017	SLOP-TW04-012017	SLOP-TW05-012017	SLOP-TW06-012017
Sample Date	1/23/17	1/25/17	1/24/17	1/23/17	1/23/17	1/25/17	1/24/17	1/24/17
Chemical Name								
Toluene	4.14	1.3	6.73	0.258 J	0.278 J	0.504 J	0.5 U	0.5 U
trans-1,2-Dichloroethene	0.5 U	3.82	3.93	0.5 U	0.5 U	10.6	0.5 U	1.94
trans-1,3-Dichloropropene	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Trichloroethene	0.454 J	400	143	0.298 J	0.311 J	611	1.03	79.7
Trichlorofluoromethane (Freon-11)	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Vinyl chloride	0.5 U	0.528 J	2.3	0.5 U	0.5 U	0.312 J	0.5 U	0.5 U
Total Metals (MG/L)								
Aluminum	0.173 J	0.149 J	0.2 U	0.162 J	0.228 J	0.2 U	0.503	0.2 U
Antimony	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Arsenic	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Barium	0.0495	0.117	0.177	0.133	0.135	0.0965	0.0918	0.0956
Beryllium	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Boron	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.0934 J	0.1 U
Cadmium	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Calcium	32.3	55.4	80.7	53.7	54	51.1	62.5	44.6
Chromium	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Cobalt	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Copper	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Iron	0.281	0.473	0.262	0.136 J	0.148 J	0.1 U	0.56	0.0692 J
Lead	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Lithium	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Magnesium	5.16	21.5	33.7	22.8	23	21.8	26.9	19.9
Manganese	0.258	2.15	2.43	0.0773	0.077	0.0375	0.0734	0.0493
Mercury	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U
Molybdenum	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Nickel	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U
Potassium	1 U	2.5	0.755 J	0.822 J	0.661 J	0.795 J	0.595 J	1 U
Selenium	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U
Silicon	3.76	10.2	4.98	12.4	13	12.1	14.3	14.3
Silver	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Sodium	80.8	31.5	62.1	56.2	56.4	46.1	45.2	33.3
Strontium	0.166	0.206	0.394	0.278	0.28	0.207	0.358	0.186
Thallium	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Titanium	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
URANIUM	0.001 U	0.000853 J	0.000559 J	0.001 U	0.001 U	0.001 U	0.000703 J	0.001 U
Vanadium	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Zinc	0.0472	0.02 U	0.02 U	0.023 J	0.02 U	0.0352 J	0.02 U	0.0227 J
Dissolved Metals (MG/L)								
Aluminum	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Antimony	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Arsenic	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Barium	0.0502	0.117	0.177	0.136	0.133	0.0968	0.0851	0.0941
Beryllium	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Boron	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.0913 J	0.1 U
Cadmium	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Calcium	32.9	55	82.8	55.3	55.2	51.9	60.7	42.5
Chromium	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Cobalt	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U

Sample ID	SLOP-MW119-012017	SLOP-TW01-012017	SLOP-TW02-012017	SLOP-TW03-012017	SLOP-TW03P-012017	SLOP-TW04-012017	SLOP-TW05-012017	SLOP-TW06-012017
Sample Date	1/23/17	1/25/17	1/24/17	1/23/17	1/23/17	1/25/17	1/24/17	1/24/17
Chemical Name								
Copper	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Iron	0.0904 J	0.239	0.128 J	0.0727 J	0.1 U	0.1 U	0.1 U	0.1 U
Lead	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Lithium	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Magnesium	5.41	21.5	34.6	23.7	23	22.1	26.1	20
Manganese	0.277	2.06	2.45	0.0755	0.0742	0.0425	0.0655	0.0495
Mercury	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U	0.0002 U
Molybdenum	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Nickel	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U
Potassium	1 U	1.41 J	0.786 J	0.681 J	0.821 J	0.697 J	1 U	1 U
Selenium	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U
Silicon	3.66	8.98	4.68	12.6	12.4	12.3	13.5	13.7
Silver	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Sodium	83.6	33.8	59.7	57.7	56.5	47	44.1	32.5
Strontium	0.174	0.216	0.388	0.287	0.281	0.211	0.35	0.184
Thallium	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Titanium	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U	0.03 U
URANIUM	0.001 U	0.00101 J	0.000512 J	0.001 U	0.001 U	0.001 U	0.000621 J	0.001 U
Vanadium	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U
Zinc	0.02 U	0.02 U	0.0133 J	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
Wet Chemistry (MG/L)								
Alkalinity	221	232	96.4	175	NS	154	233	128
Ammonia	0.18 J	0.164 J	0.0867 J	0.163 J	NS	0.0913 J	0.0951 J	0.0708 J
Chloride	31.4	22.6	228	60.4	NS	43	25.8	38.9
Fluoride	1.8	0.477	0.422 J	0.281 J	NS	0.204 J	0.257 J	0.211 J
Hardness	130	252	328	110	NS	224	260	188
Nitrate	0.2 U	0.2 U	0.922 J	0.2 U	NS	0.2 U	0.2 U	0.2 U
Nitrite	0.2 U	0.2 U	0.4 U	0.2 U	NS	0.2 U	0.2 U	0.2 U
Phosphate	0.142	0.05 U	0.05 U	0.05 U	NS	0.05 U	0.05 U	0.05 U
Sulfate	1.7 J	25.4	44	84.7	NS	107	84.8	84.4
Sulfide	1 U	1 U	1 U	1 U	NS	1 U	1 U	1 U
Total organic carbon (TOC)	11.4	17.8	27.6	5.24	NS	7.35	6.84	4.25

Notes:

J - The reported result is an estimated value (e.g., matrix interference was observed or the analyte was detected at a concentration outisde the quantitation range).

Q - One or more quality control criteria failed (e.g., LCS recovery, surrogate spike recoery or CCV recovery).

U - The material was analyzed for, but not detected

UQ - The material was analyzed for, but not detected. One or more quality control criteria failed.

UG/L - Micrograms per liter

MG/L - Milligrams per liter

NS - Not sampled

Sample ID	SLOP-MW119-012017	SLOP-TW01-012017	SLOP-TW02-012017	SLOP-TW03-012017	SLOP-TW04-012017	SLOP-TW05-012017	SLOP-TW06-012017
Sample Date	1/23/17	1/25/17	1/24/17	1/23/17	1/25/17	1/24/17	1/24/17
Analyte (Cells/mL)							
APS	6.95E+05	2.28E+02	2.31E+01	2.70E+00 J	2.70E+00 J	2.00E+01 U	3.14E+01
BAV1 R-Dase	1.30E+00 U	2.00E+00 U	2.00E+00 U	1.00E+00 U	2.00E+00 U	2.00E+00 U	1.70E+00 U
CFR	1.25E+01 U	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
DCA	1.25E+01 U	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
DCAR	1.25E+01 U	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
DCM	1.25E+01 U	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
DCMA	1.25E+01 U	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
DECO	1.15E+03	2.00E+01 U	4.40E+00 J	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
Dehalobacter	7.07E+02	2.51E+03	1.95E+03	1.00E+01 U	4.18E+01	2.00E+01 U	4.70E+00 J
Dehalococcoides	2.42E+01	5.11E+01	2.00E+00 U	1.00E+00 U	2.03E+01	2.00E+00 U	1.70E+00 U
DHG	9.69E+03	2.00E+01 U	4.19E+02	1.00E+01 U	1.78E+02	2.00E+01 U	1.67E+01 U
Desulfitobacterium	3.93E+02	1.22E+02	1.27E+02	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
Desulfuromonas	1.22E+04	5.17E+03	5.65E+03	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
Total Bacteria	7.25E+06	6.56E+05	7.76E+05	1.19E+04	1.60E+05	3.56E+03	1.46E+04
EtnC	1.25E+01 U	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
EtnE	3.89E+02	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.44E+02	2.00E+01 U	1.67E+01 U
Methanogens	4.27E+03	3.70E+01	1.55E+02	1.90E+00 J	4.14E+01	2.00E+01 U	2.90E+00 J
PHE	1.03E+04	3.81E+03	3.71E+03	1.93E+02	1.27E+03	1.00E+00 J	5.30E+02
PMMO	1.32E+04	3.99E+01	3.37E+01	3.60E+00 J	3.26E+02	2.00E+01 U	2.90E+00 J
RDEG	2.79E+03	1.25E+03	1.36E+03	1.01E+03	5.39E+03	2.00E+01 U	7.81E+01
RMO	5.17E+03	9.34E+01	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
SMMO	1.01E+04	4.03E+02	2.28E+02	4.84E+01	2.37E+02	2.00E+01 U	3.15E+02
TCBO	8.33E+01	2.00E+01 U	2.00E+01 U	1.00E+01 U	2.00E+01 U	2.00E+01 U	1.67E+01 U
TCE R-Dase	1.30E+00 U	9.00E-01 J	2.00E+00 U	1.00E+00 U	2.00E+00 U	2.00E+00 U	1.70E+00 U
Toluene Dioxygenase	8.66E+01	3.88E+01	3.37E+01	6.80E+00 J	9.74E+02	7.00E-01 J	6.60E+00 J
VC R-Dase	1.30E+00 U	5.00E-01 J	2.00E+00 U	1 U	2.00E+00 U	2.00E+00 U	1.70E+00 U

Notes:

J - The reported result is an estimated value

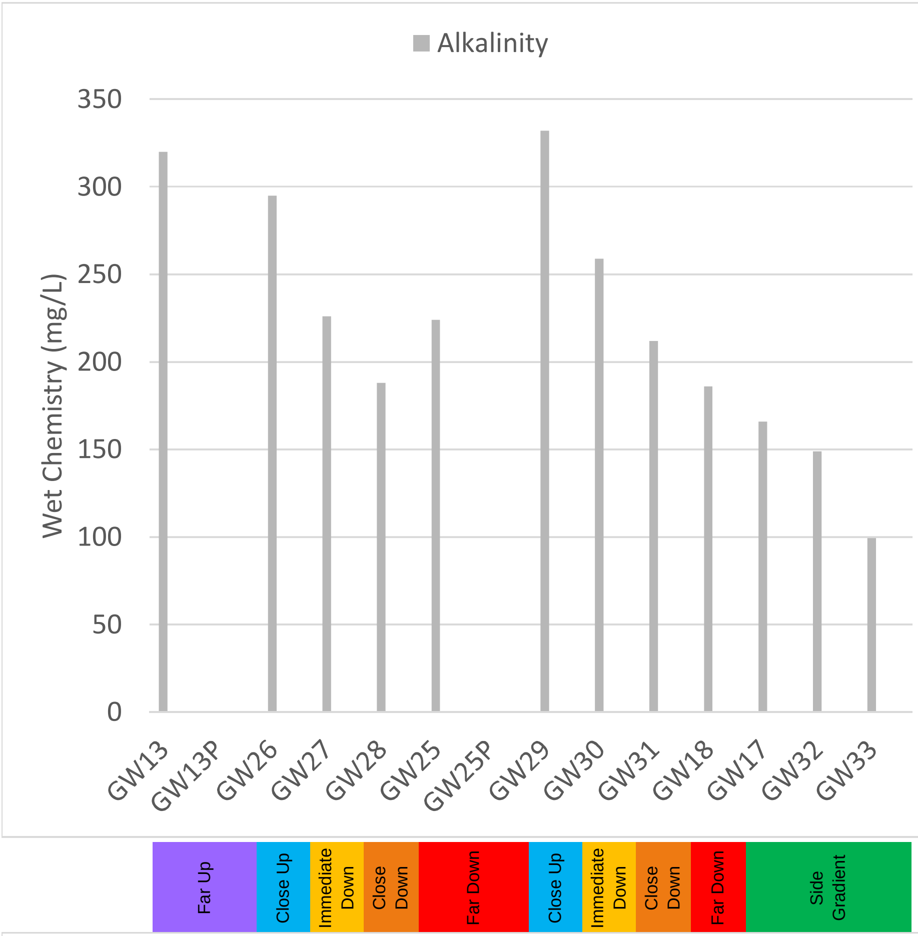
U - TAnalyzed for, but not detected

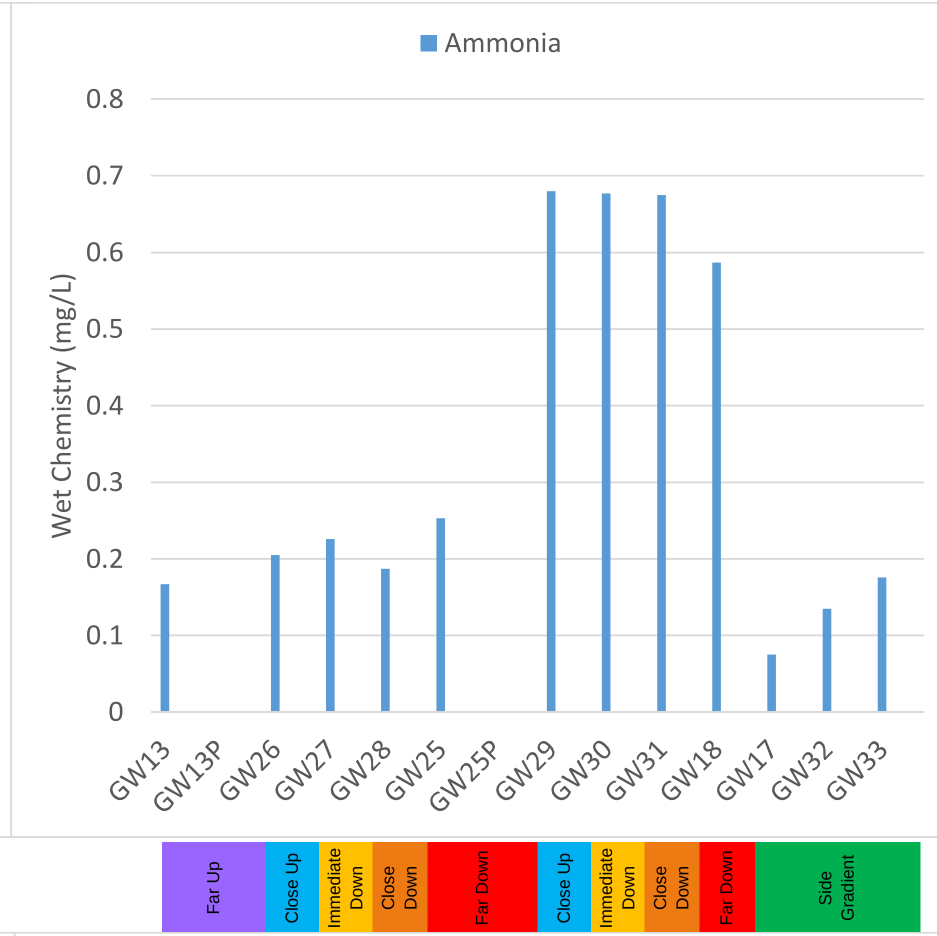
control criteria failed.

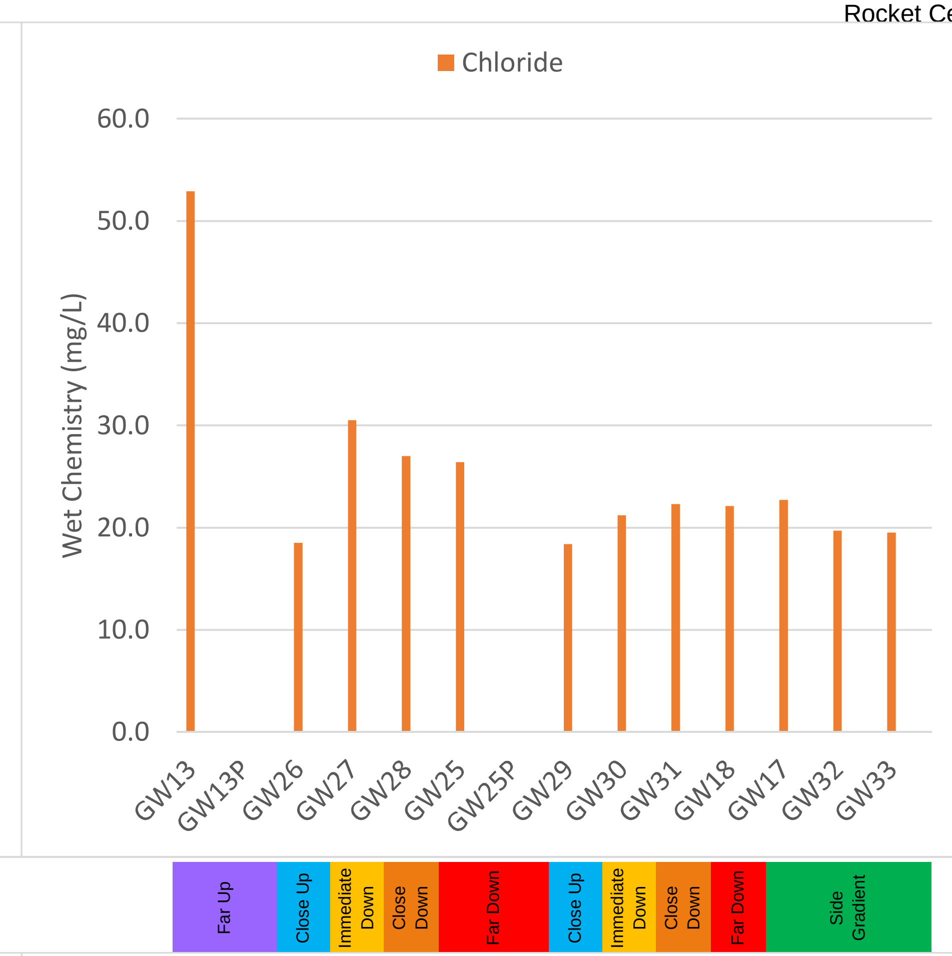
Shading indicates detection

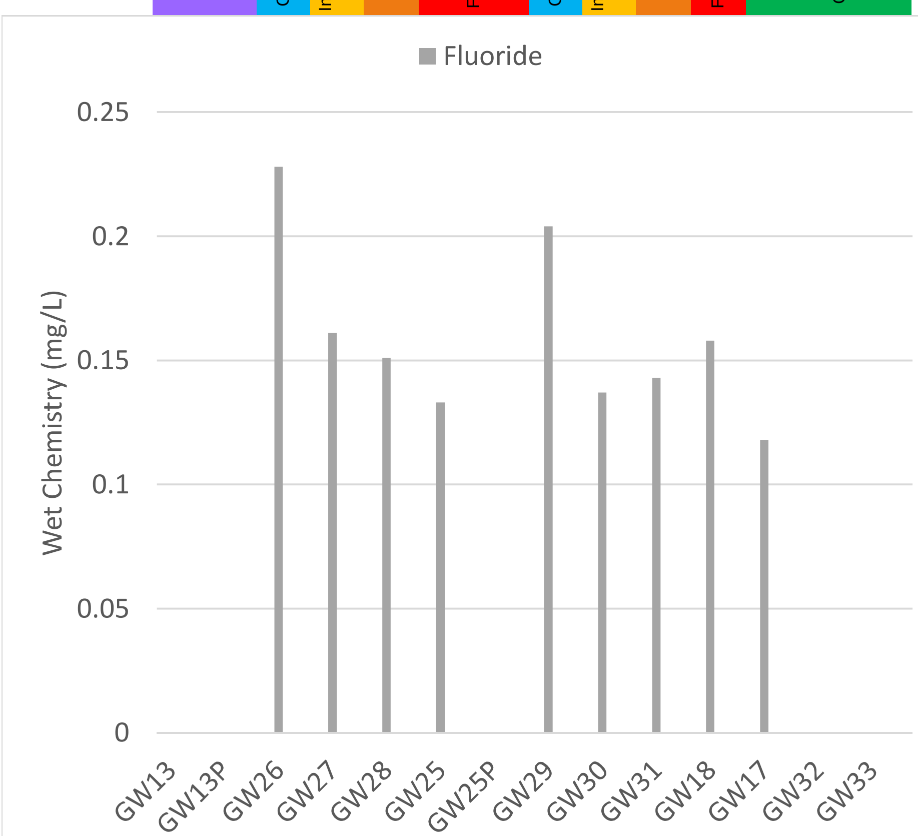
Cells/mL - cells per milliliter

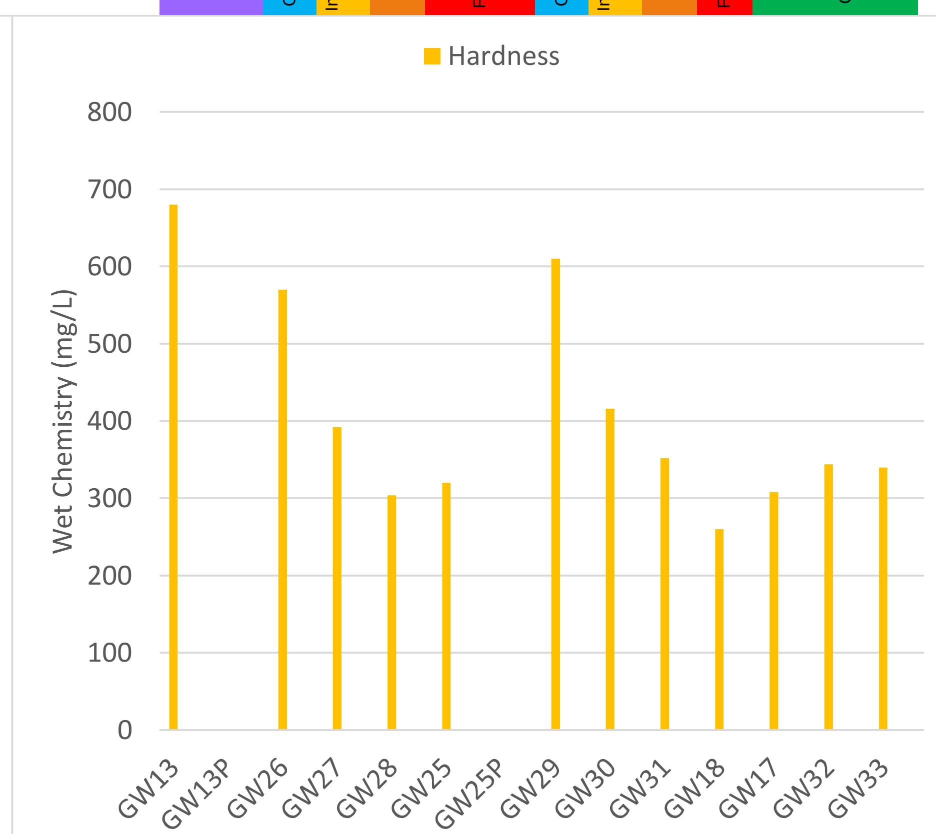
Appendix H
Trend Graphs ABL

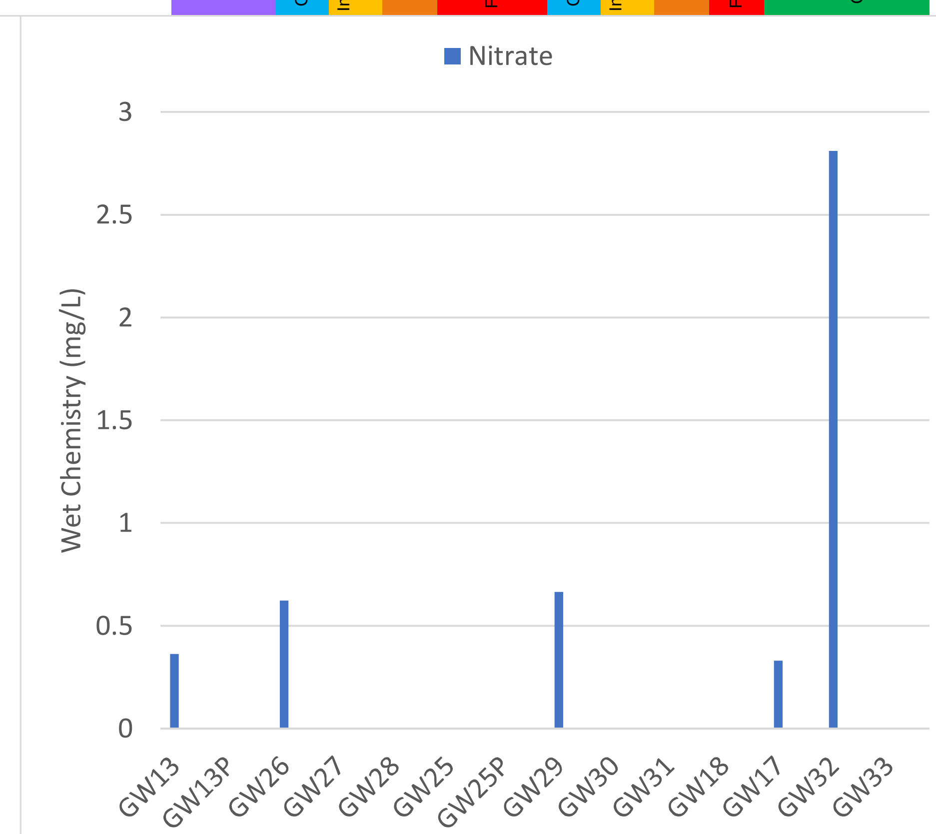

Alkalinity
Wet Chemistry (mg/L)
0
50
100
150
200
250
300
350
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Close Up
Immediate Down
Close Down
Far Down
Side Gradient

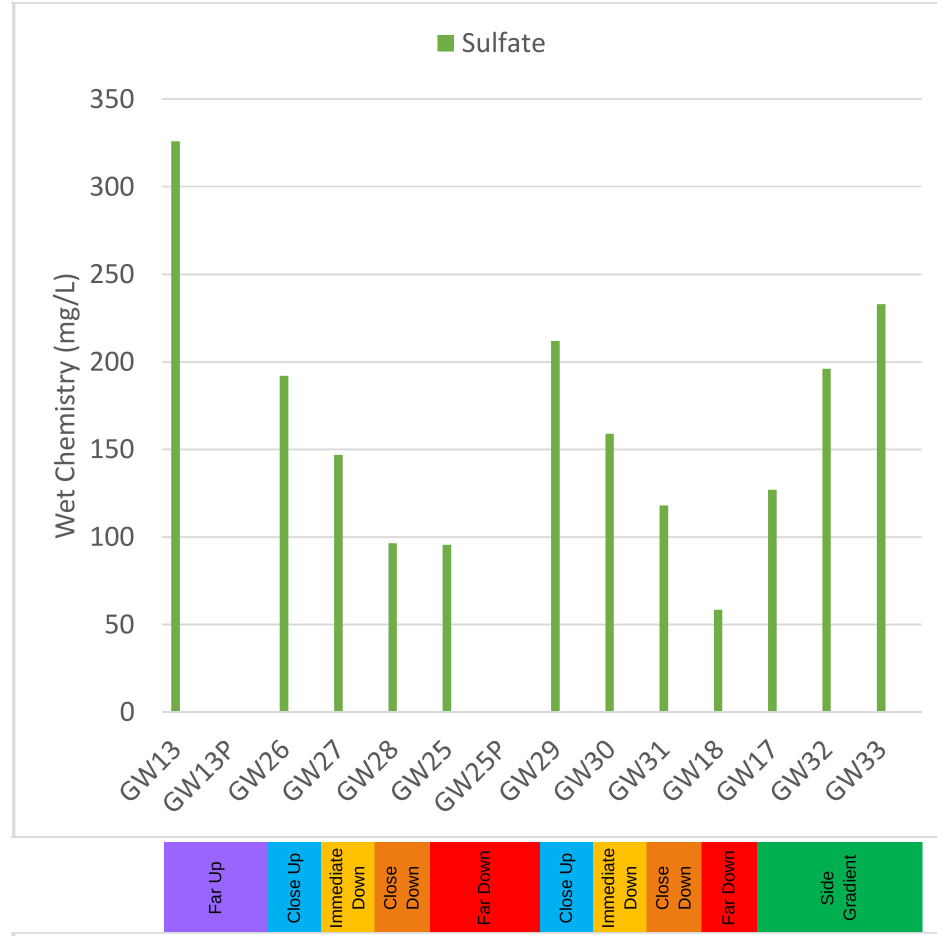

Ammonia
Wet Chemistry (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Close Up
Immediate Down
Close Down
Far Down
Side Gradient

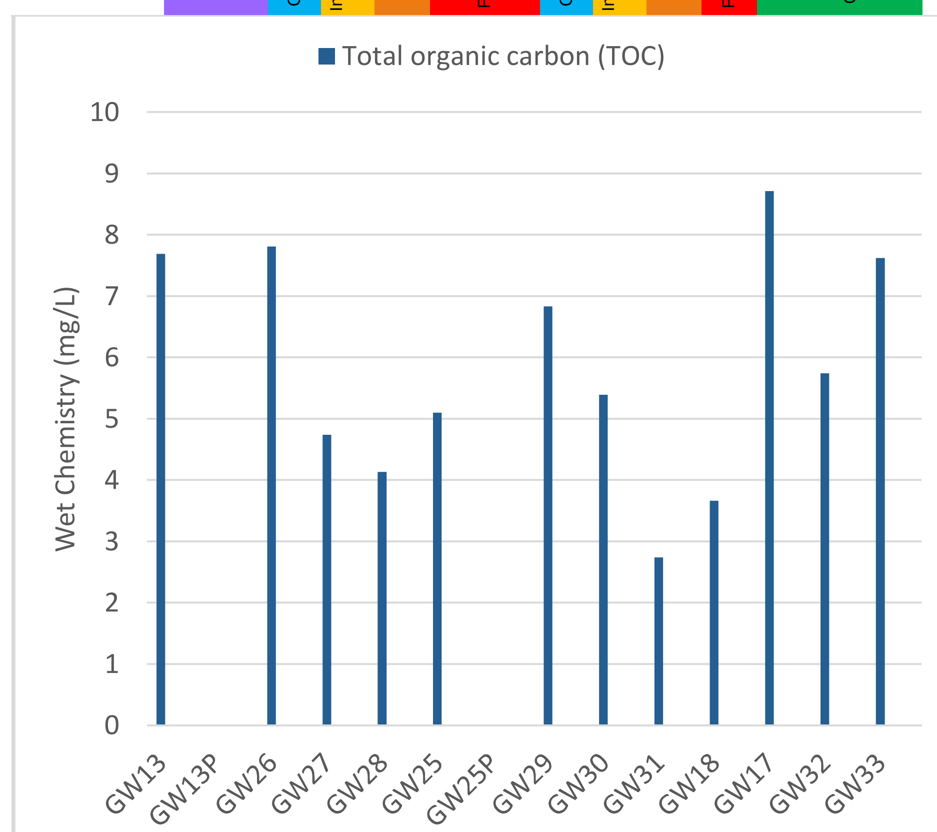

Chloride
Wet Chemistry (mg/L)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Close Up
Immediate Down
Close Down
Far Down
Side Gradient

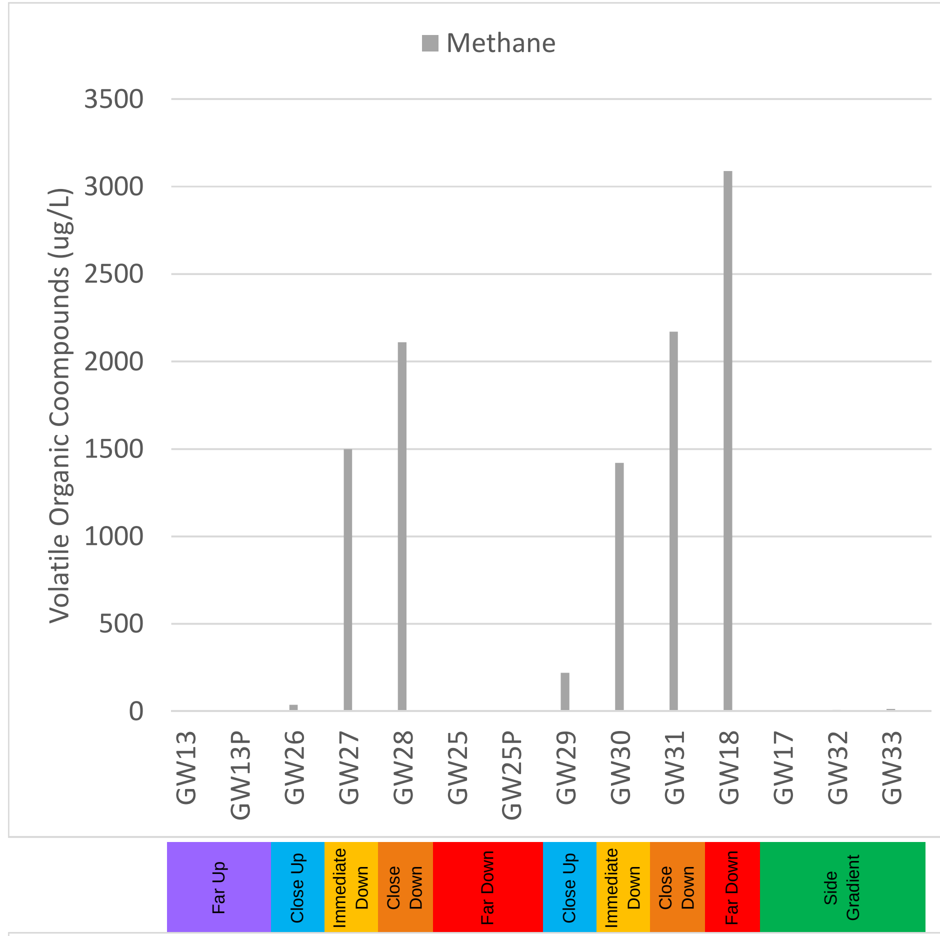

Fluoride
Wet Chemistry (mg/L)
0
0.05
0.1
0.15
0.2
0.25
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33

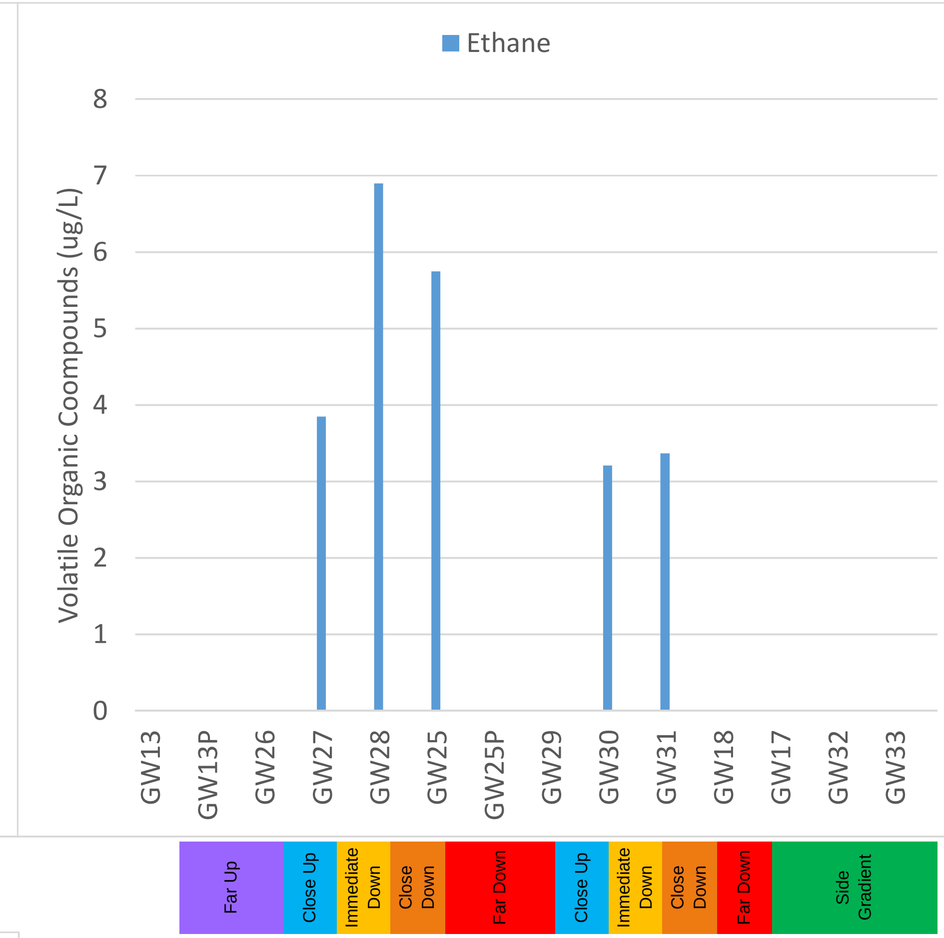

Hardness
Wet Chemistry (mg/L)
0
100
200
300
400
500
600
700
800
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33

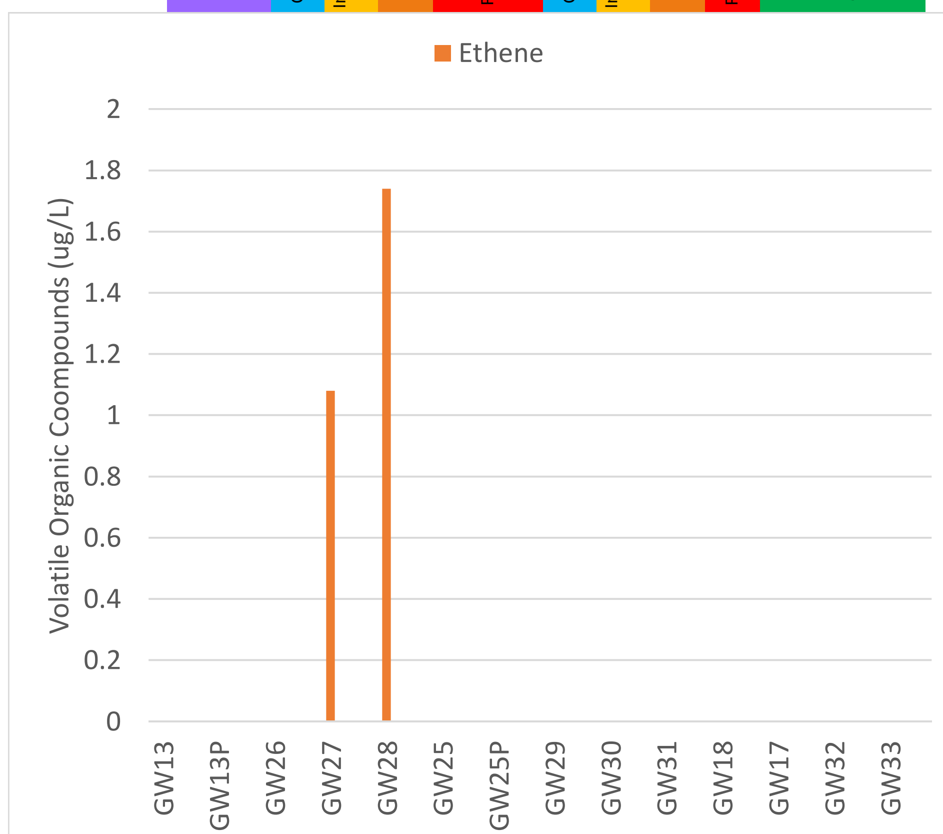

Nitrate
Wet Chemistry (mg/L)
0
0.5
1
1.5
2
2.5
3
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33

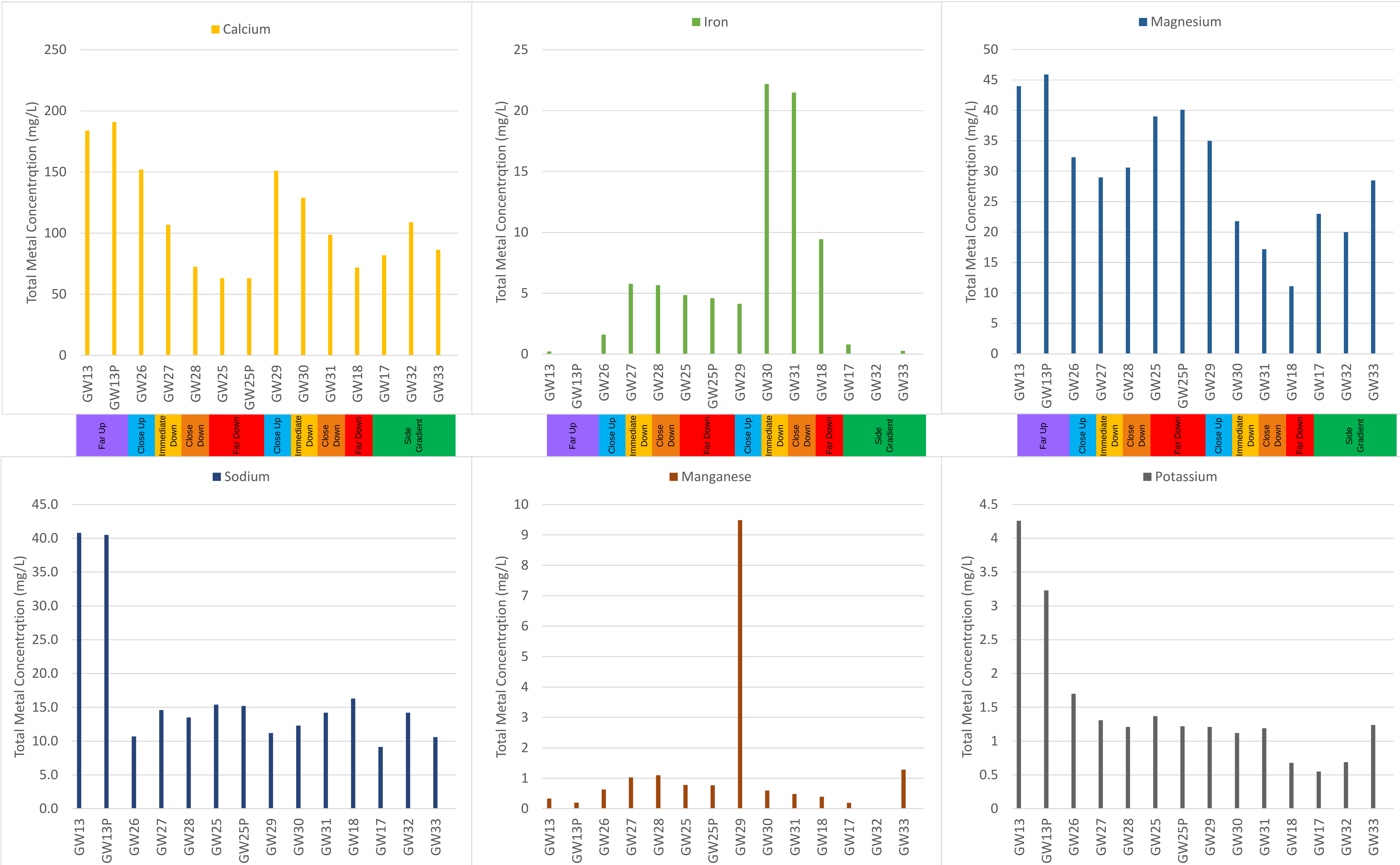

Sulfate
Wet Chemistry (mg/L)
350
300
250
200
150
100
50
0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Close Up
Immediate Down
Close Down
Far Down
Side Gradient

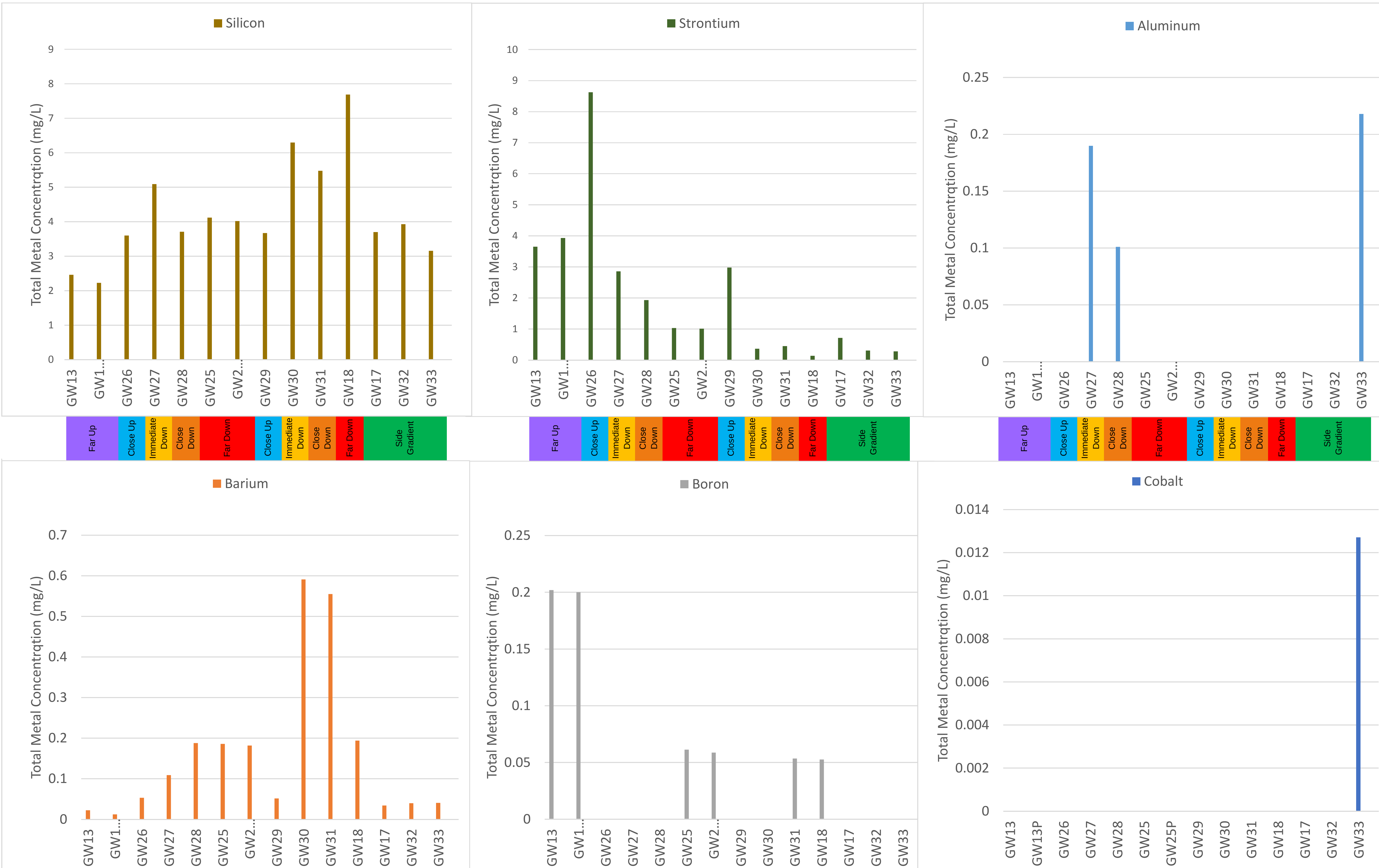

Total organic carbon (TOC)
Wet Chemistry (mg/L)
10
9
8
7
6
5
4
3
2
1
0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33

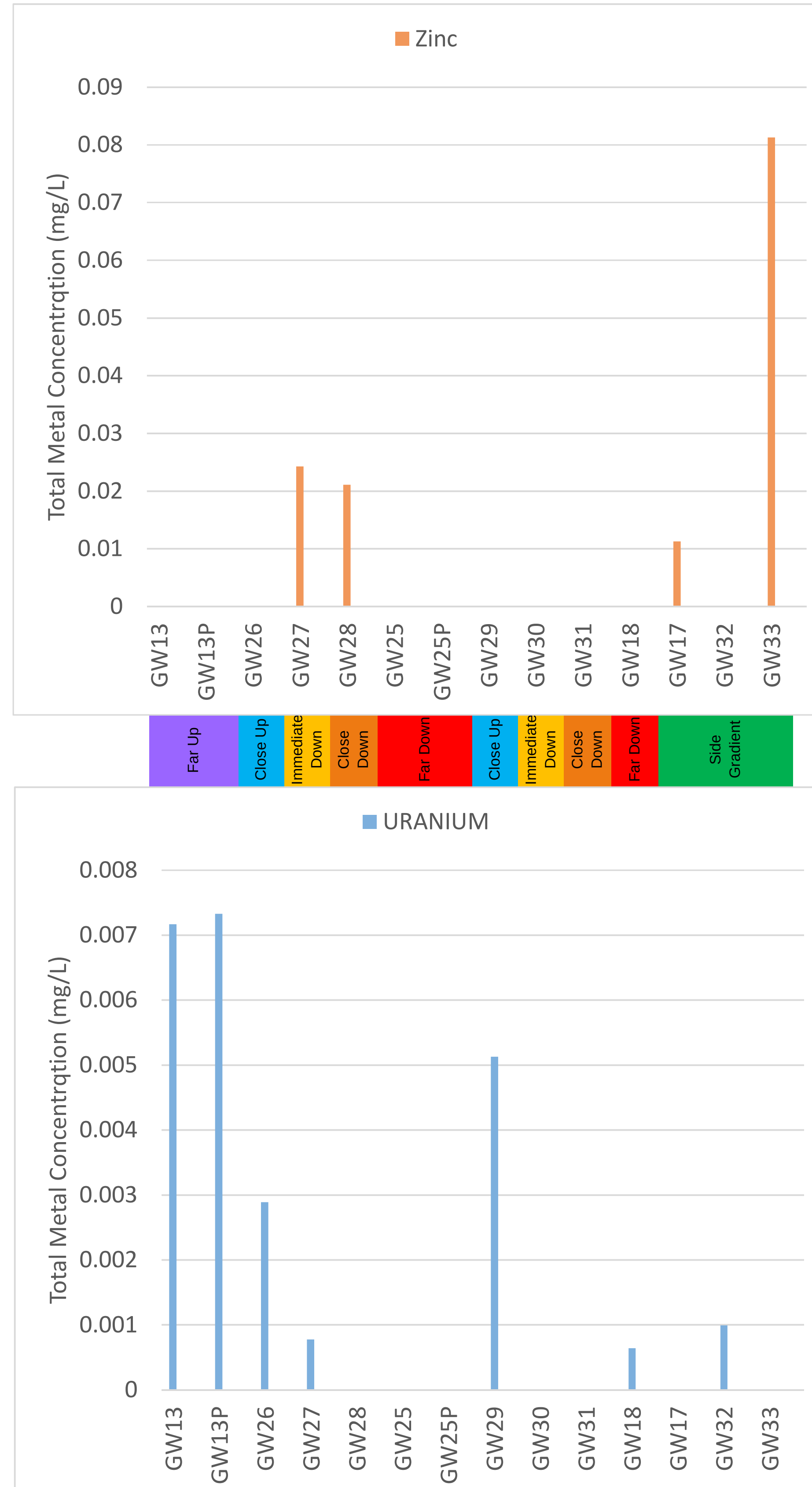

Methane
Volatile Organic Coompounds (ug/L)
3500
3000
2500
2000
1500
1000
500
0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Close Up
Immediate Down
Close Down
Far Down
Side Gradient

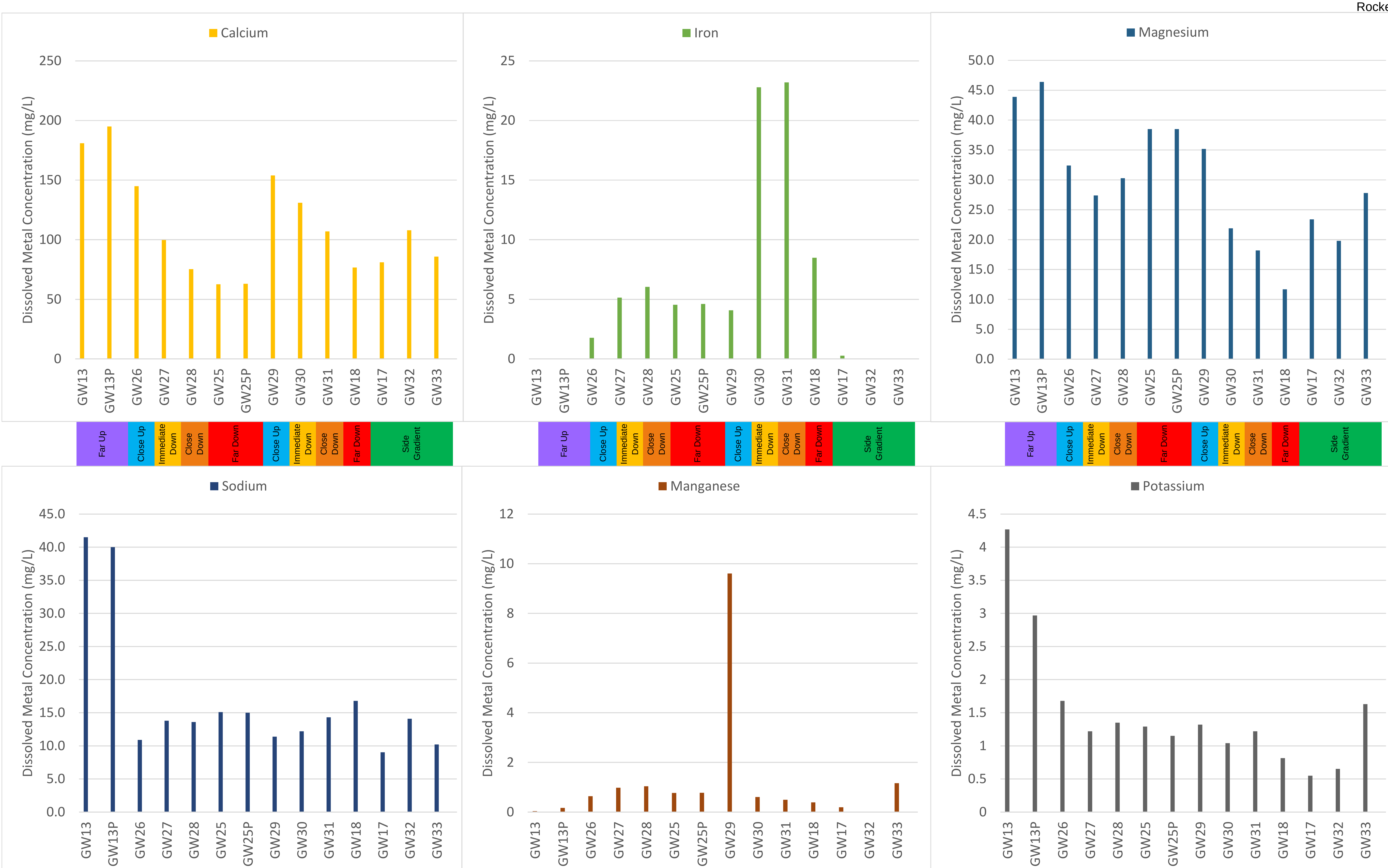

Ethane
Volatile Organic Coompounds (ug/L)
8
7
6
5
4
3
2
1
0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Close Up
Immediate Down
Close Down
Far Down
Side Gradient

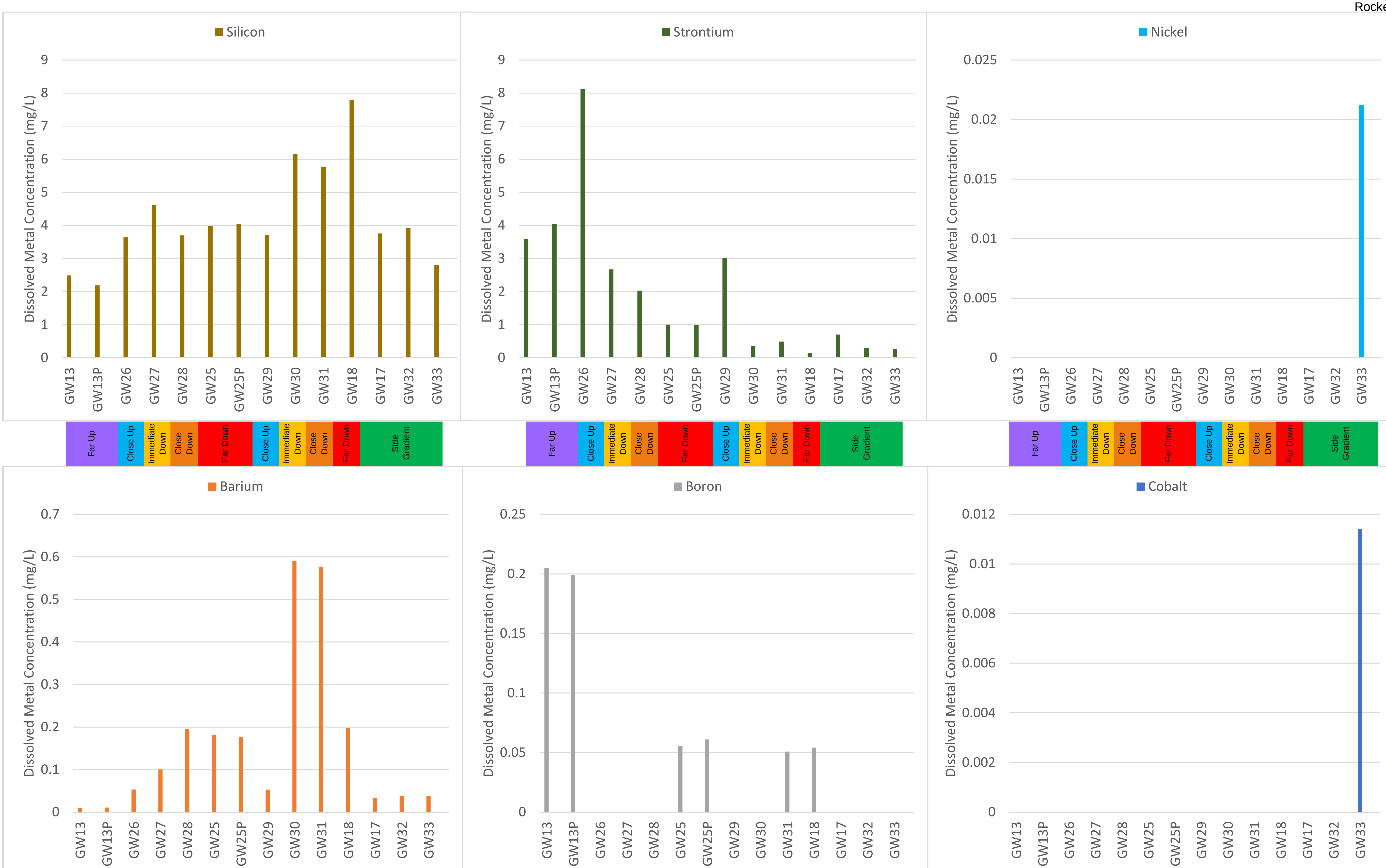

Ethene
Volatile Organic Coompounds (ug/L)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33

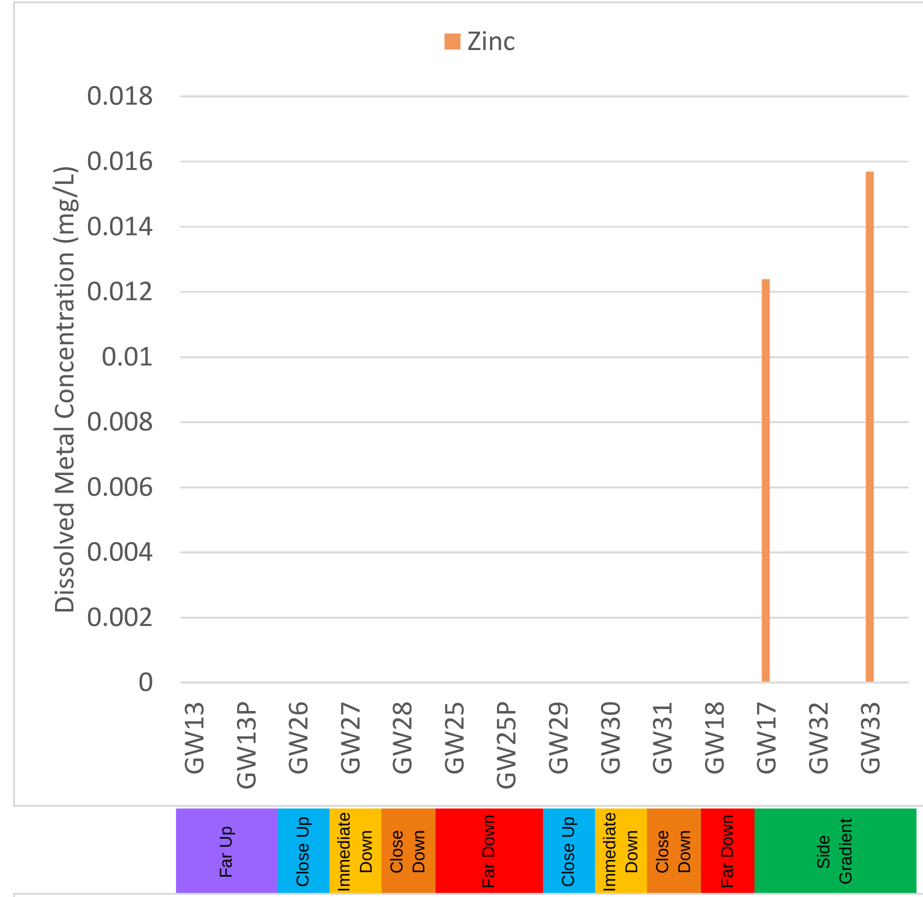

Calcium
Iron
Magnesium
Sodium
Manganese
Potassium
Total Metal Concentrtion (mg/L)
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Side Gradient

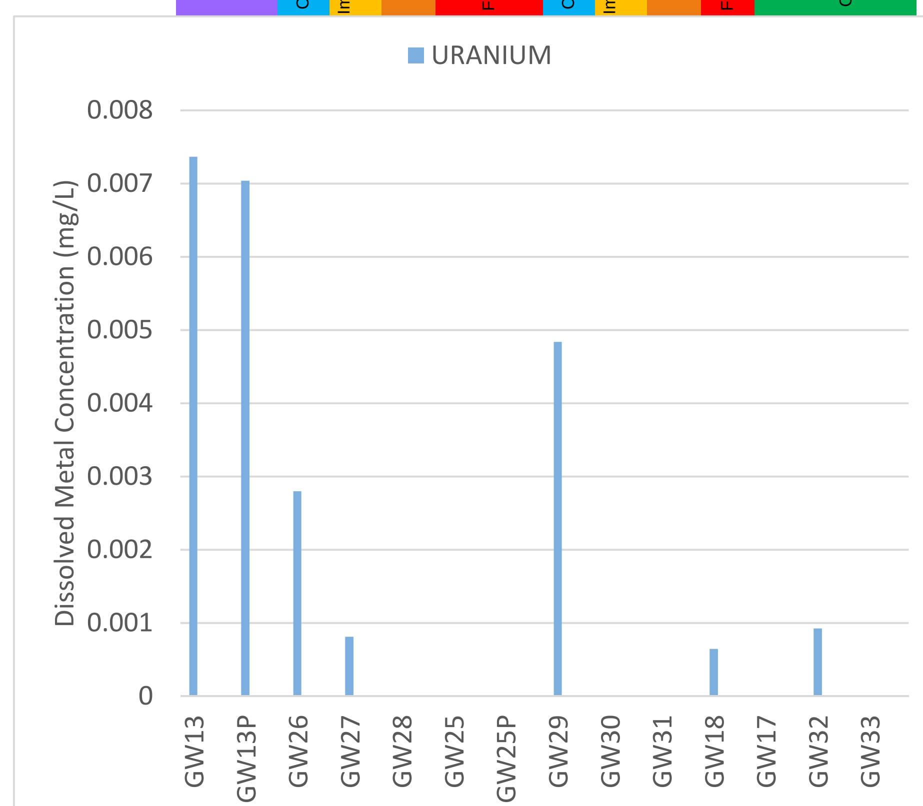

Silicon
Total Metal Concentrqtion (mg/L)
0
1
2
3
4
5
6
7
8
9
GW13
GW1…
GW26
GW27
GW28
GW25
GW2…
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Strontium
Total Metal Concentrqtion (mg/L)
0
1
2
3
4
5
6
7
8
9
10
Aluminum
Total Metal Concentrqtion (mg/L)
0
0.05
0.1
0.15
0.2
0.25
Far Up
Close Up
Immediate Down
Close Down
Far Down
Side Gradient
Barium
Total Metal Concentrqtion (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Boron
Total Metal Concentrqtion (mg/L)
0
0.05
0.1
0.15
0.2
0.25
Cobalt
Total Metal Concentrqtion (mg/L)
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
GW13P
GW25P


Zinc
Total Metal Concentrqtion (mg/L)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Close Up
Immediate Down
Close Down
Far Down
Side Gradient
URANIUM
Total Metal Concentrqtion (mg/L)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33


Calcium
Iron
Magnesium
Sodium
Manganese
Potassium
Dissolved Metal Concentration (mg/L)
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Side Gradient

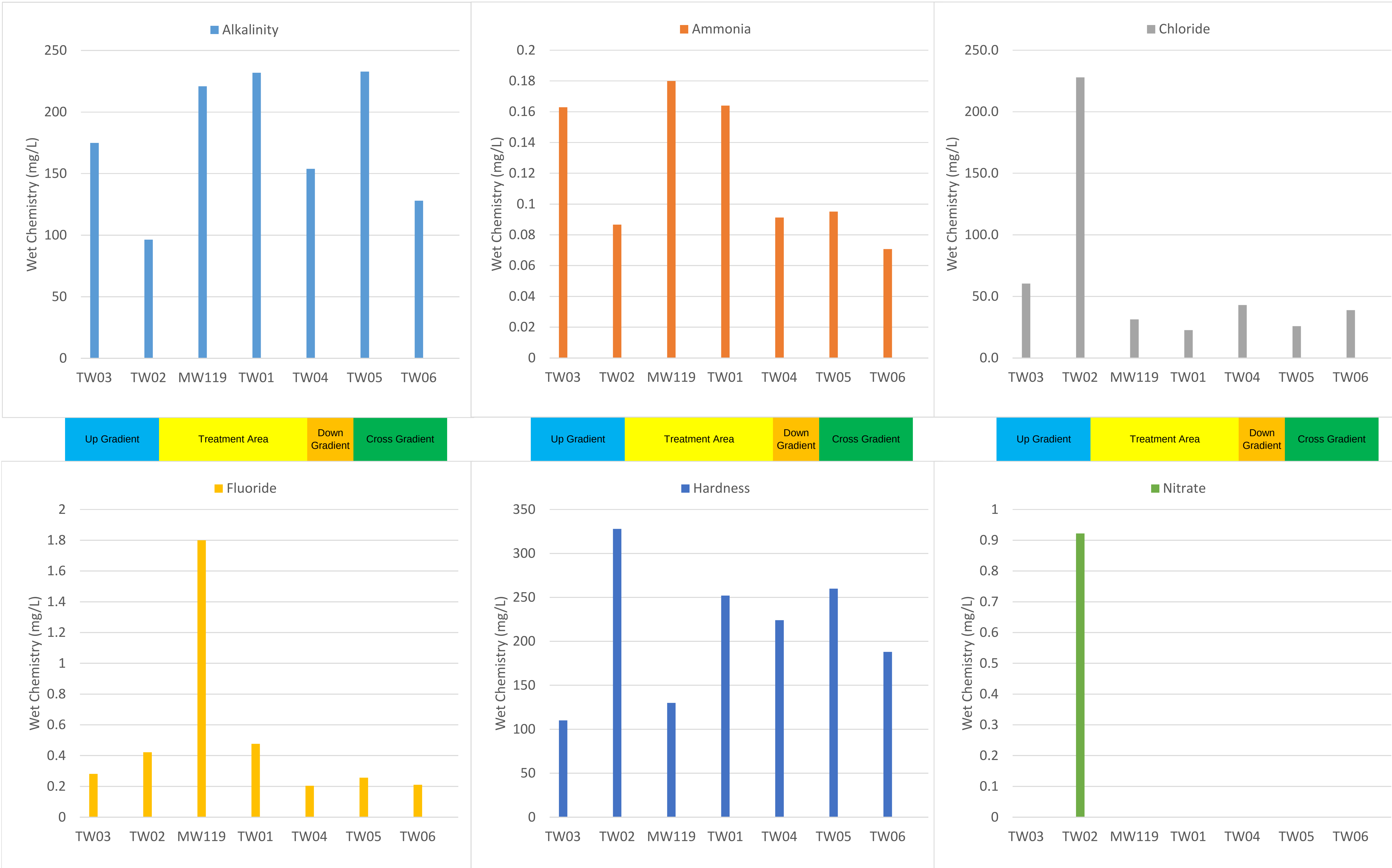

Silicon
Strontium
Nickel
Barium
Boron
Cobalt
Dissolved Metal Concentration (mg/L)
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Close Up
Immediate Down
Close Down
Far Down
Side Gradient

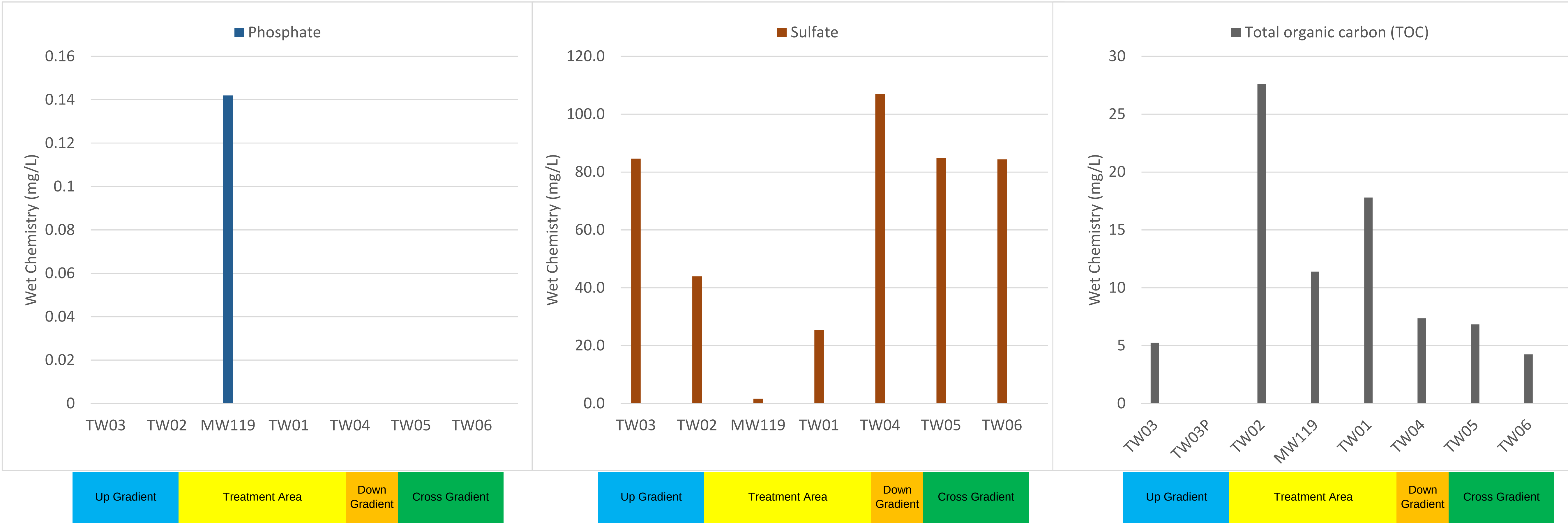

Zinc
Dissolved Metal Concentration (mg/L)
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33
Far Up
Close Up
Immediate Down
Close Down
Far Down
Close Up
Immediate Down
Close Down
Far Down
Side Gradient


URANIUM
Dissolved Metal Concentration (mg/L)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
GW13
GW13P
GW26
GW27
GW28
GW25
GW25P
GW29
GW30
GW31
GW18
GW17
GW32
GW33

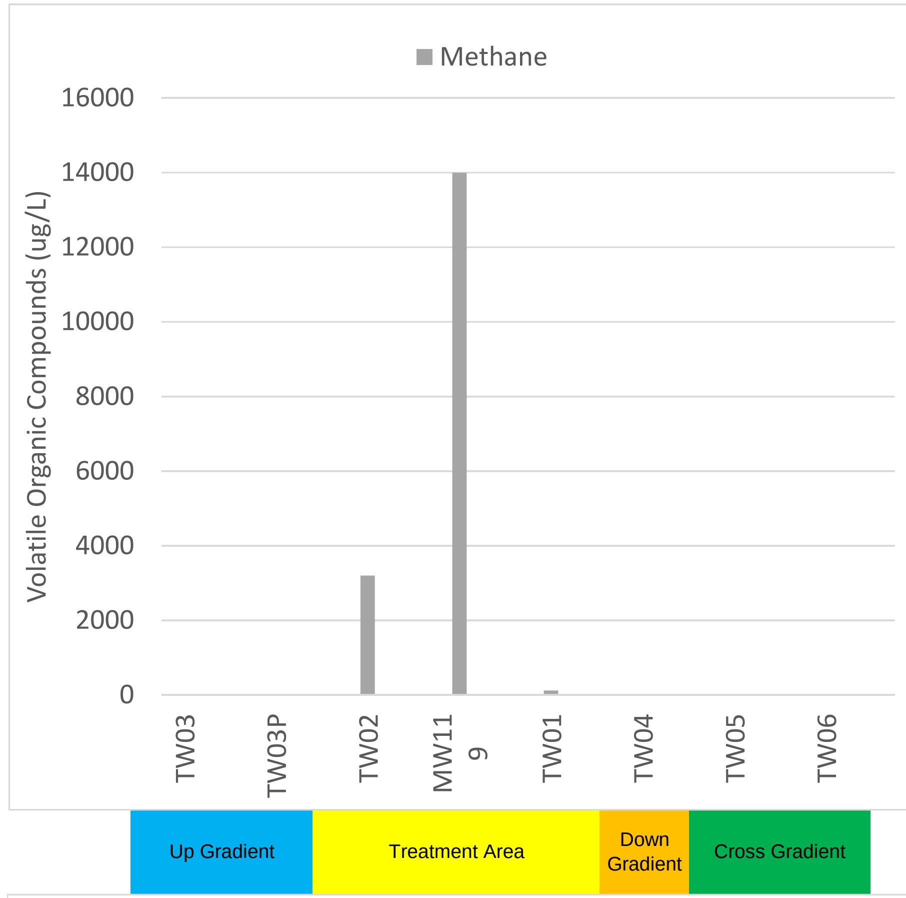
Appendix I
Trend Graphs St. Louis

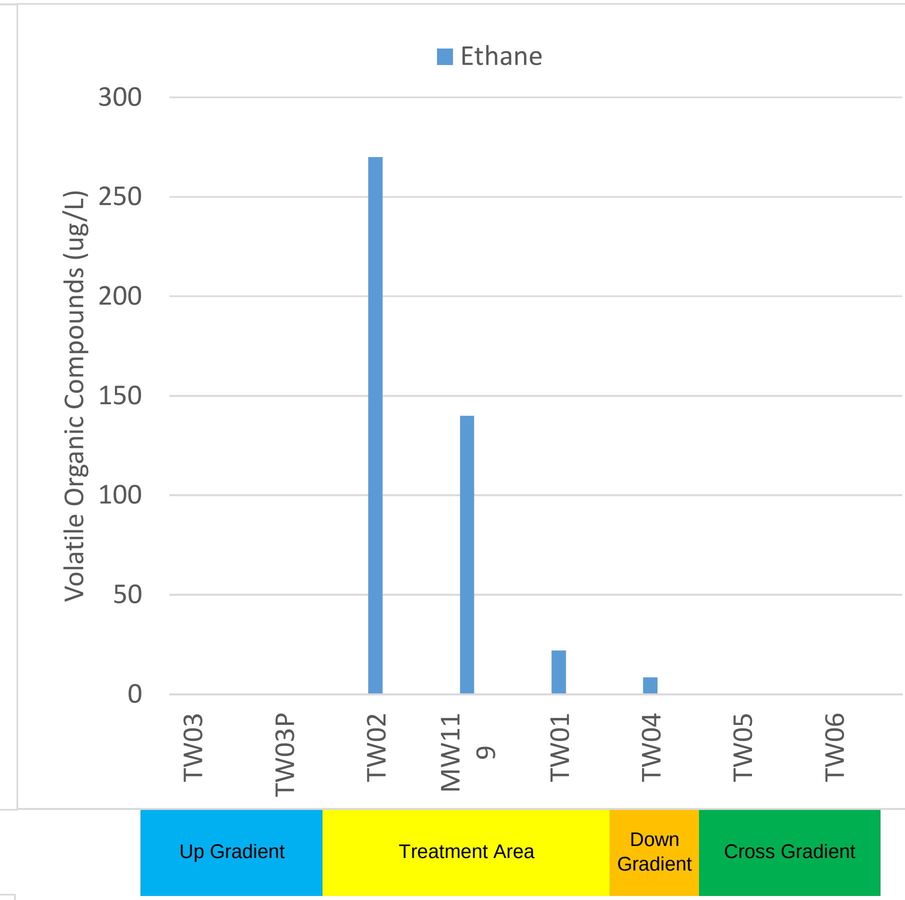
Appendix I-!A
Geochemical Concentration Trends Throughout Treatment Area
St. Louis Ordnance Depot
St. Louis, MO

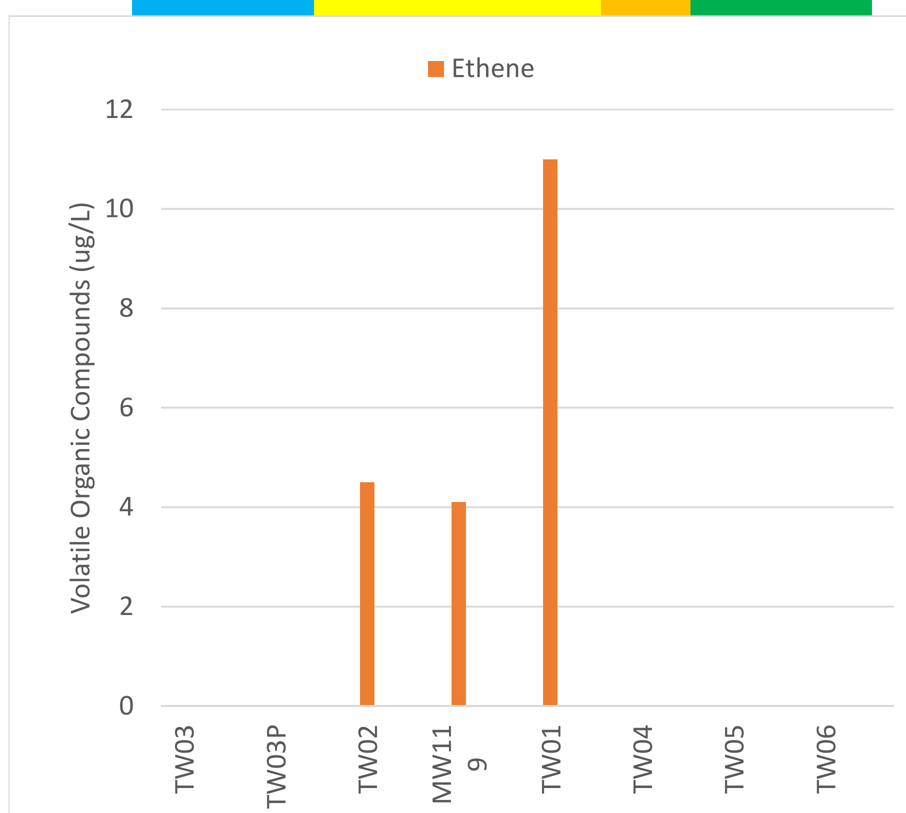



Phosphate
Wet Chemistry (mg/L)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
TW03
TW02
MW119
TW01
TW04
TW05
TW06
Sulfate
Wet Chemistry (mg/L)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
TW03
TW02
MW119
TW01
TW04
TW05
TW06
Total organic carbon (TOC)
Wet Chemistry (mg/L)
30
25
20
15
10
5
0
TW03
TW03P
TW02
MW119
TW01
TW04
TW05
TW06
Up Gradient
Treatment Area
Down Gradient
Cross Gradient
Up Gradient
Treatment Area
Down Gradient
Cross Gradient
Up Gradient
Treatment Area
Down Gradient
Cross Gradient

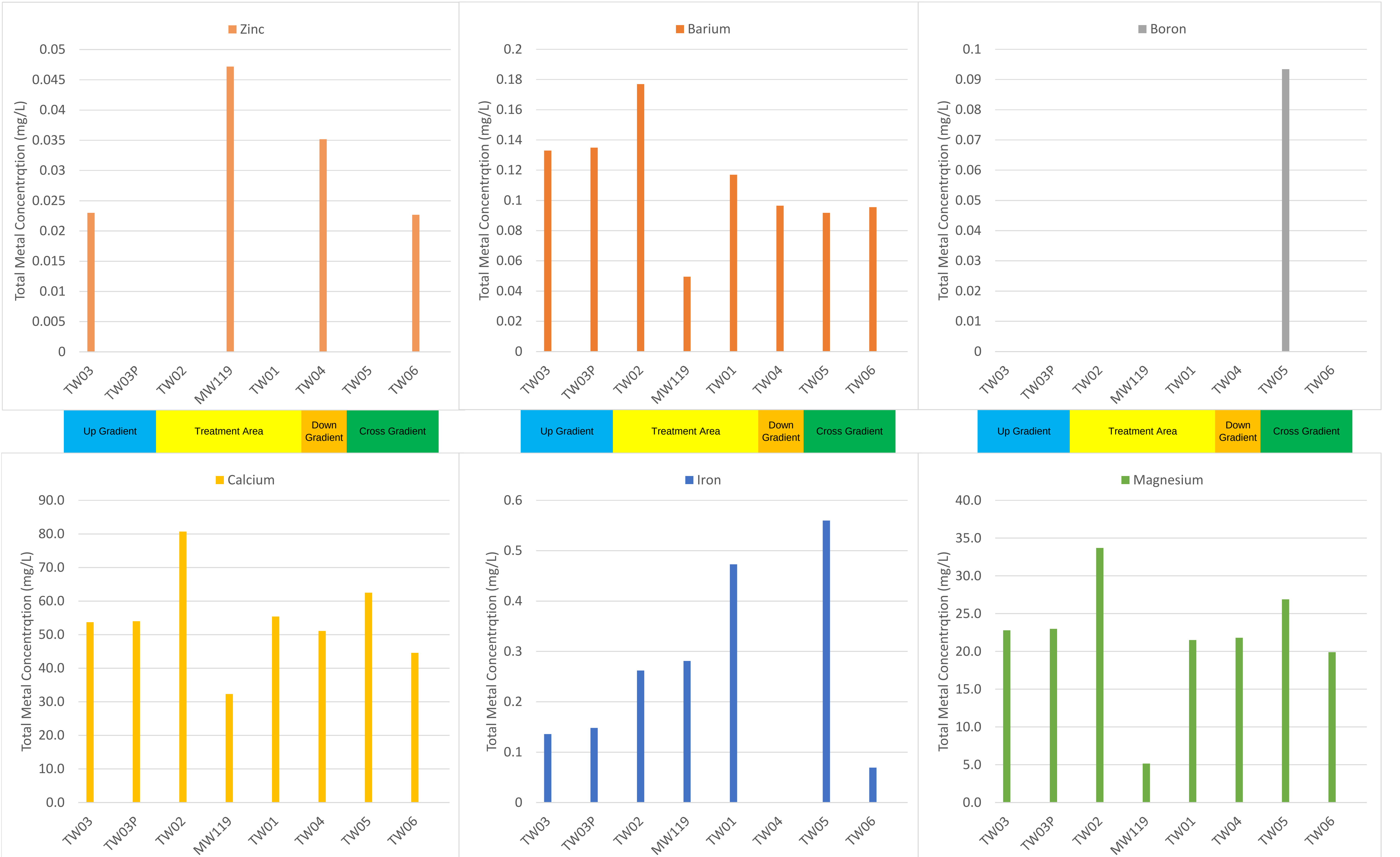
Appendix I-1B
Methane, Ethane, and Ethene Concentration Trends Throughout Treatment Area
St. Louis Ordnance Depot
St. Louis, MO

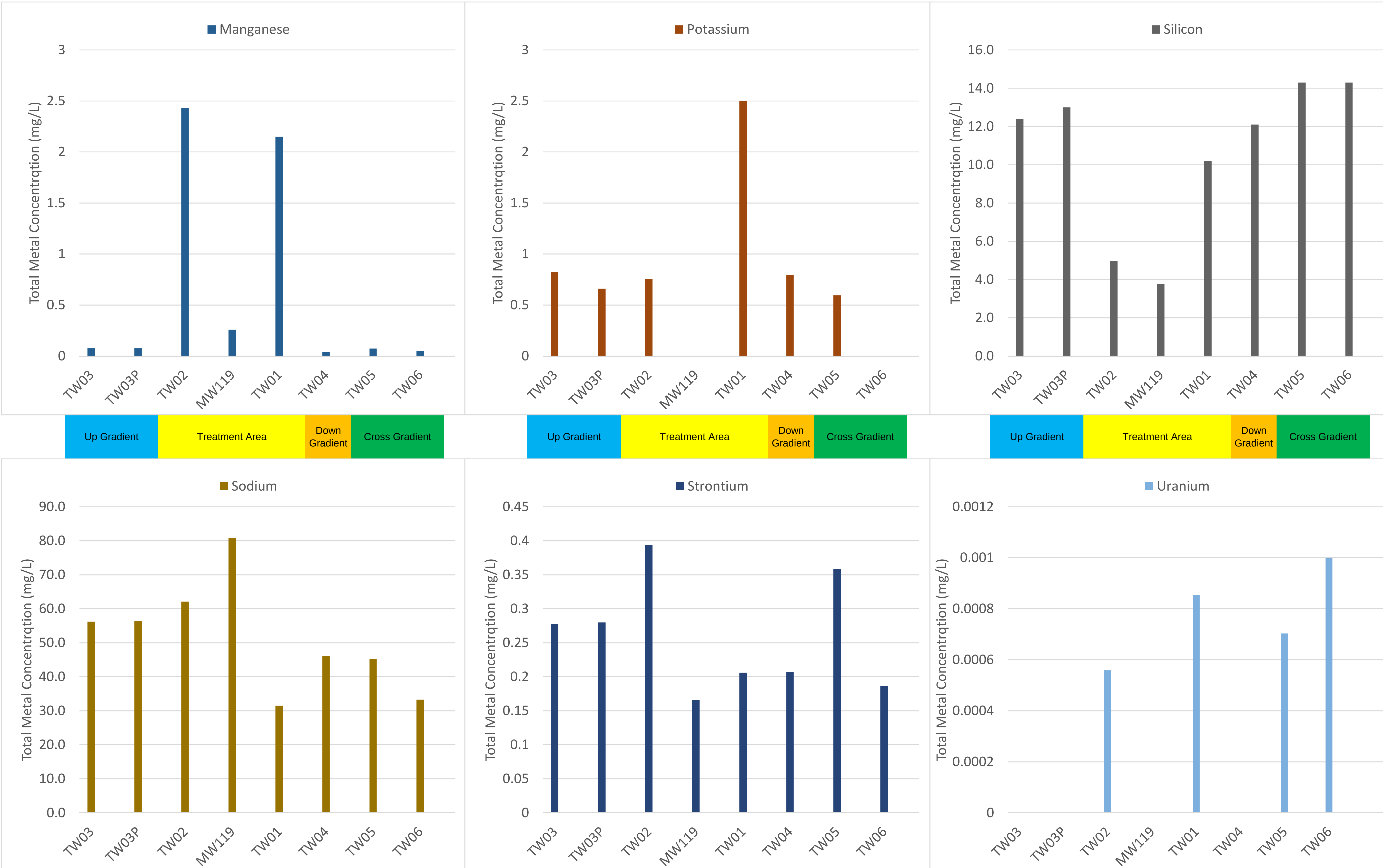


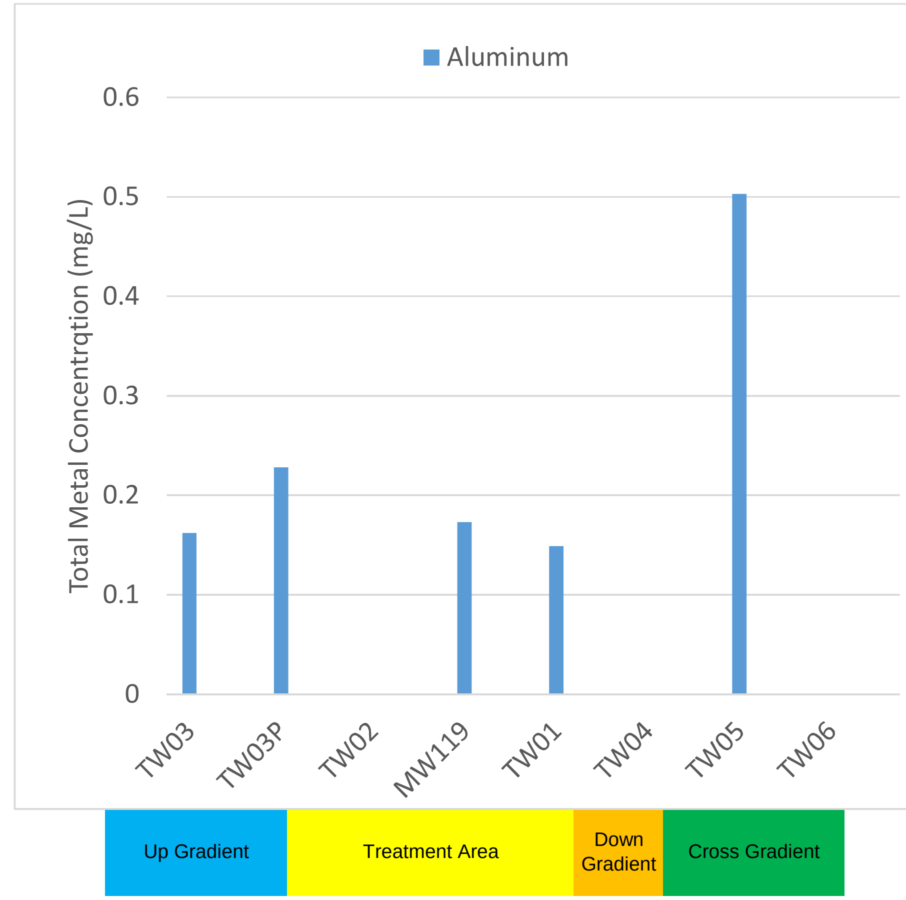


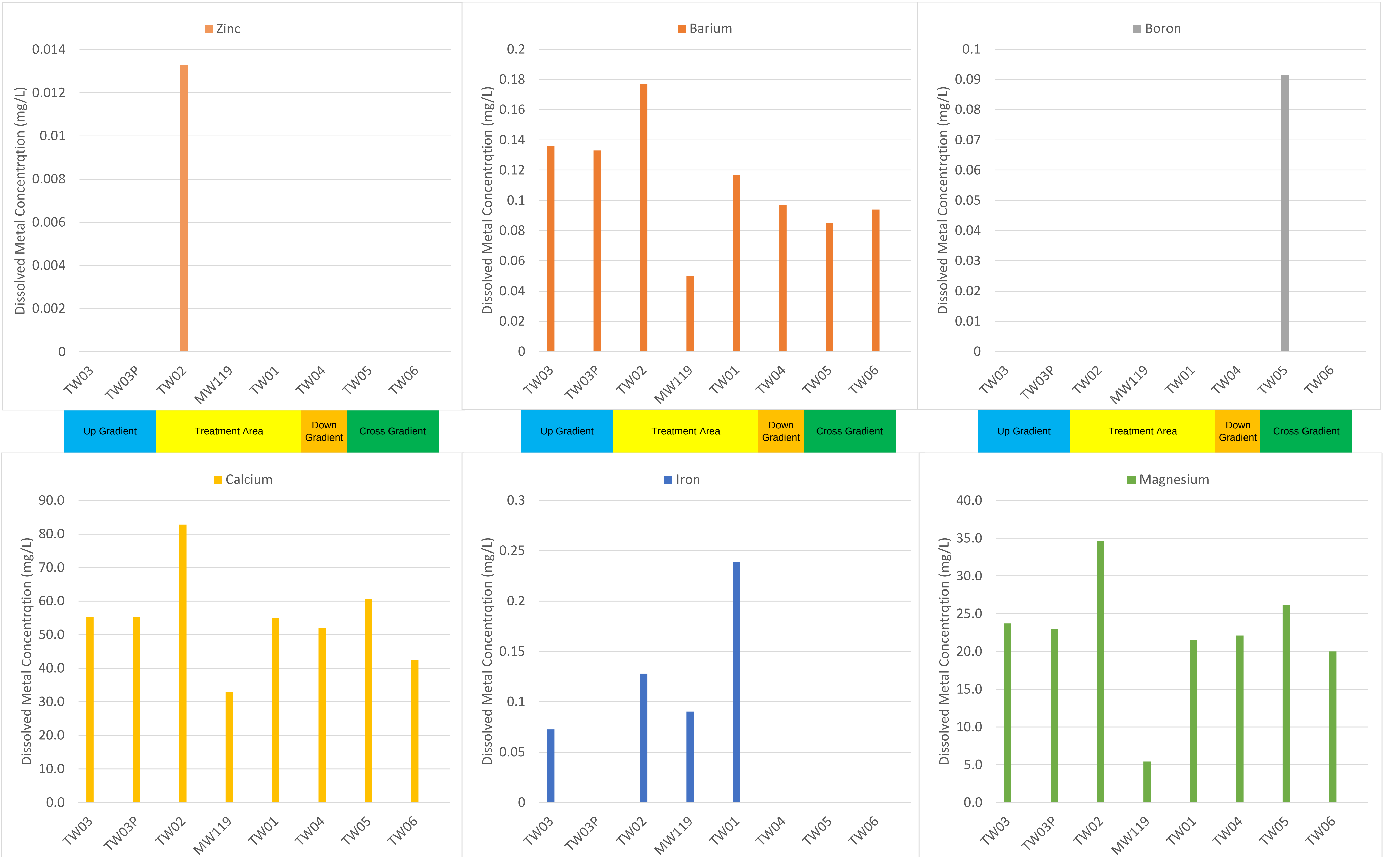


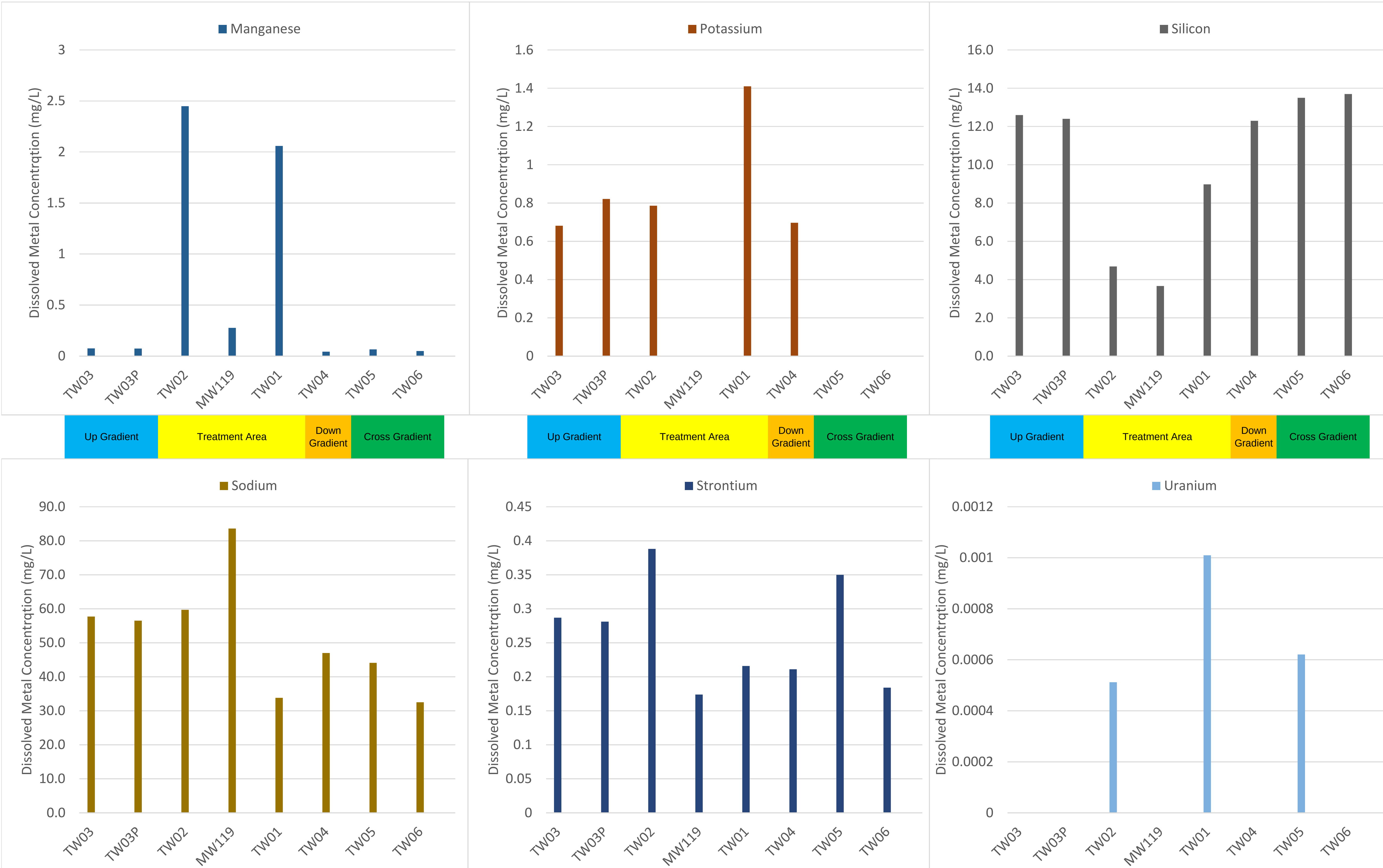
Appendix I-2A
Total Metals Concentration Trends Throughout Treatment Area
St. Louis Ordnance Depot
St. Louis, MO



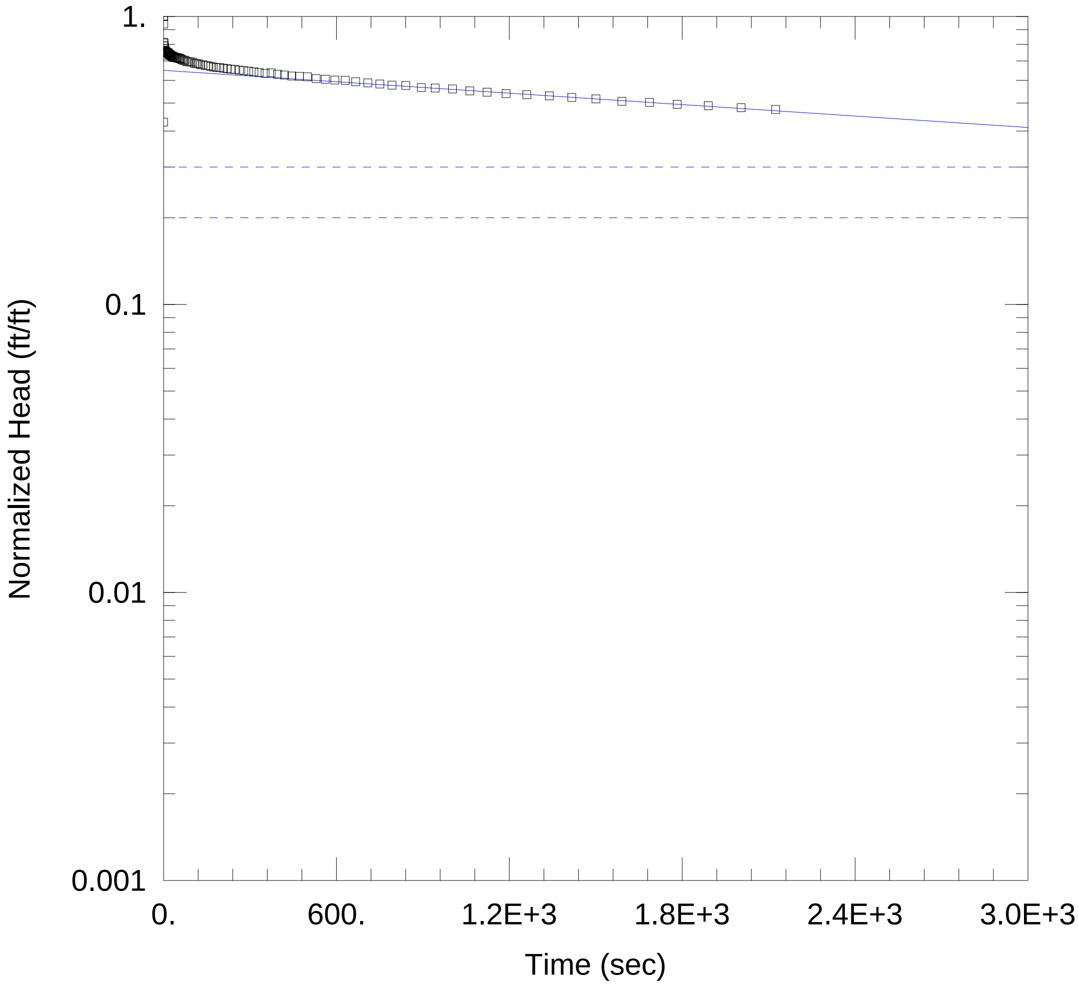

Manganese
Potassium
Silicon
Sodium
Strontium
Uranium
Total Metal Concentrqtion (mg/L)
TW03
TW03P
TW02
MW119
TW01
TW04
TW05
TW06
Up Gradient
Treatment Area
Down Gradient
Cross Gradient
3
2.5
2
1.5
1
0.5
0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0.0012
0.001
0.0008
0.0006
0.0004
0.0002


Aluminum
Total Metal Concentrqtion (mg/L)
0.6
0.5
0.4
0.3
0.2
0.1
0
TW03
TW03P
TW02
MW119
TW01
TW04
TW05
TW06
Up Gradient
Treatment Area
Down Gradient
Cross Gradient


Zinc
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Dissolved Metal Concentrqtion (mg/L)
TW03
TW03P
TW02
MW119
TW01
TW04
TW05
TW06
Barium
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Boron
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Up Gradient
Treatment Area
Down Gradient
Cross Gradient
Calcium
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Iron
0.3
0.25
0.2
0.15
0.1
0.05
0
Magnesium
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0


Manganese
Dissolved Metal Concentrqtion (mg/L)
0
0.5
1
1.5
2
2.5
3
TW03
TW03P
TW02
MW119
TW01
TW04
TW05
TW06
Potassium
Dissolved Metal Concentrqtion (mg/L)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Silicon
Dissolved Metal Concentrqtion (mg/L)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
Up Gradient
Treatment Area
Down Gradient
Cross Gradient
Sodium
Dissolved Metal Concentrqtion (mg/L)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Strontium
Dissolved Metal Concentrqtion (mg/L)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
Uranium
Dissolved Metal Concentrqtion (mg/L)
0
0.0002
0.0004
0.0006
0.0008
0.001
0.0012

Appendix J
Slug Test Results



DP001_TEST #1 RISING HEAD TEST

Data Set: C:\...\DP001_Test1_rising_BouwerRice.aqt
Date: 03/20/17 Time: 09:26:36

PROJECT INFORMATION

Company: CH2M Hill
Client: US63 Waterloo
Location: Waterloo IA
Test Well: MW-1
Test Date: 6/24/2013

AQUIFER DATA

Saturated Thickness: 15.8 ft Anisotropy Ratio (Kz/Kr): 1.

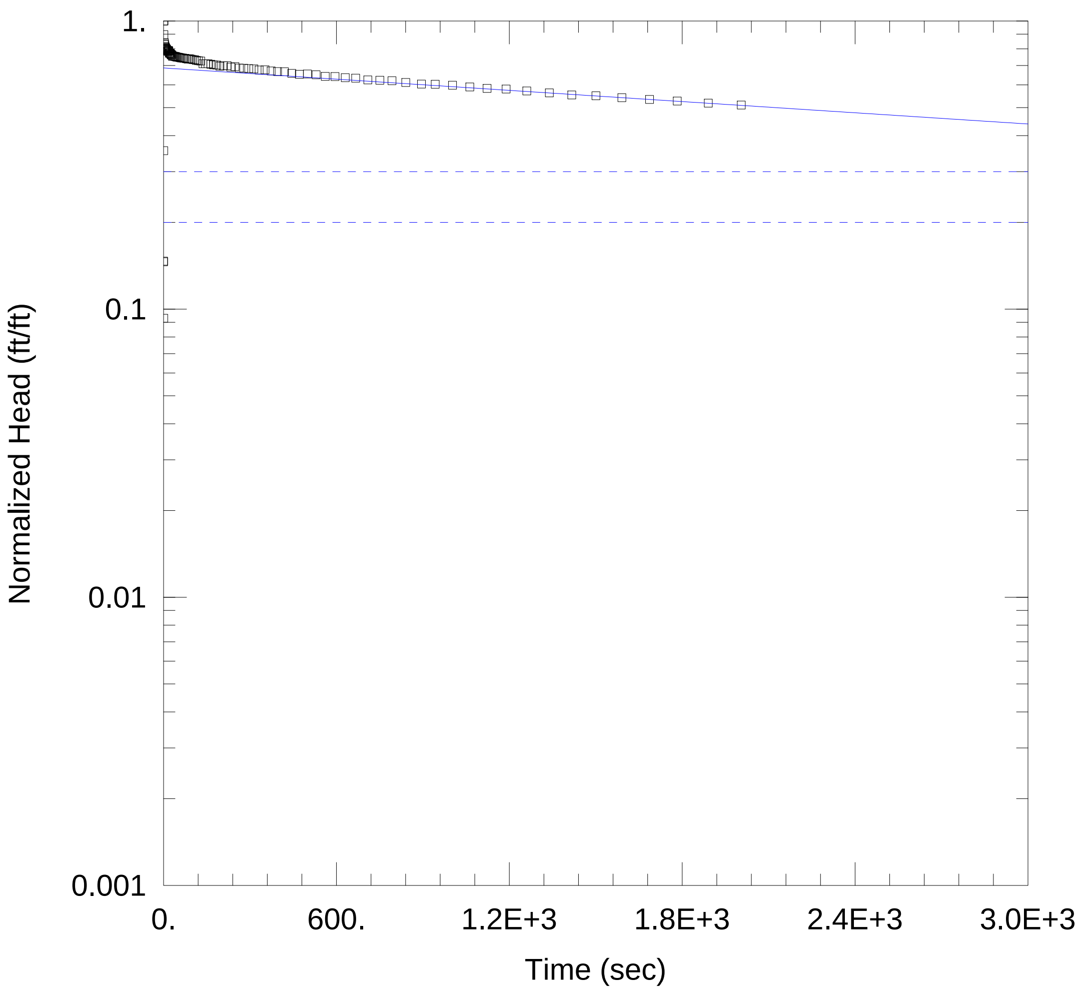
WELL DATA (DP001)

Initial Displacement: 1.17 ft
Static Water Column Height: 14.8 ft
Total Well Penetration Depth: 14.78 ft
Screen Length: 10. ft
Casing Radius: 0.083 ft
Well Radius: 0.17 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 5.006E-6 cm/sec
y0 = 0.7603 ft



DP001_TEST #2 RISING HEAD TEST

Data Set: C:\...\DP001_Test2_rising_BouwerRice.aqt
Date: 03/20/17 Time: 09:26:55

PROJECT INFORMATION

Company: CH2M Hill
Client: US63 Waterloo
Location: Waterloo IA
Test Well: MW-1
Test Date: 6/24/2013

AQUIFER DATA

Saturated Thickness: 15.8 ft
Anisotropy Ratio (Kz/Kr): 1.

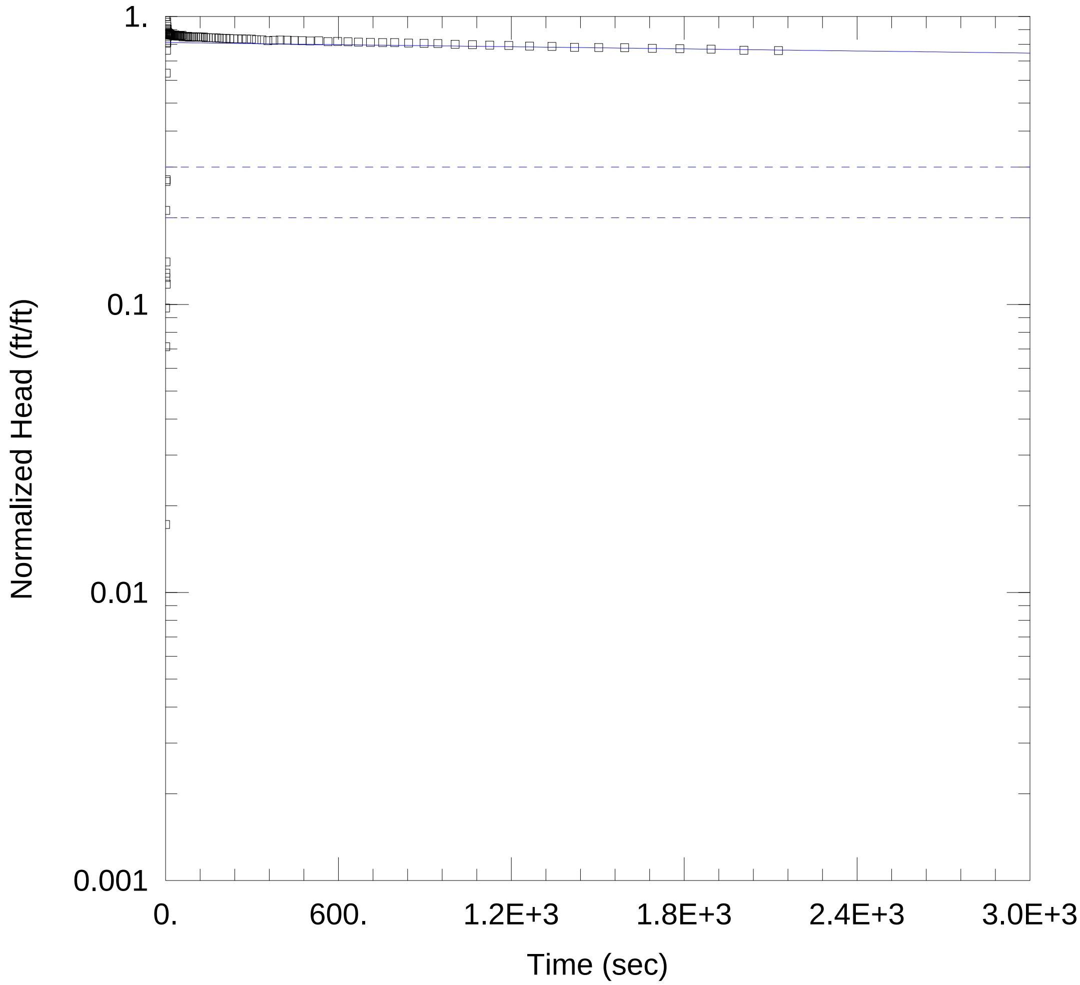
WELL DATA (DP001)

Initial Displacement: 1.3 ft
Static Water Column Height: 14.8 ft
Total Well Penetration Depth: 14.78 ft
Screen Length: 10. ft
Casing Radius: 0.083 ft
Well Radius: 0.17 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 4.908E-6 cm/sec
y0 = 0.893 ft



DP002_TEST #1 RISING HEAD TEST

Data Set: C:\...\DP002_Test1_rising_BouwerRice.aqt
Date: 03/20/17 Time: 09:27:10

PROJECT INFORMATION

Company: CH2M Hill
Client: US63 Waterloo
Location: Waterloo IA
Test Well: MW-1
Test Date: 6/24/2013

AQUIFER DATA

Saturated Thickness: 18.7 ft Anisotropy Ratio (Kz/Kr): 1.

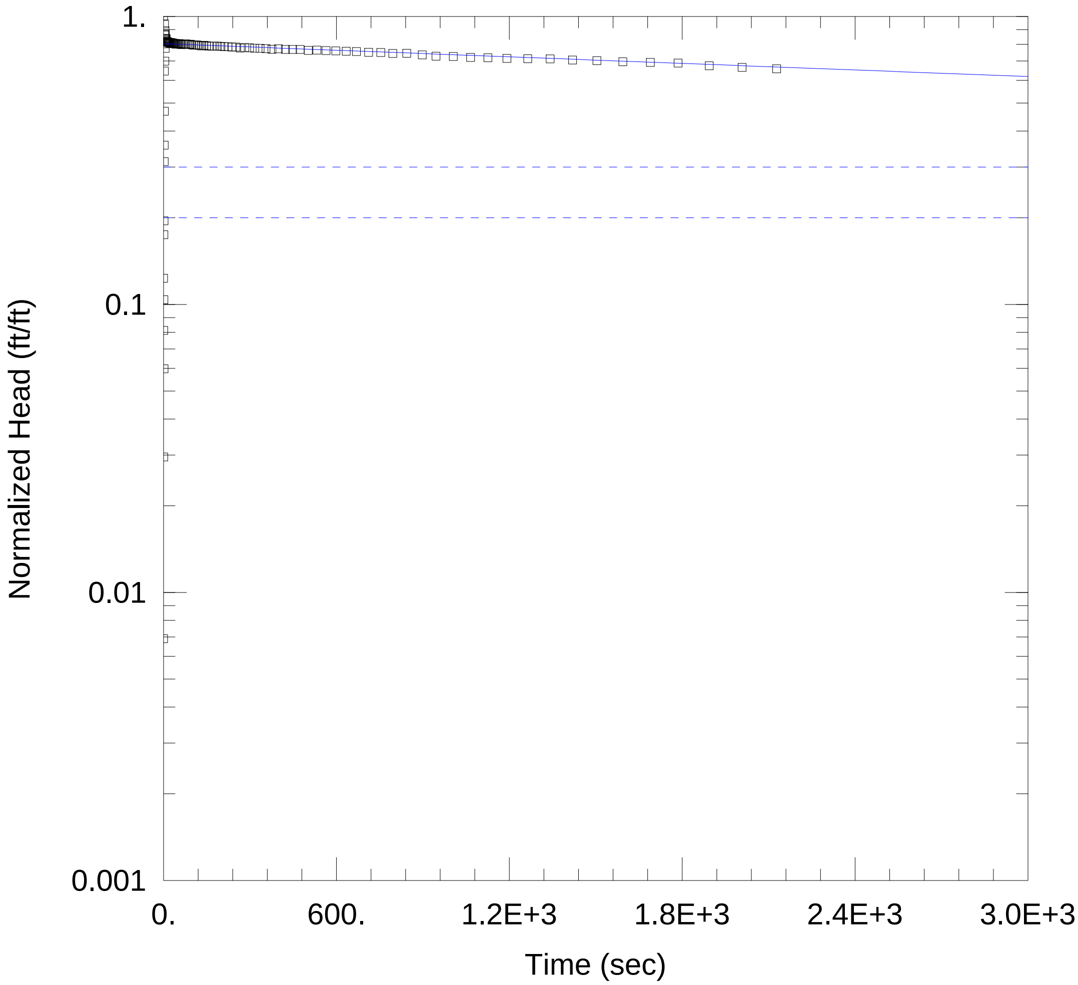
WELL DATA (DP002)

Initial Displacement: 1.31 ft Static Water Column Height: 15.7 ft
Total Well Penetration Depth: 15.71 ft Screen Length: 10. ft
Casing Radius: 0.083 ft Well Radius: 0.17 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 9.076E-7 cm/sec y0 = 1.063 ft



DP002_TEST #2 RISING HEAD TEST

Data Set: C:\...\DP002_Test2_rising_BouwerRice.aqt
Date: 03/20/17 Time: 09:27:22

PROJECT INFORMATION

Company: CH2M Hill
Client: US63 Waterloo
Location: Waterloo IA
Test Well: MW-1
Test Date: 6/24/2013

AQUIFER DATA

Saturated Thickness: 18.8 ft Anisotropy Ratio (Kz/Kr): 1.

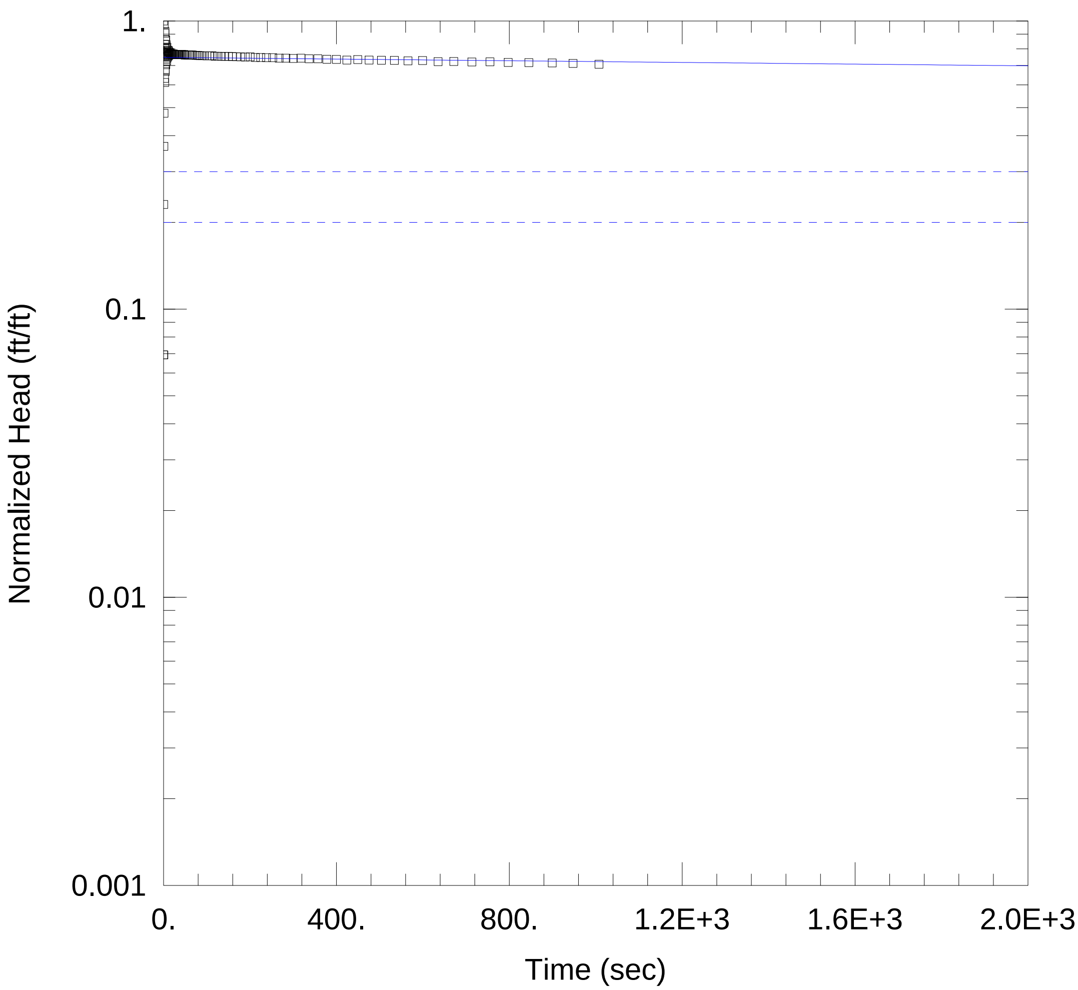
WELL DATA (DP002)

Initial Displacement: 1.41 ft Static Water Column Height: 15.8 ft
Total Well Penetration Depth: 15.75 ft Screen Length: 10. ft
Casing Radius: 0.083 ft Well Radius: 0.17 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 2.824E-6 cm/sec y0 = 1.134 ft



DO003 TEST #1 RISING HEAD TEST

Data Set: C:\...\DP003_Test1_rising_BouwerRice.aqt
Date: 03/20/17 Time: 09:27:33

PROJECT INFORMATION

Company: CH2M Hill
Client: US63 Waterloo
Location: Waterloo IA
Test Well: MW-1
Test Date: 6/24/2013

AQUIFER DATA

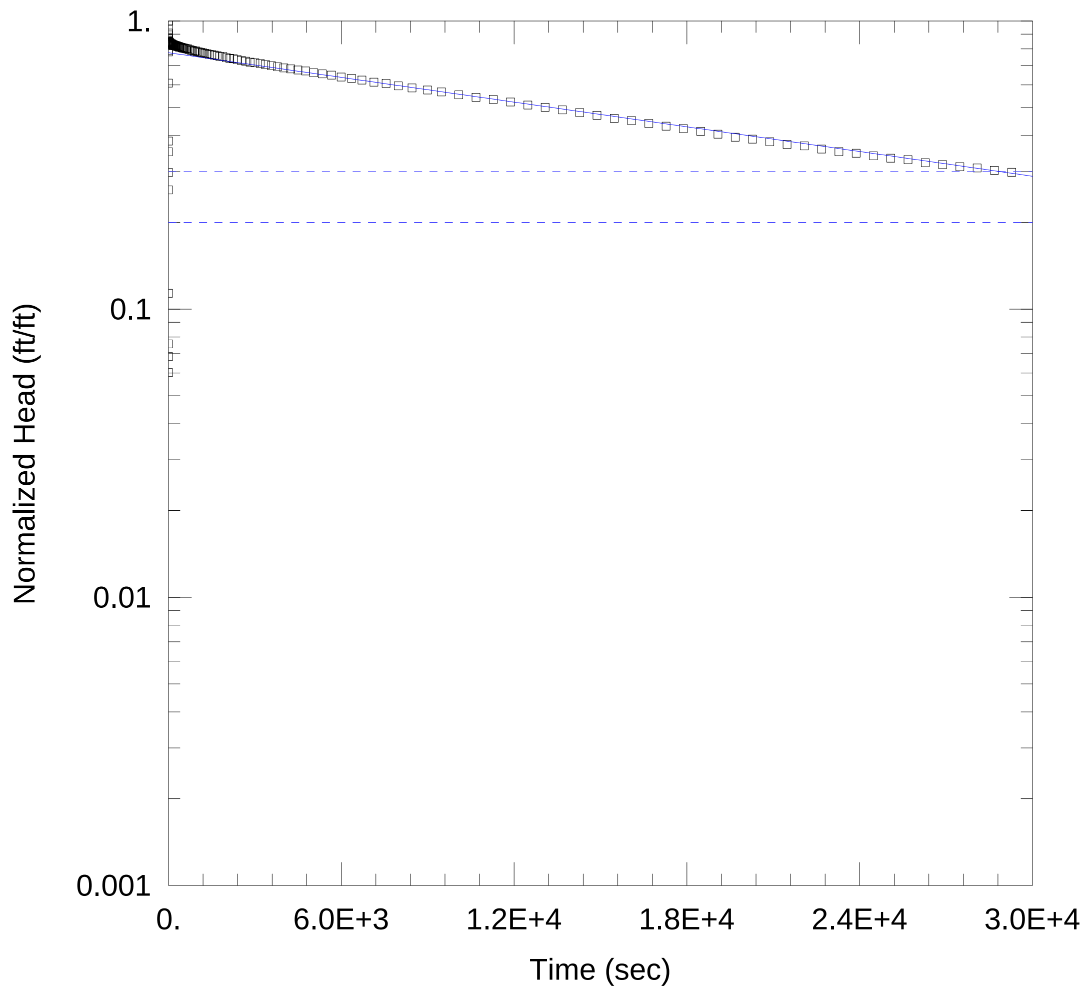
Saturated Thickness: 23.9 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (DP003)

Initial Displacement: 1.7 ft
Total Well Penetration Depth: 17.92 ft
Casing Radius: 0.083 ft
Static Water Column Height: 17.9 ft
Screen Length: 10. ft
Well Radius: 0.17 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.086E-6 cm/sec
y0 = 1.27 ft



DO004 TEST #1 RISING HEAD TEST

Data Set: C:\...\DP004_Test1_rising_BouwerRice.aqt
Date: 03/20/17 Time: 09:27:48

PROJECT INFORMATION

Company: CH2M Hill
Client: US63 Waterloo
Location: Waterloo IA
Test Well: MW-1
Test Date: 6/24/2013

AQUIFER DATA

Saturated Thickness: 25.7 ft Anisotropy Ratio (Kz/Kr): 1.

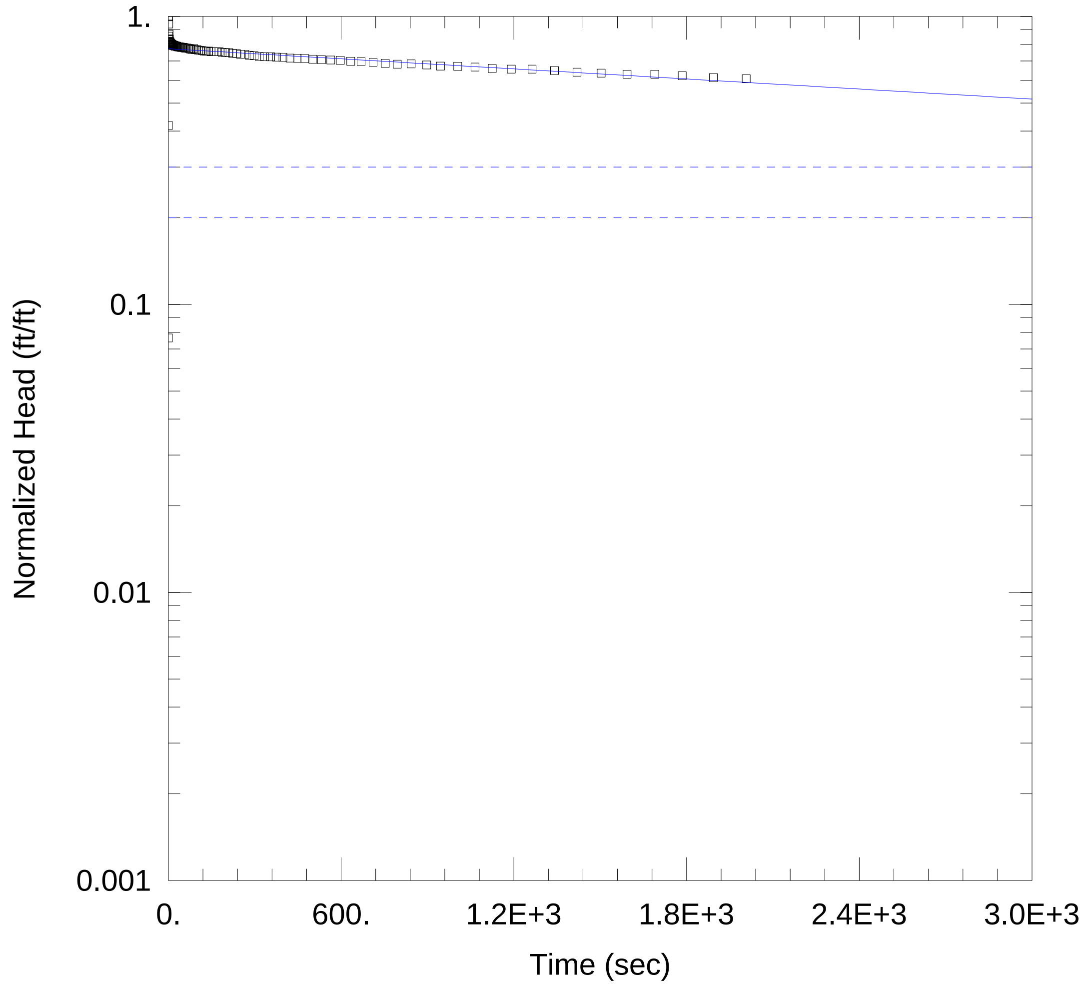
WELL DATA (DP004)

Initial Displacement: 2.41 ft Static Water Column Height: 22.7 ft
Total Well Penetration Depth: 22.74 ft Screen Length: 10. ft
Casing Radius: 0.083 ft Well Radius: 0.17 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 1.124E-6 cm/sec y0 = 1.87 ft



DO005 TEST #1 RISING HEAD TEST

Data Set: C:\...\DP005_Test1_rising_BouwerRice.aqt
Date: 03/20/17 Time: 09:27:59

PROJECT INFORMATION

Company: CH2M Hill
Client: US63 Waterloo
Location: Waterloo IA
Test Well: MW-1
Test Date: 6/24/2013

AQUIFER DATA

Saturated Thickness: 23.9 ft Anisotropy Ratio (Kz/Kr): 1.

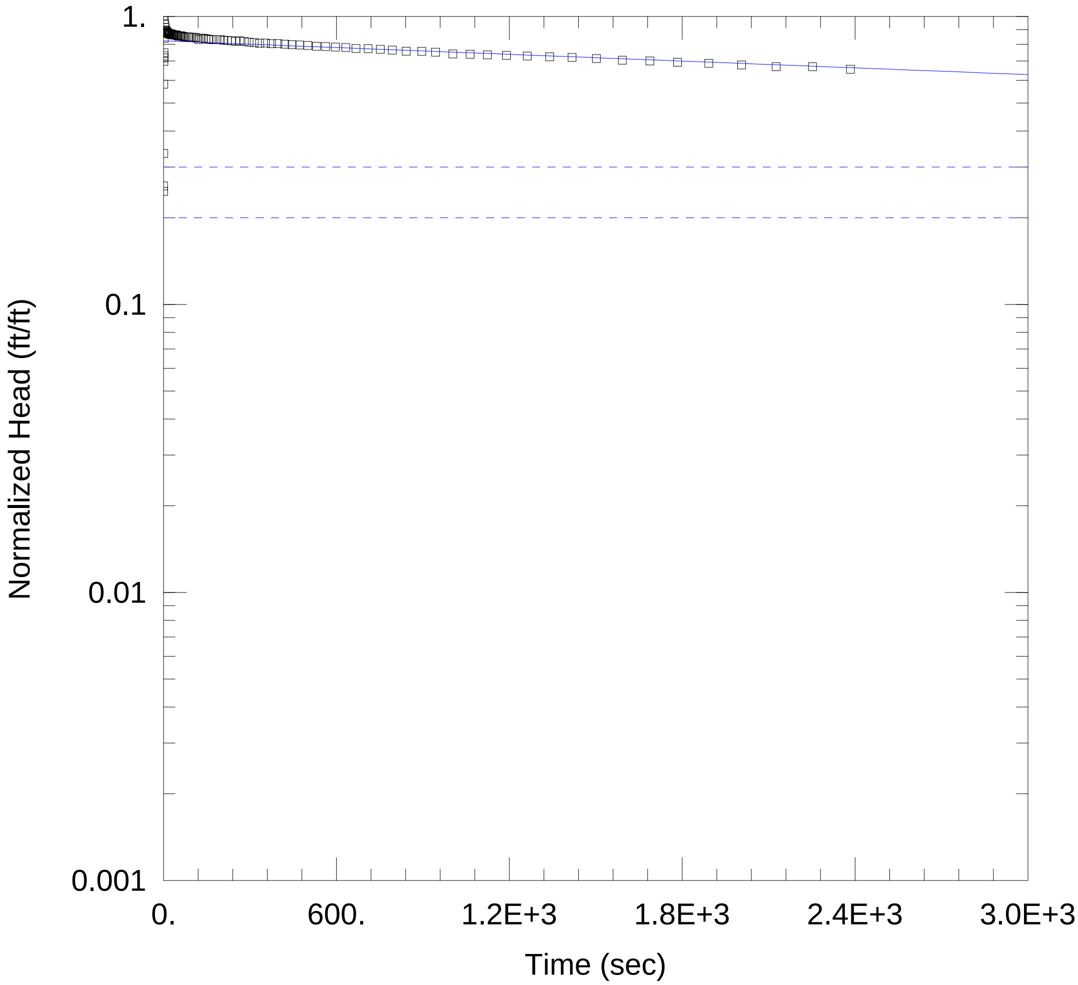
WELL DATA (DP005)

Initial Displacement: 1.3 ft Static Water Column Height: 15.9 ft
Total Well Penetration Depth: 15.85 ft Screen Length: 10. ft
Casing Radius: 0.083 ft Well Radius: 0.17 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 4.216E-6 cm/sec y0 = 1.004 ft



DO005 TEST #2 RISING HEAD TEST

Data Set: C:\...\DP005_Test2_rising_BouwerRice.aqt
Date: 03/20/17 Time: 09:28:11

PROJECT INFORMATION

Company: CH2M Hill
Client: US63 Waterloo
Location: Waterloo IA
Test Well: MW-1
Test Date: 6/24/2013

AQUIFER DATA

Saturated Thickness: 23.9 ft Anisotropy Ratio (Kz/Kr): 1.

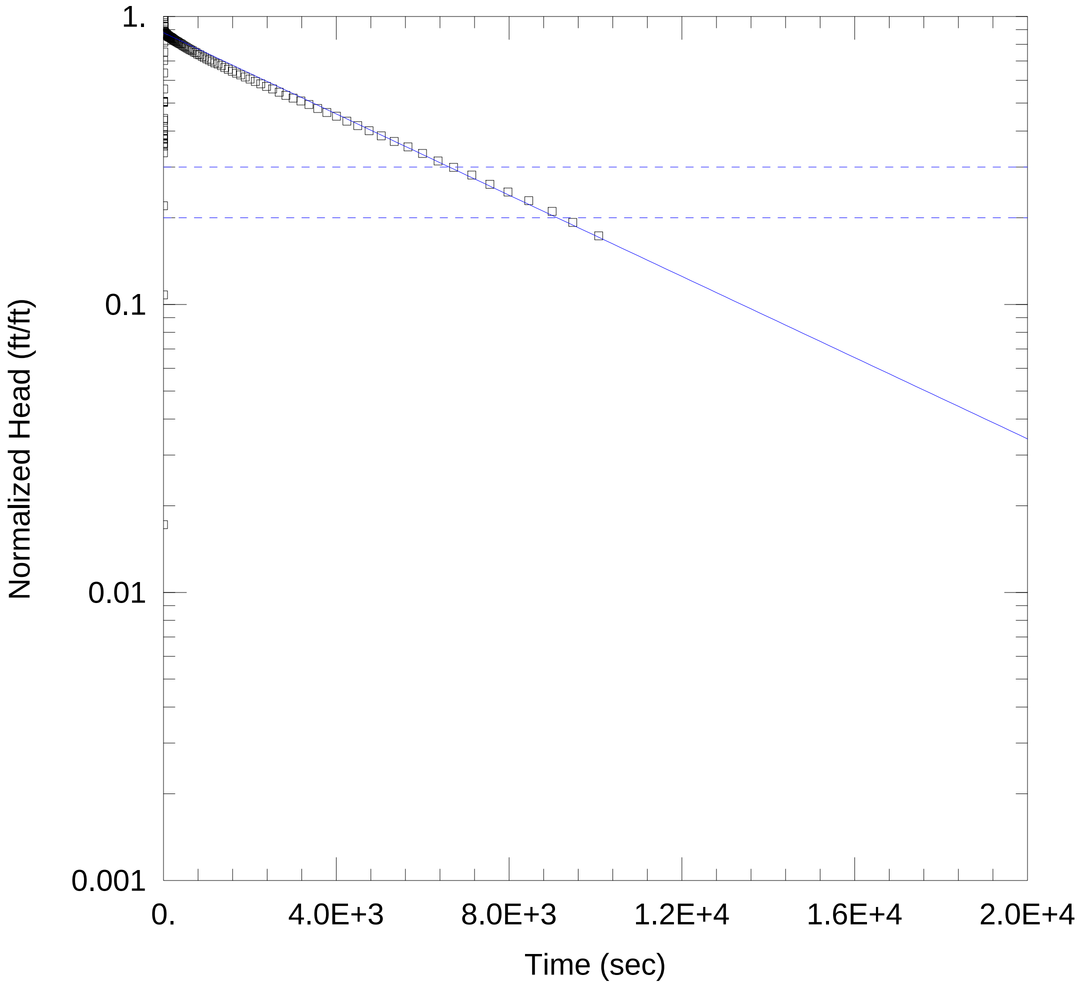
WELL DATA (DP005)

Initial Displacement: 1.2 ft Static Water Column Height: 15.9 ft
Total Well Penetration Depth: 15.87 ft Screen Length: 10. ft
Casing Radius: 0.083 ft Well Radius: 0.17 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 2.829E-6 cm/sec y0 = 0.9874 ft



DO006 TEST #1\ FALLING HEAD TEST

Data Set: C:\...\DP006_Test1_falling_BouwerRice.aqt
Date: 03/20/17 Time: 09:28:22

PROJECT INFORMATION

Company: CH2M Hill
Client: US63 Waterloo
Location: Waterloo IA
Test Well: MW-1
Test Date: 6/24/2013

AQUIFER DATA

Saturated Thickness: 24.5 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (DP006)

Initial Displacement: 2.2 ft Static Water Column Height: 23.5 ft
Total Well Penetration Depth: 23.49 ft Screen Length: 10. ft
Casing Radius: 0.083 ft Well Radius: 0.17 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 5.755E-6 cm/sec y0 = 1.931 ft

Appendix K
Points of Contact

Appendix K: Points of Contact

Point Of Contact Name	Organization Name Address	E-Mail	Role In Project
Jovan Popovic	NAVFAC EXWC	jovan.popovic@navy.mil	Principal Investigator
Kyle Kirchner	NAVFAC EXWC	kyle.kirchner@navy.mil	Co-Investigator
Laura Cook	CH2M	Laura.Cook@ch2m.com	Co-Investigator
Dean Williamson	CH2M	Dean.Williamson@ch2m.com	Co-Investigator
Rick Wilkin	USEPA	Wilkin.Rick@epa.gov	Co-Investigator
Rick Johnson	OHSU	Rick.johnson.phd@gmail.com	Co-Investigator