# FINAL REPORT

## Remediation of Explosives in Groundwater Using a Zero-Valent Iron Permeable Reactive Barrier

### ESTCP Project ER-0223

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**ESTCP**

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# LIST OF ACRONYMS

| | |
|---|---|
| ADNT | Aminodinitrotoluene |
| ASTM | American Standard for Testing and Materials |
| AVS | acid-volatile sulfides |
| BE | binding energy |
| bgs | Below Ground Surface |
| $Br^-$ | Bromide |
| COC | Chain of Custody |
| $Cl^-$ | Chloride |
| DQOs | Data Quality Objectives |
| DQIs | Data Quality Indicators |
| DoD | Department of Defense |
| DoE | Department of Energy |
| DO | dissolved oxygen |
| EHSC | Environmental Health and Safety Coordinator |
| ESTCP | Environmental Security Technology Certification Program |
| EW | Extraction Well |
| Fe | Iron |
| Ft bgs | feet below ground surface |
| FID | flame ionization detector |
| GC/MS | Gas Chromatograph/Mass Spectrometry |
| gpm | Gallons Per Minute |
| HASP | Health and Safety Plan |
| HDPE | High Density Polyethylene |
| HMX | cyclotetramethy lenetetranitramine |
| IC | Ion Chromatography |
| ID | Inside Diameter |
| IW | Injection Well |
| kg | kilogram |
| MCL | Maximum Contaminant Level |
| MDL | Method Detection Limit |
| mL | milliliters |
| MSDS | Material Safety Data Sheet |
| MS/MSD | Matrix spike/matrix spike duplicate |
| MW | Monitoring Well |
| O&M | operations and maintenance |
| ORP | Oxidation Reduction Potential |
| OSHA | Occupational Safety and Health Administration |
| PARCC | precision, bias, accuracy, representativeness, completeness, and comparability |
| PID | Photoionization Detector |
| ppb | Parts Per Billion |
| PPE | Personal Protective Equipment |
| PTA | Pilot Test Area |
| PVC | polyvinyl chloride |

| | |
|---|---|
| QAPP | Quality Assurance Project Plan |
| QC | Quality Control |
| RCRA | Resource Conservation and Recovery Act |
| RDX | hexahydro-1,3,5-trinitro-1,3,5-triazine |
| ROD | Record of Decision |
| RPD | Relative Percent Difference |
| RPM | Remedial Project Manager |
| SAP | Sampling and Analysis Plan |
| SEM | simultaneous extracted metals |
| SERDP | Strategic Environmental Research and Development Program |
| SHSO | Site Health and Safety Officer |
| $SO_4^-$ | Sulfate |
| TAT | triaminotoluene |
| TCE | trichloroethene |
| TNT | 2,4,6-trinitrotroluene |
| USEPA | United States Environmental Protection Agency |
| XPS | x-ray photoelectron spectroscopy |

# ACKNOWLEDGEMENTS

# EXECUTIVE SUMMARY

This final technical report documents the demonstration of a zero-valent iron (ZVI) permeable reactive barrier (PRB) for the removal of explosives from groundwater. The demonstration was conducted at the Cornhusker Army Ammunition Plant (CAAP) near Grand Island, Nebraska. The primary objective of this project was to evaluate the cost and performance of the ZVI PRB

Performance of the PRB was evaluated by monitoring groundwater concentrations of explosives downgradient of the PRB. Data obtained during the demonstration were used to assess the cost-effectiveness of this approach for long-term removal of explosives from groundwater.

The primary advantages of ZVI PRBs for groundwater remediation are:
— No aboveground remediation equipment is required
— Rapid conversion of groundwater to reducing conditions
— Low operation and maintenance costs
— Long-lasting (>20 years) *in situ* treatment
— Cost-effective

The cost-effective use of ZVI PRBs may be limited by the depth to groundwater and the ability to install the PRB in some geologic media. However, at sites without these physical constraints, the approach can be highly effective.

## Demonstration Design
The demonstration was conducted at the Cornhusker Army Ammunition Plant (CAAP) near Grand Island, Nebraska. Groundwater at the site is at 15-20 feet below ground surface (bgs). The shallow aquifer at the site consists of medium sands with some silty material. Groundwater velocity at the site is approximately 1-2 feet/day.

The demonstration activities included a field study that involved installation of a mixed iron/sand permeable reactive barrier (30% by weight iron). The PRB was approximately 50 feet long by 15 feet deep by 3 feet thick. Monitoring activities were conducted over an 20-month period to evaluate performance of the PRB. The PRB was located within a large groundwater plume from a diffuse source resulting from production of munitions.

## Summary of Results
The ZVI PRB reduced concentrations of TNT and RDX to below detection limits throughout the duration of the project. In addition to removal of the explosives, significant changes in groundwater chemistry occurred due to the PRB. Dissolved sulfate concentrations decreased substantially as groundwater flowed through the PRB. Detailed groundwater concentration data and measured hydraulic conductivity data suggest that a portion of the water up-gradient of the PRB was diverted beneath the PRB. The reason for this is not entirely known, however, 1) it is not related to the contaminants of concern (explosives), and 2) it is probably related to the use of guar during installation of the PRB. We believe that guar entered the formation up-gradient of the PRB and was not fully removed at the completion of the installation. This may be the primary reason for flow reduction, however, it is also possible that the guar led to strongly-

reducing conditions just up-gradient of the PRB and the removal of sulfate as sulfide precipitates just up-gradient of the PRB, as observed in core samples.

**Comparison of Results with Primary Objectives**
All of the primary performance criteria for this project were met. TNT and RDX values were consistently reduced to below detection limits in the aquifer downgradient of the PRB. Barrier hydraulics were successfully characterized, and we were able to identify design and operational factors that influence successful implementation and continued operation of the ZVI PRB.

**Cost Analysis**
A detailed cost comparison is provided in the Cost and Performance Report for this project. The installation costs for the pilot scale barrier were \$138,000. The barrier was 50 feet long by 15 feet thick (i.e., ~750 ft$^2$). This translates into a cost per square foot of ~\$180/ft$^2$, which is consistent with other demonstration-scale ZVI PRB installations (Gavaskar, 2000).

# 1.0   INTRODUCTION

This final technical report documents the demonstration of a zero-valent iron (ZVI) permeable reactive barrier (PRB) to remove explosives from groundwater.  The general purpose of the demonstration was to evaluate the efficacy of ZVI PRBs for treating explosives-contaminated groundwater. .

## 1.1 Background

Groundwater contamination related to the explosives 2,4,6-trinitrotoluene (TNT) and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) represents a significant and widespread problem at U.S. Department of Defense (DoD) facilities. Current remediation approaches for TNT- and RDX-impacted groundwater typically involve groundwater extraction & treatment (pump & treat) with treatment by carbon adsorption or UV oxidation systems, both of which are costly to install and have short life cycles (e.g., 15 year re-capitalization periods).  Furthermore, because of the chemical characteristics of RDX and in particular the sorptive properties of TNT, many of these pump & treat systems are projected to operate for decades, representing significant operation and maintenance (O&M) expenses. As an example, annual O&M costs associated with pump & treat remediation of groundwater impacted by TNT, related nitroaromatics and RDX at the Milan Army Ammunition Plant in Tennessee were estimated to be in the range of $1.4M per year (U.S. EPA, 1992) and at the Cornhusker Army Ammunition Plant (U.S. EPA, 1994) approximately $1.2M per year.

Recent research has shown that TNT and RDX can be rapidly degraded using zero-valent iron (ZVI), and that the use of *in situ* permeable reactive barriers (PRBs) has very good potential for reducing the costs associated with groundwater cleanup at TNT- and RDX-impacted sites (Tratnyek et al., 2001, Oh et al., 2001). As an added benefit, PRBs can also treat a variety of contaminants (e.g., chlorinated solvents, chromate) that may co-occur in groundwater at RDX- and TNT-impacted sites. The use of ZVI PRBs to treat TNT and RDX impacted groundwater therefore represents a significant opportunity to reduce environmental remediation costs that may jeopardize major DoD programs and initiatives.

## 1.2 Objectives of the Demonstration

The objectives of this technology demonstration are:
1. Demonstrate that TNT and RDX can be degraded in situ to acceptable levels (i.e., the MDL) using a zero-valent iron permeable reactive barrier (ZVI PRB)

2. Evaluate barrier hydraulics

3. Identify design and operational factors that influence successful implementation and continued operation of the ZVI PRB approach.

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The in situ, passive ZVI PRB system described in this final report was conducted at Load Line 2 at the Cornhusker Army Ammunitions Plant in Grand Island, NE (CAAP or "the site"). The advantages of the ZVI PRB technology are that it can provide a less costly and less operation and maintenance (O&M) intensive approach to remediating explosives-impacted groundwater and that it degrades TNT and RDX to non toxic end products rather than transferring it other media that require disposal or further treatment (e.g., carbon).

## 1.3 Stakeholder/End-User Issues

The demonstration showed that under field conditions explosives concentrations could be reduced below 1 µg/L. The results of the demonstration provide guidance for the application of this technology at other sites.

# 2  TECHNOLOGY DESCRIPTION

ZVI PRBs are conceptually simple *in situ* remediation systems that involve emplacement of iron filings/shavings in a trench or similar structure oriented perpendicular to groundwater flow to form a permeable reactive barrier or "wall".  As groundwater flows through the PRB, interactions between the water and the iron produce highly reducing conditions (i.e., a highly negative oxidation/reduction potential or ORP).  Contaminants entering this highly reducing zone are chemically altered to have a significantly reduced toxicity or mobility, or are otherwise sequestered.  ZVI PRBs have been shown to be robust and long-lived in the environment.  These systems have been successfully used for some time for the control of chlorinated solvent plumes such as trichloroethylene (TCE), and are projected to have useful lifetimes of 30 years or more (O'Hannesin and Gillham, 1998).The technologies for the installation of PRBs have advanced in recent years and lower cost installation methods have been demonstrated for a variety of different site conditions. The capital equipment costs associated with PRB installation are small when compared to the cost of decades-long pump & treat operation.  In addition, because groundwater is not removed from the subsurface (as is the case for pump & treat), the PRBs do not negatively impact groundwater levels or supplies.

Recent laboratory studies funded by SERDP have demonstrated that ZVI can rapidly degrade TNT and RDX.  For TNT, Tratnyek et al (2001) showed that essentially all of the degradation products become completely sequestered on the iron, a process which can be sustained for thousands of pore volumes, even at very high flow rates and contaminant loadings.  Similar performance is expected in the field, although site-specific geochemical conditions may have some impact on both performance and longevity. While laboratory data indicate that reduction of RDX by iron is rapid, the fate of the degradation products is not as well understood and may not be as effective as for TNT. The RDX research (Oh et al., 2001) does however indicate that the performance of the ZVI is significantly enhanced when iron-reducing bacteria are present, and therefore a combined ZVI-bioremediation approach may be most suitable to treat RDX.

Based on the available laboratory TNT and RDX degradation data, the successful history of ZVI PRB use for chlorinated solvents, and the need for cost-effective remediation technologies to address the remediation of TNT and RDX impacted groundwater, the project team believes that an ESTCP demonstration was undertaken at the site.

## 2.1 Technology Development and Application

ZVI PRBs are now an accepted remediation technology for treatment of chlorinated solvents, selected metals (e.g., chromium, arsenic), and a number of other groundwater contaminants. The technologies for PRB installation are reasonably well understood, and include conventional methodologies such as sheet pile cofferdam, continuous trenching, overlapping caissons and

biopolymer trench technologies (Day and O'Hannesin, 1999). Emplacement using some construction methods is limited to shallow groundwater systems (e.g., less than ~70 feet) in unconsolidated porous media. New construction methods such as soil mixing, or slurry injection are currently being demonstrated for deeper systems.

The main technical risks associated with this technology relate to the potential influence of site-specific geochemical conditions on: 1) RDX and TNT reactivity in the PRB, 2) completeness of removal of the primary contaminants and degradation products, and 3) long-term PRB performance. Several recent SERDP-funded projects evaluated the fate of TNT and RDX degradation with ZVI in laboratory and ex situ columns under different geochemical conditions (SERDP CU1231 and CU1232). The site-specific pre-design optimization studies discussed below (including ex situ ZVI columns and detailed geochemical analyses) also address this uncertainty.


## 2.2 Previous Testing of the Technology

As mentioned above, ZVI PRBs are being used at a growing number of sites to treat a range of contaminants, including chlorinated solvents, chromium and nitrate. In the context of explosives, to date most testing has been in the laboratory or in ex situ columns. TNT and RDX behavior have been examined in laboratory batch and column experiments, including ZVI-filled ex situ columns at the Umatilla Chemical Storage Depot in Umatilla, Oregon. The conclusions of that work can be summarized as follows:

a. Degradation of both RDX and TNT on ZVI is rapid, with half lives measured in seconds to minutes.

b. Over time, reactivity of the ZVI decreases due to passivation, but half lives are still on the order of minutes for TNT and RDX.

c. in the *ex situ* field tests and Umatilla, dissolved oxygen present in the groundwater appears to be the primary contributor to passivation of the ZVI

d. Oxygen was also the primary contributor to plugging of the columns by precipitated iron oxides.

e. Plugging of the ZVI in the presence of oxygen can be minimized by using fairly coarse (8/18 mesh) iron and iron/sand mixtures.

f. TNT is quantitatively reduced to triaminotoluene (TAT) by the ZVI.

g. the TAT is unstable in the presence of oxygen. Experiments with ^{13}C-labeled TAT show that all of the radioactivity associated with TAT disappears from solution within 2-3

days, indicating that it is quantitatively precipitated. We believe this occurs in part through polymerization..

## 2.3 Factors Affecting Cost and Performance

A number of factors affect the cost and performance of technology in field applications. The key factors are:

1. **The concentration and distribution of explosives** in the groundwater to be treated will impact the costs and performance. Higher concentrations of explosives will require longer residence times in the PRB. This is not expected to be a major issue at most sites
2. **The chemistry of the aquifer** to be treated will impact the cost and performance. The primary issues of concern will be the presence of dissolved oxygen, carbonate, nitrate, sulfate, or other species that may passivate the surface of the iron or plug the PRB
3. **The depth to groundwater** will impact the cost of barrier installation
4. **The hydraulic conductivity** of the aquifer will impact the design of the PRB (e.g., barrier thickness, iron content)
5. **The hydraulic gradient** in the aquifer will impact the design of the PRB (e.g., barrier thickness, iron content)
6. **Geological heterogeneities** in the aquifer
7. **Seasonal variation in groundwater flow direction** will impact the design of the PRB primarily by requiring increased barrier length to ensure capture of the plume.

## 2.4 Advantages and Limitations

Prominent alternative technologies to in situ ZVI PRB for explosives-impacted groundwater are: 1) groundwater pump and treat followed by ex situ degradation; and 2) groundwater pump and treat followed by adsorption on carbon.

Current approaches for the remediation of explosives-impacted groundwater typically involve long-term pump and treat solutions involving capital-intensive ex situ treatment components (ex situ bioreactors or ion exchange systems) and long-term operation and maintenance (O&M) costs. As an example, annual O&M costs associated with pump & treat remediation of groundwater impacted by TNT, related nitroaromatics and RDX at the Cornhusker Army Ammunition Plant (U.S. EPA, 1994) approximately $1.2M per year. At many sites the initial capital costs for a PRB are expected to be similar to those for pump and treat with carbon sorption. However, the O&M costs for the PRB are expected to be far lower.

The main advantages of the remediation technology are:

- Lower capital and O&M costs than alternative technologies which involve groundwater, pump and treat with high O&M costs;

- Contaminants are destroyed and not simply transferred to another medium; and

- Ability to treat possible co-contaminants such as nitrate, TCE or chromium.

The main limitations of the technology are:
- Insufficient longevity of the PRB due to passivation and/or plugging

- Installation depth limitation

- Initial capital costs

# 3 DEMONSTRATION DESIGN

This section presents the design of demonstration for remediation of explosives-impacted groundwater using a passive ZVI PRB approach. Specific subsections present:

- Performance objectives of the technology demonstration (Section 3.1);

- A description of the criteria and requirements used in selecting the test site (Section 3.2);

- A summary of the available site history and site characterization data (Section 3.3);

- A summary of ongoing operations at the demonstration site (Section 3.4);

- A detailed description of the pre-design activities to be performed as part of the technology demonstration (Section 3.5);

## 3.1 Performance Objectives

The performance objectives are provided in Table 3-1.

**Table 3-1. Performance Objectives.**

| Type of Performance Objective | Primary Performance Criteria | Expected Performance (Metric) | Actual Performance |
|---|---|---|---|
| Qualitative | 1) "Simple to operate" | Minimal effort to operate (i.e., passive operation after installation) | Performance objective met |
|  | 2) Reduction in co-contaminants (RDX,TNT) downgradient of treatment zone | Reduce concentration of contaminants (RDX,TNT) | Performance objective met |
| Quantitative | 1) Reduce explosives concentration down-gradient of treatment zone | > 90% reduction in concentration (or less than 1 ug/L) | Performance objective met |

**3.2 Selection of Test Site**

The criteria and requirements used in selecting the test site for the passive ZVI PRB demonstration were as follows:

1) Significant (i.e., > 100 μg/L) concentrations of TNT and/or RDX in groundwater so that it was be possible to demonstrate that the technology can reduce concentrations by >90%.

2) Interest on the part of the site manager to allow access to the site during the demonstration.

3) Shallow, permeable aquifer with a significant groundwater contamination plume

**3.3 Test Site History/Characteristics**

The site identified for this demonstration is Cornhusker Army Ammunition Plant, located near Grand Island, NE. Information on the test site history and characteristics is presented in the June 1998 Annual Sampling Event for the Long-Term Monitoring Program, Cornhusker Army Ammunition Plant, Grand Island, NE, by Woodward-Clyde (Woodward-Clyde, 1999). The following sections of this Demonstration Plan present a summary of this information, with significant sections of text taken directly from that report.

**3.3.1   Test Site History**

CAAP is located in central Nebraska near Grand Island. The CAAP occupies nearly 12,000 acres as shown in Figure 3-1. Figure 3-2 shows a map of the Load Line 2 area at the CAAP. The locations of the former ponds used for the demonstration are shown on the map.

**Figure 3-1. Map of Cornhusker Army Ammunition Plant.**

**Figure 3-2. Map of Load Line 2, CAAP.**
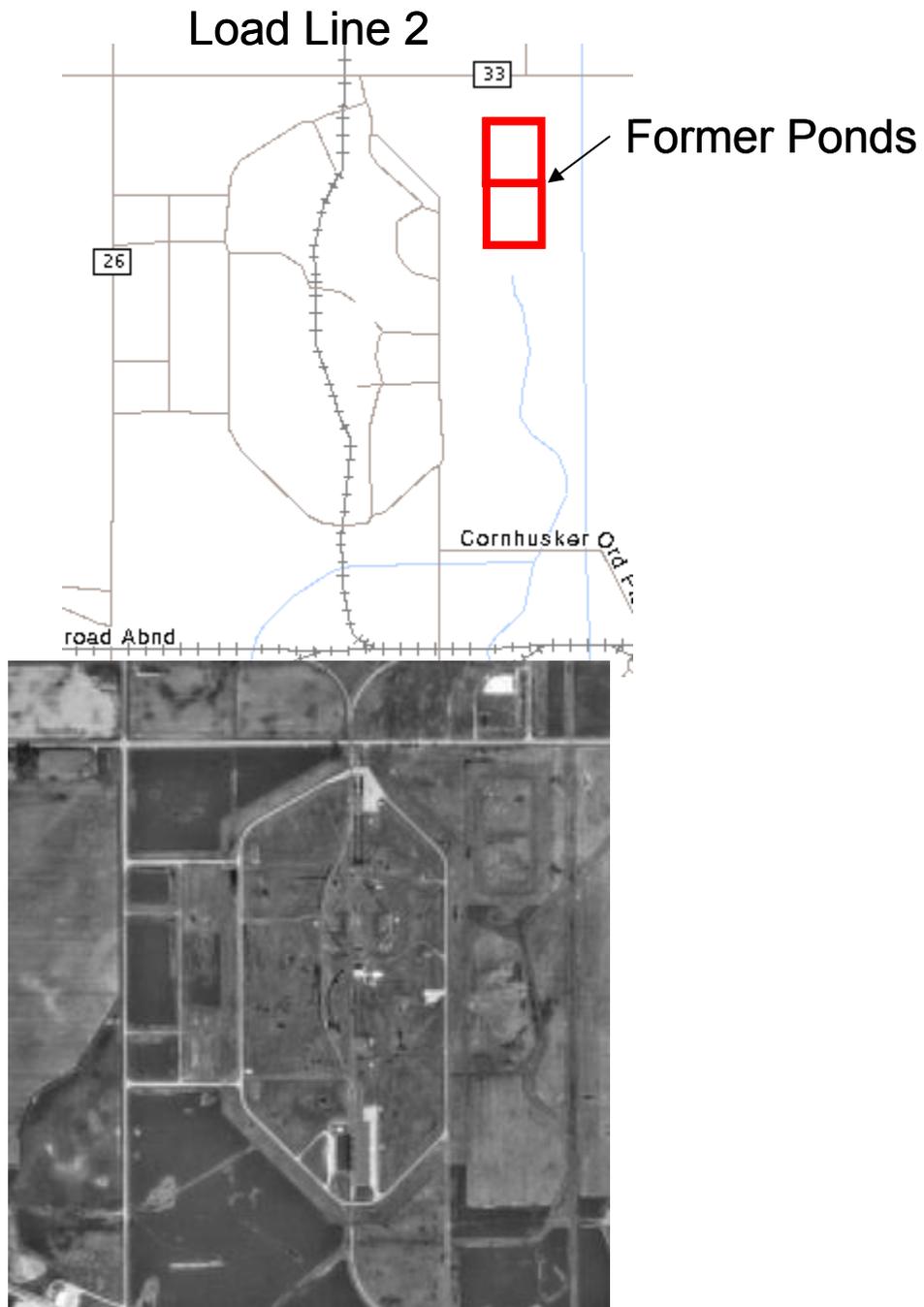
CAAP was constructed and became fully operational in 1942 as a U.S. Government-owned, contractor-operated facility. CAAP was responsible for the production of artillery shells, mines, bombs, and rockets for World War II and the Korean and Vietnam conflicts. The plant was operated intermittently for 30 years with the most recent operations ending in 1973. From 1942-1945, various bombs, shells, boosters and supplementary charges were produced at CAAP using primarily 2,4,6-trinitrotoluene (TNT). From 1950-1955, artillery shells and rockets were produced using a mixture of TNT, cyclonite (RDX), and cyclotetramethylenetetranitramine (HMX).

CAAP was activated again from 1965-1973 to produce bombs, projectiles, and gravel mini-mines. Explosive wastes and residues associated with munitions loading, assembly, and packing operations have resulted in a groundwater contamination plume that originates at waste leach pits and cesspools of the CAAP load lines and extends east-northeastward into the city of Grand Island, Nebraska.

### 3.3.2 Environmental Setting, Geology and Hydrology

The general geologic description summarized here was interpreted from soil boring logs completed during the installation of on- and off-post monitoring wells (WJE 1993), as well as regional data from the Soil Survey for Hall County (USDA 1962). In general, the geologic units underlying the CAAP study area include (in descending order from the surface) the following (see Figure 3-3):

Alluvial silty clay and topsoil near the surface (from about 0 to 5 feet in depth)

Alluvial sands and gravels of the Grand Island Formation (about 50 to 60 feet in thickness)

A low-permeability, alluvial silty clay unit of the Fullerton Formation (about 5 to 15 feet in thickness). This has also been referred to as the blue clay unit in previous reports (WJE 1993).

Alluvial sands and gravels of the Holdrege Formation (reported to be up to 200 feet in thickness)

These geologic units are laterally extensive across the CAAP facility and the northwestern part of the city of Grand Island. The deepest monitoring well borings (off post) extend 10 to 20 feet below the Fullerton clay unit into the Holdrege Formation.

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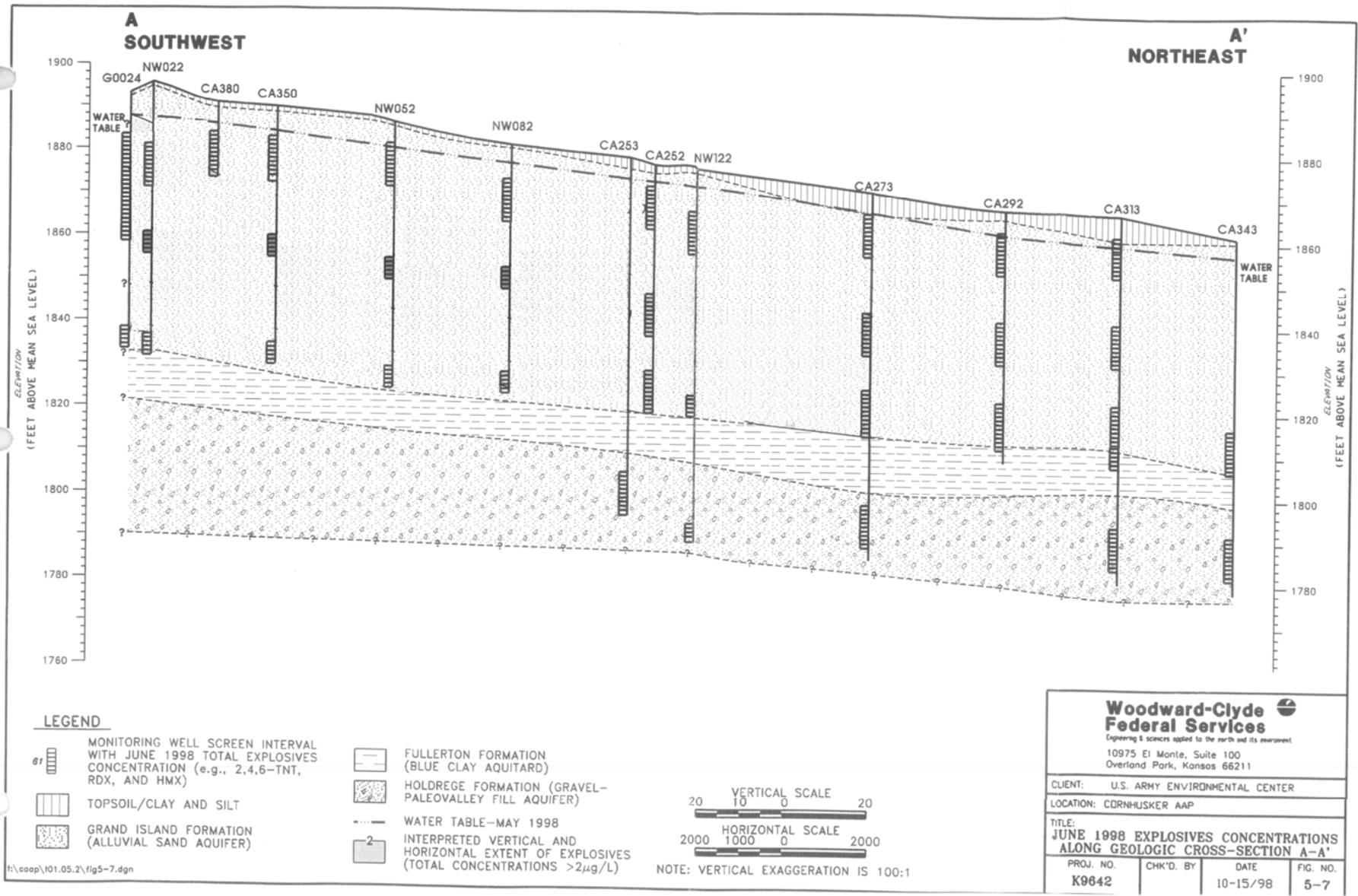
**Figure 3-3. Geologic Cross Section.**
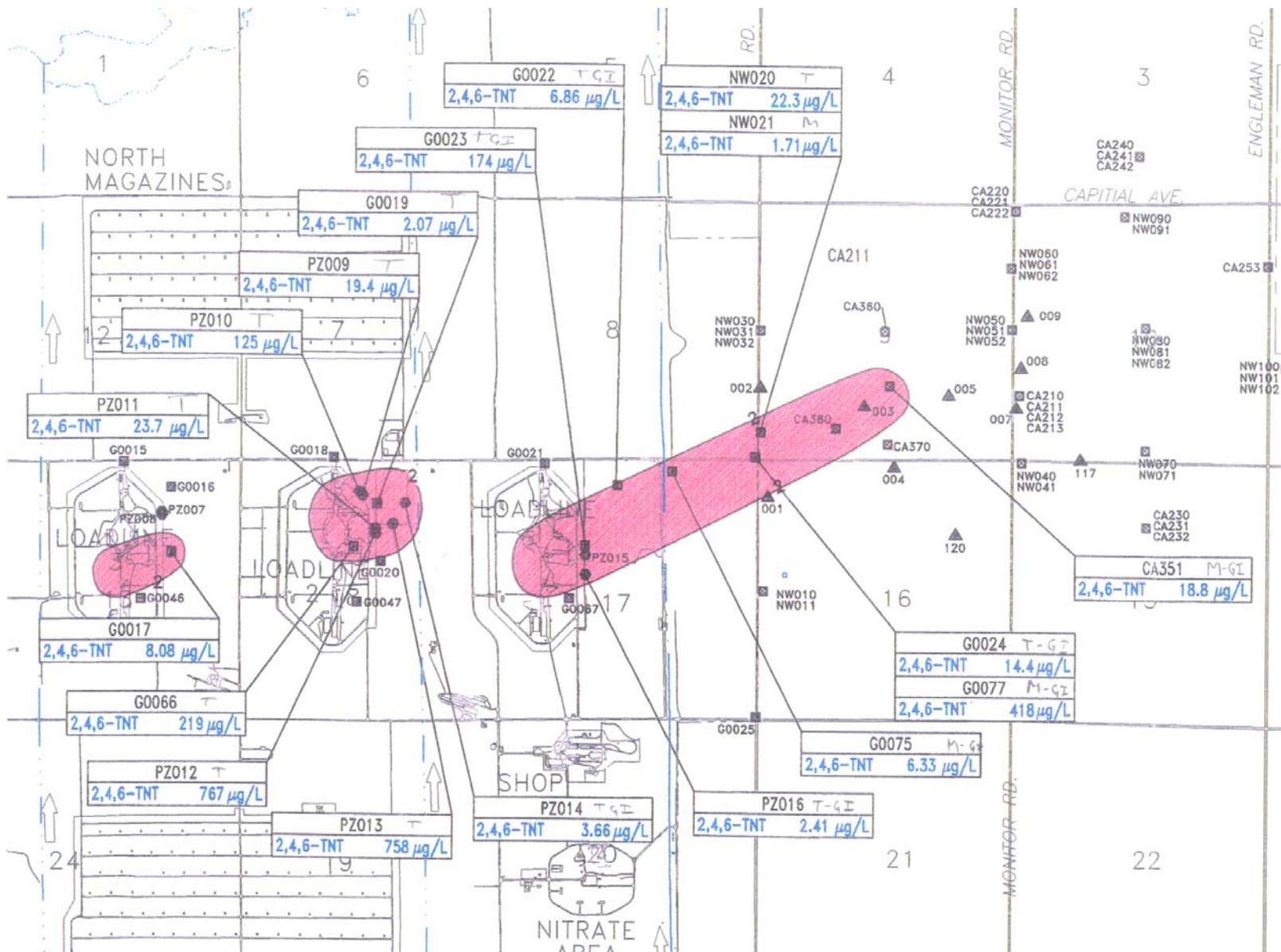
**Figure 3-4. Site plan View Showing the TNT Plumes from Load Lines 1, 2 and 3 at CAAP.**

Shallow groundwater underlying the facility occurs as an unconfined water table aquifer within the alluvial sands and gravels of the Grand Island Formation. The water table surface is generally less than 10 feet below the ground surface. Total thickness of the water table aquifer ranges from about 50 to 60 feet within the study area. Hydraulic conductivity values range up to 670 feet per day. The predominant groundwater flow direction within the water table aquifer near the CAAP facility is to the northeast towards the city of Grand Island. Regional horizontal gradients of about 0.001 have been measured in the area.

The Grand Island Formation aquifer is used regionally as a water supply source for irrigation and potable water. Locally, there are a number of irrigation wells in use east of the facility, however, all private domestic water is being supplied by the City of Grand Island. The city's municipal well field is located southeast of the city near the Platte River (about 10 miles southeast of CAAP).

The underlying clay is a relatively low-permeability unit that appears to act as a barrier to groundwater flow (i.e., aquitard) in the CAAP study area (Woodward-Clyde, 1999). Justification for this interpretation includes:

1. The presence of head differences across the Fullerton clay unit as measured between the Grand Island Formation aquifer and the underlying Holdrege Formation aquifer.

2. The absence of contamination below the Fullerton clay unit at locations where contamination is present at the base of the Grand Island Formation aquifer

The sands and gravels of the Holdrege Formation act as a confined aquifer unit (confined by the overlying Fullerton clay unit) in the CAAP study area. Based on water level data from the deep monitoring wells, the general groundwater flow direction in the Holdrege Formation appears to have a northeasterly component (similar to the overlying Grand Island Formation aquifer).

### 3.3.3  Contaminant Distribution within the Pilot Test Area

The off-post explosives plume originates on the northeast edge of the CAAP Facility (near Load Line 1) and extends over 21,000 feet northeast into the surroundings rural and urban areas. The axis of the off-post explosives plume trends from southwest to northeast (Figure 3-4). The highest explosives concentrations were located near the facility boundary. Explosives concentrations declined to the northeast. The plume was detected at depths of 6 to 57 feet bgs and approximately 5 to 33 feet below the water table. There appears to be a clean zone near the water table in the distal edges of the plume. Explosives were not detected in the deep aquifer (Holdrege Formation). The Fullerton Formation appears to act as a natural barrier, retarding the

vertical migration of explosives to the underlying Holdrege Formation (gravel-paleovalley fill aquifer).

## 3.4 Present Operations

Current operations at CAAP consist of a groundwater extraction and treatment system.  No other operations were conducted in the vicinity of Load Line 2.

## 3.5 Pre-Demonstration Testing and Analysis

Pre-demonstration testing and analysis involved groundwater sampling and field and laboratory studies as described in the following subsections.

### 3.5.1   Groundwater Chemical Analysis

Groundwater samples were collected and analyzed to determine explosives concentrations and the general characteristics of the groundwater.  Analyses included:
- Field parameters (DO, ORP, pH, conductivity, alkalinity and temperature);
- TNT, RDX
- Selected anions (nitrate and sulfate); and
- Cations  (sodium, potassium, magnesium, calcium)

Samples were collected by OHSU personnel following standard sampling protocols.  Field parameters were analyzed in on site.  TNT and RDX samples were extracted on site using Waters "Sep-Paks" and were analyzed at OHSU.  Anions and cations were analyzed at OHSU and Columbia Analytical Laboratory, Inc. by ion chromatography and wet chemical methods.  Table 3-2 summarizes the parameters that were analyzed as part of the pre-demonstration characterization, and provides details of analytical methods, container size and type, preservation method, and sample holding times.

Table 3-2.  Analytical Parameters.

| Parameter | Sample Collection Volume | Field Preservation | Analysis Location | Sample Holding Time |
|---|---|---|---|---|
| TNT/RDX | 1 liter | Sep-Pak | OHSU | 2 weeks |
| Anions | 40 mL | none | OHSU | 2 weeks |
| Cations | 40 mL | none | OHSU | 2 weeks |
| Dissolved Oxygen | In line meter | none | Field | none |
| Field Parameters (pH,temp,conductance, Eh) | In line meter | none | field | none |
| Ferrous iron | 10 mL | none | Field | none |
| Alkalinity | 25 mL | none | field | none |
|  |  |  |  |  |

### 3.5.2   Field Ex Situ Column Testing

A field ex situ column study was performed to gather data to assess the long-term performance of the ZVI PRB at the site.  The objectives of the study are:

Evaluate if plugging limited the lifetime of the ZVI PRB

Evaluate if passivation of the iron by precipitation limited the reactivity of the ZVI PRB

ZVI PRBs have been shown in the laboratory to become plugged when exposed to oxygenated groundwater (Johnson et al., 2005).  Data from CAAP indicate that DO levels at the site are ~1 mg/L.  Based on current laboratory experiments, plugging issues in the barrier could be avoided but our intent was to use ex situ columns to assess plugging under site conditions. Unfortunately, as we observed at the Umatilla Depot, dissolved oxygen levels in the pumped groundwater were significantly above ambient groundwater levels.  As a consequence, plugging occurred within a matter of a few days and longer-term studies could not be conducted.

### 3.5.3 Testing and Evaluation Plan

The demonstration was conducted in six phases of work. The first phase consisted of site characterization and engineering design (Phase 1). This was followed by installation of the ZVI PRB (Phase 2). Phase 3 was performance monitoring of the ZVI PRB. Phase 4 was numerical modeling of PRB hydraulic and degradation performance. Phase 5 was characterization of microbial community structure and dynamics in and around the PRB. The timeline for the demonstration is shown in Table 3-3.

**Table 3-3. Project Timeline.**

| Phase | Activity | 2003 J | F | M | A | M | J | J | A | S | O | N | D | 2004 J | F | M | A | M | J | J | A | S | O | N | D | 2005 J | F | M | A | M | J | J |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1a | Site characterization | | | | | | | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | |
| 1b | Final barrier design | | | | | | | | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | |
| 2 | PRB installation | | | | | | | | | | | ■ | ■ | | | | | | | | | | | | | | | | | | | |
| 3 | Performance monitroing | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 4 | Numerical modeling | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 5 | Microbial biomarkers | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |

### 3.5.4 Characterization & Engineering Design (Phase 1)

Following approval of the demonstration plan, the project team conducted a series of pre-design and design activities at the site. These included on-site ZVI reactivity testing using site groundwater and ex situ columns; site characterization, including hydraulic testing, detailed contaminant distribution measurements; assessment of groundwater geochemistry, preliminary numerical modeling and engineering design for PRB installation.

a) To assess ZVI reactivity under site conditions and to establish residence time requirements for PRB design, *ex situ* ZVI canisters were plumbed to the existing pump & treat system and TNT and RDX to monitor degradation. As discussed above, dissolved oxygen concentrations, introduced into the groundwater due to pumping, precluded long-term tests. They did, however, demonstrate that TNT and RDX degradation was rapid, with a half life of less than one minute in an iron/sand mix that was 30% iron by mass.

b) An understanding of the contaminant distribution in the vicinity of the proposed barrier was critical both for the design of the PRB and the interpretation of performance. The shallow groundwater at the site, coupled with direct push sampling, allowed a detailed three-dimensional map of the contaminants to be developed.

c) The groundwater inorganic geochemistry of the site was analyzed to assess potential precipitation problems. This analysis included major anions and cations (e.g., nitrate, sulfate, sodium, magnesium, calcium), pH, redox potential, and alkalinity. Based on those results, it was concluded that sulfate concentrations were high (~300 mg/L) and would likely be removed by the PRB, leading to potential loss of reactivity and plugging..

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d) The hydraulic conductivity of the aquifer containing the contaminant plume was determined using field slug tests and laboratory tests on core material (falling head permeameter, grain size analysis). These data were sufficiently detailed to allow a three-dimensional picture of aquifer permeability to be developed.

e) Using the characterization data described above, a preliminary three-dimensional numerical groundwater flow and transport model was developed for the PRB and surrounding aquifer. MODFLOW/MODPATH was used to model flow and conservative transport. RT3D was used to model transport and chemical reactions.
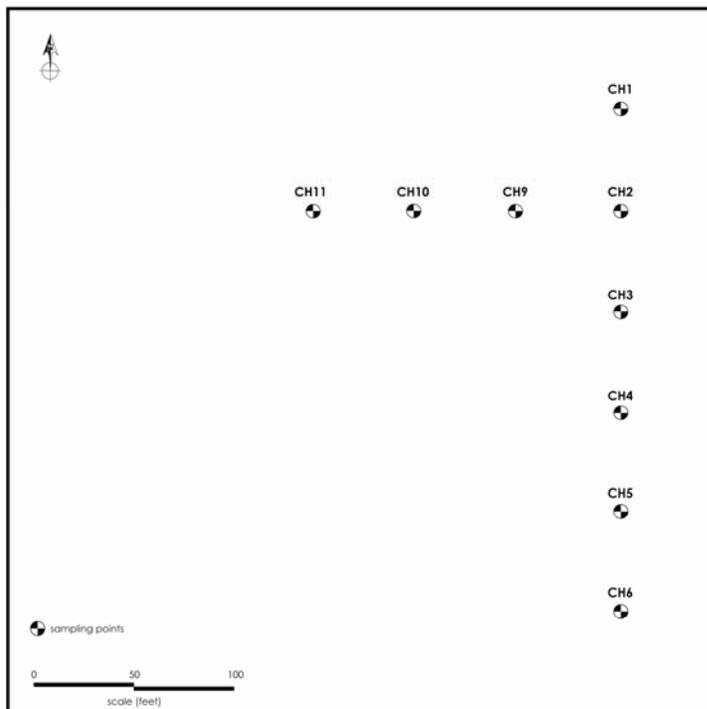


**Figure 3-5. Site Plan View Showing Locations of the Pre-installation Sampling Locations.**

f) The PRB for this project was of a "simple" design (i.e., no funnel and gate, etc.) in order to maximize our ability to understand the performance of the barrier for removing explosives from the groundwater. Because of the shallow depth to groundwater and the shallow nature of the contaminant plume, it was possible to use conventional installation techniques to emplace the PRB. The characterization data described above, as well as the prior experience of the project team in installing PRBs, provided the basis for engineering design of the PRB.

# 4 INSTALLATION OF THE ZVI PRB (PHASE 2)

Installation of the ZIV PRB is documented in annotated photograph in Appendix A and is described briefly here.  The "as built" location and design are shown in Figures 4-1 to 4-3.
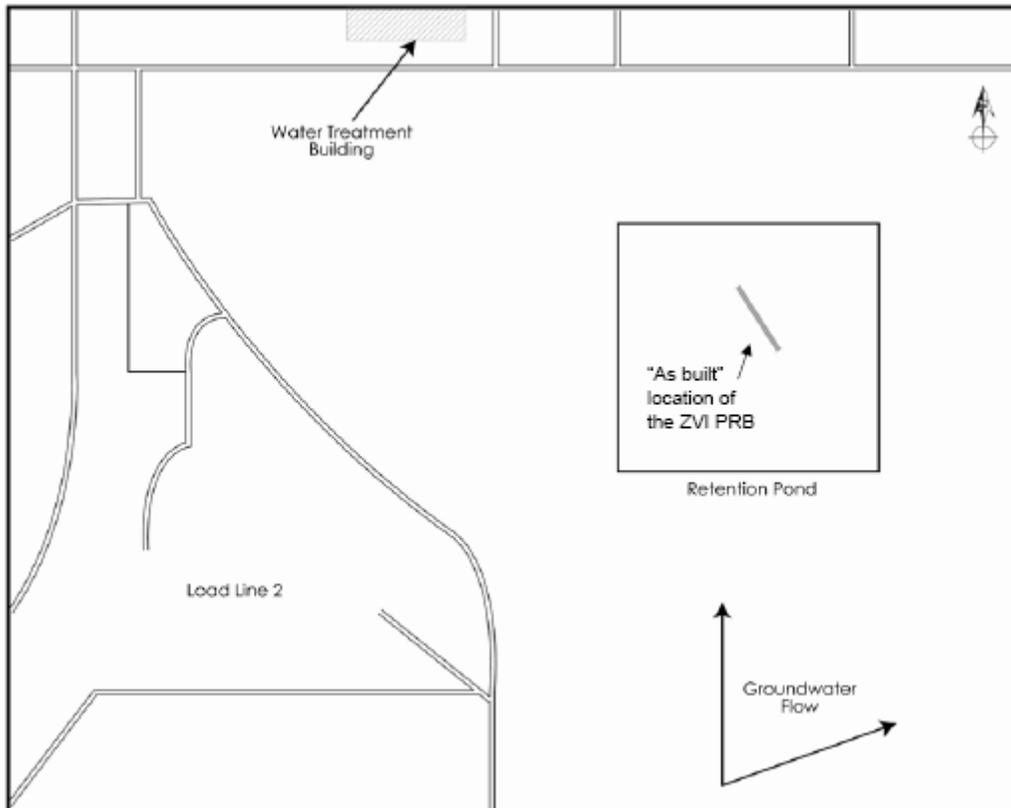


**Figure 4-1.  Site Map Showing "as built" Location of the ZVI PRB.**
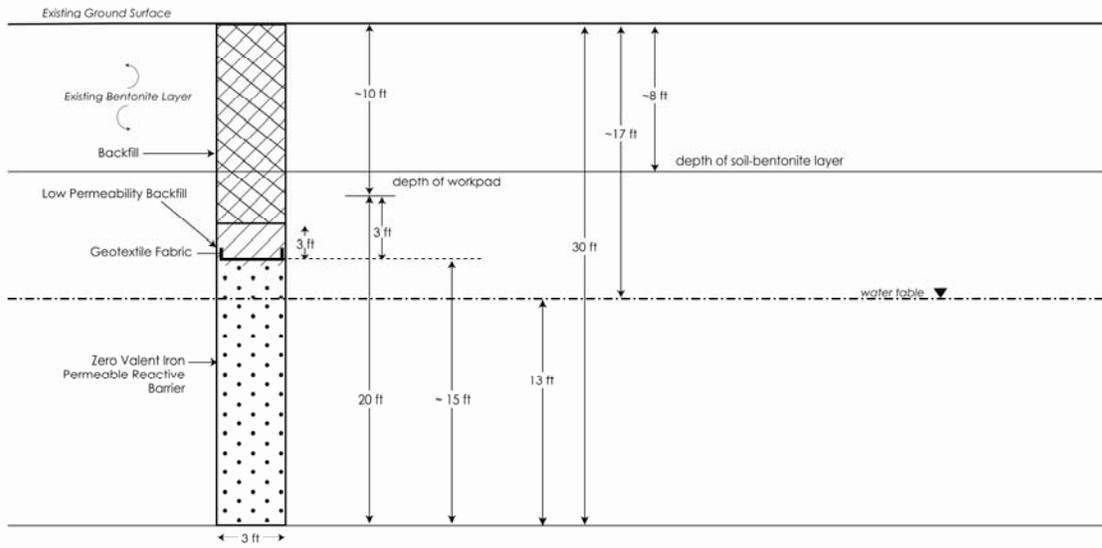
**Figure 4-2. Cross-section Drawing of the "as built" ZVI PRB.**
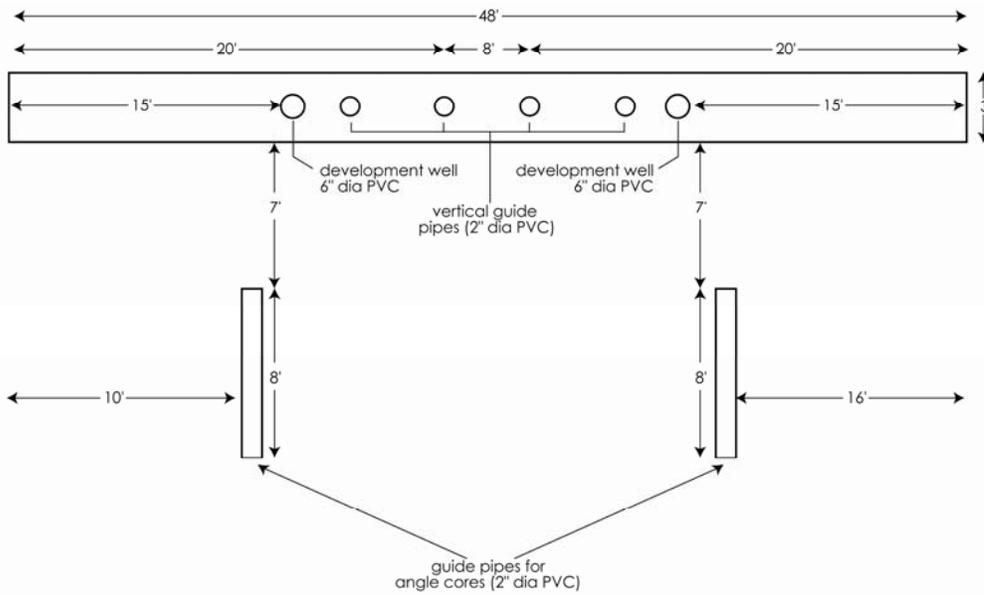


**Figure 4-3. Plan View Drawing of the "as built" ZVI PRB.**

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Steps in the intallation of the PRB included:
1) Removal of ground surface materials to a depth of ~10 feet bgs.
2) Excavation of a 50 foot long x 15 foot deep x 3 foot wide trench using a track hoe and guar slurry to maintain the integrity of the trench
3) Emplacement of a sand-ZVI mixture (30% ZVI by weight) using a "tremmie pipe"
4) Removal of guar residuals using an enzyme to break the polymer
5) Replacement of surface materials and installation of monitoring devices.

### 4.1.1 Residuals Handling

All fluids generated during well purging and equipment cleaning remained on-site. During emplacement of the PRB, both clean and contaminated soils were removed from the subsurface. The soils overlying the aquifer were clean. These soils were segregated from any contaminated soils. Soils from below the seasonally-high water table were assumed contaminated. These were stored above ground for less than 1 day and were used in the emplacement of the ZVI PRB. Uncontaminated soils were spread on site to cover the PRB excavation.

### 4.1.2 Operating Parameters for the Technology

Because the ZVI PRB technology is completely passive, there were no operating parameters critical to its performance. However, a number of parameters were monitored to demonstrate PRB performance, including:

1. explosives concentrations up- and down-gradient of the barrier; and

2. flow of water through the barrier (using tracers).

### 4.1.3 Experimental Design

The contaminated fluid to be treated by the ZVI PRB remediation technology consisted of the groundwater that flows into the treatment zone created by the PRB. The treated water stream consists of the groundwater downgradient of the groundwater treatment zone. Groundwater monitoring was conducted to confirm that the performance of the ZVI PRB technology was achieving the target objectives. Details of the technology validation approach are presented in Section 4.2. This approach demonstrated that the ZVI PRB reduced explosives concentrations at the down gradient performance monitoring wells. A combination of the field parameter data (i.e., flow rates, pore volumes, redox data), chemical data (i.e.,TNT, RDX) and microbial characterization data (i.e., population and diversity) were used to evaluate the performance of each operational phase.

### 4.1.4    Sampling Plan

The effectiveness of the ZVI PRB was determined using the results of the groundwater sampling and analysis conducted in the downgradient performance monitoring wells.   Samples were collected from the groundwater monitoring wells and analyzed in the field or in the laboratory depending on the specific parameter being measured.

The experimental controls incorporated in the design of the demonstration ensured that the monitoring data provided an unequivocal and reliable assessment of the applicability of ZVI PRB systems at DoD sites.  The tracer tests provided the project team with an understanding of advective and dispersive transport processes in the test area.

### 4.1.5    Demobilization

Upon completion of the demonstration, all aboveground equipment and structures were removed. All subsurface devices were removed in accordance with CAAP policy.

### 4.1.6    Management and Staffing

This project management personnel for this project are presented in Figure 4-5.  Rick Johnson (OHSU) was the Principal Investigator, with responsibility for the overall management, direction, and execution of the demonstration.   Paul Tratnyek (OHSU) was the Technical Reviewer and provide review of project activities, engineering design and project strategy.  R. Brad Thoms (OHSU) coordinated daily management of the project activities and acted as the Quality Assurance Officer for the demonstration.

**Figure 4-4.  Project Organization for ESTCP ZVI PRB  Pilot Test.**



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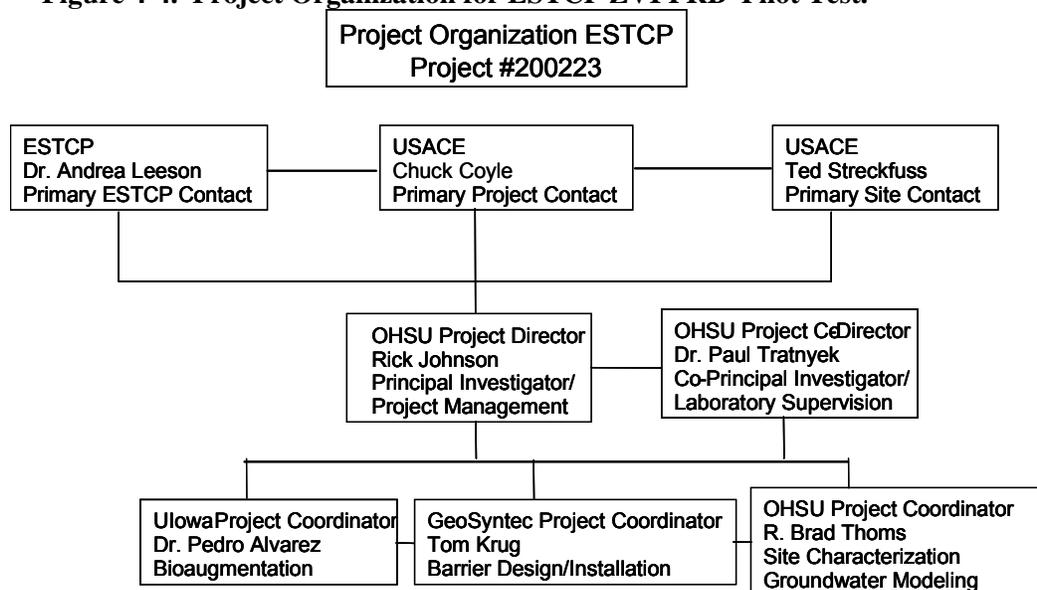
# 5  PERFORMANCE ASSESSMENT

## 5.1 Performance Criteria

Performance of the demonstration has been evaluated using the general performance criteria provided in Table 5-1.  Qualitative and quantitative criteria are classed as either primary or secondary performance assessment criteria, respectively.

The primary criteria constitute the performance objectives of the technology demonstration.  As stated in Section 1.2, the general objective of the demonstration is to evaluate the performance of the ZVI PRB to degrade explosives in groundwater.  In general, the performance criteria are used to evaluate this objective by:

Determining the ability of the ZVI PRB to degrade explosives over the period of demonstration (20 months in this case)

Determining the role played by microbiological populations associated with the ZVI PRB

Quantifying the effect of the technology on TNT and RDX degradation in groundwater, and

Evaluating the difficulty in implementing this technology at the field scale.


## 5.2 Performance Confirmation Methods

The success of the technology demonstration has been evaluated using the performance expectations and confirmation methods presented in Table 5-1.  Successful implementation of the technology demonstrated that the technology results in significant reduction in TNT and RDX concentrations over the duration of the demonstration.

**Table 5-1. Project Performance Criteria.**

| | Performance Criteria | Performance Metric | Confirmation Method | Location | Sample Matrix | Measurement |
|---|---|---|---|---|---|---|
| **Primary** | Qualitative | | | | | |
| | Extent of degradation | Decreased TNT and RDX concentrations downgradient of the PRB | TNT/RDX concentration | PTA[1] | groundwater | TNT/RDX |
| | Quantitative | | | | | |
| | Mass flux from PRB | Decreased mass flux of TNT and RDX coming from the PRB | TNT/RDX concentration | PTA | groundwater | TNT/RDX |
| **Secondary** | Qualitative | | | | | |
| | Barrier hydraulics | Tracer test | Bromide analyses | PTA | groundwater | Anion analysis, bromide specific ion electrode |
| | Barrier hydraulics | Small water level changes will occur if barrier hydraulics change | Water level measurements | PTA | groundwater | Water level tape |
| | Changes in microbial population | Microbial ecology will change due to the presence of the ZVI PRB | Various microbiological measurements | PTA | groundwater, soil, ZVI | Various microbiological measurements |
| | Changes in downgradient groundwater geochemistry | ZVI PRB chemistry will change downgradient water chemistry | Field water parameters (DO, Eh, pH) | PTA | groundwater | |

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[1] Pilot Test Area

Performance monitoring and assessment were conducted for a period of about 20 months. Groundwater samples were collected from the various monitoring wells for analysis of the parameters listed in Table 3-2.

The data obtained from the demonstration were used to estimate the rate and extent of degradation of TNT and RDX. Factors affecting remediation performance were identified and optimized through the pilot test.

### 5.2.1  Period of Operation

The ZVI PRB was installed in November 2003 and was monitored until August 2005.

### 5.2.2  Performance Monitoring (Phase 3)

During the 20-month period of operation, seven synoptic sampling events were conducted, as well as several soil and groundwater sampling events.

| |
|---|
| December 2003 |
| February 2004 |
| March 2004 |
| August 2004 |
| November 2004 |
| April 2005 |
| July 2005 |

### 5.3 Data Analysis, Interpretation, and Evaluation

### 5.3.1  Flow tracer test

Beginning in August 2004 (i.e., 9 months after installation) a bromide tracer test was conducted to evaluate flow through the PRB. A total of approximately 1000 L of groundwater containing 1000 mg/L bromide was injected at a location directly between multi-level samplers G8 and J8 (Figure 5-1). Approximately-equal volumes of tracer were injected over three 1.5m intervals

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from -5.4 to -9.9m fgs (i.e., 333 L/interval).  Groundwater samples were collected periodically from the multi-level monitoring wells over a 4-month period.

Figure 5-1 shows the maximum bromide tracer concentrations observed at each plan-view location 44 days after the start of the bromide tracer test.  The green circle represents the approximate initial aerial extent of the injected bromide source. The data confirm the general flow direction and velocity of groundwater at the site, although the average velocity of the bromide plume appears somewhat slower than the overall groundwater velocity for the site (0.1 vs. 0.2 m/d)  Time series bromide data from Row J (Figure 5-2) indicate a generally well behaved tracer plume.  Two interesting aspects of are that: 1) no tracer was observed at 6.3 m (not shown in Figure 5-2), even though the tracer was injected over the entire 5.4 to 9.9 m fgs depth interval; and 2) For the 8.7 m fgs sampling depth, significant concentrations of tracer appear at the furthest down gradient sampling location (16,-8.7) before they appear at the two locations just up-gradient (12,-8.7) and (14,-8.7).  This suggests that flow may have been deflecting upwards at that point.  However, to confirm that this is the case, it must be demonstrated that the K distribution within the aquifer does not contribute to the observed patterns of the geochemical data.  As discussed above, to accomplish this a transect of mini-slug tests were conducted between sampling rows G and J (Figure 5-1).  Data from the slug tests are discussed in Section 5.3.2.2 below, and indicate the aquifer consists of spatially-extensive strata of modest heterogeneity.

**Figure 5-1.** a) **Site Plan View Showing Maximum Bromide Tracer Concentrations Observed at Each Plan-view Location 44 Days After the Start of the Bromide Tracer Test.** b) **Cross-section view showing the depths of the multi-level monitoring wells.**
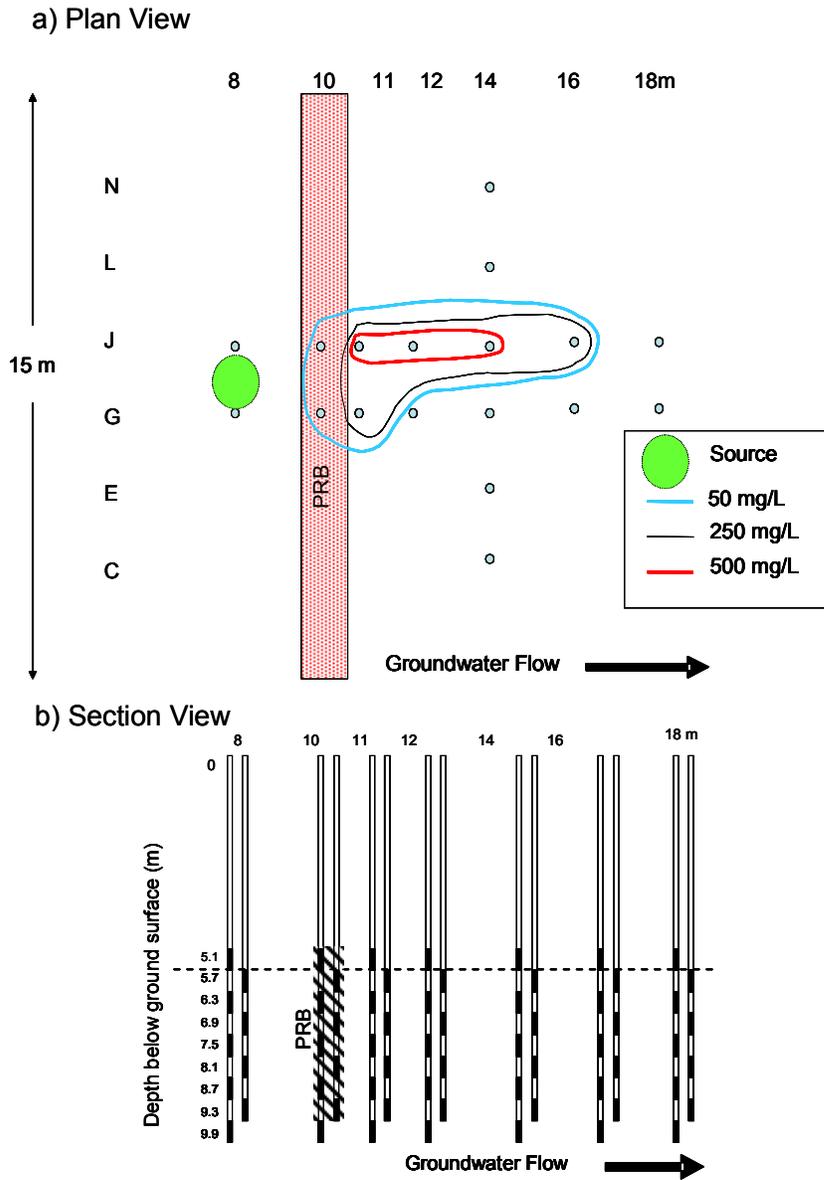
## 5.3.2 Groundwater flow

Groundwater flow direction and velocity were determined seasonally using a combination of hydraulic gradient data (i.e., water table elevations measured in wells) and hydraulic conductivity data determined either by laboratory permeameter tests or in situ "slug tests".
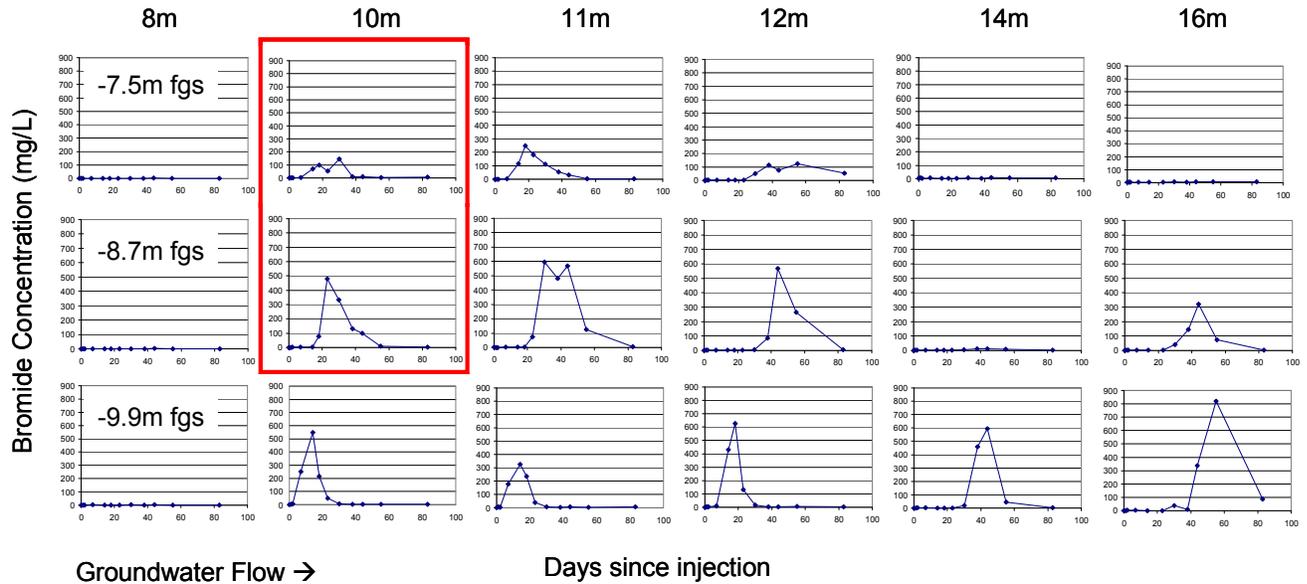


**Figure 5-2. Time-series Concentration Data for Bromide** (mg/L) **in the "J-series" Wells. The -6.3 fgs Wells Did Not Show Any Bromide Concentrations at Any Point During the Test.**

## 5.3.2.1 Hydraulic Gradient Data

Four wells were used to determine hydraulic gradient throughout the project. Figure 5-3 shows their location relative to the PRB.
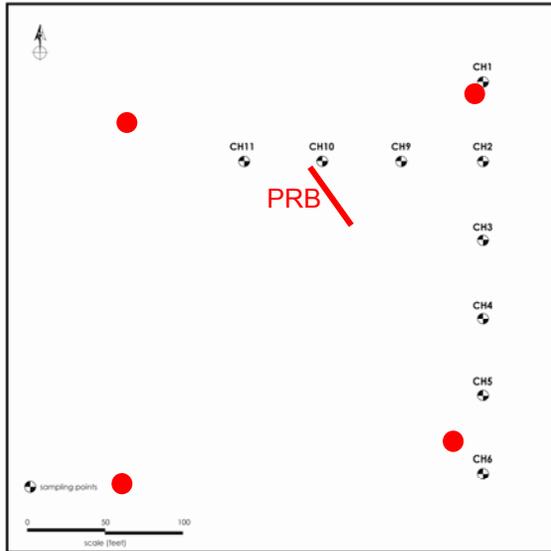
**Figure 5-3. Site Plan View Showing the PRB** (50 feet long for scale)**, Pre-installation Monitoring Locations** (U) **and Locations of the Water Table Wells (●) Used for Hydraulic Gradient Determination.**

Depth to water table measurements were taken during synoptic sampling events and water table contours for those events are shown in Figure 5-4. The data indicate that water generally flows to the north east through the PRB. This is consistent with the shapes of the large groundwater contamination plumes coming from the site (e.g., Figure 3-4). The hydraulic gradient ranges from 0.0007 to 0.002, with a typical value of 0.001. The data suggest that hydraulic gradients tend to by higher in the Spring and early Summer (April-July) and lowest in the Fall.
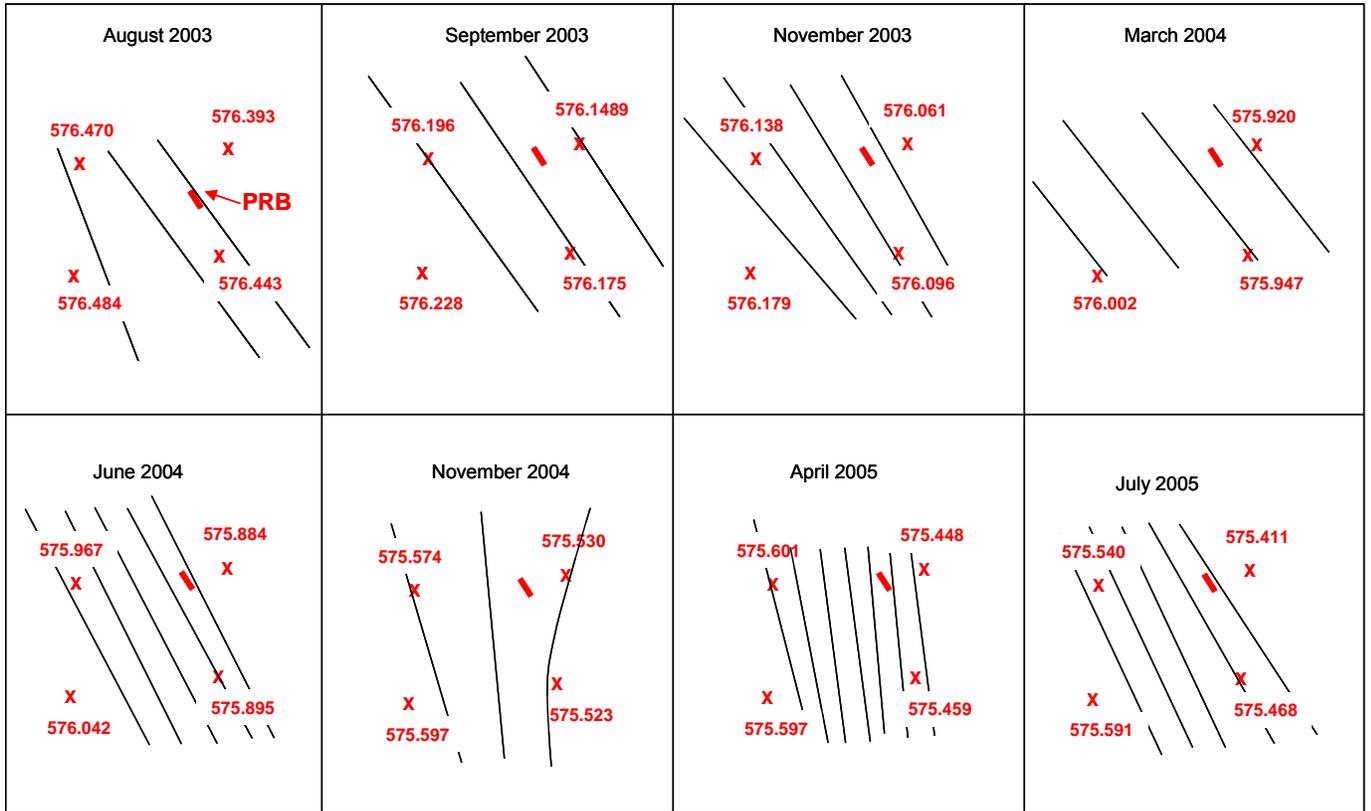
**Figure 5-4. Water Table Contour Data** (all contour intervals are 0.025 meters).

Data in Figure 5-5 show that over the course of the project the water table dropped about 1 meter.
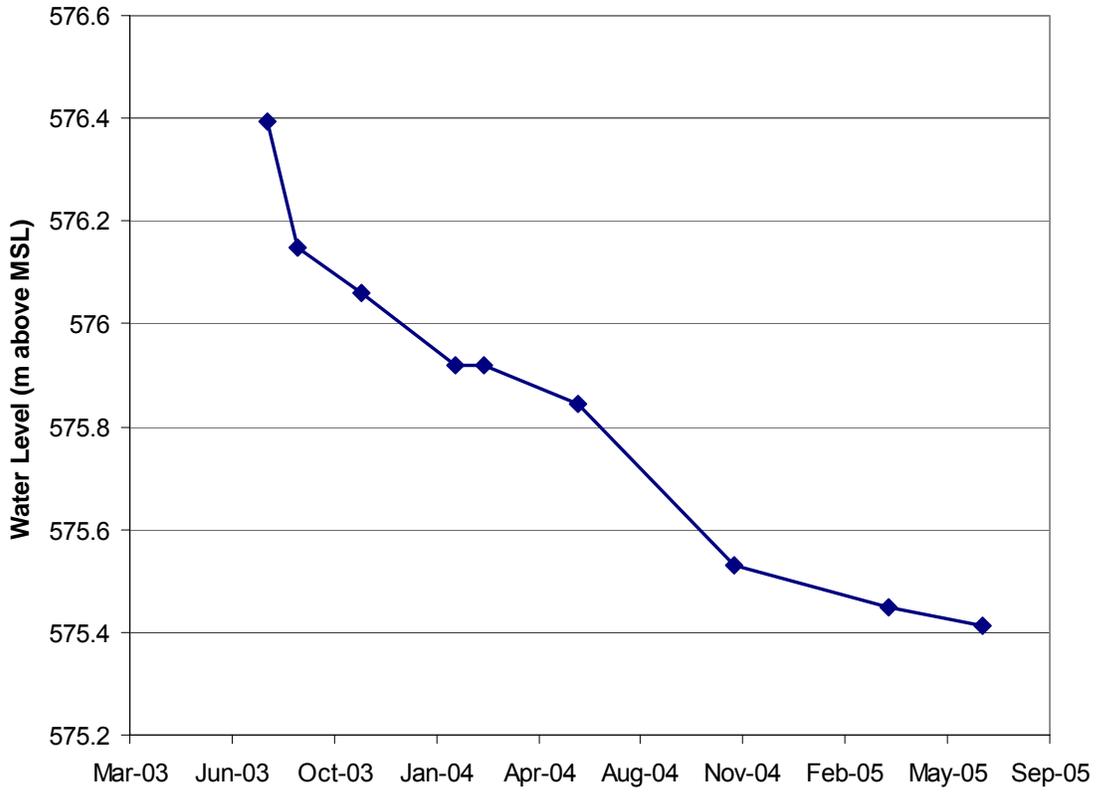


**Figure 5-5. Water Table Elevation Data for the Water Table Well CHWT1 as a Function of Time.**

## 5.3.2.2 Hydraulic conductivity data

Prior to installation of the PRB, core samples collected at some of the test holes shown in Figure 3-5 (CH10, CH2, and CH4) were analyzed by laboratory permeameter. One-foot sections of the core were sub-sampled, dried, mixed and packed into a falling-head permeameter cell. Data from these analyses are shown in Figure 4-6. For the depth of interest, hydraulic conductivities were generally in the 0.012 cm/s range, with a lower-permeability layer present in the vicinity of 8 meters below ground surface (K=0.0001 to 0.0005 cm/s).

To facilitate numerical modeling of geochemical and tracer flow patterns, a series of depth-specific slug tests was conducted. The tests were carried out using a 2.5 cm diameter by 30 cm long screened interval in a manner similar to Butler et al. (2002). The screened interval was placed at successive depths using direct-push equipment and a pressure transducer (Druck Incorporated, New Fairfield, CT) was lowered to the screen. A partial vacuum was then applied to the drill rod and water was drawn in through the screen to raise the water level in the rod by ~1m. The pressure reading of the transducer was allowed to stabilize under those conditions before releasing the vacuum and tracking the decrease in water level measured by the transducer. Three tests were conducted at each one-foot interval between 6 and 12 meters from ground surface (Figure 5-7). The tests were conducted in a transect parallel to and between sampling rows G and J. The longitudinal spacing between the sets of vertical measurements was 1 meter. Slug tests were also conducted within the PRB. Those data indicate that the K of the PRB was generally higher than the surrounding formation and it was consistent with laboratory permeameter measurements of the ZBI/sand mixture (0.02 cm/s)
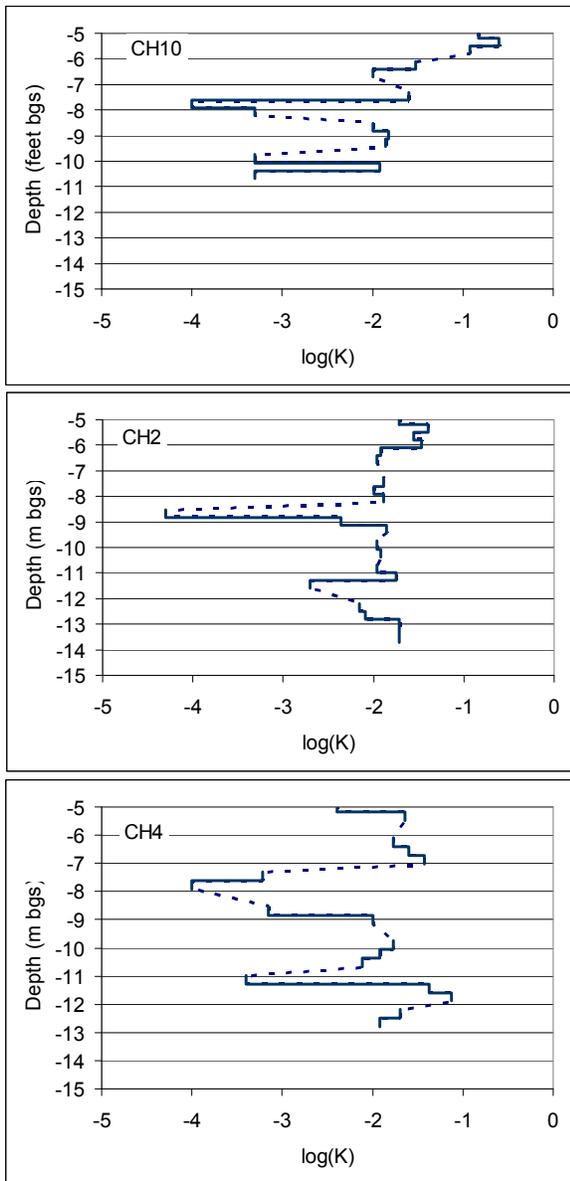
**Figure 5-6. Hydraulic Conductivity Profiles from Test Holes CH10, CH2 and CH4** (see Figure 3.5) **Measured by Laboratory Permeameter.**

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| | 7 | 8 | 9 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|---|---|
| -6 | .000 | .000 | .001 | .008 | .000 | .004 | .002 | .003 | .002 |
| -6.3 | .000 | .013 | .004 | .008 | .001 | .003 | .005 | .002 | .008 |
| -6.6 | .007 | .003 | .011 | .008 | .007 | .008 | .007 | .004 | .019 |
| -6.9 | .008 | .006 | .009 | .019 | .008 | .008 | .003 | .013 | .019 |
| -7.2 | .004 | .000 | .015 | .019 | .007 | .008 | .009 | .025 | .019 |
| -7.5 | .005 | .002 | .000 | .015 | .011 | .008 | .015 | .015 | .009 |
| -7.8 | .011 | .002 | .000 | .019 | .001 | .006 | .008 | .002 | .003 |
| -8.1 | .019 | .001 | .004 | .019 | .001 | .002 | .002 | .025 | .015 |
| -8.4 | .001 | .006 | .001 | .019 | .008 | .003 | .002 | .015 | .025 |
| -8.7 | .004 | .000 | .015 | .019 | .007 | .008 | .009 | .025 | .019 |
| -9 | .013 | .008 | .015 | .019 | .007 | .025 | .025 | .019 | .038 |
| -9.3 | .009 | .008 | .013 | .019 | .008 | .025 | .025 | .025 | .025 |
| -9.6 | .008 | .025 | .019 | .019 | .015 | .019 | .025 | .025 | .025 |
| -9.9 | .003 | .019 | .019 | .019 | .019 | .019 | .004 | .015 | .019 |
| -10.2 | .004 | .025 | .025 | .019 | .002 | .019 | .001 | .019 | .019 |
| -10.5 | .008 | .015 | .025 | .019 | .019 | .015 | .019 | .019 | .019 |
| -10.8 | .009 | .004 | .019 | .019 | .019 | .013 | .019 | .019 | .025 |
| -11.1 | .015 | .011 | .025 | .015 | .019 | .019 | .013 | .009 | .019 |
| -11.4 | .007 | .025 | .015 | .013 | .011 | .025 | .019 | .019 | .015 |
| -11.7 | .019 | .009 | .025 | .009 | .019 | .019 | .019 | .019 | .075 |
| -12 | .023 | .075 | .054 | .009 | .080 | .054 | .040 | | |

▢ = K <0.004 cm/s

▢ =PRB

**Figure 5-7. Measured Hydraulic Conductivity** (slug test) **Data Measured in a Transect Parallel to Groundwater Flow Between Sampler Rows G and J.**

### 5.3.3  Explosives concentration changes over time

All of the explosives concentrations in groundwater data are listed in Appendix C.  Explosives concentrations in groundwater measured prior to installation of the PRB are shown in Figure 5-8.  Based on those data the PRB was located between locations CH10 and CH11 in the figure.

**[TNT] (UG/L)**

| DEPTH | 11 | 10 | 9 | 2 |
|---|---|---|---|---|
| -6.1 | 28.1 | 104.0 | 110.0 | 117.6 |
| -6.7 | 91.5 | 65.2 | 91.8 | |
| -7.3 | 133.8 | 98.1 | 50.7 | 154.5 |
| -7.9 | 27.3 | 51.5 | 0.3 | |
| -8.5 | 57.9 | 26.6 | 0.8 | |
| -9.1 | 39.8 | 23.1 | 2.8 | 1.7 |
| -9.8 | 21.2 | 18.2 | 7.8 | |
| -10.4 | | | | |
| -11.0 | 17.2 | 11.8 | 13.7 | 0.1 |
| -11.6 | | | | |
| -12.2 | | | | 1.3 |
| -12.8 | | | | |
| -13.7 | | | | 0.1 |

| DEPTH | CH1 | CH2 | CH3 | CH4 | CH5 | CH6 |
|---|---|---|---|---|---|---|
| -6.1 | 131.2 | 117.6 | 131.8 | 1.6 | 1.1 | 0.0 |
| -7.6 | 2.8 | 154.5 | 4.1 | 0.3 | 0.4 | 0.1 |
| -9.1 | 41.0 | 1.7 | 0.1 | 0.0 | 0.1 | 0.1 |
| -10.7 | 1.2 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 |
| -12.2 | 0.4 | 1.3 | 0.0 | 0.2 | 0.1 | 0.1 |
| -13.7 | 0.6 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 |

Legend:
- no sample at that depth
- >100 ug/L
- >10 ug/L
- >1 ug/L
- >0.1 ug/L

**RDX (UG/L)**

| DEPTH | 11 | 10 | 9 |
|---|---|---|---|
| -6.1 | 0.6 | 0.3 | 0.4 |
| -6.7 | 0.3 | 0.3 | 0.3 |
| -7.3 | 0.3 | 0.4 | 0.2 |
| -7.9 | 0.9 | 0.4 | 0.1 |
| -8.5 | 0.0 | 0.4 | 0.0 |
| -9.1 | 0.2 | 0.5 | 0.0 |
| -9.8 | 0.1 | 0.2 | 0.2 |
| -10.4 | | | |
| -11.0 | 0.3 | 0.2 | 0.7 |
| -11.6 | | | |
| -12.2 | | | |
| -12.8 | | | |
| -13.7 | | | |

Plan view map (lower right): PRB located between CH11 and CH10. Monitoring locations CH1–CH6, CH9, CH10, CH11 shown.

**Figure 5-8.  TNT and RDX Concentrations at the Pre-installation Monitoring Locations.** (Detection Limits are 0.1 µg/L for all Analytes.  Values Below the Detection Limit are Shown as 0.0)**.  The Plan View Map in the Lower Right Corner Shows the Location of the PRB Relative to the Pre-installation Monitoring Locations.**

Following installation of the PRB and monitoring network (Figure 5-1), explosives concentrations were monitored for a period of 20 months.  Figures 5-9 through 5-14 show explosives concentrations in the monitoring wells in a vertical transect along the direction of groundwater flow during the period between December 2003 and July 2005.  The data indicate that contaminant removal remained effective throughout that period.

| TNT (ug/L) | DISTANCE (M) | | | | |
|---|---|---|---|---|---|
| DEPTH (M) | 8 | 10 | 11 | 12 | 14 |
| -5.7 | 21 | 0 | 0 | 46 | 63 |
| -6.3 | 199 | 0 | 0 | 145 | 149 |
| -6.9 | 119 | 0 | 0 | 0 | 15 |
| -7.5 | 108 | 0 | 0 | 0 | 27 |
| -8.1 | 84 | 0 | 0 | 0 | 1 |
| -8.7 | 18 | 0 | 0 | 0 | 1 |
| -9.3 | 29 | 0 | 0 | 2 | 2 |
| -9.9 | 39 | 0 | 0 | 0 | 33 |

| 2ADNT (ug/L) | DISTANCE (M) | | | | |
|---|---|---|---|---|---|
| DEPTH (M) | 8 | 10 | 11 | 12 | 14 |
| -5.7 | 31 | 0 | 0 | 17 | 18 |
| -6.3 | 29 | 0 | 0 | 25 | 25 |
| -6.9 | 34 | 0 | 0 | 0 | 15 |
| -7.5 | 51 | 0 | 0 | 0 | 62 |
| -8.1 | 76 | 0 | 0 | 0 | 40 |
| -8.7 | 56 | 0 | 0 | 0 | 0 |
| -9.3 | 44 | 0 | 0 | 0 | 0 |
| -9.9 | 17 | 0 | 0 | 0 | 14 |

GROUNDWATER FLOW

**Figure 5-9. TNT and 2-ADNT Concentration Data from December 2003** (Detection Limits are 0.1 μg/L for all Analytes. Values Below the Detection Limit are Shown as 0**).**

TNT (ug/L)

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 165 | 0 | 0 | 0 | 18 |
| -6.3 | 113 | 0 | 0 | 0 | 4 |
| -6.9 | 102 | 0 | 0 | 0 | 0 |
| -7.5 | 106 | 0 | 0 | 0 | 0 |
| -8.1 | 23 | 0 | 0 | 0 | 0 |
| -8.7 | 49 | 0 | 0 | 0 | 0 |
| -9.3 | 28 | 0 | 0 | 0 | 0 |
| -9.9 | 33 | 0 | 0 | 0 | 17 |

2ADNT (ug/L)

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 31 | 0 | 0 | 0 | 20 |
| -6.3 | 45 | 0 | 0 | 0 | 11 |
| -6.9 | 71 | 0 | 0 | 0 | 0 |
| -7.5 | 54 | 0 | 0 | 0 | 0 |
| -8.1 | 84 | 0 | 0 | 0 | 0 |
| -8.7 | 61 | 0 | 0 | 0 | 0 |
| -9.3 | 69 | 0 | 0 | 0 | 0 |
| -9.9 | 20 | 0 | 0 | 0 | 17 |

**Figure 5-10. TNT and 2-ADNT Concentration Data from February 2004.** (Detection Limits are 0.1 µg/L for all Analytes. Values Below the Detection Limit are Shown as 0).

TNT (ug/L)          Feb-04

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 136 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 120 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 91 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 88 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 25 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 51 | 0 | 0 | 0 | 1 | 0 | 0 |
| -9.3 | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.9 | 37 | 0 | 0 | 0 | 11 | 0 | 0 |

Groundwater Flow -->

**Figure 5-11. TNT Concentration Data from February 2004.** (Detection Limits are 0.1 µg/L for all Analytes. Values Below the Detection Limit are Shown as 0).

TNT (ug/L)          Aug-04

| Depth | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 112 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 109 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 58 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 97 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 12 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 65 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 27 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.9 | 20 | 0 | 0 | 0 | 12 | 7 | 4 |

**Figure 5-12. TNT Concentration Data from November 2004.** (Detection Limits are 0.1 μg/L for all Analytes. Values Below the Detection Limit are Shown as 0).

TNT (ug/L)          Ap 05

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 80 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 70 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 77 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 36 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 34 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 44 | 0 | 0 | 0 | 0 | 0 | 3 |
| -9.9 | 34 | 0 | 0 | 0 | 9 | 11 | 11 |

**Figure 5-13.  TNT Concentration Data from April 2005.** (Detection Limits are 0.1 μg/L for all Analytes.  Values Below the Detection Limit are Shown as 0).

**TNT (ug/L)**  Jul-05

| Depth | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 71 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 98 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 72 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 77 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 41 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 24 | 0 | 0 | 0 | 0 | 1 | 0 |
| -9.9 | 26 | 0 | 0 | 0 | 5 | 7 | 7 |

**2ADNT (ug/L)**

| Depth | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 13 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 40 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 45 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 40 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 92 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 93 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 68 | 0 | 0 | 0 | 0 | 1 | 0 |
| -9.9 | 12 | 0 | 0 | 0 | 1 | 3 | 6 |

**Figure 5-14.  TNT and 2-ADNT Concentration Data from July 2005. (**Detection Limits are 0.1 µg/L for all Analytes.  Values Below the Detection Limit are Shown as 0**).**

### 5.3.4  Push-pull degradation test

Since RDX concentrations were lower in the groundwater than expected, a push-pull tracer tests was conducted to examine the in situ rate of RDX (and TNT) degradation after approximately 18 months of PRB operation (May 2005).  The push-pull tracer test format was chosen because it eliminates complications associated with sorption (i.e., the extent to which movement into the formation is retarded by [linear] sorption is balanced by the retardation coming back out of the formation).  As a result, all of the tracers should act in a similar manner.

To conduct the test, 10 L of groundwater from up-gradient of the PRB (G8Y) was pumped into a 10-L Tedlar bag, and ~1 mg of RDX and 1 mL of fluorescein dye solution was added to the groundwater.  The spiked groundwater was then injected into a PVC monitoring (G10Y) well installed in the middle of the PRB (screen length ~1 meter).  The spiked groundwater was then followed by 1 L of water that came from G19Y to flush the sampling line.  The system was allowed to sit for 30 minutes and then water was removed from the well at ~1 L/min.  The first liter removed contained water from within the well and was essentially free of any of the tracers.  The next 20 L removed (i.e., samples 1-20) were analyzed for fluorescein, RDX and TNT.  The

measured injection concentration of TNT 71 µg/L and for RDX was 114 µg/L. Figure 5-15 shows normalized concentrations for each of the tracers in the successive samples. (Sample 0 represents the injection solution concentration). Detection limits for these analyses were 0.1 µg/L for TNT and 0.2 µg/L for RDX. As the data indicate, explosives concentrations were reduced to less than 1% of their initial values in ~30 minutes. That corresponds to a minimum of 7 half lives for RDX and 9 half lives for TNT (i.e., half lives of ~4 and ~3 minutes, respectively). Given that the residence time in the PRB is on the order of 3000-5000 minutes, it was expected that reactivity would not limit the lifetime of the PRB.
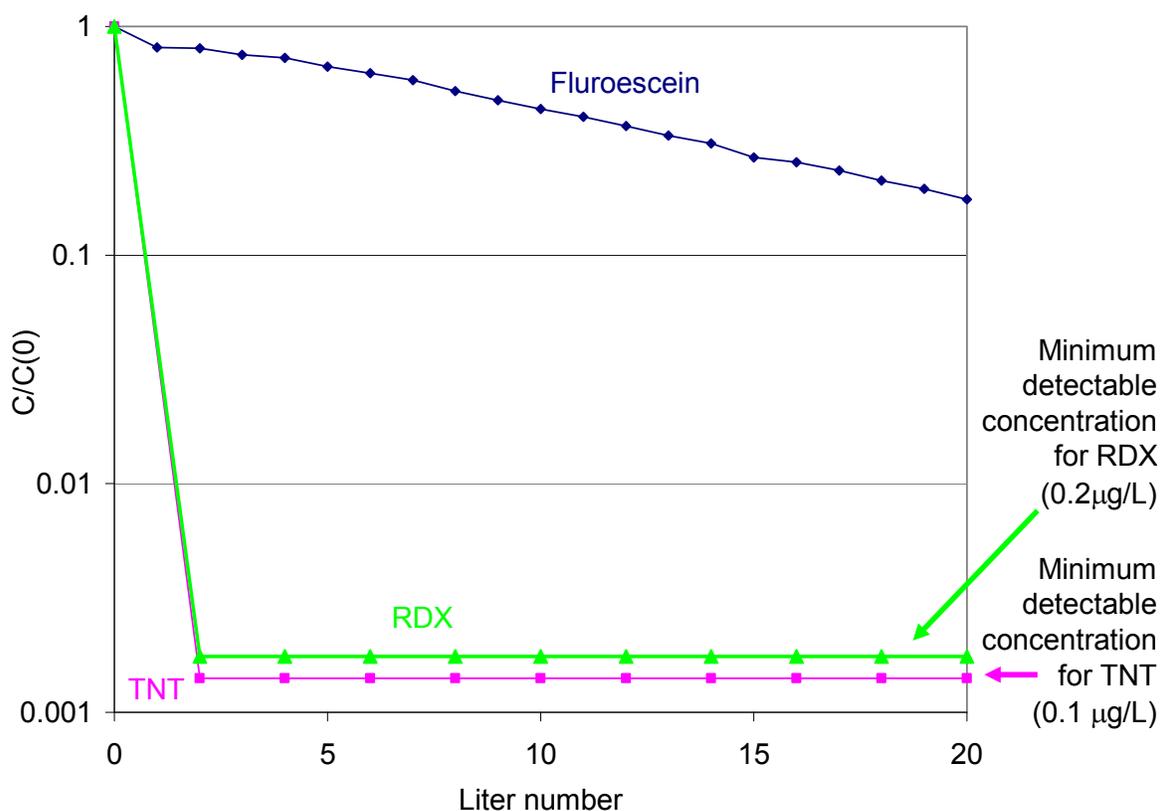


**Figure 5-15.  Tracer recovery Data for the PRB Push-pull Test.**

## 5.4 Geochemical changes and evaluation of longevity

While the performance of the PRB with respect to explosives is quite straightforward, geochemical changes observed in the groundwater tell a much more complicated story and suggest that flow through the PRB may be lower than anticipated. (A complete list of inorganic water chemistry data can be found in Appendix D)

The presence of the zero-valent iron in the subsurface has a significant impact on both the target contaminants and the inorganic geochemistry of the groundwater. Table 5-2 shows typical background groundwater concentration ranges for a number of geochemical parameters. The groundwater at the site was anoxic, fairly reducing, but with a neutral pH. The most noteworthy feature was that the sulfate concentrations were relatively high.

**Table 5-2.  Water Quality Parameters, Range of Values and Analytical Methods.**

| Parameter | Value | Analytical Method |
|---|---|---|
| Sulfate | 180-410 mg/L | Hach colorometric, Ion chromatog. |
| Nitrate | 0-12  mg/L | Hach colorometric, Ion chromatog. |
| pH | 7-7.2 | Electrode |
| Eh | -40 - -130 mV | Electrode |
| DO | 0.0 – 0.2 mg/L | Electrode |
| Alkalinity | 300-800 mg/L | Hach titration |
| Specific Conductance | 600-1200 uS-cm | Electrode |
| Ferrous Iron | 0.0-0.3 mg/L | Hach colorometric |
|  |  |  |
| 2,4,6-trinitrotoluene | 30-200 ug/L | Waters Sep-Pak and GC/MS |
| 2-amino-4,6-dinitrotoluene | 10-50 ug/L | Waters Sep-Pak and GC/MS |
| RDX | 1-2 ug/L | Waters Sep-Pak and GC/MS |

Groundwater geochemistry data from within and down-gradient from the PRB at the CAAP site one year after installation are shown in Figure 5-16.  Ferrous iron concentrations (not shown), which were elevated following installation of the PRB, became very low down-gradient of the PRB, and sulfate concentrations, were significantly reduced.  As has been shown the case at other sites, it is likely that much of the sulfate precipitated as sulfides (e.g., Phillips et al., 2000). Calcium concentrations were reduced from 150-200 mg/L to less than 1 mg/L in the PRB. Carbonate (alkalinity) concentrations were also reduced, probably due to the precipitation of calcite/aragonite ($CaCO_3$), and possibly mackinawite ($FeCO_3$) (Wilkin and Puls, 2003; Blowes and Mayer 1999; Mayer et al., 2001).  The specific conductance of the groundwater decreased as a result of passage through the PRB, due in large part to the loss of calcium, sulfate and carbonate alkalinity.

The vertical cross-section data in Figure 5-16 suggest three possible flow conditions at the PRB; either 1) flow through the bottom half of the PRB is slower than in the upper half as the result of differences in the K of the aquifer at different depths, 2) dissolved-phase concentrations in the deeper samples rebounded as the result of dissolution from aquifer materials down-gradient of the PRB, or 3) the effective K of the PRB was reduced, causing some of the groundwater to divert around the PRB.  Each of these possibilities is discussed below and lead to the conclusion that reduction in effective K of the PRB is the cause of the observed flow patterns.

With regard to the possibility of slower flow at the bottom of the PRB due to differences in aquifer K values, data in Figure 5-17 from three depths 4 meters down-gradient of the PRB (i.e.,

locations G14 and J14 in Figure 5-1) show that sulfate concentrations down-gradient of the PRB initially dropped significantly between the first and second sampling events (either as the result of sulfate reduction or water added during PRB installation). In addition, the measured hydraulic conductivity data (Figure 5-7) suggest higher, rather than lower aquifer K values at the depth of the lower portion of the PRB. These indicate that, at least initially, flow from the PRB to all sampling depths was both fairly rapid and uniform.

| Sulfate (mg/L) | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 264 | 38 | 1 | 0 | 10 | 0 | 1 |
| -6.3 | 264 | 0 | 3 | 1 | 1 | 1 | 0 |
| -6.9 | 206 | 0 | 0 | 5 | 3 | 2 | 1 |
| -7.5 | 206 | 0 | 1 | 0 | 10 | 0 | 52 |
| -8.1 | 308 | 0 | 3 | 77 | 155 | 60 | 130 |
| -8.7 | 308 | 0 | 4 | 22 | 254 | 283 | 346 |
| -9.3 | 409 | 169 | 305 | 325 | 359 | 325 | 351 |
| -9.9 | 403 | 315 | 353 | 386 | 346 | 365 | 356 |

| Ca++ (mg/L) | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 172 | 1 | 1 | 1 | 8 | 55 | 79 |
| -6.3 | 163 | 1 | 1 | 2 | 2 | 18 | 65 |
| -6.9 | 162 | 1 | 1 | 2 | 9 | 59 | 178 |
| -7.5 | 145 | 1 | 1 | 40 | 171 | 152 | 173 |
| -8.1 | 163 | 1 | 1 | 63 | 171 | 185 | 128 |
| -8.7 | 164 | 2 | 1 | 90 | 138 | 133 | 184 |
| -9.3 | 165 | 39 | 172 | 174 | 183 | 168 | 164 |
| -9.9 | 150 | 184 | 176 | 143 | 184 | 125 | 159 |

| Alkalinity (mg/L) | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 310 | 105 | 145 | 135 | 235 | 115 | 135 |
| -6.3 | 285 | 140 | 155 | 105 | 160 | 165 | 100 |
| -6.9 | 320 | 185 | 170 | 170 | 135 | 525 | 360 |
| -7.5 | 295 | 170 | 190 | 135 | 540 | 135 | 435 |
| -8.1 | 305 | 165 | 140 | 175 | 325 | 340 | 225 |
| -8.7 | 315 | 150 | 165 | 325 | 340 | 255 | 365 |
| -9.3 | 355 | 220 | 320 | 365 | 330 | 340 | 380 |
| -9.9 | 310 | 345 | 390 | 290 | 335 | 300 | 355 |

| Cond. (uS/cm) | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 808 | 318 | 360 | ns | 446 | 356 | 434 |
| -6.3 | 851 | 345 | 336 | 260 | 266 | 268 | 270 |
| -6.9 | 851 | 390 | 425 | 346 | 328 | 305 | 321 |
| -7.5 | 871 | 405 | 368 | 332 | 972 | 805 | 813 |
| -8.1 | 882 | 405 | 399 | 528 | 726 | 540 | 723 |
| -8.7 | 927 | 417 | 420 | 901 | 914 | 972 | 1022 |
| -9.3 | 1091 | 758 | 1140 | 1144 | 1157 | 1186 | 1192 |
| -9.9 | 1192 | 1125 | 1161 | 1162 | 1184 | 1161 | 1148 |

**Figure 5-16.  Groundwater Geochemistry Data from the G and J Transects in November 2004. Groundwater Flow Direction is from Left to Right.**
(Areas highlighted in gray represent zones where concentrations are reduced relative to up-gradient concentrations).
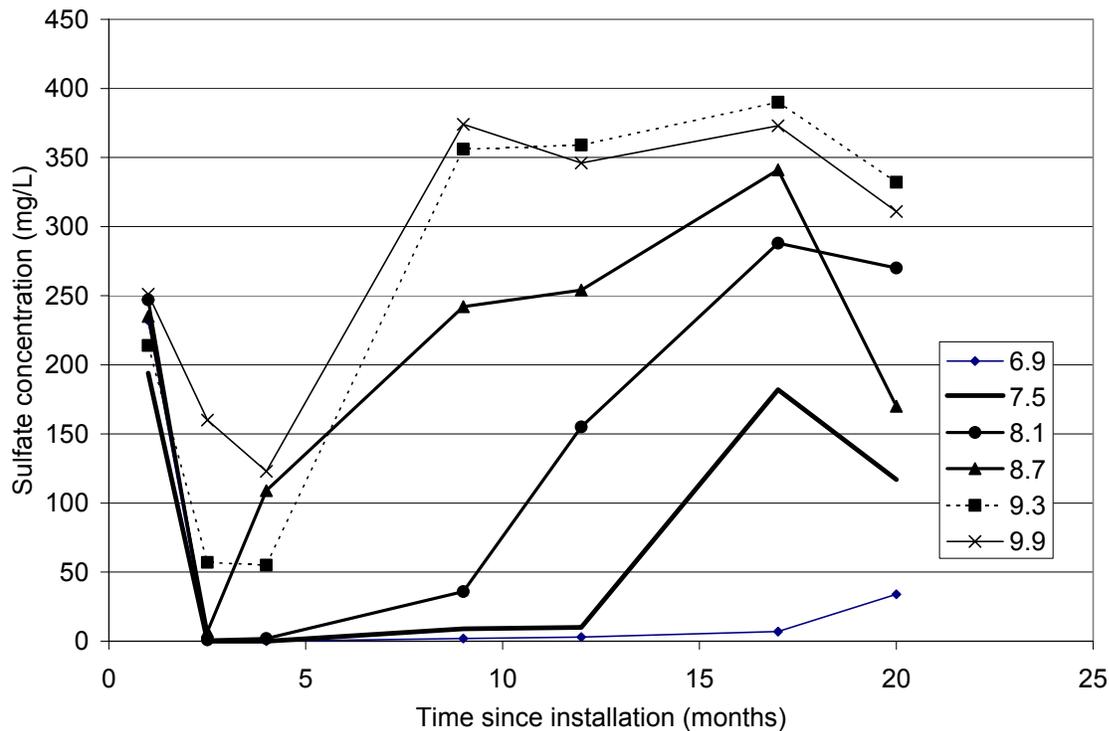
**Figure 5-17. Time Series Sulfate Data from Three Depths at 4 m Down-gradient of the PRB.**

With regard to the possibility of concentration rebound due to dissolution from aquifer materials, the data in Figure 5-17 provide two indications that dissolution from aquifer materials was not the source for rebounding concentrations. First, the fact that low concentrations of sulfate appeared 4 meters down-gradient of the PRB at 2-4 months after PRB installation suggests that there was not a reservoir of sulfate available on the aquifer materials. Second, if there were a source of sulfate in the aquifer, it would have been expected that the rebound would have occurred relatively rapidly, rather than gradually increasing over the course of a year. One possible reason for a gradual increase is that the pH increased from ~7 to ~9 during that year. To examine the effect of pH change on availability of sulfate, core samples collected prior to PRB installation were sequentially extracted using pH=9 de-ionized water.

To accomplish this, 20-gram aquifer samples were taken from 0.6-meter long core sections collected from 5.5 to 10.7 m below ground surface. 20 mL of acidified water were added to each sample in a 40-mL vial and the samples were continuously mixed for ~96 hours. The water was then separated from the core samples by centrifugation followed by filtration through a 0.45 μm filter. Sulfate and calcium were then analyzed in the extracted water. Following the initial

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extraction, samples were again suspended in 20 mL of acidified water and extracted a second time using the same procedure as the first extraction, followed by sulfate and calcium analyses.

The data in Table 5-3 indicate that extracted concentrations of both calcium and sulfate are too low to produce the groundwater concentrations observed at depths corresponding to the lower portion of the PRB[2].

**Table 5-3. Sulfate and Calcium in Core Extracts from CH10.**

| Depth (fgs, m) | Sulfate in first extraction (mg/L) | Sulfate in second extraction (mg/L*) | Calcium in first extraction (mg/L) | Calcium in second extraction (mg/L*) |
|---|---|---|---|---|
| 5.5 - 5.8 | 15 | 1 | 0.1 | 0.3 |
| 6.1 - 6.4 | 9 | 0 | 2.3 | -1.2 |
| 6.6 - 6.7 | 13 | -1 | 0.4 | 0.2 |
| 7.3 - 7.6 | 50 | 1 | 4 | -1.8 |
| 7.6 - 7.9 | 47 | 4 | 1.5 | -0.3 |
| 7.9 - 8.2 | 73 | 17 | 3.9 | -1.4 |
| 8.5 - 8.8 | 70 | 11 | 1.8 | -0.7 |
| 8.8 - 9.1 | 43 | 6 | 0.1 | 0.2 |
| 9.8 - 10.1 | 51 | 8 | 0.5 | 0.1 |
| 10.4 - 10.7 | 38 | 4 | 0.1 | 0.1 |
| *calculated after subtracting dissolved sulfate or calcium remaining in the sample after removing part of the water from the first extract. | | | | |

The preceding discussions point to the third possibility (changes in K values within the PRB) as the reason for the flow patterns observed in Figure 5-16. To assess this in greater detail, a numerical groundwater flow and transport model was developed, and is discussed in the next section.

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[2] The ratio of water to soil for the extraction is ~4 times the ratio in the aquifer. Thus, the concentrations from the first extraction can be thought of as approximating the average concentration from the first four pore volume. Similarly, the second extract would represent the average concentration of the second four pore volumes. Based on the regional groundwater flow, and the bromide tracer test discussed below, the average groundwater velocity is on the order of 0.2 m/d. Thus, over a 20-month period one would have expected perhaps 20 pore volumes to have flowed through the 6 meters down-gradient of the PRB. Based on the concentrations of sulfate and calcium observed in the extracts, we conclude that the aquifer materials could not represent a source for the observed calcium and sulfate concentrations down-gradient of the PRB.

### 5.4.1   Numerical modeling of groundwater flow

A simple 2-dimensional vertical-cross-section finite-difference model for through and beneath the PRB was developed using the hydraulic conductivity data measured at the site (Figure 5-7). Field-measured K values for the PRB material were determined using slug tests from the center of the PRB, and the values compared well with the laboratory-determined K value (~0.02 cm/s). The initial and boundary conditions for the numerical model are shown in Figure 5-18.  The model consisted of 12 columns and 21 layers, and the model domain was 12 m long by 6 m deep. The up and down-gradient boundaries of the model domain were "constant head", and the top and bottom boundaries were "no flow".  To simulate flow due to plugging, the hydraulic conductivity of the PRB was systematically reduced from a starting value of ~0.02 cm/s (i.e., the laboratory measured value for the sand/iron mix used in the PRB) to 0.0004 cm/s.)
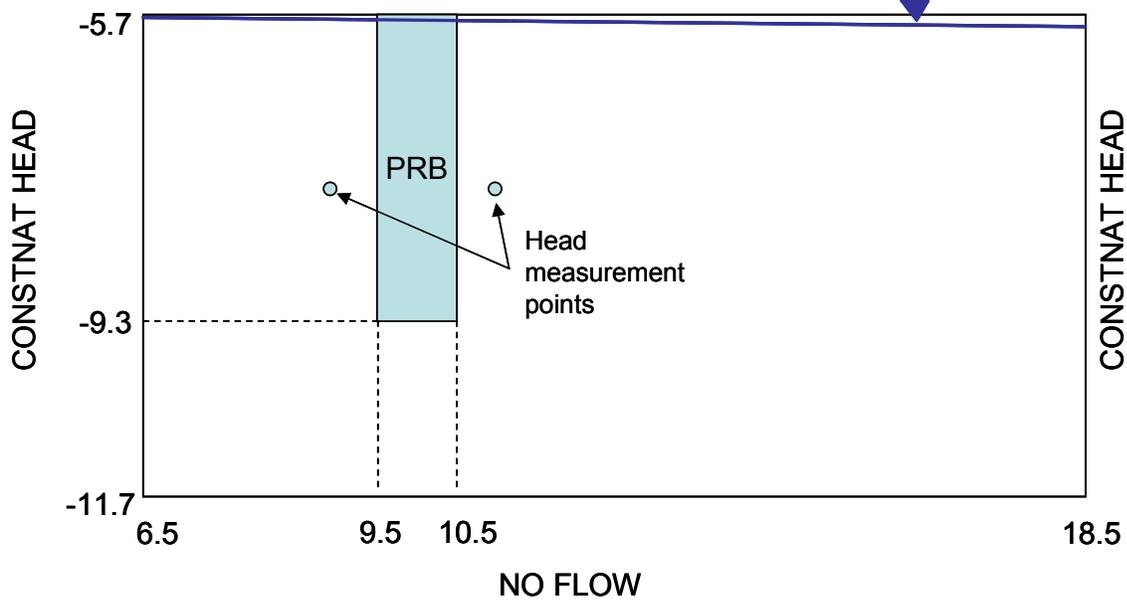


**Figure 5-18.  Boundary Conditions for the Numerical Model.**
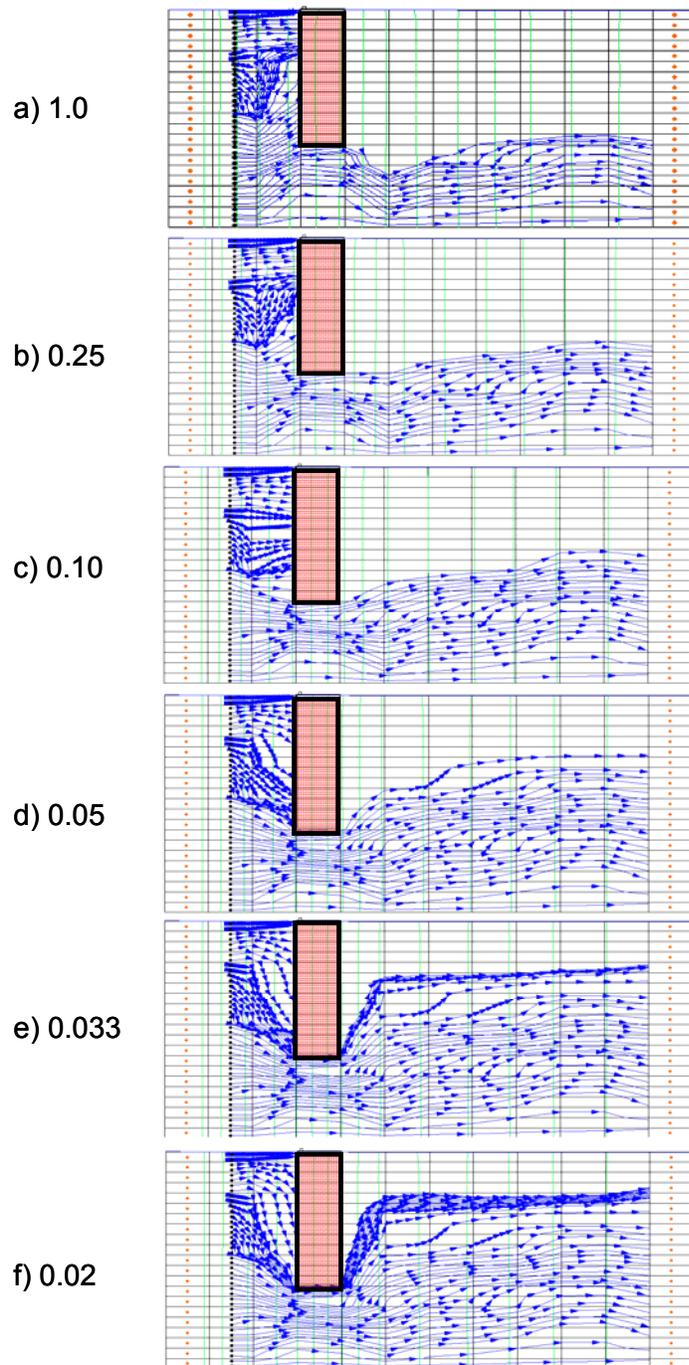
**Figure 5-19. Modeled Flow Pathways for Different PRB Hydraulic Conductivities. Numbers at Left of Figure are Ratios of Modeled to Initial Hydraulic Conductivity.**

Flow pathlines are shown in Figure 5-19 for 6 different PRB hydraulic conductivity values (note: the model assumes a uniformly-reduced K within the PRB). To make the figure more-directly

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comparable to the observed groundwater geochemical patterns in Figure 5-16, all particles entering the model PRB were removed from the simulation. In this manner the particles represent parcels of groundwater that have not passed through the PRB. The model suggests that, to reproduce the dissolved constituent patterns observed in Figure 5-20, the average K value of the PRB needed to be reduced from the original value by a factor of 20. It is worth noting that, even with a 20-fold decrease in K, modeled estimates of total head change between locations 0.5 meters up- and down-gradient of the PRB (Figure 5-19) were less than 3 millimeters, which would not be easily measured in the field.

The numerical model can also be used to estimate changes in the flux of water through the PRB. In Figure 5-20 the solid line represents the normalized flux through the up-gradient face of the PRB as a function of normalized hydraulic conductivity of the PRB. As the figure indicates, small K reductions do not result in a significant reduction in flux, in large part because the loss of K is offset by an increase in hydraulic gradient. However, if K is reduced by a factor of 5 or more, flow around the PRB becomes an important path and the flux through the PRB decreases rapidly. In the 20-fold *K*-reduction case (Figure 5-20d), the flux through the upgradient face drops to approximately 20% of the initial value.
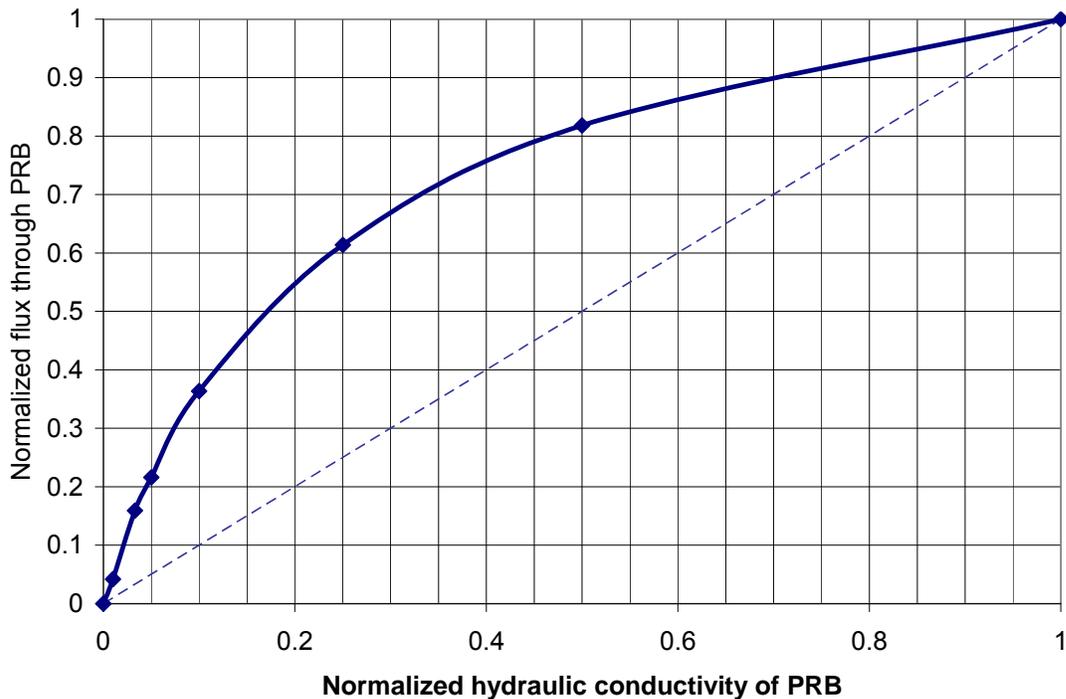


**Figure 5-20. Modeled Flux Through the PRB as a Function of Hydraulic Conductivity.**

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### 5.4.2  Characterization of Core Samples

In order to understand how changes in PRB hydraulic conductivity might have occurred, angled core samples (ca $30^o$ from vertical) were collected through the PRB sampling in a down-gradient to up-gradient direction using a Geoprobe direct-push system with 3 m long, 5 cm diameter aluminum core barrels.  Prior to core sample collection the overlying soils were removed down to near the water table.  Once the cores were retrieved from the subsurface, the intact cores were frozen with dry ice and transported to our laboratory.  At the lab the aluminum core barrels were opened by splitting them along their lengths.

### 5.4.2.1 Core Sample Analytical Methods

**Sulfur Analyses**

Total sulfur concentrations for core sample materials were determined by first reducing the pH of sample/water slurries to basic conditions and then oxidizing all of the sulfur to sulfate by sequential digestion of the slurries using hydrogen peroxide.  The sulfate concentration was then determined using ion chromatography.

Acid-volatile sulfides (AVS) were determined using a modification of the approach presented by Allen et al., (1993).  One gram of core sample was placed in a 40 mL septum-capped vial.  The vial was connected to a second 40-mL vial via a 1/16-inch diameter stainless steel tube, which went to the bottom of the second vial.  A syringe needle through the septum of the second vial to provide a vent.  The second vial contained 10 mL of 0.5 M NaOH.  To collect the AVS, 10 mL of 1 M HCl were added to the first vial, resulting in the volatilization of all AVS, as well as carbonates.  The AVS were then trapped in the NaOH and analyzed by the Hach colorometric sulfide method.

**X-ray Photoelectron Spectroscopy**

X-ray photoelectron spectroscopy (XPS) analysis was performed at the Pacific Northwest National Lab. Each of the four samples were mounted and analyzed 3 or more times.  A small portion of each sample was placed into separate sealed sample vials inside a recirculated N2 purged glove box at <1 ppm O2 and $H_2O$.  The subdivided samples were moved to a N2 purged glove bag (~20-30 ppm O2 for < 5 minutes) attached to the XPS system sample introduction port for mounting and introduction into the UHV chamber.  Samples were secured to the sample holder using a thin Mo mask. XPS measurements were performed using a Physical Electronics

Quantum 2000 Scanning ESCA Microprobe. This system uses a focused monochromatic Al Kα x-rays (1486.7 eV) source and a spherical section analyzer. The instrument has a 16 element multichannel detector. The X-ray beam used was a 99 W, 100 mm diameter beam that was rastered over a 1.4 mm by 0.2 mm rectangle on the sample. The X-ray beam was incident normal to the sample and the photoelectron detector was at 45° off-normal. Wide scan data was collected using a pass energy of 117.4 eV. For the Ag3d5/2 line, these conditions produce FWHM of better than 1.6 eV. Narrow scan data was collected using a pass energy of 46.95 eV. For the Ag3d5/2 line, these conditions produced FWHM of better than 0.98 eV. The binding energy (BE) scale was calibrated using the Cu2p3/2 feature at $932.62 \pm 0.05$ eV and Au 4f at $83.96 \pm 0.05$ eV for known standards.

**Batch Reaction Tests**

Batch experiments were conducted using 60 mL Amber vial with 1.0 g/L core material was added to an initial concentration of 20 mg/L TNT/RDX in deoxygenated site water. TNT, RDX, and TAT were analyzed using HPLC at pH = 7.0 in 20 mM phosphate buffer and methanol at a rotation of 40:60. The flowrate was 1.2 mL/min and the UV-vis was set at 230 nm. The HPLC column used was a Capcell C18 purchased from Shiseido..

**5.4.2.2 Core Sample Results**

**Time Series Sulfate Concentrations in Groundwater**

Time-series changes in groundwater sulfate concentrations both up-gradient and within the PRB are shown in (Figure 5-18a). While the up-gradient values remain fairly constant, the PRB values drops substantially over ~18 months. This behavior is significantly different than for carbonate alkalinity (Figure 5-18b). Changes in sulfate concentrations are likely due to increased sulfate reduction over time and may also be due to a decrease in flow through the PRB.

Figure 5-21 shows dissolved sulfate and sulfide concentrations in a transect along the direction of groundwater flow. These data show that essentially all of both the sulfate and any sulfide produced are removed near the PRB

Each soil core from the CAAP site was divided into 5 sections based on visual observation:

      (1)    upgradient, unimpacted
      (2)    upgradient, impacted
      (3)    PRB
      (4)    Downgradient, impacted
      (5)    Downgradient, unimpacted.

| Sulfate (mg/L) | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 80 | 3 | 3 | 3 | 4 | 1 | 1 |
| -6.3 | 96 | 2 | 4 | 1 | 15 | 5 | 11 |
| -6.9 | 146 | 5 | 1 | 33 | 34 | 29 | 21 |
| -7.5 | 161 | 2 | 1 | 28 | 117 | 79 | 139 |
| -8.1 | 129 | 1 | 3 | 1 | 270 | 164 | 158 |
| -8.7 | 199 | 4 | 20 | 172 | 170 | 181 | 180 |
| -9.3 | 260 | 4 | 213 | 262 | 332 | 376 | 355 |
| -9.9 | 343 | 285 | 338 | 329 | 311 | 335 | 352 |

Elevation (fgs)

| Sulfide (mg/L) | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 0 | 0.158 | 0 | 0 | 0 | 0 |
| -6.3 | 0 | 0 | 0.199 | 0 | 0 | 0 | 0 |
| -6.9 | 0 | 0 | 0.02 | 0.037 | 0 | 0.042 | 0 |
| -7.5 | 0 | 0 | 0 | 0.028 | 0 | 0 | 0.052 |
| -8.1 | 0 | 0 | 0 | 0 | 0.085 | 0 | 0 |
| -8.7 | 0 | 0 | 0.041 | 0.023 | 0 | 0 | 0.008 |
| -9.3 | 0 | 0 | 0.066 | 0.018 | 0.043 | 0 | 0.36 |
| -9.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Elevation (fgs)

**Figure 5-21.  Groundwater Sulfate and Sulfide Concentraitons from July 2005.**

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The impacted portions were identified by a distinctly darker color (Figure 5-22). Collection efficiency of the PRB material was generally low because it was less densely packed than the native material. However, by sampling from the down-gradient towards the up-gradient face, we were able to capture the up-gradient interface in four cores. All of the cores were visually similar to Figure 5-22, and one was selected for detailed chemical analyses by x-ray photoelectron spectroscopy (XPS), total sulfur analysis by hydrogen peroxide digestion and acid-volatile sulfides analysis.
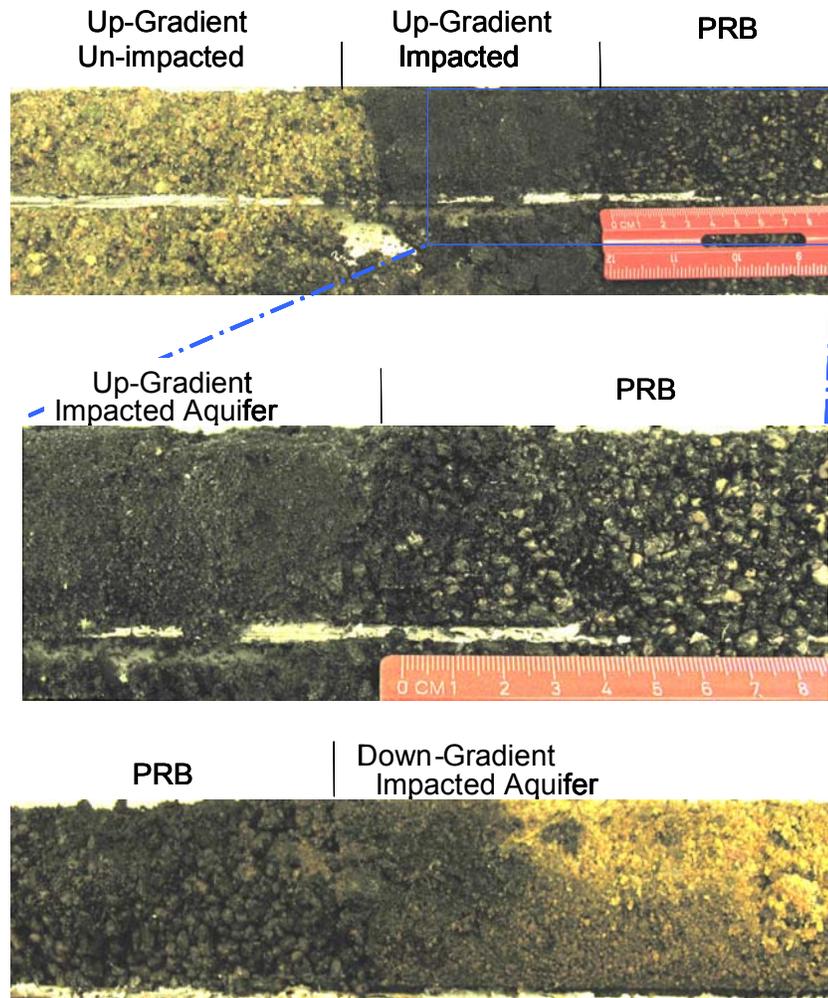


**Figure 5-22. Photographs of the Upgradient Sand/PRB Interface from CAAP Core 4.**

Total sulfur analyses of the core sections indicate that most of the precipitated sulfur occurs in the up-gradient impacted zone (Table 5-4). This result is supported by the XPS analyses (Table 5-6, discussed below). The distribution of sulfide is further supported by the AVS analyses (Table 5-4). However, the total sulfur analyses show about a factor of 5 greater sulfide concentration than the AVS analyses. Two additional cores showed similar results.

**Table 5-4. Sulfur Analyses of CAAP Core 4.**

| Analysis \ Sample # | Up-gradient, un-impacted 4-1 | Up-gradient, impacted 4-2 | PRB 4-3 | Down-gradient, impacted 4-4 | Down-gradient, un-impacted 4-5 |
|---|---|---|---|---|---|
| Total Sulfur | 39 | 554 | 148 | 0 | 0 |
| Acid-volatile Sulfide | 0.1 | 35 | 22 | 0.0 | 0.1 |
| Iron by XPS (atom %) | 3.9 | 27.4 | 34.0 | | |
| Sulfur by XPS (atom %) | 0.00 | 0.34 | 0.24 | | |

Based on the sulfide concentrations on the aquifer and PRB materials, and the difference in groundwater sulfate concentrations up- and down-gradient of the PRB, and using an approach similar to Morrison (2003), it is possible to estimate the flux through the PRB using an equation of the form:

$$q_w = \frac{M * \rho * L}{t * \Delta C}$$ [5-1]

where:
$q_w$=specific water flux (l/t)
$M$ = mass per mass of core material (m/m)
$\rho$ = density of the core material (m/l$^3$)
$L$ = length of the deposition zone along the flow path (l)
$t$ = duration over which precipitation has occurred (t)
$\Delta C$= change in concentration up- and down-gradient of the deposition interval (m/l$^3$)

Based on Darcy's Law calculation of regional groundwater flow, the specific flux into the PRB was expected to be ~0.07m/d (groundwater velocity of 0.2m/d assuming porosity =0.35). Table III presents a water flux calculation using equation 5-1 and based on measured concentration changes in groundwater and on core materials. Based on the observed ~300 mg/L change in

sulfate concentration (Table 5-4) and the assumption that there is a 10-cm thick precipitation zone up-gradient and a 50-cm thick precipitation zone in the PRB, the calculated flux would be 0.33 cm/d (Table 5-5). If the porosity is 0.35, this would correspond to an average groundwater velocity over the lifetime of the PRB of ~1 cm/d, which is only 5% of the expected value[3]. This result is consistent with the groundwater tracer data and numerical modeling presented in (Johnson et al. 2007a).

**Table 5-5. Estimated Flux into the PRB Based on Darcy's Law and Measured Sulfide Concentrations.**

| | |
|---|---|
| 300 | mg/L sulfate flowing into the PRB |
| 96 | mg/L sulfur flowing into the PRB |
| 0.096 | mg/cm^3 sulfur flowing into the PRB |
| | |
| 500 | mg/kg S on up-gradient core |
| 0.5 | mg/g S on up-gradient core |
| 0.8 | mg/mL of aquifer volume (bulk density 1.6 g/cm3) |
| 8 | mg/cm^ in 10-cm long interval of the upgradient zone |
| | |
| 125 | mg/kg on PRB materials |
| 0.125 | mg/g on PRB materials |
| 0.225 | mg/mL of wall volume (bulk density 1.8 g/cm^3) |
| 11.25 | mg/cm^ in 50-cm long interval of the PRB zone |
| | |
| | |
| 19.25 | mg/cm^2 along the flow path |
| | |
| 200.52 | mass along the flow path divided by influent concentration (cm^3/cm^2) |
| | |
| 0.33 | specific flux (cm^3/cm^2/day) |
| | |
| 0.95 | cm/d velocity through the wall (porosity = 0.35) |

XPS analysis of the core samples also showed significant increases in the surficial concentrations of iron precipitates in the up-gradient impacted zone, as well in the PRB. The source of that iron could be the up-gradient groundwater, however, background $Fe^{2+}$ concentrations are generally quite low (<0.005 mg/L). The PRB represents a potentially-more-likely source of the iron. Similarly, groundwater data from the CAAP site indicate that $H_2$ concentrations reach 35% of saturation values (i.e., 0.35 mM) within the PRB, but are very low up-gradient of the PRB. As discussed above, sulfate reduction is widely believed to be microbially mediated, and to involve molecular hydrogen in the reduction process. Thus, it is also possible that the PRB is the source

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[3] The estimated regional groundwater velocity of 20 cm/day is based on Darcy's Law calculations using porosity, hydraulic conductivity and hydraulic gradient data collected as part of this project as well as the length and time of travel of observed groundwater plumes at the site.

of hydrogen for sulfate reduction.  However, for iron and hydrogen to impact aquifer materials up-gradient of the PRB, they would have to "back-diffuse" against the groundwater flux entering the PRB.  To examine the behavior of iron and hydrogen in this context, a simple 1-D advection-diffusion model was developed, and is discussed below.

It has not been possible to experimentally confirm the sequence of events that led to permeability reduction that allowed iron precipitation and sulfate reduction up-gradient of the PRB.  Almost certainly, the guar played a role in that process by providing the initial K reduction and/or the carbon source for microbial growth.  We have conducted some qualitative experiments with guar to examine the potential for plugging of the up-gradient aquifer material by the guar.  We believe that two factors could have contributed to more-than-expected movement of the guar into the native materials.  First, conditions during emplacement of the guar were quite cold, and while the viscosity specifications of the guar were met, subsurface temperature were ~15$^{o}$C warmer than the ambient temperature and this likely led to a two-fold reduction in the viscosity of the guar.  Second, a large hydraulic head difference (~2-3m) was present at the trench interface.  Given its likely-reduced viscosity, it is possible that guar moved a significant distance into the native materials.  Since the hydraulic conductivity of the native materials varies spatially by more than a factor of 20 (<1 to >20 m/d), it is also likely that penetration of the guar would have varied correspondingly and preferentially entered the higher-K zones.  Calculations based on a guar viscosity of 100 centipoise (i.e., approximately the field-determined value for the guar) suggest that 12 hours of contact between the guar and the native materials, with a hydraulic head difference across the guar of 200 cm, could have resulted in penetration distances of 25 cm or more.  This could significantly complicate flow into the PRB, and/or provide a significant up-gradient carbon source for microbiological activity.

**XPS Analysis**

Table 5-6 shows the XPS data for core 4 and the dry Peerless iron/sand mixture. XPS showed that the surfaces of all the samples consisted mainly of O, Fe, Si, C, and Al with small amounts of N, Na, Mg, P, K, and Ca. Note that the Si concentrations decrease as you go from the up-gradient un-impacted zone (16.6%) into the PRB (3.7%). Table 5-6 also shows that the S concentration on the surface of the particles was below detection limits in the Peerless iron/sand mixture and in the up-gradient un-impacted samples. Larger concentrations were observed on the surface of the up-gradient impacted and PRB particles. In particlular, the XPS data gave a strong signal for pyrite ($FeS_2$) in the up-gradient impacted sample.

The Fe/O ratios for the various samples are of interest because this ratio typically reflects the amount of iron oxide on the surface of the particles. It appears that as you move into the PRB, the Fe concentration increases on the surface. Note that Fe/O ratio for the up-gradient impacted and PRB particles is higher than the dry Peerless/sand mixture. This is probably due to the fact

that when the iron particles are exposed to solution, active corrosion processes start in which dissolution/precipitation of the Fe particles occurs.. The fact that there is a higher Fe/O ration in the up-gradient impacted samples may indicate that $Fe^{2+}$ or $Fe^{3+}$ is back diffusing into this region.

**Table 5-6. Elemental Atomic Percentages of 3 Sub-samples of Core 4 and of the Peerless Iron/sand Mixture Obtained by XPS.**

| Element (Atomic %) | Peerless Iron/Sand Blank | Up-Gradient Un-Impacted | Up-Gradient Impacted | PRB |
|---|---|---|---|---|
| C | 7.6 | 7 | 6.1 | 6.5 |
| N | 0.22 | 0.64 | 0.75 | 0.69 |
| O | 57.4 | 63 | 54.6 | 51.3 |
| Na | 0.5 | 0.6 | 0.6 | 0.2 |
| Mg | 1 | 1.5 | 0.8 | 1 |
| Al | 3.4 | 4.6 | 1.7 | 0.8 |
| Si | 10.9 | 16.6 | 6.6 | 3.7 |
| P | 0.5 | 0.3 | 0.3 | 0.8 |
| S | 0 | 0 | 0.34[*] | 0.24 |
| K | 0.6 | 0.4 | 0.3 | 0.1 |
| Ca | 0.9 | 1.5 | 0.6 | 0.6 |
| Fe | 17.9 | 3.9 | 27.4 | 34 |
| Fe/O | 0.311 | 0.062 | 0.502 | 0.663 |

## TNT and RDX Degradation Kinetics

One of the most prescient questions regarding the use of PRBs concerns how long the PRB would continue to function properly. There are a few ways in which a PRB can fail; (i) the PRB becomes plugged with oxides, biofilms, or other groundwater constituents in which case the groundwater flow goes around the PRB, and (ii) the iron particles become passivated and the

reactivity of the particles decreases. Johnson et al., (2007a) showed that flow through the CAAP PRB may be reduced due to plugging. We show here, that the reactivity of the particles in the PRB are still reactive and that particles in the up-gradient impacted zone are also reactive toward TNT and RDX.

Table 5-7 shows the results for 3 cores and their sub-samples compared to the dry Peerless iron/sand mixture. As expected, the samples from the up-gradient un-impacted zone showed no reactivity toward TNT or RDX. With core 3 and 5, the up-gradient impacted samples showed reduction of TNT and RDX. The up-gradient impacted sample from core 4 was ambiguous, showing slow if any reduction of TNT/RDX. All of the samples from inside the PRB demonstrated reduction of TNT and RDX. All of the rates of the core samples are approximately an order of magnitude slower than the dry Peerless iron/sand mixture, probably due to the formation of iron oxide films. The rates observed are still within the range that will be effective for removing explosives from the groundwater. The reason that an observed rate constant value is missing for the PRB sample of core 5 is because the data is not first order and difficult to fit, although after 2 hours, all of the TNT was degraded.

**Table 5-7. Rate Constants for TNT and RDX for 3 Core Samples and a Peerless Iron/sand Mixture** (T7)**.**

| TNT/RDX $K_{obs}$ (min$^{-1}$) | Up-Gradient Un-Impacted | Up-Gradient Impacted | PRB |
|---|---|---|---|
| T7 (sample collected during installation of the PRB) | | | 0.1240/0.0032 |
| Core 3 | No degradation | 0.0121/0.0061 | 0.0139/0.0058 |
| Core 4 | No degradation | No degradation | 0.0140/0.0094 |
| Core 5 | No degradation | 0.0230/0.0100 | * |

* $K_{obs}$ was not able to be determined due to lack of "first orderness" of the data. TNT degraded to below detection limits in 2 hours.

# 6 COST ASSESSMENT

This section discusses cost considerations involved in the application of PRBs to remediate explosives in groundwater. The cost factors that provide the driver for application of PRBs are primarily related to annual operation and maintenance (O&M) costs. For example, at CAAP the current O&M costs for pumping and treating (P&T) groundwater are approximately $1.2M per year (U.S. EPA, 1994). This cost comes in addition to an initial capital equipment cost that is quite high (~$9M). A detailed discussion of the relative costs of P&T and ZVI PRBs can be found in the Cost and Performance report for this project.

## 6.1 Summary of Treatment Costs for the Demonstration

Groundwater treatment and monitoring costs incurred during the CAAP demonstraton are shown in Table 5.1. Only costs associated with the treatment of groundwater are included. Costs associated with validation of the technology are not included. The cost of purchasing the iron ($17,600) and the construction cost ($121,000) were based on actual subcontractor invoices. The other costs are best available estimates.

**Table 6-1. Summary of Treatment Costs.**

| Item | Sub-Total ($) | Total Cost ($) |
|---|---|---|
| Pre-installation | | |
|     Site Characterization | $100,000 | |
|     Bench-scale tests | $50,000 | |
|     Engineering Design | $45,000 | |
| Materials | $17,600 | |
|     Iron | | |
| Barrier Construction | $121,000 | |
|     Site preparation and barrier emplacement | | |
| Monitoring Network | $30,000 | |
| Disposal of trench spoils | $0 | |
| *Total Barrier Construction Costs* | | $363,300 |
| Maintenance costs (20 months) | $0 | |
| Groundwater Monitoring | $210,000 | |
| PRB Core Collection and Analysis | $30,000 | |
| *Total Operation and Maintenance Costs* | | $240,000 |
| *Total Demonstration Cost* | | $603,600 |

As with most ZIV PRBs, a primary advantage of this approach is that there are few operation and maintenance costs associated with it.  The approach also means that groundwater monitoring can occur on a timeframe that is consistent with most regulatory requirements (e.g., quarterly, annually) rather than on a more-frequent basis if system shutdowns were likely.

## 6.2 Summary of validation costs for the demonstration

In addition to the costs described in section 5.1, there were a number of additional costs that fall in the area of validation, rather than demonstration.  (We believe this is the case because they do not directly involve the project performance criteria.)  These activities were deemed necessary in order to meet peer-reviewed science standards.

Table 6-2.  Summary of Validation Costs for the Demonstration.

| Item | Sub-Total ($) | Total Cost ($) |
|---|---|---|
| Hydraulic conductivity characterization | $60,000 | |
| In situ reactivity testing | $30,000 | |
| Other validation costs | $60,000 | |
| Microbiological characterization | $15,000 | |
| *Total validation costs* | | $165,000 |

## 6.3 Scale-up recommendations

### 6.3.1   Options for Design of Full-scale Barriers for Explosives

Zero-valent iron is extremely effective at degrading explosives in groundwater.  In that context, the design of the PRB was more than required to meet the needs of the site.  Alternate installation approaches (e.g., continuous trenching) could be more cost effective.  Mobilization costs for a continuous trencher were too high for this demonstration, but might be appropriate for full-scale implementation

Construction of the PRB with a lower iron content could also have been appropriate, given the reactivity of the explosives to the iron.  However, the cost of the iron was relatively small and there may be installation issues that would argue against this approach.

Finally, in the context of this particular site, groundwater chemistry was almost naturally-reducing enough to degrade the contaminants.  It is likely that, in this particular context, other approaches (e.g., edible oils) could also have been effective at a lower cost.

# 7  IMPLEMENTATION ISSUES

## 7.1 Cost Observations

The costs associated with this ZVI PRB demonstration are consistent with other ZVI PRB sites. The calculated installation cost per square foot was ~$180. Monitoring costs were considerably higher than would be the case at a full-scale installation because of the detailed multi-level samplers installed at the demonstration site.

## 7.2 Performance Observations

As with previous PRB projects, it proved difficult to determine the actual flow through the PRB with certainty. A variety of tools were utilized, including mass balance analysis, detailed hydraulic conductivity determinations, numerical modeling geochemical changes and tracer tests. All of these presented a consistent picture that flow through the PRB was less than expected based on the regional hydraulic gradient and hydraulic conductivity. It is our conclusion that reduced flow was likely due to the guar used during PRB emplacement. This could have resulted from the movement of guar into the formation prior to and during emplacement, or to microbiological changes resulting from an influx of carbon from the guar.

## 7.3 Regulatory Issues

Regulatory issues did not pose any problems for this demonstration. However, our ability to use direct-push wells was contingent on the fact that we were located on a federal facility, and thus did not have to comply with current state regulations about the construction of wells. State of Nebraska regulators were very helpful in this context, however, this may not be the case in other states where current regulations do not reflect changing understanding of the role of direct-push wells.

## 7.4 Research Needs

The two primary research needs that were evidenced in this project relate to: 1) measurement of flux through PRB; and 2) assessment of the role of guar in limiting flow through the PRB. Neither of these is specific to the treatment of explosives, and both have been previously identified. Nevertheless, they both remain important issues in the context of assessing field performance of PRBs.

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# 9 POINTS OF CONTACT

A summary of contact information for all personnel associated with this demonstration project is presented in Table 8-1.

**Table 9-1 Project Team Points of Contact.**

| Point of Contact | Organization | Phone | email | Role |
|---|---|---|---|---|
| Rick Johnson | OHSU | 503 7481193 | rjohnson@ebs.ogi.edu | PI Project Manager |
| Paul Tratnyek | OHSU | | Tratnyek@ebs.ogi.edu | Co-PI |
| Tom Krug | GeoSyntec | | tkrug@geosyntec.com | GeoSyntec Field Study Leader |

Appendix A.  Photos showing PRB installation
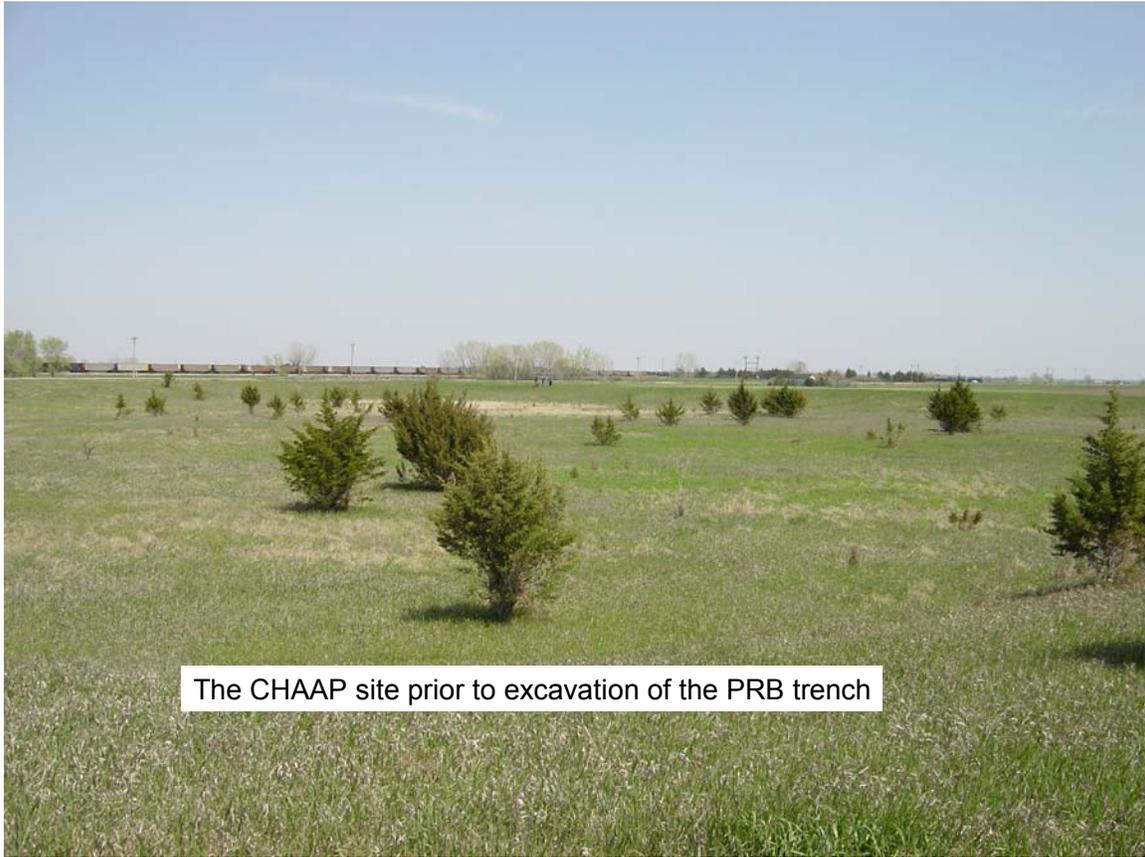


The CHAAP site prior to excavation of the PRB trench



Initial removal of the overburden

Removal of the overburden



Guar Storage Tank

Guar Mixing Plant

Water Truck

Guar mixing plant and testing the viscosity of the guar


Initial excavation of the trench and filling of the trench with guar.

Excavation of the trench


Excavation of the trench

60% completion of the excavation



A portion of the 32 bags of ZVI used in the barrier

Loading the ZVI into the cement trucks and mixing with the sand



Loading the cement trucks with ZVI

Loading the cement trucks with ZVI


Determining the iron content of the sand/ZVI mix using magnetic separation

Transfer of the ZVI/sand mixture from the cement trucks to the trench


Transfer of the ZVI/sand mixture from the cement trucks to the trench

Transfer of the ZVI/sand mixture from the cement trucks to the trench
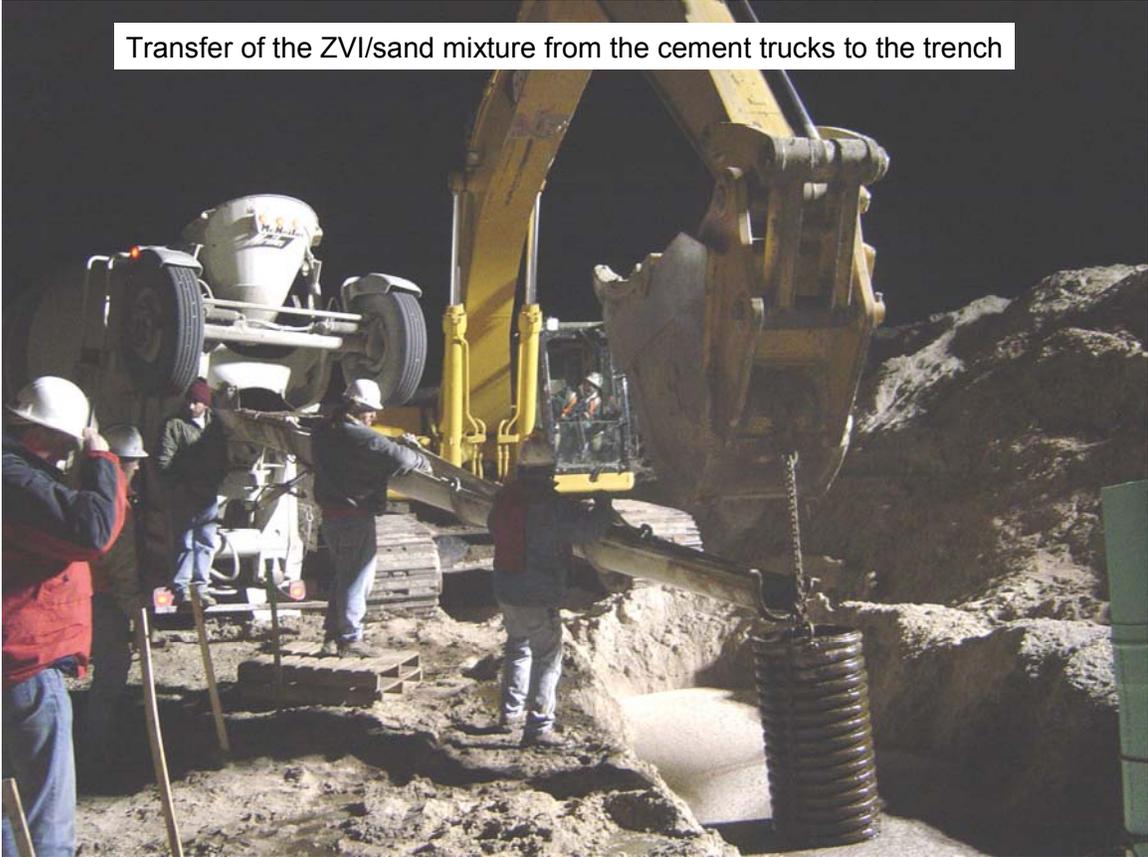

Removal of the guar following emplacement of the iron

Six inch diameter development wells


Preparing the geotextile used to cap the PRB

Geotextile placed in the top of the trench prior to clay addition



Backfilling above the PRB.  The white pipes are 3-inch access tubes for coring

Backfilling above the PRB.  The white pipes are 3-inch access tubes for coring
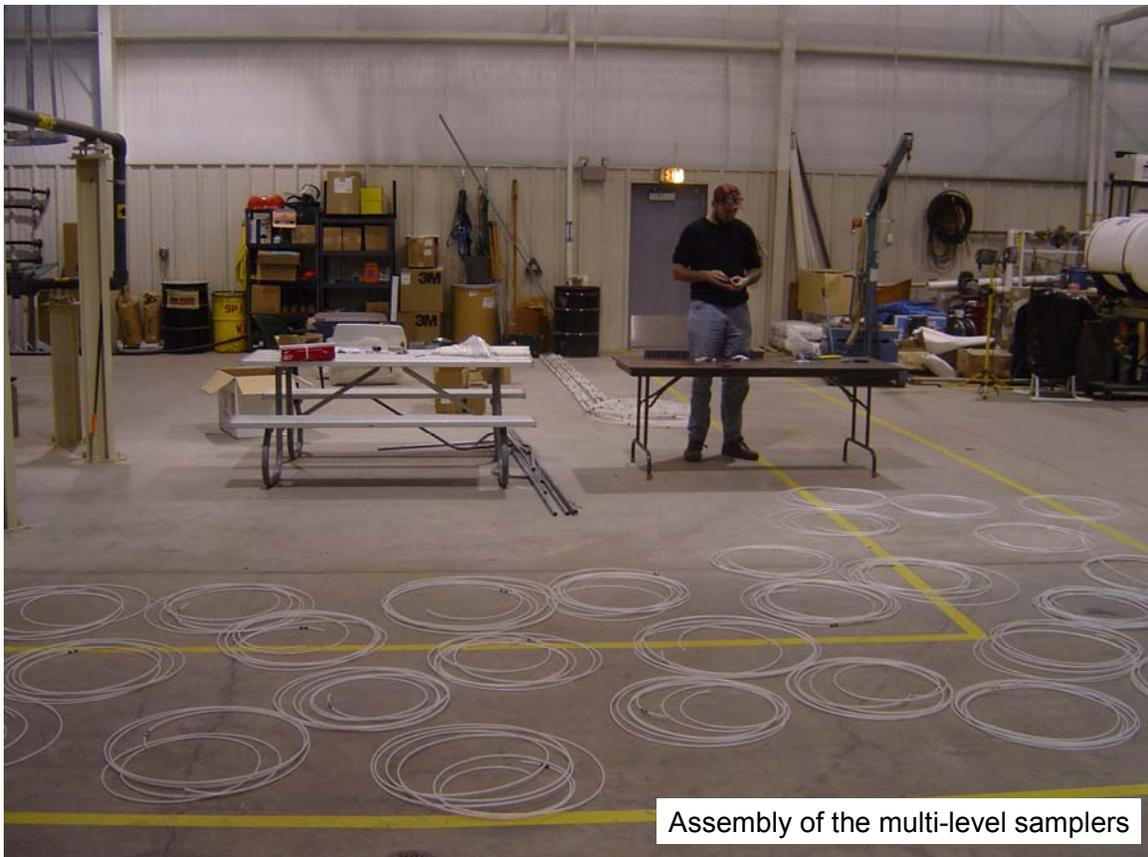

Assembly of the multi-level samplers
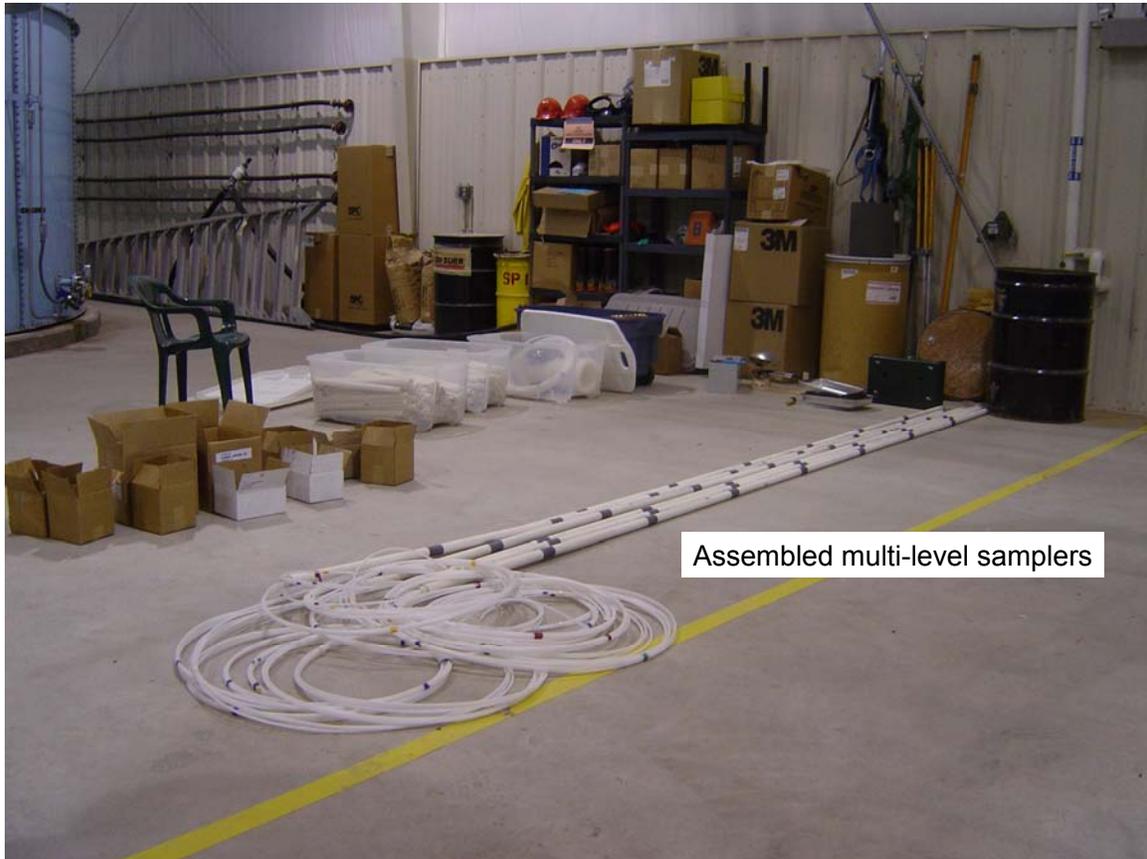
Assembled multi-level samplers



View looking SE (cross-gradient) along the line of the PRB. Green well in foreground is a recirculation well located about 15 feet from the NW end of the PRB. Dashed red line is the approximate footprint of the PRB.

# Appendix B. Explosives Concentrations in Groundwater

Dec 03

| TNT (ug/L) | DISTANCE (M) | | | | |
|---|---|---|---|---|---|
| DEPTH (M) | 8 | 10 | 11 | 12 | 14 |
| -5.7 | 21 | 0 | 0 | 46 | 63 |
| -6.3 | 199 | 0 | 0 | 145 | 149 |
| -6.9 | 119 | 0 | 0 | 0 | 15 |
| -7.5 | 108 | 0 | 0 | 0 | 27 |
| -8.1 | 84 | 0 | 0 | 0 | 1 |
| -8.7 | 18 | 0 | 0 | 0 | 1 |
| -9.3 | 29 | 0 | 0 | 2 | 2 |
| -9.9 | 39 | 0 | 0 | 0 | 33 |

| 2ADNT (ug/L) | DISTANCE (M) | | | | |
|---|---|---|---|---|---|
| DEPTH (M) | 8 | 10 | 11 | 12 | 14 |
| -5.7 | 31 | 0 | 0 | 17 | 18 |
| -6.3 | 29 | 0 | 0 | 25 | 25 |
| -6.9 | 34 | 0 | 0 | 0 | 15 |
| -7.5 | 51 | 0 | 0 | 0 | 62 |
| -8.1 | 76 | 0 | 0 | 0 | 40 |
| -8.7 | 56 | 0 | 0 | 0 | 0 |
| -9.3 | 44 | 0 | 0 | 0 | 0 |
| -9.9 | 17 | 0 | 0 | 0 | 14 |

GROUNDWATER FLOW →

Aug 2004

| TNT (ug/L) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
| -5.7 | 112 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 109 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 58 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 97 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 12 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 65 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 27 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.9 | 20 | 0 | 0 | 0 | 12 | 7 | 4 |

Nov 04

| TNT (ug/L) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
| -5.7 | 83 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 111 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 60 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 94 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 38 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 48 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 36 | 0 | 0 | 0 | 0 | 0 | 2 |
| -9.9 | 29 | 0 | 0 | 0 | 7 | 10 | 8 |

Feb 04
TNT (ug/L)

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 165 | 0 | 0 | 0 | 18 |
| -6.3 | 113 | 0 | 0 | 0 | 4 |
| -6.9 | 102 | 0 | 0 | 0 | 0 |
| -7.5 | 106 | 0 | 0 | 0 | 0 |
| -8.1 | 23 | 0 | 0 | 0 | 0 |
| -8.7 | 49 | 0 | 0 | 0 | 0 |
| -9.3 | 28 | 0 | 0 | 0 | 0 |
| -9.9 | 33 | 0 | 0 | 0 | 17 |

2ADNT (ug/L)

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 31 | 0 | 0 | 0 | 20 |
| -6.3 | 45 | 0 | 0 | 0 | 11 |
| -6.9 | 71 | 0 | 0 | 0 | 0 |
| -7.5 | 54 | 0 | 0 | 0 | 0 |
| -8.1 | 84 | 0 | 0 | 0 | 0 |
| -8.7 | 61 | 0 | 0 | 0 | 0 |
| -9.3 | 69 | 0 | 0 | 0 | 0 |
| -9.9 | 20 | 0 | 0 | 0 | 17 |

Ap 05
TNT (ug/L)

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 80 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 70 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 77 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 36 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 34 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 44 | 0 | 0 | 0 | 0 | 0 | 3 |
| -9.9 | 34 | 0 | 0 | 0 | 9 | 11 | 11 |

Jul 05

TNT (ug/L)  Jul-05

| Depth | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 71 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 98 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 72 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 77 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 41 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 24 | 0 | 0 | 0 | 0 | 1 | 0 |
| -9.9 | 26 | 0 | 0 | 0 | 5 | 7 | 7 |

2ADNT (ug/L)

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 13 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 40 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 45 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 40 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 92 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 93 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 68 | 0 | 0 | 0 | 0 | 1 | 0 |
| -9.9 | 12 | 0 | 0 | 0 | 1 | 3 | 6 |

Appendix C.  Water Chemistry Data


Summary of Concentration Units used in Appendix B


**Table Appendix B- 1. Summary of Concentration Units used in Appendix D.**

| pH | - |
|---|---|
| Eh | mV |
| Conductivity | µSiemens/cm |
| Alkalinity | mg/L |
| Anions (Br, NO3, PO4, SO4, sulfide) | mg/L |
| Cations (Ca, Mg, Mn, Na, K, NH4, Fe2+, Fe(tot)) | mg/L |
| Dissolved gases (hydrogen, methane) | % of saturation |

**Table Appendix B- 2. Water Chemistry Data for December 2003.**

| | | | Z | Dec-03 COND | DO | pH | Eh | Fe2 | ALK | Br | NO3 | PO4 | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G | 8 | B | -5.7 | 599 | 1.8 | 7.1 | -75 | 1.82 | 360 | 0.14 | 0.0 | 0.0 | 157 |
| J | 8 | B | -6.3 | 742 | <1 | 7 | -118 | 2.92 | 320 | 0.00 | 13.2 | 0.0 | 184 |
| G | 8 | G | -6.9 | 785 | <1 | 7.2 | -74 | 2.6 | 335 | 0.22 | 2.2 | 0.0 | 198 |
| J | 8 | G | -7.5 | 810 | <1 | 7.1 | -125 | 2.48 | 310 | 0.17 | 3.8 | 0.0 | 174 |
| G | 8 | Y | -8.1 | 809 | <1 | 7.2 | -85 | 1.61 | 325 | 0.26 | 0.9 | 0.0 | 214 |
| J | 8 | Y | -8.7 | 811 | <1 | 7.1 | -121 | 1.91 | 335 | 0.21 | 0.7 | 0.0 | 200 |
| G | 8 | R | -9.3 | 599 | <1 | 7.2 | -75 | 0.6 | 335 | 0.41 | 1.5 | 0.0 | 244 |
| J | 8 | R | -9.9 | 970 | <1 | 7.1 | -85 | 1.63 | 360 | 0.30 | 0.9 | 0.0 | 248 |
| G | 10 | B | -5.7 | 974 | <1 | 7.9 | -317 | 3.91 | 195 | 0.00 | 0.0 | 0.0 | 71 |
| J | 10 | B | -6.3 | 477 | <1 | 9.7 | -470 | 0.01 | 95 | 0.00 | 0.2 | 0.0 | 37 |
| G | 10 | G | -6.9 | 808 | <1 | 7.9 | -330 | 4.68 | 195 | 0.19 | 0.8 | 0.0 | 90 |
| J | 10 | G | -7.5 | 1011 | <1 | 7.9 | -325 | 3.73 | 230 | 0.22 | 0.5 | 0.8 | 89 |
| G | 10 | Y | -8.1 | 1001 | <1 | 8.5 | -370 | 3.43 | 95 | 0.15 | 0.5 | 0.0 | 85 |
| J | 10 | Y | -8.7 | 859 | <1 | 8.4 | -340 | 4.38 | 145 | 0.22 | 0.5 | 0.7 | 115 |
| G | 10 | R | -9.3 | 997 | <1 | 7.2 | -252 | 4.51 | 195 | 0.19 | 0.9 | 0.0 | 88 |
| J | 10 | R | -9.9 | 861 | <1 | 6 | -26 | 4.62 | 230 | 0.18 | 0.6 | 0.7 | 121 |
| G | 11 | B | -5.7 | 1540 | <1 | 6.2 | -145 | 4.42 | 425 | 0.00 | 0.0 | 0.0 | 59 |
| J | 11 | B | -6.3 | 1184 | <1 | 6.2 | -100 | 5 | 465 | 0.00 | 0.2 | 0.0 | 52 |
| G | 11 | G | -6.9 | 800 | <1 | 8 | -343 | 4.66 | 155 | 0.00 | 0.0 | 0.0 | 0 |
| J | 11 | G | -7.5 | 946 | <1 | 7.8 | -390 | 4.96 | 195 | 0.21 | 0.3 | 0.7 | 172 |
| G | 11 | Y | -8.1 | 1066 | <1 | 8.7 | -340 | 4.87 | 100 | 0.00 | 0.7 | 0.3 | 18 |
| J | 11 | Y | -8.7 | 741 | <1 | 8.1 | -454 | 3.95 | 180 | 0.22 | 0.3 | 0.6 | 98 |
| G | 11 | R | -9.3 | 1063 | <1 | 6 | -77 | 5 | 105 | 0.00 | 0.4 | 0.0 | 119 |
| J | 11 | R | -9.9 | 905 | <1 | 5.9 | -73 | 3.38 | 240 | 0.00 | 0.3 | 0.0 | 176 |
| G | 12 | B | -5.7 | 508 | <1 | 7.9 | -171 | 0.36 | 380 | 0.29 | 0.2 | 0.0 | 248 |
| J | 12 | B | -6.3 | 466 | <1 | 7.3 | -155 | 2.04 | 255 | 0.00 | 0.3 | 0.0 | 129 |
| G | 12 | G | -6.9 | 1288 | <1 | 6.8 | -177 | 2.3 | 555 | 0.00 | 0.1 | 1.6 | 173 |
| J | 12 | G | -7.5 | 780 | <1 | 6.4 | -185 | 3.08 | 445 | 0.18 | 2.8 | 0.0 | 182 |
| G | 12 | Y | -8.1 | 1020 | <1 | 6.8 | -177 | 0.96 | 320 | 0.00 | 0.2 | 1.0 | 150 |

| J | 12 | Y | -8.7 | 1087 | <1 | 6.1 | -120 | 1.53 | 575 | 0.00 | 0.3 | 0.8 | 78 |
|---|----|---|------|------|----|-----|------|------|-----|------|-----|-----|-----|
| G | 12 | R | -9.3 | 1045 | <1 | 7.2 | -79 | 2.07 | 230 | 0.00 | 0.2 | 0.0 | 222 |
| J | 12 | R | -9.9 | 790 | <1 | 5.1 | -25 | 3.34 | 180 | 0.00 | 0.3 | 0.0 | 183 |
| G | 14 | B | -5.7 | 668 | <1 | 6.9 | -142 | 1.9 | 245 | 0.15 | 12.7 | 0.0 | 154 |
| J | 14 | B | -6.3 | 574 | <1 | 6.7 | -152 | 1.35 | 235 | 0.11 | 8.9 | 0.0 | 150 |
| G | 14 | G | -6.9 | 761 | <1 | 6.9 | -151 | 1.94 | 445 | 0.20 | 0.1 | 0.0 | 232 |
| J | 14 | G | -7.5 | 1047 | <1 | 6.9 | -192 | 1.33 | 260 | 0.00 | 0.3 | 0.0 | 194 |
| G | 14 | Y | -8.1 | 1056 | <1 | 7.1 | -101 | 0.59 | 450 | 0.00 | 0.1 | 0.0 | 247 |
| J | 14 | Y | -8.7 | 1008 | <1 | 6.9 | -183 | 0.88 | 365 | 0.27 | 0.2 | 0.0 | 235 |
| G | 14 | R | -9.3 | 1014 | <1 | 7 | -78 | 0.94 | 350 | 0.46 | 0.3 | 0.0 | 214 |
| J | 14 | R | -9.9 | 822 | <1 | 6.8 | -189 | 0.76 | 310 | 0.32 | 0.4 | 0.0 | 251 |

**Table Appendix B- 3. Water Chemistry Data for February 2004.**

|   |   |   | Z | COND | pH | Eh | Fe2 | ALK | NO3 | SO4 |
|---|---|---|------|------|------|-----|------|------|------|------|
| G | 8 | B | -5.7 | 752 | 7.2 | ns | 0.5 | 330 | 12 | 126 |
| J | 8 | B | -6.3 | 850 | 7.2 | ns | 0.08 | 330 | 12 | 188 |
| G | 8 | G | -6.9 | 890 | 7.2 | ns | 0.38 | 385 | 2 | 213 |
| J | 8 | G | -7.5 | 903 | 7.1 | ns | 0.44 | 355 | 3 | 217 |
| G | 8 | Y | -8.1 | 906 | 7.2 | ns | 1.61 | 360 | 0 | 233 |
| J | 8 | Y | -8.7 | 957 | 7 | ns | 0.32 | 390 | 0 | 195 |
| G | 8 | R | -9.3 | 1028 | 7.2 | ns | 0.4 | 385 | 0 | 281 |
| J | 8 | R | -9.9 | 1129 | 7.2 | ns | 0.33 | 390 | 0 | 325 |
| G | 10 | B | -5.7 | 348 | 9.9 | ns | 0.06 | 90 | 0 | 56 |
| J | 10 | B | -6.3 | 313 | 9.2 | ns | 0.05 | 65 | 0 | 50 |
| G | 10 | G | -6.9 | 354 | 10.1 | ns | 0.09 | 100 | 0 | 56 |
| J | 10 | G | -7.5 | 377 | 9.9 | ns | 0.05 | 65 | 0 | 91 |
| G | 10 | Y | -8.1 | 378 | 9.8 | ns | 1.93 | 110 | 0 | 40 |
| J | 10 | Y | -8.7 | 400 | 9.1 | ns | 2.41 | 80 | 0 | 28 |
| G | 10 | R | -9.3 | 636 | 8.6 | ns | 2.96 | 280 | 0 | 87 |
| J | 10 | R | -9.9 | 1015 | 7.5 | ns | 0.31 | 415 | 0 | 223 |
| G | 11 | B | -5.7 | 754 | 7.2 | ns | 4.85 | 170 | 0 | 1 |
| J | 11 | B | -6.3 | 490 | 7.5 | ns | 5.09 | 135 | 0 | 1 |
| G | 11 | G | -6.9 | 383 | 9.1 | ns | 0.04 | 180 | 0 | 49 |
| J | 11 | G | -7.5 | 316 | 9.7 | ns | 0.05 | 65 | 0 | 33 |
| G | 11 | Y | -8.1 | 438 | 7.9 | ns | 0.04 | 150 | 0 | 24 |
| J | 11 | Y | -8.7 | 685 | 7 | ns | 4.36 | 125 | 0 | 45 |
| G | 11 | R | -9.3 | 860 | 7.1 | ns | 4.2 | 485 | 0 | 5 |
| J | 11 | R | -9.9 | 1030 | 7.1 | ns | 0.12 | 380 | 0 | 263 |
| G | 12 | B | -5.7 | 568 | 7 | ns | 4.46 | 215 | 0 | 0 |
| J | 12 | B | -6.3 | 662 | 7 | ns | 2.13 | 600 | 0 | 0 |
| G | 12 | G | -6.9 | 359 | 7.2 | ns | 3.71 | 150 | 0 | 1 |
| J | 12 | G | -7.5 | 1430 | 6.5 | ns | 4.44 | 430 | 0 | 0 |
| G | 12 | Y | -8.1 | 1634 | 6.5 | ns | 3.73 | 145 | 0 | 0 |
| J | 12 | Y | -8.7 | 645 | 5.9 | ns | 3.58 | 240 | 0 | 6 |
| G | 12 | R | -9.3 | 717 | 6.5 | ns | 4.35 | 370 | 0 | 0 |
| J | 12 | R | -9.9 | 1041 | 6.8 | ns | 0.64 | 450 | 0 | 228 |
| G | 14 | B | -5.7 | 842 | 7 | ns | 3.21 | 385 | 0 | 52 |
| J | 14 | B | -6.3 | 1142 | 6.9 | ns | 3.04 | 375 | 0 | 12 |
| G | 14 | G | -6.9 | 454 | 6.9 | ns | 2.13 | 230 | 0 | 0 |
| J | 14 | G | -7.5 | 1720 | 6.5 | ns | 4.44 | 735 | 0 | 0 |
| G | 14 | Y | -8.1 | 1371 | 6.5 | ns | 2.77 | 675 | 0 | 1 |
| J | 14 | Y | -8.7 | 1205 | 6.1 | ns | 4.6 | 410 | 0 | 7 |
| G | 14 | R | -9.3 | 871 | 6 | ns | 3.14 | 245 | 0 | 57 |
| J | 14 | R | -9.9 | 1113 | 7.2 | ns | 0.61 | 360 | 0 | 160 |

Feb 04

**Table Appendix B- 4. Water Chemistry Data for March 2004.**

Mar 04

| | | | X | Z | pH | DO | Cond | Eh | Fe2 | ALK | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G | 8 | B | -2 | -5.7 | 7 | ns | 710 | -38 | 0.03 | 364 | 175 |
| J | 8 | B | -2 | -6.3 | 7 | 0.4 | 816 | -36 | 0.06 | 392 | 234 |
| G | 8 | G | -2 | -6.9 | 7 | 0.5 | 842 | -65 | 0.07 | 772 | 246 |
| J | 8 | G | -2 | -7.5 | 7 | 0.2 | 818 | -56 | 0.09 | 408 | 258 |
| G | 8 | Y | -2 | -8.1 | 7 | 0.6 | 840 | -86 | 1 | 436 | 250 |
| J | 8 | Y | -2 | -8.7 | 7 | 0.2 | 1029 | -57 | 0.28 | 384 | 289 |
| G | 8 | R | -2 | -9.3 | 7 | 0.6 | 968 | -57 | 0.29 | 416 | 372 |
| J | 8 | R | -2 | -9.9 | 7 | 0.2 | 1030 | -39 | 0.13 | 396 | 407 |
| G | 10 | B | 0 | -5.7 | 10.2 | 0 | 288 | -408 | 0.01 | 120 | 4 |
| J | 10 | B | 0 | -6.3 | 10.3 | 0.1 | 301 | -378 | 0.01 | 136 | 6 |
| G | 10 | G | 0 | -6.9 | 10.1 | 0.1 | 342 | -418 | 0.09 | 140 | 28 |
| J | 10 | G | 0 | -7.5 | 10 | 0.3 | 379 | -363 | 0.01 | 132 | 47 |
| G | 10 | Y | 0 | -8.1 | 10.4 | 0 | 320 | -453 | 0.08 | 100 | 34 |
| J | 10 | Y | 0 | -8.7 | 9.8 | 0.3 | 373 | -361 | 0.03 | 88 | 98 |
| G | 10 | R | 0 | -9.3 | 8.2 | 0.1 | 732 | -338 | 2.9 | 280 | 224 |
| J | 10 | R | 0 | -9.9 | 7 | 0.4 | 966 | -192 | 0.73 | 488 | 316 |
| G | 11 | B | 1 | -5.7 | 8.1 | 0.2 | 206 | -295 | 0.1 | 36 | |
| J | 11 | B | 1 | -6.3 | 7.5 | 0.6 | 218 | -260 | 0.56 | 92 | |
| G | 11 | G | 1 | -6.9 | 9.9 | 0.67 | 363 | -369 | 0.02 | 196 | |
| J | 11 | G | 1 | -7.5 | 10.1 | 0.5 | 259 | -435 | 0.05 | 88 | |
| G | 11 | Y | 1 | -8.1 | 10.4 | 0.1 | 353 | -428 | 0.06 | 156 | |
| J | 11 | Y | 1 | -8.7 | 9.9 | 0.5 | 326 | -387 | 0.03 | 96 | |
| G | 11 | R | 1 | -9.3 | 7.4 | 0.2 | 1025 | -232 | 1.9 | 448 | |
| J | 11 | R | 1 | -9.9 | 7.1 | 0.6 | 967 | -226 | 0.23 | 428 | |
| G | 12 | B | 2 | -5.7 | 7.2 | 0.3 | 377 | -215 | 2.9 | 156 | |
| J | 12 | B | 2 | -6.3 | 7 | 0.8 | 404 | -175 | 1.3 | 152 | |
| G | 12 | G | 2 | -6.9 | 8 | 0.2 | 245 | -295 | 0.13 | 152 | |
| J | 12 | G | 2 | -7.5 | 6.9 | 0.9 | 1475 | -118 | 3.6 | 156 | |
| G | 12 | Y | 2 | -8.1 | 6.3 | 0.3 | 965 | -114 | 4.7 | 384 | |
| J | 12 | Y | 2 | -8.7 | 5.9 | 0 | 671 | -73 | 4.4 | 272 | |
| G | 12 | R | 2 | -9.3 | 6.9 | 0.2 | 1010 | -160 | 2.8 | 408 | |
| J | 12 | R | 2 | -9.9 | 6.9 | 0.6 | 1006 | -195 | 0.12 | 420 | |
| G | 14 | B | 4 | -5.7 | 7 | 0.4 | 645 | -182 | 3.41 | 356 | 3 |
| J | 14 | B | 4 | -6.3 | 6.7 | 0.7 | 746 | -149 | 2.7 | 304 | 2 |
| G | 14 | G | 4 | -6.9 | 7.5 | 0.5 | 268 | -224 | 0.11 | 152 | 0 |
| J | 14 | G | 4 | -7.5 | 6.4 | 0.8 | 1420 | -130 | 3.7 | 560 | 0 |
| G | 14 | Y | 4 | -8.1 | 6.4 | 0.6 | 916 | -125 | 4 | 508 | 2 |
| J | 14 | Y | 4 | -8.7 | 6.1 | 0.7 | 566 | -107 | 4.3 | 340 | 109 |
| G | 14 | R | 4 | -9.3 | 6.7 | 0.6 | 1005 | -147 | 4.5 | 388 | 55 |
| J | 14 | R | 4 | -9.9 | 7.1 | 0.7 | 1047 | -118 | 0.87 | 404 | 123 |
| G | 16 | B | 6 | -5.7 | 7.2 | 0.2 | 672 | -178 | 2.8 | 332 | |
| J | 16 | B | 6 | -6.3 | 7 | 0.1 | 724 | -149 | 3.3 | 272 | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| G | 16 | G | 6 | -6.9 | 7.5 | 0.2 | 299 | -223 | 0.23 | 148 | |
| J | 16 | G | 6 | -7.5 | 6.6 | 0.2 | 1148 | -122 | 2-Jan | 548 | |
| G | 16 | Y | 6 | -8.1 | 6.6 | 0.25 | 1042 | -122 | 4.7 | 712 | |
| J | 16 | Y | 6 | -8.7 | 6.5 | 0.2 | 650 | -102 | 4.7 | 416 | |
| G | 16 | R | 6 | -9.3 | 6.9 | 0.2 | 611 | -111 | 5 | 296 | |
| J | 16 | R | 6 | -9.9 | 7.4 | 0.3 | 760 | -144 | 4.3 | 364 | |
| G | 18 | B | 8 | -5.7 | 7.2 | 0.5 | 605 | -186 | 2.9 | 352 | |
| J | 18 | B | 8 | -6.3 | 6.9 | 0.3 | 875 | -158 | 4.8 | 352 | |
| G | 18 | G | 8 | -6.9 | 7.2 | 0.4 | 708 | -208 | 5.8 | 320 | |
| J | 18 | G | 8 | -7.5 | 6.5 | 0.3 | 1256 | -148 | 7.5 | 436 | |
| G | 18 | Y | 8 | -8.1 | 6.4 | 0.5 | 931 | -119 | 4.9 | 552 | |
| J | 18 | Y | 8 | -8.7 | 6.8 | 0.2 | 758 | -165 | 2.5 | 508 | |
| G | 18 | R | 8 | -9.3 | 7 | 0.4 | 650 | -149 | 4.8 | 372 | |
| J | 18 | R | 8 | -9.9 | 7 | 0.3 | 510 | -147 | 4.6 | 356 | |

**Table Appendix B- 5. Water Chemistry Data for June 2004.**

Jun 04

| | | | Z | pH | DO | Cond | Eh | Fe2 | NH3 | Fe(tot) | ALK |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G | 8 | B | -5.7 | 7.10 | 0.10 | 729.00 | -50.00 | 0.00 | 0.00 | 0.00 | 284 |
| J | 8 | B | -6.3 | 7.10 | 0.10 | 790.00 | -65.00 | 0.00 | 0.17 | 0.01 | 308 |
| G | 8 | G | -6.9 | 7.10 | 0.10 | 797.00 | -62.00 | 0.00 | 0.58 | 0.13 | 252 |
| J | 8 | G | -7.5 | 7.20 | 0.10 | 790.00 | -82.00 | 0.00 | 0.47 | 0.08 | 312 |
| G | 8 | Y | -8.1 | 7.20 | 0.10 | 885.00 | -81.00 | 0.11 | 0.60 | 0.60 | 352 |
| J | 8 | Y | -8.7 | 7.30 | 0.10 | 851.00 | -88.00 | 0.00 | 0.55 | 0.15 | 328 |
| G | 8 | R | -9.3 | 7.10 | 0.10 | 990.00 | -59.00 | 0.04 | 0.50 | 0.21 | 308 |
| J | 8 | R | -9.9 | 7.20 | 0.10 | 1053.00 | -100.00 | 0.15 | 0.52 | 0.21 | 304 |
| G | 10 | B | -5.7 | 10.20 | 0.10 | 330.00 | -412.00 | 0.00 | 0.00 | 0.03 | 112 |
| J | 10 | B | -6.3 | 10.40 | 0.10 | 330.00 | -342.00 | 0.00 | 0.23 | 0.03 | 100 |
| G | 10 | G | -6.9 | 10.10 | 0.10 | 350.00 | -413.00 | 0.00 | 0.07 | 0.05 | 140 |
| J | 10 | G | -7.5 | 10.00 | 0.10 | 381.00 | -304.00 | 0.00 | 0.20 | 0.03 | 136 |
| G | 10 | Y | -8.1 | 10.30 | 0.10 | 361.00 | -453.00 | 0.00 | 0.50 | 0.04 | 120 |
| J | 10 | Y | -8.7 | 10.10 | 0.10 | 372.00 | -342.00 | 0.00 | 0.40 | 0.05 | 116 |
| G | 10 | R | -9.3 | 8.50 | 0.10 | 723.00 | -305.00 | 0.02 | 0.60 | 3.68 | 176 |
| J | 10 | R | -9.9 | 8.30 | 0.10 | 1027.00 | -162.00 | 0.90 | 0.90 | 1.34 | 320 |
| G | 11 | B | -5.7 | 10.20 | 0.10 | 321.00 | -336.00 | 0 | 1.2 | 0.05 | 108 |
| J | 11 | B | -6.3 | 10.1 | 0.10 | 313.00 | -294.00 | 0.02 | 1.30 | 0.10 | 108 |
| G | 11 | G | -6.9 | 10.10 | 0.10 | 391.00 | -329.00 | 0.00 | 0.49 | 0.15 | 172 |
| J | 11 | G | -7.5 | 10.2 | 0.10 | 329.00 | -297.00 | 0.00 | 0.90 | 0.22 | 116 |
| G | 11 | Y | -8.1 | 10.30 | 0.10 | 358.00 | -360.00 | 0.00 | 0.12 | 0.04 | 116 |
| J | 11 | Y | -8.7 | 10.20 | 0.10 | 317.00 | -306.00 | 0.00 | 0.90 | 0.04 | 100 |
| G | 11 | R | -9.3 | 8.40 | 0.10 | 927.00 | -155.00 | 2.30 | 1.10 | 2.90 | 264 |
| J | 11 | R | -9.9 | 7.20 | 0.10 | 1027.00 | -129.00 | 0.06 | 0.80 | 0.44 | 320 |
| G | 12 | B | -5.7 | 8.00 | 0.10 | 240.00 | -208.00 | 0.91 | 0.37 | 2.31 | 96 |
| J | 12 | B | -6.3 | 7.30 | 0.10 | 256.00 | -150.00 | 0.35 | 1.70 | 1.24 | 92 |
| G | 12 | G | -6.9 | 8.50 | 0.10 | 265.00 | -275.00 | 0.04 | 0.40 | 0.61 | 108 |
| J | 12 | G | -7.5 | 6.80 | 0.10 | 755.00 | -103.00 | 3.30 | 0.63 | 4.00 | 200 |
| G | 12 | Y | -8.1 | 6.70 | 0.10 | 576.00 | -102.00 | 2.22 | 0.90 | 2.81 | 204 |
| J | 12 | Y | -8.7 | 6.80 | 0.10 | 814.00 | -120.00 | 9.60 | 2.30 | 16.20 | 260 |
| G | 12 | R | -9.3 | 7.1 | 0.10 | 1031.00 | -123.00 | 2.00 | 1.90 | 0.98 | 304 |
| J | 12 | R | -9.9 | 7.00 | 0.10 | 1046.00 | -108.00 | 0.04 | 0.79 | 0.31 | 296 |
| G | 14 | B | -5.7 | 7.30 | 0.10 | 395.00 | -173.00 | 3.50 | 0.09 | 4.60 | 188 |
| J | 14 | B | -6.3 | 7.00 | 0.10 | 363.00 | -136.00 | 0.65 | 0.03 | 1.08 | 164 |
| G | 14 | G | -6.9 | 7.90 | 0.10 | 269.00 | -195.00 | 0.00 | 0.23 | 0.60 | 120 |
| J | 14 | G | -7.5 | 6.60 | 0.10 | 839.00 | -103.00 | 4.52 | 0.20 | 10.01 | 684 |
| G | 14 | Y | -8.1 | 6.70 | 0.10 | 820.00 | -83.00 | 3.34 | 0.95 | 3.84 | 248 |
| J | 14 | Y | -8.7 | 6.80 | 0.10 | 845.00 | -115.00 | 4.45 | 2.10 | 5.50 | 284 |
| G | 14 | R | -9.3 | 7.00 | 0.10 | 518.00 | -98.00 | 2.94 | 1.90 | 3.47 | 284 |
| J | 14 | R | -9.9 | 7.00 | 0.20 | 397.00 | -88.00 | 0.36 | 0.46 | 0.59 | 360 |
| G | 16 | B | -5.7 | 6.90 | 0.10 | 517.00 | -150.00 | 3.17 | 0.08 | 27.00 | 228 |
| J | 16 | B | -6.3 | 7.00 | 0.10 | 318.00 | -163.00 | 1.31 | 0.03 | 2.54 | 152 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| G | 16 | G | -6.9 | 7.30 | 0.10 | 272.00 | -185.00 | 0.04 | 0.16 | 1.10 | 124 |
| J | 16 | G | -7.5 | 6.30 | 0.10 | 1103.00 | -92.00 | 5.10 | 0.08 | 6.70 | 536 |
| G | 16 | Y | -8.1 | 6.40 | 0.10 | 896.00 | -96.00 | 4.13 | 0.90 | 4.80 | 444 |
| J | 16 | Y | -8.7 | 6.80 | 0.10 | 928.00 | -107.00 | 1.90 | 4.70 | 2.50 | 304 |
| G | 16 | R | -9.3 | 6.80 | 0.10 | 1036.00 | -97.00 | 2.28 | 1.40 | 2.64 | 308 |
| J | 16 | R | -9.9 | 7.10 | 0.10 | 1065.00 | -97.00 | 0.63 | 0.45 | 1.34 | 320 |
| G | 18 | B | -5.7 | 6.90 | 0.40 | 582.00 | -163.00 | 3.92 | 0.05 | 5.50 | 316 |
| J | 18 | B | -6.3 | 6.70 | 0.10 | 330.00 | -142.00 | 0.83 | 0.04 | 1.25 | 120 |
| G | 18 | G | -6.9 | 7.20 | 0.30 | 265.00 | -194.00 | 0.37 | 0.60 | 1.07 | 108 |
| J | 18 | G | -7.5 | 6.40 | 0.20 | 978.00 | -128.00 | 5.10 | 0.43 | 8.00 | 372 |
| G | 18 | Y | -8.1 | 6.70 | 0.40 | 875.00 | -129.00 | 1.06 | 0.48 | 1.06 | 356 |
| J | 18 | Y | -8.7 | 6.80 | 0.10 | 938.00 | -149 | 0.73 | 2.80 | 1.23 | 300 |
| G | 18 | R | -9.3 | 7.10 | 0.30 | 1060.00 | -120.00 | 0.83 | 1.50 | 1.18 | 320 |
| J | 18 | R | -9.9 | 6.90 | 0.20 | 1058.00 | -127 | 1.02 | 0.36 | 2.19 | 332 |

**Table Appendix B- 6. Water Chemistry Data for Aug 04.**

| | | | Z | pH | DO | Cond | Eh | Fe2 | NH3 | ALK | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G | 8 | B | -5.7 | 7.1 | 2 | 786 | -55 | 0 | 0 | 54 | 170 |
| J | 8 | B | -6.3 | 7.1 | 0.7 | 830 | -60 | 0 | 0.12 | 54 | 160 |
| G | 8 | G | -6.9 | 7.1 | 0.2 | 840 | -68 | 0 | 0.41 | 61 | 217 |
| J | 8 | G | -7.5 | 7.1 | 0.2 | 850 | -67 | 0 | 0.47 | 54 | 200 |
| G | 8 | Y | -8.1 | 7.1 | 0.2 | 862 | -66 | 0.61 | 0.79 | 53 | 258 |
| J | 8 | Y | -8.7 | 7.1 | 0.2 | 872 | -68 | 0.03 | 1 | 52 | 220 |
| G | 8 | R | -9.3 | 7.1 | 0.2 | 1017 | -57 | 0.13 | 0.51 | 64 | 328 |
| J | 8 | R | -9.9 | 7.1 | 0.2 | 1117 | -68 | 0 | 0.57 | 54 | 380 |
| G | 10 | B | -5.7 | 9.7 | 0.2 | 350 | -360 | 0 | 0 | 25 | 0 |
| J | 10 | B | -6.3 | 9.7 | 0.2 | 371 | -339 | 0 | 0.01 | 22 | 1 |
| G | 10 | G | -6.9 | 9.7 | 0.2 | 370 | -359 | 0 | 0.2 | 30 | 25 |
| J | 10 | G | -7.5 | 9.3 | 0.2 | 379 | -318 | 0 | 0.06 | 30 | 1 |
| G | 10 | Y | -8.1 | 9.5 | 0.2 | 357 | -404 | 0 | 0.48 | 25 | 9 |
| J | 10 | Y | -8.7 | 8.9 | 0.2 | 376 | -338 | 0 | 0.52 | 21 | 5 |
| G | 10 | R | -9.3 | 9.4 | 0.2 | 436 | -345 | 0 | 0.48 | 23 | 46 |
| J | 10 | R | -9.9 | 7.6 | 0.2 | 1016 | -146 | 0.52 | 0.86 | 58 | 215 |
| G | 11 | B | -5.7 | 9.8 | 0.2 | 358 | -319 | 0 | 0.79 | 27 | 2 |
| J | 11 | B | -6.3 | 9.7 | 0.2 | 373 | -302 | 0 | 0.6 | 23 | 2 |
| G | 11 | G | -6.9 | 9.6 | 0.2 | 420 | -301 | 0 | 0.06 | 26 | 0 |
| J | 11 | G | -7.5 | 9.6 | 0.2 | 377 | -289 | 0.06 | 0.54 | 31 | 0 |
| G | 11 | Y | -8.1 | 9.3 | 0.6 | 365 | -323 | 0 | 0.38 | 23 | 2 |
| J | 11 | Y | -8.7 | 9 | 0.6 | 337 | -296 | 0.03 | 0.9 | 26 | 4 |
| G | 11 | R | -9.3 | 8.3 | 0.6 | 622 | -150 | 0.02 | 0.49 | 52 | 44 |
| J | 11 | R | -9.9 | 7.3 | 0.2 | 1034 | -99 | 0.1 | 1 | 49 | 227 |
| G | 12 | B | -5.7 | 7.9 | 0.2 | 426 | -191 | 0.78 | 0.3 | 34 | 3 |
| J | 12 | B | -6.3 | 7.4 | 0.2 | 247 | -150 | 0.4 | 0.9 | 16 | 4 |
| G | 12 | G | -6.9 | 8.2 | 0.2 | 286 | -252 | 0 | 0.29 | 21 | 3 |
| J | 12 | G | -7.5 | 7.1 | 0.2 | 390 | -110 | 1 | 0.51 | 32 | 2 |
| G | 12 | Y | -8.1 | 6.9 | 0.8 | 587 | -87 | 0.9 | 1.2 | 34 | 38 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J | 12 | Y | -8.7 | 7.2 | 0.2 | 796 | -109 | 1.13 | 3.5 | 53 | 40 |
| G | 12 | R | -9.3 | 7.2 | 0.2 | 968 | -104 | 0.1 | 0.93 | 64 | 246 |
| J | 12 | R | -9.9 | 7.2 | 0.2 | 1076 | -105 | 0.18 | 0.6 | 59 | 176 |
| G | 14 | B | -5.7 | 7.8 | 0.2 | 319 | -172 | 0.45 | 0 | 28 | 1 |
| J | 14 | B | -6.3 | 7.1 | 0.8 | 280 | -123 | 0.12 | 0.18 | 18 | 3 |
| G | 14 | G | -6.9 | 8 | 0.2 | 250 | -238 | 0.05 | 0 | 28 | 2 |
| J | 14 | G | -7.5 | 6.7 | 0.2 | 1259 | -76 | 0.86 | 2.8 | 138 | 9 |
| G | 14 | Y | -8.1 | 7.1 | 0.2 | 606 | -91 | 0.28 | 0.7 | 42 | 36 |
| J | 14 | Y | -8.7 | 7 | 0.2 | 885 | -97 | 1.1 | 0.18 | 52 | 242 |
| G | 14 | R | -9.3 | 7.1 | 0.2 | 1074 | -98 | 0.26 | 1.8 | 70 | 356 |
| J | 14 | R | -9.9 | 7.1 | 0.2 | 1076 | -88 | 0.32 | 0.32 | 74 | 374 |
| G | 16 | B | -5.7 | 7.2 | 0.2 | 345 | -138 | 0.81 | 0 | 33 | 1 |
| J | 16 | B | -6.3 | 6.8 | 0.2 | 1205 | -136 | 0.32 | 0 | 25 | 5 |
| G | 16 | G | -6.9 | 7.2 | 0.2 | 247 | -154 | 0.22 | 0 | 17 | 23 |
| J | 16 | G | -7.5 | 6.4 | 0.2 | 1202 | -102 | 0.85 | 0.05 | 135 | 6 |
| G | 16 | Y | -8.1 | 7 | 0.2 | 842 | -91 | 1.03 | 0.18 | 97 | 206 |
| J | 16 | Y | -8.7 | 7 | 0.2 | 990 | -118 | 0.71 | 0.25 | 70 | 287 |
| G | 16 | R | -9.3 | 7.4 | 0.2 | 1094 | -84 | 0.97 | 1.5 | 69 | 356 |
| J | 16 | R | -9.9 | 7.2 | 0.2 | 1270 | -91 | 0.41 | 0.33 | 81 | 380 |
| G | 18 | B | -5.7 | 7.2 | 0.2 | 505 | -124 | 0.97 | 0 | 65 | 1 |
| J | 18 | B | -6.3 | 7 | 0.2 | 308 | -108 | 0.25 | 0.02 | 26 | 4 |
| G | 18 | G | -6.9 | 7.4 | 0.2 | 261 | -148 | 0.03 | 0.15 | 30 | 17 |
| J | 18 | G | -7.5 | 6.7 | 0.2 | 841 | -88 | 0.35 | 0.03 | 107 | 32 |
| G | 18 | Y | -8.1 | 6.8 | 0.6 | 887 | -97 | 0.29 | 0.14 | 80 | 182 |
| J | 18 | Y | -8.7 | 7.1 | 0.6 | 1008 | -92 | 0.49 | 2 | 80 | 273 |
| G | 18 | R | -9.3 | 7.1 | 0.2 | 1077 | -97 | 0.85 | 0.65 | 77 | 386 |
| J | 18 | R | -9.9 | 7.1 | 0.2 | 1088 | -88 | 0.14 | 0.38 | 77 | 295 |

**Table Appendix B- 7 Water Chemistry Data for the Cross-gradient Wells for August 2004.**

| | | | Z | pH | DO | Cond | Eh | Fe2 | NH3 | ALK |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Aug 04 | | | | |
| C | 14 | B | -5.7 | 7.1 | 0.2 | 460 | -181 | na | | 54 |
| C | 14 | G | -6.9 | 7.5 | 0.2 | 341 | -278 | na | | 29 |
| C | 14 | Y | -8.1 | 6.9 | 0.2 | 777 | -158 | 1.11 | | 36 |
| C | 14 | R | -9.3 | 6.7 | 0.2 | 1129 | -124 | 1.44 | | 70 |
| E | 14 | B | -6.3 | 8.8 | 0.2 | 323 | -310 | na | | 38 |
| E | 14 | G | -7.5 | 8.5 | 0.2 | 392 | -291 | na | | 34 |
| E | 14 | Y | -8.7 | 8.3 | 0.2 | 391 | -293 | 1.32 | | 33 |
| E | 14 | R | -9.9 | 6.7 | 0.2 | 1127 | -131 | 1.43 | | 74 |
| G | 14 | B | -5.7 | 7.8 | 0.2 | 319 | -172 | 0.45 | 0 | 28 |
| G | 14 | G | -6.9 | 8 | 0.2 | 250 | -238 | 0.05 | 0 | 28 |
| G | 14 | Y | -8.1 | 7.1 | 0.2 | 606 | -91 | 0.28 | 0.7 | 42 |
| G | 14 | R | -9.3 | 7.1 | 0.2 | 1074 | -98 | 0.26 | 1.8 | 70 |
| J | 14 | B | -6.3 | 7.1 | 0.8 | 280 | -123 | 0.12 | 0.18 | 18 |
| J | 14 | G | -7.5 | 6.7 | 0.2 | 1259 | -76 | 0.86 | 2.8 | 138 |
| J | 14 | Y | -8.7 | 7 | 0.2 | 885 | -97 | 1.1 | 0.18 | 52 |
| J | 14 | R | -9.9 | 7.1 | 0.2 | 1076 | -88 | 0.32 | 0.32 | 74 |
| L | 14 | B | -5.7 | 6.8 | 0.2 | 256 | -205 | 0.17 | | 33 |
| L | 14 | G | -6.9 | 6.6 | 0.2 | 292 | -188 | 1.07 | | 23 |
| L | 14 | Y | -8.1 | 6.5 | 0.2 | 802 | -135 | 1.04 | | 86 |
| L | 14 | R | -9.3 | 7.1 | 0.2 | 1063 | -152 | 1.21 | | 68 |
| N | 14 | B | -6.3 | 6.7 | 0.2 | 295 | -192 | 0.13 | | 82 |
| N | 14 | G | -7.5 | 6.4 | 0.2 | 760 | -145 | 1.4 | | 62 |
| N | 14 | Y | -8.7 | 6.7 | 0.2 | 944 | -149 | 1.16 | | 73 |
| N | 14 | R | -9.9 | 6.7 | 0.2 | 1065 | -141 | 1.35 | | 62 |

**Table Appendix B- 8. Water chemistry data for November 2004.**

|   |   |   |   |   | Nov 04 |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|   |   |   | X | Z | pH | DO | Cond | Eh | Fe2 | Alk | SO4 | Ca++ |
| G | 8 | B | -2 | -5.7 | 6.90 | 2.30 | 808.00 | -56.00 | 0.00 | 310 | 264 | 172 |
| J | 8 | B | -2 | -6.3 | 7.00 | <0.5 | 851.00 | -81.00 | 0.00 | 285 | 264 | 163 |
| G | 8 | G | -2 | -6.9 | 6.90 | <0.5 | 851.00 | -86.00 | 0.00 | 320 | 206 | 162 |
| J | 8 | G | -2 | -7.5 | 7.00 | <0.5 | 871.00 | -95.00 | 0.00 | 295 | 206 | 145 |
| G | 8 | Y | -2 | -8.1 | 7.00 | <0.5 | 882.00 | -104.00 | 0.00 | 305 | 308 | 163 |
| J | 8 | Y | -2 | -8.7 | 7.00 | <0.5 | 927.00 | -104.00 | 0.00 | 315 | 308 | 164 |
| G | 8 | R | -2 | -9.3 | 7.00 | <0.5 | 1091.00 | -86.00 | 0.00 | 355 | 409 | 165 |
| J | 8 | R | -2 | -9.9 | 7.00 | <0.5 | 1192.00 | -104.00 | 0.00 | 310 | 403 | 150 |
| G | 10 | B | 0 | -5.7 | 9.70 | <0.5 | 318.00 | -384.00 | 0.00 | 105 | 38 | 1 |
| J | 10 | B | 0 | -6.3 | 9.60 | <0.5 | 345.00 | -344.00 | 0.00 | 140 | 2 | 1 |
| G | 10 | G | 0 | -6.9 | 9.60 | <0.5 | 390.00 | -390.00 | 0.10 | 185 | 2 | 1 |
| J | 10 | G | 0 | -7.5 | 9.50 | <0.5 | 405.00 | -327.00 | 0.00 | 170 | 2 | 1 |
| G | 10 | Y | 0 | -8.1 | 9.40 | <0.5 | 405.00 | -418.00 | 0.00 | 165 | 2 | 1 |
| J | 10 | Y | 0 | -8.7 | 9.40 | <0.5 | 417.00 | -358.00 | 0.00 | 150 | 2 | 2 |
| G | 10 | R | 0 | -9.3 | 8.00 | <0.5 | 758.00 | -323.00 | 1.40 | 220 | 169 | 39 |
| J | 10 | R | 0 | -9.9 | 7.10 | <0.5 | 1125.00 | -216.00 | 0.40 | 345 | 315 | 184 |
| G | 11 | B | 1 | -5.7 | 9.80 | <0.5 | 360.00 | -379.00 | 0 | 145 | 1 | 1 |
| J | 11 | B | 1 | -6.3 | 9.7 | <0.5 | 336.00 | -327.00 | 0.20 | 155 | 3 | 1 |
| G | 11 | G | 1 | -6.9 | 9.60 | <0.5 | 425.00 | -365.00 | 0.00 | 170 | 0 | 1 |
| J | 11 | G | 1 | -7.5 | 9.7 | <0.5 | 368.00 | -329.00 | 0.00 | 190 | 1 | 1 |
| G | 11 | Y | 1 | -8.1 | 9.50 | <0.5 | 399.00 | -393.00 | 0.00 | 140 | 3 | 1 |
| J | 11 | Y | 1 | -8.7 | 9.60 | <0.5 | 420.00 | -339.00 | 0.00 | 165 | 4 | 1 |
| G | 11 | R | 1 | -9.3 | 7.40 | <0.5 | 1140.00 | -235.00 | 0.10 | 320 | 305 | 172 |
| J | 11 | R | 1 | -9.9 | 7.00 | <0.5 | 1161.00 | -189.00 | 0.00 | 390 | 353 | 176 |
| G | 12 | B | 2 | -5.7 | ns | ns | ns | ns | 0.00 | 135 | 0 | 1 |
| J | 12 | B | 2 | -6.3 | 7.60 | <0.5 | 260.00 | -235.00 | 0.00 | 105 | 1 | 2 |
| G | 12 | G | 2 | -6.9 | 9.00 | <0.5 | 346.00 | -331.00 | 0.00 | 170 | 5 | 2 |
| J | 12 | G | 2 | -7.5 | 6.90 | <0.5 | 332.00 | -183.00 | 0.20 | 135 | 0 | 40 |

| G | 12 | Y | 2 | -8.1 | 6.90 | <0.5 | 528.00 | -187.00 | 1.40 | 175 | 77 | 63 |
|---|----|---|---|------|------|------|--------|---------|------|-----|----|----|
| J | 12 | Y | 2 | -8.7 | 7.00 | <0.5 | 901.00 | -179.00 | 0.90 | 325 | 22 | 90 |
| G | 12 | R | 2 | -9.3 | 7.1 | <0.5 | 1144.00 | -204.00 | 0.00 | 365 | 325 | 174 |
| J | 12 | R | 2 | -9.9 | 7.00 | <0.5 | 1162.00 | -171.00 | 0.1 | 290 | 386 | 143 |
| G | 14 | B | 4 | -5.7 | 7.20 | <0.5 | 446.00 | -211.00 | 1.80 | 235 | 10 | 8 |
| J | 14 | B | 4 | -6.3 | 7.20 | <0.5 | 266.00 | -204.00 | 0.00 | 160 | 1 | 2 |
| G | 14 | G | 4 | -6.9 | 8.60 | <0.5 | 328.00 | -326.00 | 0.20 | 135 | 3 | 9 |
| J | 14 | G | 4 | -7.5 | 6.50 | <0.5 | 972.00 | -154.00 | 2.40 | 540 | 10 | 171 |
| G | 14 | Y | 4 | -8.1 | 6.80 | <0.5 | 726.00 | -178.00 | 1.30 | 325 | 155 | 171 |
| J | 14 | Y | 4 | -8.7 | 6.90 | <0.5 | 914.00 | -157.00 | 1.10 | 340 | 254 | 138 |
| G | 14 | R | 4 | -9.3 | 7.00 | <0.5 | 1157.00 | -181.00 | 0.20 | 330 | 359 | 183 |
| J | 14 | R | 4 | -9.9 | 7.00 | <0.5 | 1184.00 | -123.00 | 0.10 | 335 | 346 | 184 |
| G | 16 | B | 6 | -5.7 | 6.90 | 1.60 | 356 | -133.00 | 1.00 | 115 | 0 | 55 |
| J | 16 | B | 6 | -6.3 | 7.20 | <0.5 | 268.00 | -206.00 | 0.00 | 165 | 1 | 18 |
| G | 16 | G | 6 | -6.9 | 7.70 | <0.5 | 305.00 | -266.00 | 0.00 | 525 | 2 | 59 |
| J | 16 | G | 6 | -7.5 | 6.60 | <0.5 | 805.00 | -158.00 | 2.90 | 135 | 0 | 152 |
| G | 16 | Y | 6 | -8.1 | 6.80 | <0.5 | 540.00 | -189.00 | 0.40 | 340 | 60 | 185 |
| J | 16 | Y | 6 | -8.7 | 7.00 | <0.5 | 972.00 | -162.00 | 0.00 | 255 | 283 | 133 |
| G | 16 | R | 6 | -9.3 | 6.90 | <0.5 | 1186.00 | -169.00 | 0.70 | 340 | 325 | 168 |
| J | 16 | R | 6 | -9.9 | 7.00 | <0.5 | 1161.00 | -110.00 | 0.10 | 300 | 365 | 125 |
| G | 18 | B | 8 | -5.7 | 7.00 | 1.20 | 434.00 | -135.00 | 0.20 | 135 | 1 | 79 |
| J | 18 | B | 8 | -6.3 | 6.90 | <0.5 | 270.00 | -182.00 | 0.00 | 100 | 0 | 65 |
| G | 18 | G | 8 | -6.9 | 7.70 | <0.5 | 321.00 | -242.00 | 0.10 | 360 | 1 | 178 |
| J | 18 | G | 8 | -7.5 | 6.80 | <0.5 | 813.00 | -168.00 | 2.50 | 435 | 52 | 173 |
| G | 18 | Y | 8 | -8.1 | 6.90 | <0.5 | 723.00 | -180.00 | 0.00 | 225 | 130 | 128 |
| J | 18 | Y | 8 | -8.7 | 7.10 | <0.5 | 1022.00 | -151 | 0.00 | 365 | 346 | 184 |
| G | 18 | R | 8 | -9.3 | 6.90 | <0.5 | 1192.00 | -152.00 | 0.30 | 380 | 351 | 164 |
| J | 18 | R | 8 | -9.9 | 7.10 | <0.5 | 1148.00 | -98 | 0.00 | 355 | 356 | 159 |

**Table Appendix B- 9. Water Chemistry Data for April 2005.**

| | | | X | Z | Ap 05 pH | DO | Cond | Eh | Fe2 | ALK | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G | 8 | B | -2 | -5.7 | | | | | | | |
| J | 8 | B | -2 | -6.3 | 7.30 | 0.70 | 820.00 | 69.00 | 0.01 | 232 | 344 |
| G | 8 | G | -2 | -6.9 | 7.20 | <0.5 | 876.00 | 71 | 0.01 | 224 | 353 |
| J | 8 | G | -2 | -7.5 | 7.30 | <0.5 | 873.00 | 68.00 | 0.01 | 276 | 358 |
| G | 8 | Y | -2 | -8.1 | 7.20 | <0.5 | 874.00 | 69 | 0.05 | 272 | 350 |
| J | 8 | Y | -2 | -8.7 | 7.40 | <0.5 | 939.00 | 68.00 | 0.02 | 244 | 367 |
| G | 8 | R | -2 | -9.3 | 7.30 | <0.5 | 1074.00 | 85 | 0.01 | 232 | 436 |
| J | 8 | R | -2 | -9.9 | 7.10 | <0.5 | 1161.00 | 65.00 | 0.08 | 268 | 440 |
| G | 10 | B | 0 | -5.7 | | <0.5 | | | | | |
| J | 10 | B | 0 | -6.3 | 10.20 | <0.5 | 336.00 | -265.00 | 0.01 | 124 | 0 |
| G | 10 | G | 0 | -6.9 | 10.00 | <0.5 | 370.00 | -317.00 | 0.01 | 120 | 0 |
| J | 10 | G | 0 | -7.5 | 10.00 | <0.5 | 410.00 | -269.00 | 0.01 | 152 | 0 |
| G | 10 | Y | 0 | -8.1 | 10.30 | <0.5 | 401.00 | -372.00 | 0.01 | 100 | 0 |
| J | 10 | Y | 0 | -8.7 | 10.00 | <0.5 | 422.00 | -290.00 | 0.01 | 132 | 11 |
| G | 10 | R | 0 | -9.3 | 8.10 | <0.5 | 471.00 | -295.00 | 1.40 | 216 | 318 |
| J | 10 | R | 0 | -9.9 | 7.50 | <0.5 | 1126.00 | -189.00 | 0.11 | 296 | 401 |
| G | 11 | B | 1 | -5.7 | 10.50 | <0.5 | 370.00 | -282.00 | | 148 | 0 |
| J | 11 | B | 1 | -6.3 | 10.1 | <0.5 | 340.00 | -224.00 | 0.01 | 116 | 0 |
| G | 11 | G | 1 | -6.9 | 10.10 | <0.5 | 438.00 | -280.00 | 0.01 | 124 | 9 |
| J | 11 | G | 1 | -7.5 | 10.4 | <0.5 | 394.00 | -252.00 | 0.01 | 104 | 0 |
| G | 11 | Y | 1 | -8.1 | 10.40 | <0.5 | 415.00 | -286.00 | 0.01 | 120 | 0 |
| J | 11 | Y | 1 | -8.7 | 10.00 | <0.5 | 389.00 | -276.00 | 0.01 | 152 | 7 |
| G | 11 | R | 1 | -9.3 | 7.80 | <0.5 | 998.00 | -209.00 | 0.81 | 252 | 380 |
| J | 11 | R | 1 | -9.9 | 7.50 | <0.5 | 1115.00 | -157.00 | 0.08 | 248 | 399 |
| G | 12 | B | 2 | -5.7 | | ns | | | | | |
| J | 12 | B | 2 | -6.3 | 9.70 | <0.5 | 336.00 | -231.00 | 0.01 | 144 | 6 |
| G | 12 | G | 2 | -6.9 | 9.80 | <0.5 | 361.00 | -303.00 | 0.01 | 160 | 6 |
| J | 12 | G | 2 | -7.5 | 7.50 | <0.5 | 253.00 | -158.00 | 0.07 | 112 | 8 |
| G | 12 | Y | 2 | -8.1 | 7.70 | <0.5 | 606.00 | -156.00 | 0.59 | 132 | 222 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| J | 12 | Y | 2 | -8.7 | 7.30 | <0.5 | 913.00 | -159.00 | 0.05 | 264 | 332 |
| G | 12 | R | 2 | -9.3 | 8.2 | <0.5 | 1153.00 | -169.00 | 0.06 | 260 | 379 |
| J | 12 | R | 2 | -9.9 | 7.30 | <0.5 | 1129.00 | -155.00 | 0.01 | 316 | 380 |
| G | 14 | B | 4 | -5.7 | | <0.5 | | | | 128 | 15 |
| J | 14 | B | 4 | -6.3 | 7.70 | <0.5 | 272.00 | -163.00 | 0.01 | 96 | 8 |
| G | 14 | G | 4 | -6.9 | 9.40 | <0.5 | 337.00 | -236.00 | 0.01 | 148 | 7 |
| J | 14 | G | 4 | -7.5 | 7.00 | <0.5 | 679.00 | -127.00 | 1.23 | 192 | 182 |
| G | 14 | Y | 4 | -8.1 | 7.50 | <0.5 | 853.00 | -90.00 | 0.52 | 212 | 288 |
| J | 14 | Y | 4 | -8.7 | 7.20 | <0.5 | 986.00 | -129.00 | 0.26 | 276 | 341 |
| G | 14 | R | 4 | -9.3 | 7.60 | <0.5 | 1177.00 | -72.00 | 0.21 | 288 | 390 |
| J | 14 | R | 4 | -9.9 | 7.30 | <0.5 | 1175.00 | -89.00 | 0.01 | 296 | 373 |
| G | 16 | B | 6 | -5.7 | | 1.60 | | | | | |
| J | 16 | B | 6 | -6.3 | 7.70 | <0.5 | 285.00 | -146.00 | 0.01 | 116 | 3 |
| G | 16 | G | 6 | -6.9 | 8.90 | <0.5 | 320.00 | -209.00 | 0.01 | 112 | 6 |
| J | 16 | G | 6 | -7.5 | 7.10 | <0.5 | 624.00 | -110.00 | 1.51 | 228 | 111 |
| G | 16 | Y | 6 | -8.1 | 7.30 | <0.5 | 820.00 | -120.00 | 0.33 | 216 | 376 |
| J | 16 | Y | 6 | -8.7 | 7.30 | <0.5 | 1067.00 | -108.00 | 0.07 | 284 | 341 |
| G | 16 | R | 6 | -9.3 | 7.60 | <0.5 | 1176.00 | -104.00 | 0.09 | 284 | 381 |
| J | 16 | R | 6 | -9.9 | 7.30 | <0.5 | 1174.00 | -60.00 | 0.01 | 272 | 350 |
| G | 18 | B | 8 | -5.7 | | 1.20 | | | | | |
| J | 18 | B | 8 | -6.3 | 7.70 | <0.5 | 271.00 | -143.00 | 0.02 | 104 | 2 |
| G | 18 | G | 8 | -6.9 | 9.00 | <0.5 | 300.00 | -206.00 | 0.01 | 104 | 0 |
| J | 18 | G | 8 | -7.5 | 7.20 | <0.5 | 887.00 | -114.00 | 0.07 | 248 | 255 |
| G | 18 | Y | 8 | -8.1 | 7.50 | <0.5 | 946.00 | -123.00 | 0.04 | 284 | 326 |
| J | 18 | Y | 8 | -8.7 | 7.40 | <0.5 | 1043.00 | -114 | 0.01 | 312 | 361 |
| G | 18 | R | 8 | -9.3 | 7.70 | <0.5 | 1148.00 | -110.00 | 0.06 | 280 | 400 |
| J | 18 | R | 8 | -9.9 | 7.40 | <0.5 | 1160.00 | -75 | 0.01 | 280 | 369 |

**Table Appendix B- 10. Water Chemistry Data for the Cross-gradient Wells for April 2005.**

|  |  |  |  | X | Z | pH | DO | Cond | Eh (mV) | Fe2 | SO4 | ALK | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C |  | 14 | B | 4 | -5.7 | 7.33 | 0.53 | 589 | 110.1 | 0.06 | 2.847127 | 310 | 52 |
| C |  | 14 | G | 4 | -6.9 | 9.41 | <0.1 | 398 | -252.1 | 0 | 5.342533 | 180 | 2 |
| C |  | 14 | Y | 4 | -8.1 | 7.79 | <0.1 | 901 | -153.2 | 0 | 175.6896 | 150 | 26 |
| C |  | 14 | R | 4 | -9.3 | 7.28 | <0.1 | 1307 | -124.5 | 0.07 | 373.1201 | 340 | 119 |
| E |  | 14 | B | 4 | -6.3 | 9.44 | <0.1 | 371 | -242.1 | 0 | 15.67445 | 160 | 1 |
| E |  | 14 | G | 4 | -7.5 | 9.56 | <0.1 | 413 | -242.1 | 0 | 177.1915 | 120 | 1 |
| E |  | 14 | Y | 4 | -8.7 | 7.38 | <0.1 | 1099 | -152.1 | 0.11 | 188.6665 | 210 | 65 |
| E |  | 14 | R | 4 | -9.9 | 7.26 | <0.1 | 1362 | -132.9 | 0 | 374.9143 | 240 | 124 |
| G |  | 14 | B | 4 | -5.7 | 7.35 | 0.3 | 393 | -138.1 | 0.06 | 3.810083 | 200 | 35 |
| G |  | 14 | G | 4 | -6.9 | 8.93 | <0.1 | 449 | -215.3 | 0 | 33.96303 | 220 | 5 |
| G |  | 14 | Y | 4 | -8.1 | 7.27 | <0.1 | 580 | -115.8 | 0.06 | 104.1344 | 220 | 47 |
| G |  | 14 | R | 4 | -9.3 | 7.28 | <0.1 | 1280 | -130.9 | 0 | 331.5794 | 250 | 155 |
| J |  | 14 | B | 4 | -6.3 | 8.78 | <0.1 | 311 | -198.7 | 0.24 | 15.08876 | 90 | 5 |
| J |  | 14 | G | 4 | -7.5 | 6.95 | <0.1 | 580 | -99.8 | 1.9 | 116.6325 | 210 | 98 |
| J |  | 14 | Y | 4 | -8.7 | 7.28 | <0.1 | 1033 | -78.8 | 0.18 | 170.4232 | 420 | 139 |
| J |  | 14 | R | 4 | -9.9 | 7.23 | <0.1 | 1241 | -28.9 | 0 | 310.6333 | 380 | 139 |
| L |  | 14 | B | 4 | -5.7 | 7.57 | 0.27 | 407 | -163.9 | 0 | 1.616895 | 160 | 10 |
| L |  | 14 | G | 4 | -6.9 | 7.55 | <0.1 | 304 | -148.1 | 0 | 0.940049 | 120 | 6 |
| L |  | 14 | Y | 4 | -8.1 | 7.06 | <0.1 | 1072 | -109.1 | 0.9 | 171.3338 | 320 | 111 |
| L |  | 14 | R | 4 | -9.3 | 7.21 | <0.1 | 1302 | -62.7 | 0 | 363.6042 | 370 | 127 |
| N |  | 14 | B | 4 | -6.3 | 9.46 | <0.1 | 340 | -269.6 | 0 | 2.242629 | 120 | 1 |
| N |  | 14 | G | 4 | -7.5 | 7.18 | <0.1 | 961 | -142.8 | 0.32 | 161.4412 | 230 | 100 |
| N |  | 14 | Y | 4 | -8.7 | 7.15 | <0.1 | 1210 | -135.1 | 0.52 | 185.8533 | 290 | 115 |
| N |  | 14 | R | 4 | -9.9 | 7.16 | <0.1 | 1231 | -114.5 | 0 | 311.7532 | 280 | 127 |

AP 05

**Table Appendix B- 11.Water Chemistry Data for July 2005.**

Jul 05

| | | | Z | pH | DO | Cond | Eh (mV) | Fe2 | SO4 | ALK | H2 (%SAT) | CH4 (%SAT) | Mg | K | Na | Ca |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G | 8 | B | -5.7 | 7.14 | 2.54 | 993.00 | -27 | 0.00 | 80 | 250 | 0.0 | 0.0 | 12.7 | 13.9 | 97 | 38 |
| J | 8 | B | -6.3 | 7.14 | 0.53 | 906.00 | -50 | 0.00 | 96 | 350 | 0.0 | 2.4 | 14.4 | 16.6 | 95 | 41 |
| G | 8 | G | -6.9 | 7.17 | <0.1 | 996.00 | -34 | 0.00 | 146 | 330 | 0.0 | 0.0 | 17.6 | 16.1 | 99 | 57 |
| J | 8 | G | -7.5 | 7.15 | <0.1 | 1007.00 | -48 | 0.00 | 161 | 210 | 0.0 | 0.0 | 19 | 17.6 | 99 | 48 |
| G | 8 | Y | -8.1 | 7.18 | <0.5 | 998.00 | -51 | 0.00 | 129 | 240 | 0.0 | 0.0 | 18 | 14.2 | 99 | 66 |
| J | 8 | Y | -8.7 | 7.19 | <0.1 | 1056.00 | -48 | 0.00 | 199 | 330 | 0.0 | 0.0 | 18.7 | 15.1 | 101 | 56 |
| G | 8 | R | -9.3 | 7.38 | <0.1 | 1295.00 | -53 | 0.00 | 260 | 330 | 0.0 | 0.0 | 21 | 14 | 131 | 100 |
| J | 8 | R | -9.9 | 7.23 | <0.1 | 1296.00 | -49 | 0.07 | 343 | 360 | 0.0 | 0.0 | 22.1 | 14.4 | 148 | 61 |
| G | 10 | B | -5.7 | 9.94 | <0.1 | 399.00 | -271.00 | 0.00 | 3 | 90 | 1.0 | 5.2 | 0.2 | 17.6 | 87 | 0 |
| J | 10 | B | -6.3 | 10.09 | 0.37 | 491.00 | -295.00 | 0.00 | 2 | 200 | 35.0 | 58.1 | 0.3 | 24.2 | 103 | 0 |
| G | 10 | G | -6.9 | 9.65 | <0.1 | 449.00 | -254.00 | 0.00 | 5 | 230 | 0.4 | 0.0 | 11.6 | 22.7 | 98 | 1 |
| J | 10 | G | -7.5 | 9.76 | <0.1 | 456.00 | -280.00 | 0.00 | 2 | 170 | 0.5 | 0.0 | 6.3 | 16.2 | 95 | 0 |
| G | 10 | Y | -8.1 | 9.84 | <0.1 | 429.00 | -260.00 | 0.00 | 1 | 100 | 0.9 | 0.0 | 1.1 | 13.8 | 97 | 0 |
| J | 10 | Y | -8.7 | 9.91 | <0.1 | 509.00 | -290.00 | 0.00 | 4 | 170 | 0.4 | 0.0 | 4.9 | 14.3 | 101 | 0 |
| G | 10 | R | -9.3 | 7.90 | <0.1 | 1022.00 | -224.00 | 0.00 | 4 | 190 | 0.0 | 0.0 | 17.3 | 13.1 | 108 | 23 |
| J | 10 | R | -9.9 | 7.32 | <0.1 | 1315.00 | -196.00 | 0.07 | 285 | 360 | 0.5 | 0.0 | 21.1 | 14.3 | 135 | 60 |
| G | 11 | B | -5.7 | 9.94 | <0.1 | 314.00 | -213.60 | 0.07 | 3 | 140 | 2.5 | 13.4 | 0.06 | 9.4 | 85 | 1 |
| J | 11 | B | -6.3 | 10.1 | <0.1 | 404.00 | -215.30 | 0.05 | 4 | 80 | 1.2 | 13.6 | 0.04 | 15.1 | 105 | 0 |
| G | 11 | G | -6.9 | 9.95 | <0.1 | 420.00 | -177.60 | 0.00 | 1 | 130 | 4.5 | 0.0 | 102 | 13.2 | 90 | 0 |
| J | 11 | G | -7.5 | 10.2 | <0.1 | 413.00 | -169.20 | 0.00 | 1 | 180 | 5.0 | 0.5 | 0.1 | 14.8 | 101 | 0 |
| G | 11 | Y | -8.1 | 10.05 | <0.1 | 483.00 | -180.30 | 0.00 | 3 | 220 | 6.0 | 0.0 | 0.06 | 18.9 | 101 | 0 |
| J | 11 | Y | -8.7 | 9.81 | <0.1 | 428.00 | 33.00 | 0.00 | 20 | 120 | 3.6 | 0.0 | 2.2 | 21.3 | 96 | 0 |
| G | 11 | R | -9.3 | 7.41 | <0.1 | 1074.00 | -101.50 | 0.06 | 213 | 360 | 0.0 | 0.0 | 20.1 | 14.8 | 127 | 43 |
| J | 11 | R | -9.9 | 7.44 | <0.1 | 1223.00 | -84.40 | 0.06 | 338 | 430 | 0.0 | 0.0 | 22.6 | 15.4 | 143 | 90 |
| G | 12 | B | -5.7 | 7.42 | 0.36 | 544.00 | -120.30 | 0.08 | 3 | 290 | 1.0 | 5.9 | 2.9 | 9.4 | 95 | 14 |
| J | 12 | B | -6.3 | 9.98 | <0.1 | 383.00 | -247.10 | 0.06 | 1 | 140 | 10.0 | 8.6 | 0.05 | 2 | 107 | 0 |
| G | 12 | G | -6.9 | 9.37 | <0.1 | 402.00 | -223.50 | 0.00 | 33 | 160 | 0.5 | 0.0 | 6.8 | 12.6 | 91 | 1 |

| J | 12 | G | -7.5 | 7.76 | <0.1 | 266.00 | -133.70 | 0.10 | 28 | 120 | 0.0 | 0.0 | 1.9 | 2.7 | 54 | 22 |
|---|----|---|------|------|------|--------|---------|------|-----|-----|-----|------|------|------|-----|-----|
| G | 12 | Y | -8.1 | 7.31 | <0.1 | 280.00 | -122.70 | 0.08 | 1 | 100 | 0.0 | 0.0 | 1.1 | 3.3 | 60 | 3 |
| J | 12 | Y | -8.7 | 7.42 | <0.1 | 949.00 | -112.70 | 0.09 | 172 | 410 | 0.0 | 0.0 | 19.9 | 15.2 | 107 | 132 |
| G | 12 | R | -9.3 | 7.38 | <0.1 | 1249.00 | -137.90 | 0.08 | 262 | 300 | 0.0 | 0.0 | 22.9 | 14.2 | 142 | 141 |
| J | 12 | R | -9.9 | 7.47 | <0.1 | 1216.00 | -127.80 | 0.00 | 329 | 390 | 0.0 | 0.0 | 21.8 | 14.1 | 144 | 159 |
| G | 14 | B | -5.7 | 7.35 | 0.30 | 393.00 | -138.10 | 0.06 | 4 | 200 | 0.0 | 26.4 | 2 | 44 | 71 | 35 |
| J | 14 | B | -6.3 | 8.78 | <0.1 | 311.00 | -198.70 | 0.24 | 15 | 90 | 0.0 | 4.7 | 0.4 | 2 | 93 | 5 |
| G | 14 | G | -6.9 | 8.93 | <0.1 | 449.00 | -215.30 | 0.00 | 34 | 220 | 0.0 | 0.0 | 0.3 | 10.4 | 87 | 5 |
| J | 14 | G | -7.5 | 6.95 | <0.1 | 580.00 | -99.80 | 1.90 | 117 | 210 | 0.0 | 27.8 | 9.9 | 5.9 | 51 | 98 |
| G | 14 | Y | -8.1 | 7.27 | <0.1 | 580.00 | -115.80 | 0.06 | 270 | 220 | 0.0 | 0.0 | 6.6 | 6.7 | 85 | 47 |
| J | 14 | Y | -8.7 | 7.28 | <0.1 | 1033.00 | -78.80 | 0.18 | 170 | 420 | 0.0 | 0.0 | 20 | 12.7 | 109 | 139 |
| G | 14 | R | -9.3 | 7.28 | <0.1 | 1280.00 | -130.90 | 0.00 | 332 | 250 | 0.0 | 0.0 | 23.8 | 14.5 | 145 | 155 |
| J | 14 | R | -9.9 | 7.23 | <0.1 | 1241.00 | -28.90 | 0.00 | 311 | 380 | 0.0 | 0.0 | 22.7 | 14.8 | 147 | 139 |
| G | 16 | B | -5.7 | 9.02 | 0.57 | 410 | 105.70 | 0.06 | 1 | 140 | 0.0 | 8.6 | 4.4 | 7.2 | 58 | 35 |
| J | 16 | B | -6.3 | 9.18 | <0.1 | 309.00 | -220.10 | 0.15 | 5 | 110 | 0.0 | 8.0 | 0.3 | 2 | 87 | 1 |
| G | 16 | G | -6.9 | 8.68 | <0.1 | 382.00 | -190.50 | 0.06 | 29 | 120 | 0.0 | 0.0 | 0.4 | 2.7 | 90 | 5 |
| J | 16 | G | -7.5 | 6.90 | <0.1 | 510.00 | -97.90 | 1.65 | 79 | 160 | 0.0 | 41.3 | 7 | 5.6 | 44 | 65 |
| G | 16 | Y | -8.1 | 7.14 | <0.1 | 754.00 | -122.10 |  | 164 | 180 | 0.0 | 0.0 | 13 | 8.5 | 93 | 84 |
| J | 16 | Y | -8.7 | 7.21 | <0.1 | 1120.00 | -108.50 | 0.06 | 181 | 280 | 0.0 | 0.0 | 21.2 | 13.4 | 123 | 121 |
| G | 16 | R | -9.3 | 7.29 | <0.1 | 1278.00 | -110.80 | 0.05 | 376 | 240 | 0.0 | 0.0 | 23.4 | 13.8 | 145 | 160 |
| J | 16 | R | -9.9 | 7.25 | <0.1 | 1220.00 | -76.10 | 0.00 | 335 | 240 | 0.0 | 0.0 | 22.4 | 14.4 | 145 | 121 |
| G | 18 | B | -5.7 | 7.30 | <0.1 | 389.00 | -152.00 | 0.00 | 1 | 170 |  | 11.7 | 4.8 | 8.1 | 47 | 44 |
| J | 18 | B | -6.3 | 8.16 | <0.1 | 316.00 | -152.50 | 0.10 | 11 | 120 |  | 12.8 | 1.2 | 2.8 | 64 | 8 |
| G | 18 | G | -6.9 | 7.10 | <0.1 | 701.00 | -135.00 | 0.06 | 21 | 100 |  | 0.0 | 0.4 | 2 | 98 | 2 |
| J | 18 | G | -7.5 | 6.98 | <0.1 | 750.00 | -122.30 | 1.88 | 139 | 250 |  | 20.0 | 16.1 | 8.3 | 80 | 121 |
| G | 18 | Y | -8.1 | 7.10 | <0.1 | 1233.00 | -118.00 | 0.05 | 158 | 270 |  | 0.0 | 17.5 | 9.8 | 100 | 98 |
| J | 18 | Y | -8.7 | 7.32 | <0.1 | 1130.00 | -131.30 | 0.00 | 180 | 300 |  | 0.0 | 21.3 | 14 | 124 | 136 |
| G | 18 | R | -9.3 | 7.10 | <0.1 | 1188.00 | -122.00 | 0.08 | 355 | 370 |  | 0.0 | 23.6 | 14.7 | 139 | 137 |
| J | 18 | R | -9.9 | 7.37 | <0.1 | 1235.00 | -113.50 | 0.00 | 352 | 240 |  | 0.0 | 21.8 | 13.8 | 144 | 133 |

**Dec 03**

**ALK (mg/L as CaCO3)**

| Distance (m) | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 360 | 195 | 425 | 380 | 245 |
| -6.3 | 320 | 95 | 465 | 255 | 235 |
| -6.9 | 335 | 195 | 155 | 555 | 445 |
| -7.5 | 310 | 230 | 195 | 445 | 260 |
| -8.1 | 325 | 95 | 100 | 320 | 450 |
| -8.7 | 335 | 145 | 180 | 575 | 365 |
| -9.3 | 335 | 195 | 105 | 230 | 350 |
| -9.9 | 360 | 230 | 240 | 180 | 310 |

**Conductivity**

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 599 | 974 | 1540 | 508 | 668 |
| -6.3 | 742 | 477 | 1184 | 466 | 574 |
| -6.9 | 785 | 808 | 800 | 1288 | 761 |
| -7.5 | 810 | 1011 | 946 | 780 | 1047 |
| -8.1 | 809 | 1001 | 1066 | 1020 | 1056 |
| -8.7 | 811 | 859 | 741 | 1087 | 1008 |
| -9.3 | 599 | 997 | 1063 | 1045 | 1014 |
| -9.9 | 970 | 861 | 905 | 790 | 822 |

**Fe2+ (mg/L)**

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 1.82 | 3.91 | 4.42 | 0.36 | 1.9 |
| -6.3 | 2.92 | | 5 | 2.04 | 1.35 |
| -6.9 | 2.6 | 4.68 | 4.66 | 2.3 | 1.94 |
| -7.5 | 2.48 | 3.73 | 4.96 | 3.08 | 1.33 |
| -8.1 | 1.61 | 3.43 | 4.87 | 0.96 | 0.59 |
| -8.7 | 1.91 | 4.38 | 3.95 | 1.53 | 0.88 |
| -9.3 | 0.6 | 4.51 | 5 | 2.07 | 0.94 |
| -9.9 | 1.63 | 4.62 | 3.38 | 3.34 | 0.76 |

**pH**

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 7.1 | 7.9 | 6.2 | 7.9 | 6.9 |
| -6.3 | 7 | 9.7 | 6.2 | 7.3 | 6.7 |
| -6.9 | 7.2 | 7.9 | 8 | 6.8 | 6.9 |
| -7.5 | 7.1 | 7.9 | 7.8 | 6.4 | 6.9 |
| -8.1 | 7.2 | 8.5 | 8.7 | 6.8 | 7.1 |
| -8.7 | 7.1 | 8.4 | 8.1 | 6.1 | 6.9 |
| -9.3 | 7.2 | 7.2 | 6 | 7.2 | 7 |
| -9.9 | 7.1 | 6 | 5.9 | 5.1 | 6.8 |

**Groundwater Flow -->**

**DO(mg/L)**

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 1.8 | 0 | 0 | 0 | 0 |
| -6.3 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 0 | 0 | 0 | 0 | 0 |
| -9.9 | 0 | 0 | 0 | 0 | 0 |

**Eh (mv)**

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | -75 | -317 | -145 | -171 | -142 |
| -6.3 | -118 | -470 | -100 | -155 | -152 |
| -6.9 | -74 | -330 | -343 | -177 | -151 |
| -7.5 | -125 | -325 | -390 | -185 | -192 |
| -8.1 | -85 | -370 | -340 | -177 | -101 |
| -8.7 | -121 | -340 | -454 | -120 | -183 |
| -9.3 | -75 | -252 | -77 | -79 | -78 |
| -9.9 | -85 | -26 | -73 | -25 | -189 |

Dec 03

**Sulfate (mg/L)**

|      | 8   | 10  | 11  | 12  | 14  |
| ---- | --- | --- | --- | --- | --- |
| -5.7 | 157 | 71  | 59  | 248 | 154 |
| -6.3 | 184 | 37  | 52  | 129 | 150 |
| -6.9 | 198 | 90  |     | 173 | 232 |
| -7.5 | 174 | 89  | 172 | 182 | 194 |
| -8.1 | 214 | 85  | 18  | 150 | 247 |
| -8.7 | 200 | 115 | 98  | 78  | 235 |
| -9.3 | 244 | 88  | 119 | 222 | 214 |
| -9.9 | 248 | 121 | 176 | 183 | 251 |

**Nitrate (mg/L)**

|      | 8    | 10  | 11  | 12  | 14   |
| ---- | ---- | --- | --- | --- | ---- |
| -5.7 | 10.0 | 0.0 | 0.0 | 0.2 | 12.7 |
| -6.3 | 13.2 | 0.2 | 0.2 | 0.3 | 8.9  |
| -6.9 | 2.2  | 0.8 |     | 0.1 | 0.1  |
| -7.5 | 3.8  | 0.5 | 0.3 | 2.8 | 0.3  |
| -8.1 | 0.9  | 0.5 | 0.7 | 0.2 | 0.1  |
| -8.7 | 0.7  | 0.5 | 0.3 | 0.3 | 0.2  |
| -9.3 | 1.5  | 0.9 | 0.4 | 0.2 | 0.3  |
| -9.9 | 0.9  | 0.6 | 0.3 | 0.3 | 0.4  |

**Bromide (mg/L)**

|      | 8    | 10   | 11   | 12   | 14   |
| ---- | ---- | ---- | ---- | ---- | ---- |
| -5.7 | 0.14 | 0.00 | 0.00 | 0.29 | 0.15 |
| -6.3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 |
| -6.9 | 0.22 | 0.19 | 0.00 | 0.00 | 0.20 |
| -7.5 | 0.17 | 0.22 | 0.21 | 0.18 | 0.00 |
| -8.1 | 0.26 | 0.15 | 0.00 | 0.00 | 0.00 |
| -8.7 | 0.21 | 0.22 | 0.22 | 0.00 | 0.27 |
| -9.3 | 0.41 | 0.19 | 0.00 | 0.00 | 0.46 |
| -9.9 | 0.30 | 0.18 | 0.00 | 0.00 | 0.32 |

Feb 04 — ALK (mg/L as CaCO3)

| Distance (m) | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 330 | 90 | 170 | 215 | 385 |
| -6.3 | 330 | 65 | 135 | 600 | 375 |
| -6.9 | 385 | 100 | 180 | 150 | 230 |
| -7.5 | 355 | 65 | 65 | 430 | 735 |
| -8.1 | 360 | 110 | 150 | 145 | 675 |
| -8.7 | 390 | 80 | 125 | 240 | 410 |
| -9.3 | 385 | 280 | 485 | 370 | 245 |
| -9.9 | 390 | 415 | 380 | 450 | 360 |

Conductivity

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 752 | 348 | 754 | 568 | 842 |
| -6.3 | 850 | 313 | 490 | 662 | 1142 |
| -6.9 | 890 | 354 | 383 | 359 | 454 |
| -7.5 | 903 | 377 | 316 | 1430 | 1720 |
| -8.1 | 906 | 378 | 438 | 1634 | 1371 |
| -8.7 | 957 | 400 | 685 | 645 | 1205 |
| -9.3 | 1028 | 636 | 860 | 717 | 871 |
| -9.9 | 1129 | 1015 | 1030 | 1041 | 1113 |

Fe2+ (mg/L)

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 0.5 | 0.06 | 4.85 | 4.46 | 3.21 |
| -6.3 | 0.08 | 0.05 | 5.09 | 2.13 | 3.04 |
| -6.9 | 0.38 | 0.09 | 0.04 | 3.71 | 2.13 |
| -7.5 | 0.44 | 0.05 | 0.05 | 4.44 | 4.44 |
| -8.1 | 0.61 | 1.93 | 0.04 | 3.73 | 2.77 |
| -8.7 | 0.32 | 2.41 | 4.36 | 3.58 | 4.6 |
| -9.3 | 0.4 | 2.96 | 4.2 | 4.35 | 3.14 |
| -9.9 | 0.33 | 0.31 | 0.12 | 0.64 | 0.61 |

pH

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 7.2 | 9.9 | 7.2 | 7 | 7 |
| -6.3 | 7.2 | 9.2 | 7.5 | 7 | 6.9 |
| -6.9 | 7.2 | 10.1 | 9.1 | 7.2 | 6.9 |
| -7.5 | 7.1 | 9.9 | 9.7 | 6.5 | 6.5 |
| -8.1 | 7.2 | 9.8 | 7.9 | 6.5 | 6.5 |
| -8.7 | 7 | 9.1 | 7 | 5.9 | 6.1 |
| -9.3 | 7.2 | 8.6 | 7.1 | 6.5 | 6 |
| -9.9 | 7.2 | 7.5 | 7.1 | 6.8 | 7.2 |

Groundwater Flow -->

SULFATE (mg/L)

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 126 | 56 | 1 | 0 | 52 |
| -6.3 | 188 | 50 | 1 | 0 | 12 |
| -6.9 | 213 | 56 | 49 | 1 | 0 |
| -7.5 | 217 | 91 | 33 | 0 | 0 |
| -8.1 | 233 | 40 | 24 | 0 | 1 |
| -8.7 | 195 | 28 | 45 | 6 | 7 |
| -9.3 | 281 | 87 | 5 | 0 | 57 |
| -9.9 | 325 | 223 | 263 | 228 | 160 |

NITRATE (mg/L)

| | 8 | 10 | 11 | 12 | 14 |
|---|---|---|---|---|---|
| -5.7 | 11.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| -6.3 | 11.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| -6.9 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| -7.5 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| -8.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| -8.7 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| -9.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| -9.9 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |

**Mar 04**

**ALK (mg/L as CaCO3)**

| Distance (m) | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 364 | 120 | 36 | 39 | 156 | 332 | 352 |
| -6.3 | 392 | 136 | 92 | 38 | 152 | 272 | 352 |
| -6.9 | 772 | 140 | 196 | 38 | 152 | 148 | 320 |
| -7.5 | 408 | 132 | 88 | 39 | 156 | 548 | 436 |
| -8.1 | 436 | 100 | 156 | 96 | 384 | 712 | 552 |
| -8.7 | 384 | 88 | 96 | 68 | 272 | 416 | 508 |
| -9.3 | 416 | 280 | 448 | 102 | 408 | 296 | 372 |
| -9.9 | 396 | 488 | 428 | 105 | 420 | 364 | 356 |

**Conductivity**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 710 | 288 | 206 | 377 | 645 | 672 | 605 |
| -6.3 | 816 | 301 | 218 | 404 | 746 | 724 | 875 |
| -6.9 | 842 | 342 | 363 | 245 | 268 | 299 | 708 |
| -7.5 | 818 | 379 | 259 | 1475 | 1420 | 1148 | 1256 |
| -8.1 | 840 | 320 | 353 | 965 | 916 | 1042 | 931 |
| -8.7 | 1029 | 373 | 326 | 671 | 566 | 650 | 758 |
| -9.3 | 968 | 732 | 1025 | 1010 | 1005 | 611 | 650 |
| -9.9 | 1030 | 966 | 967 | 1006 | 1047 | 760 | 510 |

**Fe2+ (mg/L)**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0.03 | 0.01 | 0.1 | 2.9 | 3.41 | 2.8 | 2.9 |
| -6.3 | 0.06 | 0.01 | 0.56 | 1.3 | 2.7 | 3.3 | 4.8 |
| -6.9 | 0.07 | 0.09 | 0.02 | 0.13 | 0.11 | 0.23 | 5.8 |
| -7.5 | 0.09 | 0.01 | 0.05 | 3.6 | 3.7 | 2.7 | 7.5 |
| -8.1 | 1 | 0.08 | 0.06 | 4.7 | 4 | 4.7 | 4.9 |
| -8.7 | 0.28 | 0.03 | 0.03 | 4.4 | 4.3 | 4.7 | 2.5 |
| -9.3 | 0.29 | 2.9 | 1.9 | 2.8 | 4.5 | 5 | 4.8 |
| -9.9 | 0.13 | 0.73 | 0.23 | 0.12 | 0.87 | 4.3 | 4.6 |

**pH**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 7 | 10.2 | 8.1 | 7.2 | 7 | 7.2 | 7.2 |
| -6.3 | 7 | 10.3 | 7.5 | 7 | 6.7 | 7 | 6.9 |
| -6.9 | 7 | 10.1 | 9.9 | 8 | 7.5 | 7.5 | 7.2 |
| -7.5 | 7 | 10 | 10.1 | 6.9 | 6.4 | 6.6 | 6.5 |
| -8.1 | 7 | 10.4 | 10.4 | 6.3 | 6.4 | 6.6 | 6.4 |
| -8.7 | 7 | 9.8 | 9.9 | 5.9 | 6.1 | 6.5 | 6.8 |
| -9.3 | 7 | 8.2 | 7.4 | 6.9 | 6.7 | 6.9 | 7 |
| -9.9 | 7 | 7 | 7.1 | 6.9 | 7.1 | 7.4 | 7 |

**TNT (ug/L)**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 136 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 120 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 91 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 88 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 25 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 51 | 0 | 0 | 0 | 1 | 0 | 0 |
| -9.3 | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.9 | 37 | 0 | 0 | 0 | 11 | 0 | 0 |

**Eh (mv)**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | -38 | -408 | -295 | -215 | -182 | -178 | -186 |
| -6.3 | -36 | -378 | -260 | -175 | -149 | -149 | -158 |
| -6.9 | -65 | -418 | -369 | -295 | -224 | -223 | -208 |
| -7.5 | -56 | -363 | -435 | -118 | -130 | -122 | -148 |
| -8.1 | -86 | -453 | -428 | -114 | -125 | -122 | -119 |
| -8.7 | -57 | -361 | -387 | -73 | -107 | -102 | -165 |
| -9.3 | -57 | -338 | -232 | -160 | -147 | -111 | -149 |
| -9.9 | -39 | -192 | -226 | -195 | -118 | -144 | -147 |

Jun 04

| Fe2+ | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 0 | 0 | 0.91 | 3.5 | 3.17 | 3.92 |
| -6.3 | 0 | 0 | 0.02 | 0.35 | 0.65 | 1.31 | 0.83 |
| -6.9 | 0 | 0 | 0 | 0.04 | 0 | 0.04 | 0.37 |
| -7.5 | 0 | 0 | 0 | 3.3 | 4.52 | 5.1 | 5.1 |
| -8.1 | 0.11 | 0 | 0 | 2.22 | 3.34 | 4.13 | 1.06 |
| -8.7 | 0 | 0 | 0 | 9.6 | 4.45 | 1.9 | 0.73 |
| -9.3 | 0.04 | 0.02 | 2.3 | 2 | 2.94 | 2.28 | 0.83 |
| -9.9 | 0.15 | 0.9 | 0.06 | 0.04 | 0.36 | 0.63 | 1.02 |

| pH | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 7.1 | 10.2 | 10.2 | 8 | 7.3 | 6.9 | 6.9 |
| -6.3 | 7.1 | 10.4 | 10.1 | 7.3 | 7 | 7 | 6.7 |
| -6.9 | 7.1 | 10.1 | 10.1 | 8.5 | 7.9 | 7.3 | 7.2 |
| -7.5 | 7.2 | 10 | 10.2 | 6.8 | 6.6 | 6.3 | 6.4 |
| -8.1 | 7.2 | 10.3 | 10.3 | 6.7 | 6.7 | 6.4 | 6.7 |
| -8.7 | 7.3 | 10.1 | 10.2 | 6.8 | 6.8 | 6.8 | 6.8 |
| -9.3 | 7.1 | 8.5 | 8.4 | 7.1 | 7 | 6.8 | 7.1 |
| -9.9 | 7.2 | 8.3 | 7.2 | 7 | 7 | 7.1 | 6.9 |

| Eh | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | -50 | -412 | -336 | -208 | -173 | -150 | -163 |
| -6.3 | -65 | -342 | -294 | -150 | -136 | -163 | -142 |
| -6.9 | -62 | -413 | -329 | -275 | -195 | -185 | -194 |
| -7.5 | -82 | -304 | -297 | -103 | -103 | -92 | -128 |
| -8.1 | -81 | -453 | -360 | -102 | -83 | -96 | -129 |
| -8.7 | -88 | -342 | -306 | -120 | -115 | -107 | -149 |
| -9.3 | -59 | -305 | -155 | -123 | -98 | -97 | -120 |
| -9.9 | -100 | -162 | -129 | -108 | -88 | -97 | -127 |

| cond | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 729 | 330 | 321 | 240 | 395 | 517 | 582 |
| -6.3 | 790 | 330 | 313 | 256 | 363 | 318 | 330 |
| -6.9 | 797 | 350 | 391 | 265 | 269 | 272 | 265 |
| -7.5 | 790 | 381 | 329 | 755 | 839 | 1103 | 978 |
| -8.1 | 885 | 361 | 358 | 576 | 820 | 896 | 875 |
| -8.7 | 851 | 372 | 317 | 814 | 845 | 928 | 938 |
| -9.3 | 990 | 723 | 927 | 1031 | 518 | 1036 | 1060 |
| -9.9 | 1053 | 1027 | 1027 | 1046 | 1059 | 1065 | 1058 |

| nh3 | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 0 | 1.2 | 0.37 | 0.09 | 0.08 | 0.05 |
| -6.3 | 0.17 | 0.23 | 1.3 | 1.7 | 0.03 | 0.03 | 0.04 |
| -6.9 | 0.58 | 0.07 | 0.49 | 0.4 | 0.23 | 0.16 | 0.6 |
| -7.5 | 0.47 | 0.2 | 0.9 | 0.63 | 0.2 | 0.08 | 0.43 |
| -8.1 | 0.6 | 0.5 | 0.12 | 0.9 | 0.95 | 0.9 | 0.48 |
| -8.7 | 0.55 | 0.4 | 0.9 | 2.3 | 2.1 | 4.7 | 2.8 |
| -9.3 | 0.5 | 0.6 | 1.1 | 1.9 | 1.9 | 1.4 | 1.5 |
| -9.9 | 0.52 | 0.9 | 0.8 | 0.79 | 0.46 | 0.45 | 0.36 |

| alk | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 284 | 112 | 108 | 96 | 188 | 228 | 316 |
| -6.3 | 308 | 100 | 108 | 92 | 164 | 152 | 120 |
| -6.9 | 252 | 140 | 172 | 108 | 120 | 124 | 108 |
| -7.5 | 312 | 136 | 116 | 200 | 684 | 536 | 372 |
| -8.1 | 352 | 120 | 116 | 204 | 248 | 444 | 356 |
| -8.7 | 328 | 116 | 100 | 260 | 284 | 304 | 300 |
| -9.3 | 308 | 176 | 264 | 304 | 284 | 308 | 320 |
| -9.9 | 304 | 320 | 320 | 296 | 360 | 320 | 332 |

Jun 04
Fe(tot)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 0.03 | 0.05 | 2.31 | 4.6 | 27 | 5.5 |
| -6.3 | 0.01 | 0.03 | 0.1 | 1.24 | 1.08 | 2.54 | 1.25 |
| -6.9 | 0.13 | 0.05 | 0.15 | 0.61 | 0.6 | 1.1 | 1.07 |
| -7.5 | 0.08 | 0.03 | 0.22 | 4 | 10.01 | 6.7 | 8 |
| -8.1 | 0.6 | 0.04 | 0.04 | 2.81 | 3.84 | 4.8 | 1.06 |
| -8.7 | 0.15 | 0.05 | 0.04 | 16.2 | 5.5 | 2.5 | 1.23 |
| -9.3 | 0.21 | 3.68 | 2.9 | 0.98 | 3.47 | 2.64 | 1.18 |
| -9.9 | 0.21 | 1.34 | 0.44 | 0.31 | 0.59 | 1.34 | 2.19 |

Aug 04

**Fe2+**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 0 | 0 | 0.78 | 0.45 | 0.81 | 0.97 |
| -6.3 | 0 | 0 | 0 | 0.4 | 0.12 | 0.32 | 0.25 |
| -6.9 | 0 | 0 | 0 | 0 | 0.05 | 0.22 | 0.03 |
| -7.5 | 0 | 0 | 0.06 | 1 | 0.86 | 0.85 | 0.35 |
| -8.1 | 0.06 | 0 | 0 | 0.9 | 0.28 | 1.03 | 0.29 |
| -8.7 | 0.03 | 0 | 0.03 | 1.13 | 1.1 | 0.71 | 0.49 |
| -9.3 | 0.13 | 0 | 0.02 | 0.1 | 0.26 | 0.97 | 0.85 |
| -9.9 | 0 | 0.52 | 0.1 | 0.18 | 0.32 | 0.41 | 0.14 |

**pH**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 7.1 | 9.7 | 9.8 | 7.9 | 7.8 | 7.2 | 7.2 |
| -6.3 | 7.1 | 9.7 | 9.7 | 7.4 | 7.1 | 6.8 | 7 |
| -6.9 | 7.1 | 9.7 | 9.6 | 8.2 | 8 | 7.2 | 7.4 |
| -7.5 | 7.1 | 9.3 | 9.6 | 7.1 | 6.7 | 6.4 | 6.7 |
| -8.1 | 7.1 | 9.5 | 9.3 | 6.9 | 7.1 | 7 | 6.8 |
| -8.7 | 7.1 | 8.9 | 9 | 7.2 | 7 | 7 | 7.1 |
| -9.3 | 7.1 | 9.4 | 8.3 | 7.2 | 7.1 | 7.4 | 7.1 |
| -9.9 | 7.1 | 7.6 | 7.3 | 7.2 | 7.1 | 7.2 | 7.1 |

**Eh**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | -55 | -360 | -319 | -191 | -172 | -138 | -124 |
| -6.3 | -60 | -339 | -302 | -150 | -123 | -136 | -108 |
| -6.9 | -68 | -359 | -301 | -252 | -238 | -154 | -148 |
| -7.5 | -67 | -318 | -289 | -110 | -76 | -102 | -88 |
| -8.1 | -66 | -404 | -323 | -87 | -91 | -91 | -97 |
| -8.7 | -68 | -338 | -296 | -109 | -97 | -118 | -92 |
| -9.3 | -57 | -345 | -150 | -104 | -98 | -84 | -97 |
| -9.9 | -68 | -146 | -99 | -105 | -88 | -91 | -88 |

**cond**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 786 | 350 | 358 | 426 | 319 | 345 | 505 |
| -6.3 | 830 | 371 | 373 | 247 | 280 | 1205 | 308 |
| -6.9 | 840 | 370 | 420 | 286 | 250 | 247 | 261 |
| -7.5 | 850 | 379 | 377 | 390 | 1259 | 1202 | 841 |
| -8.1 | 862 | 357 | 365 | 587 | 606 | 842 | 887 |
| -8.7 | 872 | 376 | 337 | 796 | 885 | 990 | 1008 |
| -9.3 | 1017 | 436 | 622 | 968 | 1074 | 1094 | 1077 |
| -9.9 | 1117 | 1016 | 1034 | 1076 | 1076 | 1270 | 1088 |

**nh3**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 0 | 0.79 | 0.3 | 0 | 0 | 0 |
| -6.3 | 0.12 | 0.01 | 0.6 | 0.9 | 0.18 | 0 | 0.02 |
| -6.9 | 0.41 | 0.2 | 0.06 | 0.29 | 0 | 0 | 0.15 |
| -7.5 | 0.47 | 0.06 | 0.54 | 0.51 | 2.8 | 0.05 | 0.03 |
| -8.1 | 0.79 | 0.48 | 0.38 | 1.2 | 0.7 | 0.18 | 0.14 |
| -8.7 | 1 | 0.52 | 0.9 | 3.5 | 0.18 | 0.25 | 2 |
| -9.3 | 0.51 | 0.48 | 0.49 | 0.93 | 1.8 | 1.5 | 0.65 |
| -9.9 | 0.57 | 0.86 | 1 | 0.6 | 0.32 | 0.33 | 0.38 |

**alk**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 270 | 125 | 135 | 170 | 140 | 165 | 325 |
| -6.3 | 270 | 110 | 115 | 80 | 90 | 125 | 130 |
| -6.9 | 305 | 150 | 130 | 105 | 140 | 85 | 150 |
| -7.5 | 270 | 150 | 155 | 160 | 690 | 675 | 535 |
| -8.1 | 265 | 125 | 115 | 170 | 210 | 485 | 400 |
| -8.7 | 260 | 105 | 130 | 265 | 260 | 350 | 400 |
| -9.3 | 320 | 115 | 260 | 320 | 350 | 345 | 385 |
| -9.9 | 270 | 290 | 245 | 295 | 370 | 405 | 385 |

Aug 04

| Sulfate | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 170 | 0 | 2 | 3 | 1 | 1 | 1 |
| -6.3 | 160 | 1 | 2 | 4 | 3 | 5 | 4 |
| -6.9 | 217 | 25 | 0 | 3 | 2 | 23 | 17 |
| -7.5 | 200 | 1 | 0 | 2 | 9 | 6 | 32 |
| -8.1 | 258 | 9 | 2 | 38 | 36 | 206 | 182 |
| -8.7 | 220 | 5 | 4 | 40 | 242 | 287 | 273 |
| -9.3 | 328 | 46 | 44 | 246 | 356 | 356 | 386 |
| -9.9 | 380 | 215 | 227 | 176 | 374 | 380 | 295 |

| Nitrate | 8 | 10 | 11 | 12 |
|---|---|---|---|---|
| -5.7 | 11.3 | <0.5 | <0.5 | <0.5 |
| -6.3 | 6.7 | <0.5 | <0.5 | <0.5 |
| -6.9 | 5.1 | <0.5 | 0.5 | <0.5 |
| -7.5 | 11.9 | <0.5 | <0.5 | <0.5 |
| -8.1 | <0.5 | <0.5 | <0.5 | 0.5 |
| -8.7 | <0.5 | <0.5 | <0.5 | <0.5 |
| -9.3 | <0.5 | <0.5 | <0.5 | <0.5 |
| -9.9 | <0.5 | 1.1 | <0.5 | <0.5 |

| Sulfide | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 0 | 0.128 | 0 | 0 | 0 | 0 |
| -6.3 | 0 | 0 | 0.233 | 0 | 0 | 0 | 0.032 |
| -6.9 | 0 | 0 | 0 | 0.014 | 0 | 0.011 | 0 |
| -7.5 | 0 | 0 | 0.008 | 0.032 | 0 | 0 | 0.099 |
| -8.1 | 0 | 0 | 0 | 0 | 0.044 | 0.009 | 0.006 |
| -8.7 | 0 | 0 | 0.025 | 0.023 | 0 | 0 | 0.012 |
| -9.3 | 0 | 0 | 0.038 | 0.023 | 0.017 | 0 | 0.021 |
| -9.9 | 0 | 0 | 0.066 | 0.007 | 0 | 0 | 0 |

TNT (ug/L) #####

| Depth | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 112 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.3 | 109 | 0 | 0 | 0 | 0 | 0 | 0 |
| -6.9 | 58 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 97 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.1 | 12 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 65 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 27 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.9 | 20 | 0 | 0 | 0 | 12 | 7 | 4 |

Nov-04

**Fe2+**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 0 | 0 | 0 | 1.8 | 1 | 0.2 |
| -6.3 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0 |
| -6.9 | 0 | 0.1 | 0 | 0 | 0.2 | 0 | 0.1 |
| -7.5 | 0 | 0 | 0 | 0.2 | 2.4 | 2.9 | 2.5 |
| -8.1 | 0 | 0 | 0 | 1.4 | 1.3 | 0.4 | 0 |
| -8.7 | 0 | 0 | 0 | 0.9 | 1.1 | 0 | 0 |
| -9.3 | 0 | 1.4 | 0.1 | 0 | 0.2 | 0.7 | 0.3 |
| -9.9 | 0 | 0.4 | 0 | 0.1 | 0.1 | 0.1 | 0 |

**pH**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 6.9 | 9.7 | 9.8 | ns | 7.2 | 6.9 | 7 |
| -6.3 | 7 | 9.6 | 9.7 | 7.6 | 7.2 | 7.2 | 6.9 |
| -6.9 | 6.9 | 9.6 | 9.6 | 9 | 8.6 | 7.7 | 7.7 |
| -7.5 | 7 | 9.5 | 9.7 | 6.9 | 6.5 | 6.6 | 6.8 |
| -8.1 | 7 | 9.4 | 9.5 | 6.9 | 6.8 | 6.8 | 6.9 |
| -8.7 | 7 | 9.4 | 9.6 | 7 | 6.9 | 7 | 7.1 |
| -9.3 | 7 | 8 | 7.4 | 7.1 | 7 | 6.9 | 6.9 |
| -9.9 | 7 | 7.1 | 7 | 7 | 7 | 7 | 7.1 |

**Eh**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | -56 | -384 | -379 | ns | -211 | -133 | -135 |
| -6.3 | -81 | -344 | -327 | -235 | -204 | -206 | -182 |
| -6.9 | -86 | -390 | -365 | -331 | -326 | -266 | -242 |
| -7.5 | -95 | -327 | -329 | -183 | -154 | -158 | -168 |
| -8.1 | -104 | -418 | -393 | -187 | -178 | -189 | -180 |
| -8.7 | -104 | -358 | -339 | -179 | -157 | -162 | -151 |
| -9.3 | -86 | -323 | -235 | -204 | -181 | -169 | -152 |
| -9.9 | -104 | -216 | -189 | -171 | -123 | -110 | -98 |

**cond**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 808 | 318 | 360 | ns | 446 | 356 | 434 |
| -6.3 | 851 | 345 | 336 | 260 | 266 | 268 | 270 |
| -6.9 | 851 | 390 | 425 | 346 | 328 | 305 | 321 |
| -7.5 | 871 | 405 | 368 | 332 | 972 | 805 | 813 |
| -8.1 | 882 | 405 | 399 | 528 | 726 | 540 | 723 |
| -8.7 | 927 | 417 | 420 | 901 | 914 | 972 | 1022 |
| -9.3 | 1091 | 758 | 1140 | 1144 | 1157 | 1186 | 1192 |
| -9.9 | 1192 | 1125 | 1161 | 1162 | 1184 | 1161 | 1148 |

**Sulfate**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 264 | 38 | 1 | 0 | 10 | 0 | 1 |
| -6.3 | 264 | 0 | 3 | 1 | 1 | 1 | 0 |
| -6.9 | 206 | 0 | 0 | 5 | 3 | 2 | 1 |
| -7.5 | 206 | 0 | 1 | 0 | 10 | 0 | 52 |
| -8.1 | 308 | 0 | 3 | 77 | 155 | 60 | 130 |
| -8.7 | 308 | 0 | 4 | 22 | 254 | 283 | 346 |
| -9.3 | 409 | 169 | 305 | 325 | 359 | 325 | 351 |
| -9.9 | 403 | 315 | 353 | 386 | 346 | 365 | 356 |

**alk**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 310 | 105 | 145 | 135 | 235 | 115 | 135 |
| -6.3 | 285 | 140 | 155 | 105 | 160 | 165 | 100 |
| -6.9 | 320 | 185 | 170 | 170 | 135 | 525 | 360 |
| -7.5 | 295 | 170 | 190 | 135 | 540 | 135 | 435 |
| -8.1 | 305 | 165 | 140 | 175 | 325 | 340 | 225 |
| -8.7 | 315 | 150 | 165 | 325 | 340 | 255 | 365 |
| -9.3 | 355 | 220 | 320 | 365 | 330 | 340 | 380 |

**Ca++**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 172 | 1 | 1 | 1 | 8 | 55 | 79 |
| -6.3 | 163 | 1 | 1 | 2 | 2 | 18 | 65 |
| -6.9 | 162 | 1 | 1 | 2 | 9 | 59 | 178 |
| -7.5 | 145 | 1 | 1 | 40 | 171 | 152 | 173 |
| -8.1 | 163 | 1 | 1 | 63 | 171 | 185 | 128 |
| -8.7 | 164 | 2 | 1 | 90 | 138 | 133 | 184 |
| -9.3 | 165 | 39 | 172 | 174 | 183 | 168 | 164 |
| -9.9 | 150 | 184 | 176 | 143 | 184 | 125 | 159 |

## April 05

### Fe2+

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | | | 0.01 | | | | |
| -6.3 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| -6.9 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| -7.5 | 0.01 | 0.01 | 0.01 | 0.07 | 1.23 | 1.51 | 0.07 |
| -8.1 | 0.05 | 0.01 | 0.01 | 0.59 | 0.52 | 0.33 | 0.04 |
| -8.7 | 0.02 | 0.01 | 0.01 | 0.05 | 0.26 | 0.07 | 0.01 |
| -9.3 | 0.01 | 1.40 | 0.81 | 0.06 | 0.21 | 0.09 | 0.06 |
| -9.9 | 0.08 | 0.11 | 0.08 | 0.01 | 0.01 | 0.01 | 0.01 |

### pH

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | | | 10.5 | | | | |
| -6.3 | 7.3 | 10.2 | 10.1 | 9.7 | 7.7 | 7.7 | 7.7 |
| -6.9 | 7.2 | 10.0 | 10.1 | 9.8 | 9.4 | 8.9 | 9.0 |
| -7.5 | 7.3 | 10.0 | 10.4 | 7.5 | 7.0 | 7.1 | 7.2 |
| -8.1 | 7.2 | 10.3 | 10.4 | 7.7 | 7.5 | 7.3 | 7.5 |
| -8.7 | 7.4 | 10.0 | 10.0 | 7.3 | 7.2 | 7.3 | 7.4 |
| -9.3 | 7.3 | 8.1 | 7.8 | 8.2 | 7.6 | 7.6 | 7.7 |
| -9.9 | 7.1 | 7.5 | 7.5 | 7.3 | 7.3 | 7.3 | 7.4 |

### Eh

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | ✕ | | -282 | | | | |
| -6.3 | ✕ | -265 | -224 | -231 | -163 | -146 | -143 |
| -6.9 | ✕ | -317 | -280 | -303 | -236 | -209 | -206 |
| -7.5 | ✕ | -269 | -252 | -158 | -127 | -110 | -114 |
| -8.1 | ✕ | -372 | -286 | -156 | -90 | -120 | -123 |
| -8.7 | ✕ | -290 | -276 | -159 | -129 | -108 | -114 |
| -9.3 | ✕ | -295 | -209 | -169 | -72 | -104 | -110 |
| -9.9 | ✕ | -189 | -157 | -155 | -89 | -60 | -75 |

impacted by tracer injection

### cond

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | | | 370 | | | | |
| -6.3 | 820 | 336 | 340 | 336 | 272 | 285 | 271 |
| -6.9 | 876 | 370 | 438 | 361 | 337 | 320 | 300 |
| -7.5 | 873 | 410 | 394 | 253 | 679 | 624 | 887 |
| -8.1 | 874 | 401 | 415 | 606 | 853 | 820 | 946 |
| -8.7 | 939 | 422 | 389 | 913 | 986 | 1067 | 1043 |
| -9.3 | 1074 | 471 | 998 | 1153 | 1177 | 1176 | 1148 |
| -9.9 | 1161 | 1126 | 1115 | 1129 | 1175 | 1174 | 1160 |

### Sulfate

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | | | 0 | | | | |
| -6.3 | 344 | 0 | 0 | 6 | 8 | 3 | 2 |
| -6.9 | 353 | 0 | 9 | 6 | 7 | 6 | 0 |
| -7.5 | 358 | 0 | 0 | 8 | 182 | 111 | 255 |
| -8.1 | 350 | 0 | 0 | 222 | 288 | 376 | 326 |
| -8.7 | 367 | 11 | 7 | 332 | 341 | 341 | 361 |
| -9.3 | 436 | 318 | 380 | 379 | 390 | 381 | 400 |
| -9.9 | 440 | 401 | 399 | 380 | 373 | 350 | 369 |

### alk

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | | | 148 | | | | |
| -6.3 | 232 | 124 | 116 | 144 | 96 | 116 | 104 |
| -6.9 | 224 | 120 | 124 | 160 | 148 | 112 | 104 |
| -7.5 | 276 | 152 | 104 | 112 | 192 | 228 | 248 |
| -8.1 | 272 | 100 | 120 | 132 | 212 | 216 | 284 |
| -8.7 | 244 | 132 | 152 | 264 | 276 | 284 | 312 |
| -9.3 | 232 | 216 | 252 | 260 | 288 | 284 | 280 |
| -9.9 | 268 | 296 | 248 | 316 | 296 | 272 | 280 |

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**Fe2+ (m**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 |
| -6.3 | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 |
| -6.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 |
| -7.5 | 0.0 | 0.0 | 0.0 | 0.1 | 1.9 | 1.7 | 1.9 |
| -8.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.1 |
| -8.7 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.1 | 0.0 |
| -9.3 | 0.0 | 1.0 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 |
| -9.9 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |

**pH**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 7.1 | 9.9 | 9.9 | 7.4 | 7.4 | 9.0 | 7.3 |
| -6.3 | 7.1 | 10.1 | 10.1 | 10.0 | 8.8 | 9.2 | 8.2 |
| -6.9 | 7.2 | 9.7 | 10.0 | 9.4 | 8.9 | 8.7 | 7.1 |
| -7.5 | 7.2 | 9.8 | 10.2 | 7.8 | 7.0 | 6.9 | 7.0 |
| -8.1 | 7.2 | 9.8 | 10.1 | 7.3 | 7.3 | 7.1 | 7.1 |
| -8.7 | 7.2 | 9.9 | 9.8 | 7.4 | 7.3 | 7.2 | 7.3 |
| -9.3 | 7.4 | 7.9 | 7.4 | 7.4 | 7.3 | 7.3 | 7.1 |
| -9.9 | 7.2 | 7.3 | 7.4 | 7.5 | 7.2 | 7.3 | 7.4 |

**Eh**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | -27 | -271 | -214 | -120 | -138 | 106 | -152 |
| -6.3 | -50 | -295 | -215 | -247 | -199 | -220 | -153 |
| -6.9 | -34 | -254 | -178 | -224 | -215 | -191 | -135 |
| -7.5 | -48 | -280 | -169 | -134 | -100 | -98 | -122 |
| -8.1 | -51 | -260 | -180 | -123 | -116 | -122 | -118 |
| -8.7 | -48 | -290 | -196 | -113 | -79 | -109 | -131 |
| -9.3 | -53 | -224 | -102 | -138 | -131 | -111 | -122 |
| -9.9 | -49 | -196 | -84 | -128 | -29 | -76 | -114 |

**cond**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 993 | 399 | 314 | 544 | 393 | 410 | 389 |
| -6.3 | 906 | 491 | 404 | 383 | 311 | 309 | 316 |
| -6.9 | 996 | 449 | 420 | 402 | 449 | 382 | 701 |
| -7.5 | 1007 | 456 | 413 | 266 | 580 | 510 | 750 |
| -8.1 | 998 | 429 | 483 | 280 | 580 | 754 | 1233 |
| -8.7 | 1056 | 509 | 428 | 949 | 1033 | 1120 | 1130 |
| -9.3 | 1295 | 1022 | 1074 | 1249 | 1280 | 1278 | 1188 |
| -9.9 | 1296 | 1315 | 1223 | 1216 | 1241 | 1220 | 1235 |

**Sulfate (**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 80 | 3 | 3 | 3 | 4 | 1 | 1 |
| -6.3 | 96 | 2 | 4 | 1 | 15 | 5 | 11 |
| -6.9 | 146 | 5 | 1 | 33 | 34 | 29 | 21 |
| -7.5 | 161 | 2 | 1 | 28 | 117 | 79 | 139 |
| -8.1 | 129 | 1 | 3 | 1 | 270 | 164 | 158 |
| -8.7 | 199 | 4 | 20 | 172 | 170 | 181 | 180 |
| -9.3 | 260 | 4 | 213 | 262 | 332 | 376 | 355 |
| -9.9 | 343 | 285 | 338 | 329 | 311 | 335 | 352 |

**alk**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 250 | 90 | 140 | 290 | 200 | 140 | 170 |
| -6.3 | 350 | 200 | 80 | 140 | 90 | 110 | 120 |
| -6.9 | 330 | 230 | 130 | 160 | 220 | 120 | 100 |
| -7.5 | 310 | 170 | 180 | 120 | 210 | 160 | 250 |
| -8.1 | 340 | 100 | 220 | 100 | 220 | 180 | 270 |
| -8.7 | 330 | 170 | 120 | 410 | 420 | 280 | 300 |
| -9.3 | 330 | 190 | 360 | 300 | 250 | 240 | 370 |
| -9.9 | 360 | 360 | 430 | 390 | 380 | 240 | 240 |

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**Ca++ (m**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 38 | 0 | 1 | 14 | 35 | 35 | 44 |
| -6.3 | 41 | 0 | 0 | 0 | 5 | 1 | 8 |
| -6.9 | 57 | 1 | 0 | 1 | 5 | 5 | 2 |
| -7.5 | 48 | 0 | 0 | 22 | 98 | 65 | 121 |
| -8.1 | 66 | 0 | 0 | 3 | 47 | 84 | 98 |
| -8.7 | 56 | 0 | 0 | 132 | 139 | 121 | 136 |
| -9.3 | 100 | 23 | 43 | 141 | 155 | 160 | 137 |
| -9.9 | 61 | 60 | 90 | 159 | 139 | 121 | 133 |

| | 58 | 4 | 40 | 1.364 | | | |
|---|---|---|---|---|---|---|---|

**DO (mg.L)**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 2.54 | <0.1 | <0.1 | 0.36 | 0.3 | 0.57 | <0.1 |
| -6.3 | 0.53 | 0.37 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| -6.9 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| -7.5 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| -8.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| -8.7 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| -9.3 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| -9.9 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |

**hydroge**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 1 | 3 | 1 | 0 | 0 | 0 |
| -6.3 | 0 | 35 | 1 | 10 | 0 | 0 | 0 |
| -6.9 | 0 | 0 | 4 | 1 | 0 | 0 | 0 |
| -7.5 | 0 | 1 | 5 | 0 | 0 | 0 | 0 |
| -8.1 | 0 | 1 | 6 | 0 | 0 | 0 | 0 |
| -8.7 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| -9.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**methane**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 5 | 13 | 6 | 26 | 9 | 12 |
| -6.3 | 2 | 58 | 14 | 9 | 5 | 8 | 13 |
| -6.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -7.5 | 0 | 0 | 0 | 0 | 28 | 41 | 20 |
| -8.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -8.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -9.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Sulfide (**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 0 | 0 | 0.158 | 0 | 0 | 0 | 0 |
| -6.3 | 0 | 0 | 0.199 | 0 | 0 | 0 | 0 |
| -6.9 | 0 | 0 | 0.02 | 0.037 | 0 | 0.042 | 0 |
| -7.5 | 0 | 0 | 0 | 0.028 | 0 | 0 | 0.052 |
| -8.1 | 0 | 0 | 0 | 0 | 0.085 | 0 | 0 |
| -8.7 | 0 | 0 | 0.041 | 0.023 | 0 | 0 | 0.008 |
| -9.3 | 0 | 0 | 0.066 | 0.018 | 0.043 | 0 | 0.36 |
| -9.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Sulfate (**

| | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 80 | 3 | 3 | 3 | 4 | 1 | 1 |
| -6.3 | 96 | 2 | 4 | 1 | 15 | 5 | 11 |
| -6.9 | 146 | 5 | 1 | 33 | 34 | 29 | 21 |
| -7.5 | 161 | 2 | 1 | 28 | 117 | 79 | 139 |
| -8.1 | 129 | 1 | 3 | 1 | 270 | 164 | 158 |
| -8.7 | 199 | 4 | 20 | 172 | 170 | 181 | 180 |
| -9.3 | 260 | 4 | 213 | 262 | 332 | 376 | 355 |
| -9.9 | 343 | 285 | 338 | 329 | 311 | 335 | 352 |

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**Mg++**

| Mg++ | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 12.7 | 0.2 | 0.06 | 2.9 | 2 | 4.4 | 4.8 |
| -6.3 | 14.4 | 0.3 | 0.04 | 0.05 | 0.4 | 0.3 | 1.2 |
| -6.9 | 17.6 | 11.6 | 10.2 | 6.8 | 0.3 | 0.4 | 0.4 |
| -7.5 | 19 | 6.3 | 0.1 | 1.9 | 9.9 | 7 | 16.1 |
| -8.1 | 18 | 1.1 | 0.06 | 1.1 | 6.6 | 13 | 17.5 |
| -8.7 | 18.7 | 4.9 | 2.2 | 19.9 | 20 | 21.2 | 21.3 |
| -9.3 | 21 | 17.3 | 20.1 | 22.9 | 23.8 | 23.4 | 23.6 |
| -9.9 | 22.1 | 21.1 | 22.6 | 21.8 | 22.7 | 22.4 | 21.8 |

**Na+**

| Na+ | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 96.8 | 86.9 | 85.3 | 94.7 | 71.4 | 58.3 | 47.4 |
| -6.3 | 95.4 | 103 | 105 | 107 | 93 | 87.3 | 63.6 |
| -6.9 | 99 | 98.1 | 89.5 | 90.6 | 87.1 | 89.5 | 97.9 |
| -7.5 | 99.1 | 94.5 | 101 | 53.6 | 51.2 | 43.8 | 80.1 |
| -8.1 | 99.2 | 96.6 | 101 | 59.7 | 85 | 93.1 | 100 |
| -8.7 | 101 | 101 | 95.9 | 107 | 109 | 123 | 124 |
| -9.3 | 131 | 108 | 127 | 142 | 145 | 145 | 139 |
| -9.9 | 148 | 135 | 143 | 144 | 147 | 145 | 144 |

**K+**

| K+ | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 | 13.9 | 17.6 | 9.4 | 9.4 | 14 | 7.2 | 8.1 |
| -6.3 | 16.6 | 24.2 | 15.1 | 2 | 2 | 2 | 2.8 |
| -6.9 | 16.1 | 22.7 | 13.2 | 12.6 | 10.4 | 2.7 | 2 |
| -7.5 | 17.6 | 16.2 | 14.8 | 2.7 | 5.9 | 5.6 | 8.3 |
| -8.1 | 14.2 | 13.8 | 18.9 | 3.3 | 6.7 | 8.5 | 9.8 |
| -8.7 | 15.1 | 14.3 | 21.3 | 15.2 | 12.7 | 13.4 | 14 |
| -9.3 | 14 | 13.1 | 14.8 | 14.2 | 14.5 | 13.8 | 14.7 |
| -9.9 | 14.4 | 14.3 | 15.4 | 14.1 | 14.8 | 14.4 | 13.8 |

**Mn++**

| Mn++ | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 |  |  |  |  |  |  |  |
| -6.3 |  |  |  |  |  |  | 0.1 |
| -6.9 |  |  |  |  |  |  |  |
| -7.5 |  |  |  |  |  |  |  |
| -8.1 |  |  |  |  | 0.05 |  |  |
| -8.7 |  |  |  |  | 0.02 | 0.07 | 0.07 |
| -9.3 |  |  |  |  |  |  |  |
| -9.9 |  |  |  |  |  |  |  |

**Fe++**

| Fe++ | 8 | 10 | 11 | 12 | 14 | 16 | 18 |
|---|---|---|---|---|---|---|---|
| -5.7 |  |  | 0.03 |  | 0.2 |  | 0.02 |
| -6.3 |  |  |  | 0.03 | 0.08 | 0.1 |  |
| -6.9 |  |  |  |  | 0 | 0.08 | 0.03 |
| -7.5 |  |  |  |  | 0.17 | 0.05 |  |
| -8.1 |  |  |  | 0.05 | 4 |  |  |
| -8.7 |  |  |  |  |  |  |  |
| -9.3 |  |  |  |  | 0.08 | 0.03 | 0.03 |
| -9.9 |  |  |  |  |  |  |  |