FINAL REPORT

Prediction of Groundwater Quality Down-gradient of In Situ Permeable Treatment Barriers and Fully-remediated Source Zones

ESTCP Project ER-0320

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In situ permeable treatment barriers (PTBs) are designed such that contaminated groundwater flows through an engineered treatment zone within which contaminants are eliminated or the concentrations are significantly reduced. These systems are often considered for the containment of dissolved contaminant plumes, or for controlling the discharge and larger-scale impact of dissolved contaminants from source zones to aquifers. Previous studies have concluded that a better understanding of the subsequent improvement in down-gradient groundwater quality with time is needed. The objectives of this project were to: a) propose a practicable approach that can be used to project reasonable order-of-magnitude estimates of groundwater quality improvements with time down-gradient of a PTB, b) conduct detailed monitoring and characterization down-gradient of a well-understood PTB site, and c) illustrate and reflect on the use of the proposed approach for the PTB system studied in this project.

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ABBREVIATIONS AND ACRONYMS

ASU	Arizona State University
BB	biobarrier
BGS	below ground surface
BDL	below detection limit
BToC	below top of casing
CBC	construction battalion center (used as prefix for monitoring well names)
cm	centimeter
d	day
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DoD	Department of Defense
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FID	flame ionization detector
ft	foot/feet
g	gram
GC	gas chromatograph
GPS	Geographic Positioning System
GW	groundwater
hr	hour
in	inch
K	hydraulic conductivity
kg	kilogram
L	liter
m	meter
mg	milligram
mL	milliliter
MTBE	methyl-tert-butyl ether
mV	millivolt
MW	monitoring well

NBVC	Naval Base Ventura County
ND	non-detect
NFESC	Naval Facilities Engineering Service Center
OC	organic carbon
ORP	oxidation reduction potential
PID	photo-ionization detector
PRB	permeable reactive barrier
PTB	permeable treatment barrier
QAPP	quality assurance project plan
QC	quality control
RPD	relative percent difference
s	second
ug	microgram
UXO	unexploded ordnance
VOA	volatile organic analysis
yr	year

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EXECUTIVE SUMMARY

In situ permeable treatment barriers (PTB) are designed so that contaminated groundwater flows through an engineered treatment zone within which contaminants are eliminated or the concentrations are significantly reduced. These systems are often considered for the containment of dissolved groundwater contaminant plumes, or for controlling the discharge and larger-scale impact of dissolved contaminants from source zones to aquifers. The performance of a PTB is typically judged by short-term changes in groundwater concentrations with time within the treatment zone and also in wells located some distance down-gradient. Typically, expectations for groundwater concentration changes with time are based on a single site-wide average linear groundwater velocity estimate. For example, clean groundwater would be expected to be observed from 0 feet (ft) to 365 ft down-gradient of a PTB after one year at a site having a 1 ft/d average linear groundwater velocity. Previous ESTCP-sponsored studies have concluded that this approach does not agree well with observations at PTB sites and that a better understanding of the subsequent improvements in down-gradient groundwater quality with time is needed. Realistic projections of how the down-gradient concentrations will change with time are important, or else incorrect performance conclusions might be drawn in the short-term, leading to premature abandonment of the PTB technology and investment in other remedial options.

The objectives of this project were to: a) propose a practicable approach that can be used to project reasonable order-of-magnitude estimates of groundwater quality improvements with time down-gradient of a PTB, b) conduct detailed monitoring and characterization down-gradient of a well-understood PTB site, and c) illustrate and reflect on the use of the proposed approach for the PTB system studied in this project.

Detailed monitoring and characterization of groundwater concentration changes with time down-gradient of a full-scale MTBE Biobarrier PTB system were conducted at the NBVC to illustrate the issue discussed above. This included discrete depth groundwater sampling at 37 locations and analysis of over 680 groundwater samples for MTBE during three sampling trips (1226, 1324, and 1709 d after the biobarrier treatment zone was well-oxygenated and seeded), conventional slug tests (in 2-in and 4-in wells) and constant drawdown pumping-tests (in 3/4-in wells) conducted at existing full-length monitoring wells, water level measurements in monitoring wells, constant draw-down mini pumping-tests conducted at 1-ft (0.3-m) intervals during direct-push sampling, soil cores collected at 20 locations, and 245 laboratory permeameter tests with at least a 1-ft (0.3 m) resolution on the soil cores.

In brief, this is a site where the aquifer of interest is about 12-ft (3.7 m) thick and hydraulic conductivities tend to be lowest ($<10^{-5}$ cm/s or <0.028 ft/day) at shallow depths and highest (10^{-2} cm/s or 28 ft/day) at deeper depths. As a result, horizontal average linear groundwater velocity estimates increase with depth from $<1.3 \times 10^{-7}$ cm/s (3.8×10^{-4} ft/day) to 2.8×10^{-3} cm/s (7.9 ft/day). The site-wide average linear velocity estimate commonly used in reports for this site is about 1 ft/day.

Variations in horizontal groundwater velocity were reflected in the movement of clean water down-gradient from the NBVC PTB. Overall, the highest concentrations (180 μg/L to 880 μg/L) of MTBE persisted longest in the areas of lower hydraulic conductivity (and hence lower groundwater velocity). These findings further demonstrated that use of a single site-wide estimate of groundwater velocity (i.e. 3.5×10^{-4} cm/s or 1 ft/day) for NBVC would lead to unreasonably-low predicted concentrations at shallower depths and unreasonably-high predicted concentrations at deeper depths. For samples collected from a typical groundwater monitoring well (which mixes concentrations across deep and shallow zones at this site), the single site-wide velocity estimate would significantly overestimate the apparent movement of clean water down-gradient of the NBVC PTB.

Therefore, the recommended site-specific assessment approach for PTB systems is one that focuses on characterization of vertical variations in horizontal hydraulic conductivity. This can be done at most sites through coring followed by lab tests, or by using in situ discrete pump tests, both of which are discussed in this document and were demonstrated at the NBVC site. Using this information along with hydraulic gradient data, well construction information (i.e., screened interval data), pre-treatment concentrations, and treatment zone concentration data, estimates of down-gradient groundwater quality change with time can be produced assuming that horizontal groundwater flow is the dominant dissolved chemical transport mechanism. A spreadsheet-based tool was developed to help users perform these calculations and better visualize the projected concentration vs. time behavior in the aquifer and at the wells.

INTRODUCTION

1.1 BACKGROUND

In situ permeable reaction barriers (PRB) and in situ biobarriers (BB) are examples of technologies that will be referred to more generally in this document as "in situ PTB. As shown in Figure 1-1, these treatment systems may be installed at the edge of the source of a dissolved groundwater contaminant plume, at the leading edge of a dissolved groundwater contaminant plume, or anywhere in between. These systems are designed such that contaminated groundwater flows through an engineered treatment zone within which contaminants are eliminated or the concentrations are significantly reduced. The hydraulic design of the system may rely on natural groundwater flow, or may involve pumping to direct the contaminated groundwater through a treatment system (i.e., a "funnel and gate" system). The treatment system may utilize chemical reactions (e.g., iron barriers), biochemical reactions (e.g., aerobic or anaerobic biodegradation), or physical-chemical processes (e.g., air sparging to induce volatilization).

These systems are often considered for the containment of dissolved contaminant plumes, especially in cases where: a) near-term complete source zone treatment is unlikely and long-term containment is necessary, or b) where it is necessary to prevent the continued growth of a dissolved groundwater contaminant plume. Situations like this are often encountered at complex DNAPL spill sites or at sites where sources are distributed over large areas (e.g., unexploded ordinaces [UXO] sites). Relative to the typical pump-and-treat/hydraulic containment alternatives, natural-gradient (non-pumping) PTB systems are attractive because they are less maintenance-intensive and above-ground treatment and discharge systems are not required. Cost comparisons and performance-risk analyses of PTB and pump-and-treat systems often favor PTB, except in deeper groundwater settings (i.e., >100 ft below ground surface to groundwater) where the PTB installation costs begin to off-set the savings from the lower operation and maintenance costs.

As mentioned above, the PTB might be installed just down-gradient of the leading edge of the plume; however, there are a number of situations for which placement further up-gradient and between the source and leading edge of the dissolved plume is necessary or desirable. For example, as shown in Figure 1-1:

- Physical constraints and property access might prevent installation of a PTB at the leading edge of the dissolved plume, so that the PTB is placed to bisect the plume further upgradient and a second treatment scheme (e.g., hydraulic containment) is used to address the detached plume.

- The dissolved plume may be of great length, and the remedy may involve installation of more than one PTB along the length of the dissolved plume; the long-term remedy is one in which the PTB immediately down-gradient of the source continues operating, while the others operate only as long as necessary to treat the bisected portions of the dissolved plume.

- It also may be acceptable to install the PTB across the down-gradient edge of the source zone, and to allow the detached dissolved phase plume to naturally attenuate over time.

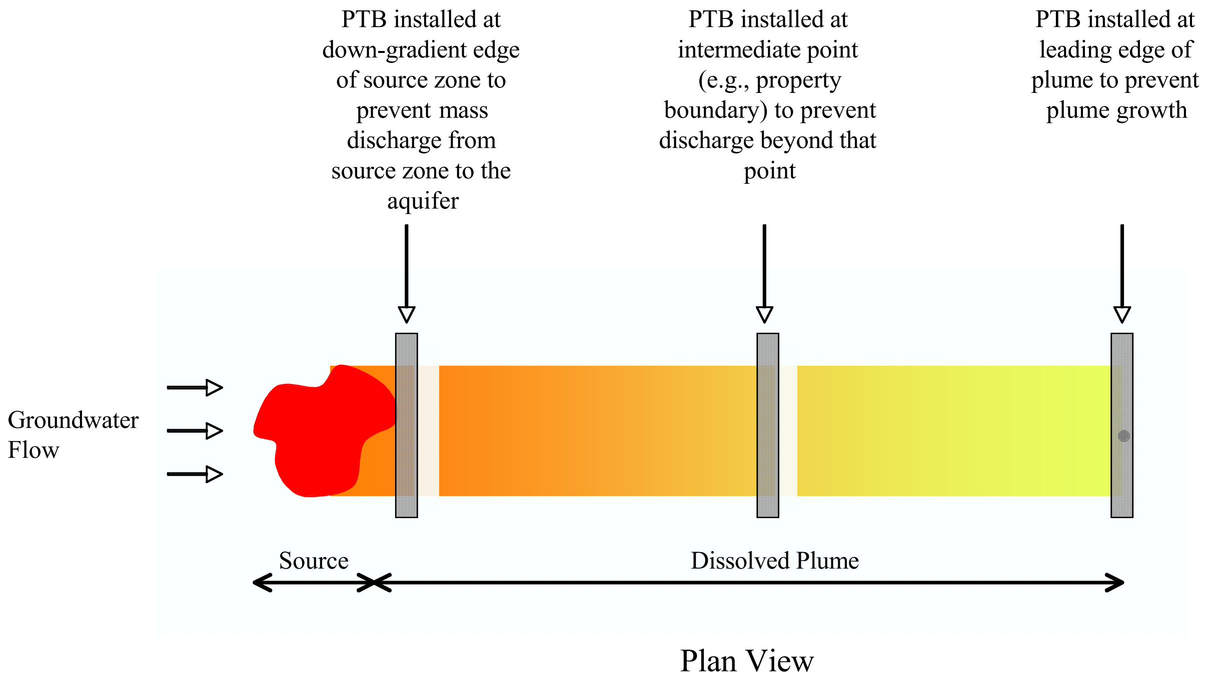


Figure 1-1. Schematic of Deployment Options for Permeable Treatment Barriers (PTB).

In all cases, prediction as well as monitoring of the dynamic movement of the clean/treated groundwater (e.g., distance vs. time relationships for the clean groundwater) is needed. This is critical because the economic analysis for designing, operating and maintaining these down-gradient detached plume treatment options will depend on the duration of treatment. For example, the results of the economic analysis (projected annual and lifetime costs for each treatment option) will depend on whether the projected duration is 5 years (yr), 50 yr, or 100 yr. Typically, expectations for groundwater concentration changes with time are based on a single aquifer-wide average linear groundwater velocity estimate. For example, improvements in groundwater quality would be expected between 0 ft and 365 ft down-gradient of a PTB after one year at a site having a 1 ft/d average linear groundwater velocity. Previous studies (i.e., Battelle 2002) have concluded that this approach does not agree well with observations and that a better understanding of the subsequent improvements in down-gradient groundwater quality with time is needed.

Gaining a better understanding of this behavior is also of interest because the performance of a PTB may be judged by the short-term changes in dissolved concentrations with time immediately down-gradient of the PTB. It is important to have realistic projections of how the concentrations will change with time as shown in Figure 1-2, or incorrect performance conclusions might be drawn in the short-term.

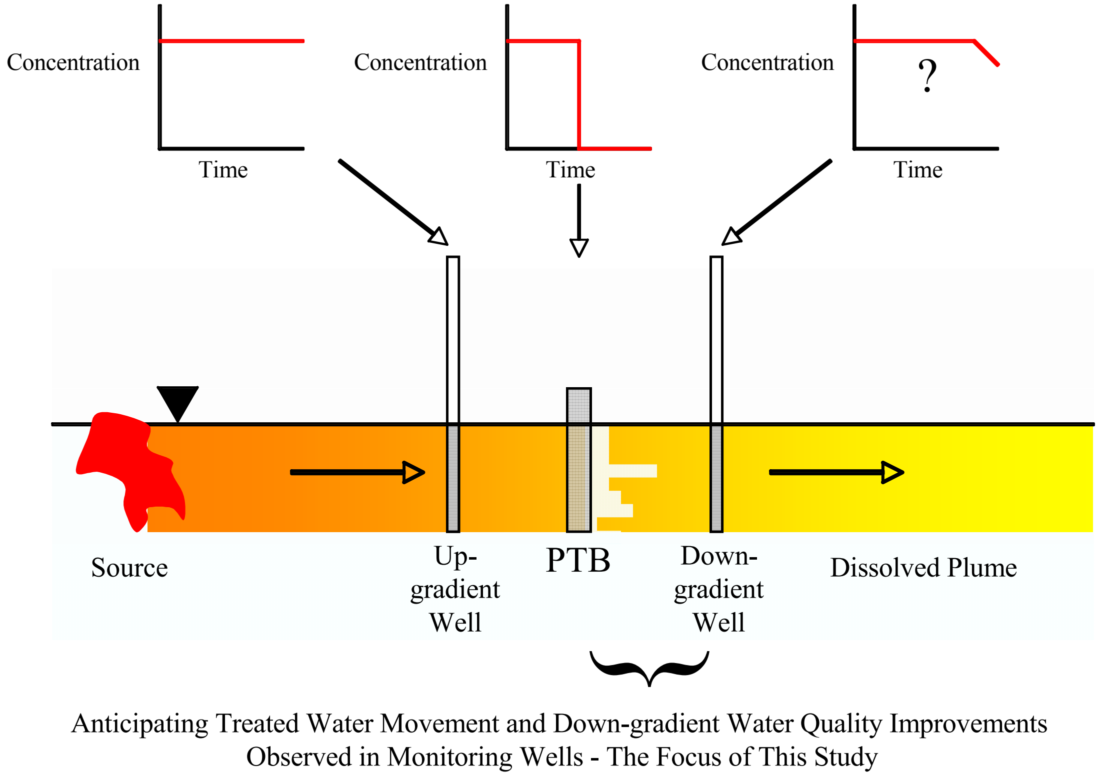


Figure 1-2. Schematic of the Ground Water Quality Issue Down-gradient of a Permeable Treatment Barrier (PTB).

While the discussion above is focused narrowly on PTB’s, this work has broader application. For example, it should be noted that the same questions and challenges arise in the context of selecting technologies for DNAPL source zone corrective action. For example, one must often consider DNAPL source zone treatment objectives ranging from complete source removal to partial DNAPL source removal, to containment. The selection between these options might very well be dictated by their projected effect on down-gradient groundwater quality. For example, the net benefit of the installation of a down-gradient PTB is very similar to that of complete source removal with respect to down-gradient groundwater quality. The selection between these two treatment objectives might significantly depend on the projection of the resulting detached plume’s behavior and in particular, the time frame over which it will need to be monitored or treated.

NBVC at Port Hueneme, California, a permeable biobarrier ESTCP demonstration system was installed in late 2000 at the down-gradient edge of the associated NAPL source zone as shown in Figure 1-3. It has achieved a >99% dissolved MTBE concentration reduction, and NBVC has integrated this system as a part of the final remedy for the site. Annual operating costs for the original pump and treat system were significantly greater than those of the biobarrier; thus, the economic analysis was particularly sensitive to estimates of the projected duration of operation. Central to this was the estimation of groundwater quality improvements with time down-gradient of the biobarrier and how long it would take the trailing edge of the now-detached plume to reach the down-gradient pump and treat system. This same information was of interest to the regulatory agency when they reviewed the proposed final remedy for the installation of additional PTB.

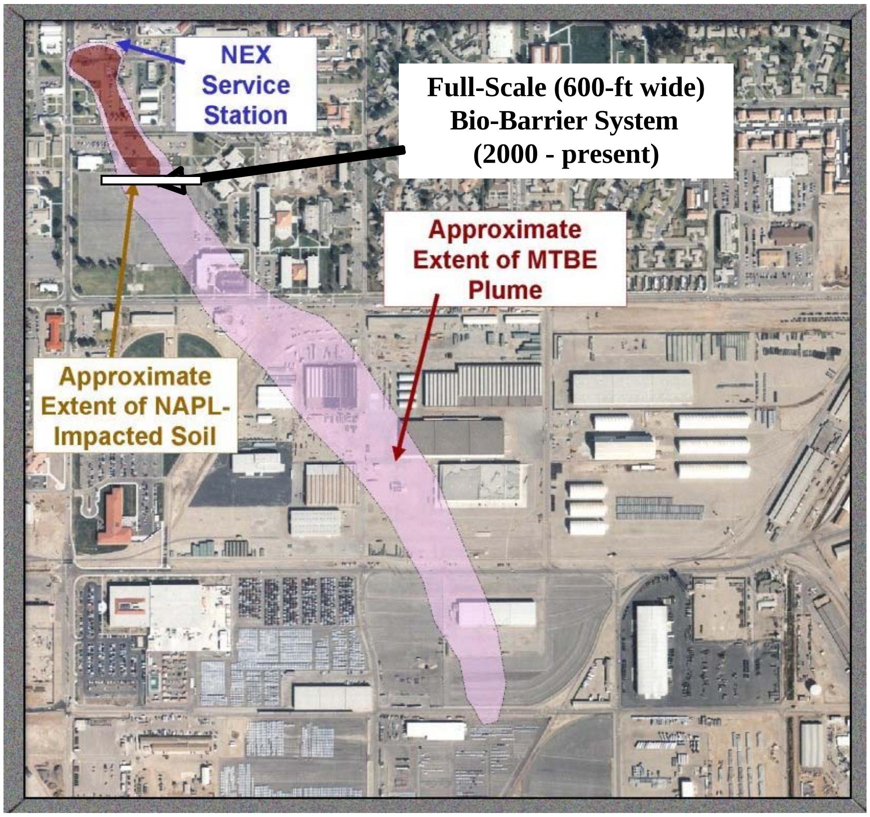


Figure 1-3. Location of the MTBE Source Zone, Full-scale Biobarrier, and Dissolved MTBE Plume at the NBVC Port Hueneme, California.

The prediction of dissolved contaminant plume migration has been the focus of many studies through the years, and DoD has invested in the development and use of valuable computational tools like BIOSCREEN and BIOPLUME. Therefore, it might seem that projection of detached plume behavior for economic analysis could be addressed easily through straight-forward application and calibration of existing groundwater flow and transport models, or through even more simplistic calculations involving estimates of the average linear groundwater velocity and distance of interest. Readers should note that a distinction is made here between “tools” like GMS and BIOSCREEN, and “models”. In this discussion, a “model” is site-specific and is the combination of a tool, the mathematical discretization and characterization of the site, and the calibration data and process that are reflected in the final mathematical characterization.

There is a subtle, but significant fundamental difference between the modeling needs identified above and the historical development and calibration of site-specific groundwater transport models. In brief, the typical development and calibration of a site-specific groundwater transport model is inherently biased towards projection of the leading edge of a dissolved contaminant plume (due to the preference for monitoring of these zones for compliance purposes), whereas this project focuses on improving our confidence in the projected movement of treated water found at the trailing edge of the plume. Usually little is known from historical data about the dynamics of the trailing edge because it does not exist unless the source has been removed, depleted (naturally), or contained.

The result is that most site-specific model projections would show the trailing edge of the dissolved plume moving in a similar manner to the leading edge. The actual migration of the trailing edge could be much slower, however, because the leading edge of migration most strongly reflects the fastest flow paths, while the trailing edge most strongly reflects the slower flow paths and back-diffusion from hydraulically stagnant zones. Proper description and characterization of these processes in site-specific models is generally not critical to traditional model calibration that focuses on dissolved plume growth. Therefore, a model calibrated based on plume growth data may not incorporate the necessary information to reasonably predict the trailing edge of a plume that has been cut-off from the source.

For example, at NBVC, the aquifer is sandy and relatively homogeneous. Historical data shows that the leading edge of the plume migrated approximately one-mile from the gas station source in an estimated timeframe of approximately 15 years (or approximately 350 ft/y or 110 m/y of leading-edge migration). Meanwhile, three years of data from the operation of three pilot-scale biobarrier systems showed the appearance of clean water down-gradient at transport rates that were at least ten times slower than the rate of movement of the leading edge of the plume. Therefore, while the plume grew to its current length in 15 years, it might take 200 years for full cleanup of the aquifer between the biobarrier and the location of an hydraulic capture system at the leading-edge of the dissolved MTBE plume. This difference in clean-up time estimates significantly impacts the economic analysis and feasibility assessment when comparing different treatment options (i.e. multiple biobarriers vs. pump-and-treat operations).

The primary benefit of this project is the demonstration and validation of a practicable approach to estimate the rate at which treated water migrates down-gradient from a PTB, and expected groundwater quality changes with time measured in conventional wells. This is important because we know that reasonable estimates are critical to: (a) assessing whether or not the PTB is working (i.e., by comparing data vs. expectations with time and distance), and (b) comparing the economics and acceptability of different options (i.e., cost and acceptability are linked to cleanup times).

1.2 OBJECTIVES OF THE DEMONSTRATION

The objectives of this project were to:

- Develop a practicable approach that can be used to project reasonable order-of-magnitude estimates of groundwater quality changes with time down-gradient of a PTB, with emphasis on modeling the migration of the treated water, and
- Illustrate the use of this approach for an existing PTB system.

The "approach" referred to above was a set of data collection/aquifer characterization recommendations combined with a practicable predictive spreadsheet-based tool.

The predictive tool was to be only as complex as necessary to reasonably anticipate groundwater quality changes relatively close to the biobarrier. For example, implementation in spreadsheet format was desirable.

1.3 REGULATORY DRIVERS

Federal and state regulatory agencies generally require groundwater cleanup to prescribed numerical standards, but the agencies also generally have flexibility to choose points in time and space where these are achieved. PTB are often installed to achieve these numerical standards at specific strategic locations.

1.4 STAKEHOLDER/END-USER ISSUES

At about the time that this study was initiated, Battelle (2002) issued a report that inventoried PTB applications and reviewed the data available from a number of sites. The authors of that report commented that "*it may be several years before a noticeable decline in contaminant concentrations is observed at a down-gradient compliance point, as indicated by the difficulty in discerning a clean front emerging from various existing PRB*." Given this apparent slow rate of clean groundwater propagation down-gradient of the treatment zone, the authors also recommended that "*it may be important to determine, through monitoring and understanding of the site, possible causes of persistent down-gradient contamination, in order to allay regulatory concerns*."

This project was initiated to address the issue raised by that report – namely the need for an approach to estimate down-gradient water quality improvements with time, so that realistic performance expectations can be set and so that the decision-makers are better prepared to interpret the performance data.

TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

This project did not involve the demonstration of a developing cleanup technology, as is common for most ESTCP projects. Rather it was conducted to supplement our understanding of PTB systems through:

- the detailed monitoring of groundwater quality changes with time and distance down-gradient of a well-monitored PTB system in order to better understand the dynamics of treated water movement and reasons why groundwater quality improvements do not occur as quickly as typically anticipated, and

- the testing of a practicable approach to anticipate groundwater quality changes with time and distance down-gradient of PTB systems in order develop reasonable performance expectations.

For those readers interested in the development and application of PTB, the Battelle (2002) and Interstate Technology and Regulatory Council (2005) reports are valuable sources of information

To be clear, any mention of "technology" in the following text or headings refers not to PTB technology, but to the practicable approach proposed to project reasonable order-of-magnitude estimates of groundwater quality changes with time down-gradient of a PTB or remediated source zone. This approach is summarized below in Table 2-1 and discussed in §2.5.

2.2 PREVIOUS TESTING OF THE TECHNOLOGY

The use of the overall approach proposed and demonstrated in this project had not been tested prior to this project. The recommended suite of characterization activities involves the use of conventional characterization tools. The underlying mechanisms and mathematics considered in the spreadsheet calculation tool are part of all groundwater flow and transport codes. A full description of the development of this approach and its testing is contained in Maass (2005).

2.3 FACTORS AFFECTING COST AND PERFORMANCE

The cost of any approach is dependent on the required detail of characterization data and the sophistication and ease of use of the mathematical/calculational tool. The goal of this project was to develop and demonstrate an approach that requires minimal data collection beyond what is routinely done or is reasonably practicable and the use of a mathematical tool that is easily accessible to, and understood by project managers, regulators, and environmental consultants/contractors.

If incorporated in the initial site characterization, the data collection needs for this approach should result in minimal cost increases to the project.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The advantage of this technology is that it addresses the identified need for an approach to estimate down-gradient water quality improvements with time, so that realistic PTB performance expectations can be set and so that the decision-makers are better prepared to interpret the performance data.

The limitation of this technology is that it involves the use of a relatively simplistic model of treated water movement down-gradient of a PTB. Sites are characterized as being layered with homogeneous hydraulic and chemical transport properties within each layer, gradients are assumed to be horizontal, and there is no vertical transport between the layers (i.e., no back-diffusion). Thus the tool is not applicable at sites where this simplification is not appropriate.

2.5 OVERVIEW OF THE APPROACH TO ESTIMATE GROUNDWATER QUALITY CHANGES WITH TIME DOWN-GRADIENT OF A PTB OR REMEDIATED SOURCE ZONE

As discussed above, this project was conducted to better understand the dynamics of treated water movement down-gradient of PTB and reasons why groundwater quality improvements do not occur as quickly as typically anticipated. It involved detailed data collection down-gradient of a well-monitored PTB system, and the use of that data to test a simple/practicable approach to anticipate groundwater quality changes with time and distance down-gradient of PTB systems.

The proposed approach is summarized below in Table 2-1. In brief, it involves:

- Collection of pre-PTB groundwater concentration data in order to form a conceptual model of the initial dissolved groundwater concentration distribution

- Collection of hydrogeologic data in order to form a layered conceptual model of the groundwater system and the flow direction

- Entry of this data into an Excel spreadsheet-based tool that estimates changes in groundwater quality with time and space, and concentration vs. time in selected monitoring well locations.

This approach can be integrated into the overall design approach for PTB systems as shown in Figure 2-1.

Table 2-1. Summary of Proposed Approach for Anticipating Dissolved Groundwater Qquality Changes Down-gradient of Permeable Treatment Barriers (PTB).

	Components of the Approach	Measurement and Discussion	Analysis
1	Determination of groundwater flow direction and horizontal hydraulic gradient	Groundwater level measurements should be collected from at least three groundwater monitoring wells located in the vicinity of the proposed (or existing) PTB. The number of wells and their positions should be selected based on recommendations provided in Dahlen (2004) in order to minimize error.	Groundwater level measurements are contoured to determine the groundwater flow direction and to calculate the horizontal hydraulic gradient (it is assumed that vertical gradients at most PTB sites will be small, although that may not always be the case).
2a	Determination of vertical variations in horizontal hydraulic conductivity	This can be accomplished through soil coring and subsequent testing of soil properties, through in situ testing of hydraulic properties across discrete vertical intervals, or some combination of the two. If making in situ measurements, groundwater samples should be collected at the same time from the intervals being characterized.	The data must be sufficient to create a layered conceptual model of the section of the aquifer of interest and to assign quantitative properties (hydraulic conductivity, effective porosity, and fraction of organic carbon).
2b	Determination of groundwater concentration distribution and the concentration of chemicals of concern leaving the PTB	Groundwater sampling down-gradient of PTB location followed by chemical-specific analysis to determine the initial distribution of chemical concentrations. Ideally, samples are collected at the same vertical intervals as the hydraulic conductivity data discussed above.	These initial contaminant concentrations are input into the spreadsheet tool (discussed below) as the initial (t=0) concentrations.
3	Estimation of rate of down-gradient propagation of treated water leaving the PTB and corresponding changes in groundwater quality in wells or discrete sampling points	Uses the data from the three items listed above.	Data are entered into an Excel spreadsheet that calculates advection-dominated transport model results as a first-order approximation of the real behavior of the system.

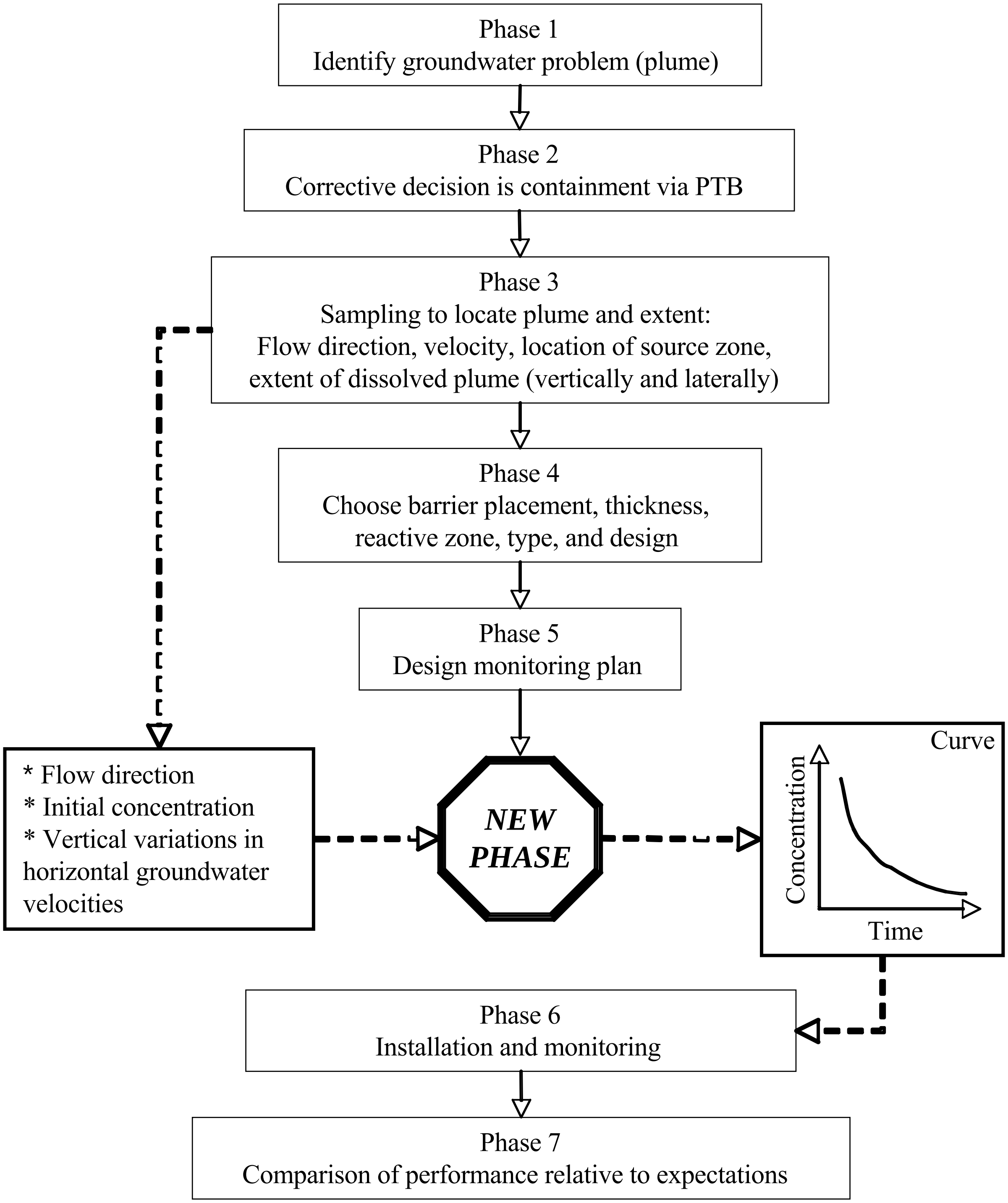


Figure 2-1. Integration of Proposed Approach for Estimating Expected Down-gradient Water Quality Changes with Time within the Generic PTB Design and Implementation Framework.

Inherent in this approach is the assumption that, to first-order, groundwater flow and transport occur primarily within distinct horizontal layers. It is also assumed that the PTB full-intersects the dissolved plume.

The following provide some additional insight to items in Table 2-1:

Item 1: Determination of the groundwater flow direction and hydraulic gradient are critical steps in this approach. While this is a common exercise at impacted-groundwater sites, it is our experience that the number and sub-optimal placement of wells often leads to significant errors in flow direction and gradient determination (e.g., too few wells placed too close together or in a linear alignment). Dahlen (2004) suggests that monitoring well coverage should extend at least 200 ft, and preferably at least 250 ft, in both the direction of groundwater flow and perpendicular to it. In addition, Dahlen found that the temporal variations associated with calculated flow direction decrease as the hydraulic gradient increases and the number of monitoring wells increases. Based on initial estimates of hydraulic gradient for a given site, he suggests the following number of monitoring wells for a site:

Hydraulic Gradient Estimate [m/m]	Minimum Number of Monitoring Wells
< 0.004	12
> 0.004 and < 0.01	8
> 0.01	5

Items 2a and 2b: As stated above, the approach discussed here is predicated on the assumption that, to first-order, groundwater flow and dissolved chemical migration are primarily horizontal and occur in layers. Thus, Items 2a and 2b focus on collecting data necessary to form a layered conceptual model of the subsurface. This can be done in any number of ways, but it is important that the vertical resolution be sufficient to identify significant changes that occur. It is difficult to give guidance that would apply to every site, but the following should be considered:

- Initial visualization of site geology through the collection of at least one soil core over the interval that the PTB will be installed

- Hydraulic conductivity measurements over geologic intervals suggested by visual observations as being likely to have order of magnitude changes in hydraulic conductivity

Hydraulic conductivity can be measured using pump tests, slug tests, and lab-scale permeameter tests. The method of choice will be dictated by each aquifer's characteristics (i.e., slug tests may be better suited for lower permeability materials). It is difficult to give guidance on the number of locations where such measurements should be made. The spreadsheet tool discussed below projects changes along flowpaths, so its results are specific to the flowpath corresponding to the sampling location. Confidence in the results is increased by increasing the number of sampling locations. Usually one has a reasonable understanding of the lateral variations in hydrogeologic properties before entering the PTB evaluation phase, so that knowledge should be used to determine a reasonable number of sampling locations across the width of the proposed PTB.

If vertical variations in hydrogeologic properties are determined using in situ tests, then that activity can also be leveraged to collect groundwater samples. The co-location of aquifer property and groundwater concentration data is preferred.

Item 3: A simple spreadsheet tool (DGCHANGE v1.0) was created to estimate approximate time frames over which significant concentration reductions should be observed in near-field down-gradient monitoring wells. The user enters data from Items 1, 2a, and 2b above into the spreadsheet tool and the output is presented graphically as a series of time-sequence plots showing concentration vs. depth plots and expected concentrations in conventional wells located at selected distances down-gradient. DGCHANGE v1.0 was developed using a simplified form of the flow and chemical transport equations for cases of one-dimensional advection-dominated scenarios. This simplification does not take into account layer mixing, the breakdown of contaminants by processes such as biodegradation, dispersion or diffusion.

A description of the underlying assumptions and equations built into DGCHANGE v1.0 are given in Appendix A.

A detailed user's manual for the operation of DGCHANGE v1.0 is provided in Appendix B.

DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The performance objectives for this project are captured below in Table 3.1.

Table 3-1. Performance Objectives.

Type of Performance Objective	Primary Performance Criteria	Expected Performance Metric	Actual Performance (Objective met?)
Qualitative	Develop a "practicable" approach that can be used to project reasonable order-of-magnitude estimates of groundwater quality changes with time down-gradient of a PTB	- Data collection requirements utilize available technology (i.e., sampling methodologies) and do not significantly increase base-case characterization costs. - Calculation tool for projection of performance can be used by most environmental professionals, regulators, and project managers.	Yes, the approach incorporates use of conventional characterization tools and the calculation tool is in spreadsheet format
Semi-Quantitative	Be able to project reasonable order-of-magnitude estimates of groundwater quality changes with time down-gradient of a PTB	- Comparison of projected concentration vs. time and distance relationship with that observed at the NBVC site.	Yes, the approach leads to better estimates of down-gradient concentration changes with time than conventional approaches
Quantitative	Collect data set for the NBVC site that can be used to test the approach and provides insight to factors controlling groundwater quality changes with time.	- The data satisfies data quality objectives and the density of samples is sufficient to be useful for testing models of varying sophistication, including the tool developed in this project.	Yes, data set is the most comprehensive ever collected down-gradient of a PTB

3.2 TEST SITE SELECTION

For this project, the desired test site was one that met the following criteria:

Criteria	Reasoning
- A PTB is installed and has been operational for at least 6 - 12 months - The operational history of the PTB is known - Detailed monitoring of the PTB system has been conducted and the data is available - Groundwater samples collected from within the PTB treatment zone indicate significant and consistent concentration reduction - The hydrogeology of the site is reasonably well-characterized and it has been demonstrated that flow is through, and not around the PTB - Access to sampling locations down-gradient of the PTB	Necessary as the objective of this demonstration is to demonstrate and assess water quality changes down-gradient of an operational and fully effective PTB
- Relatively shallow groundwater (to minimize project costs) - Base personnel are present to facilitate the logistics associated with sampling events	Necessary so that cost-effective direct-push drilling and well installation techniques can be used and so that groundwater sampling can be achieved with peristaltic pumps
- The estimated groundwater average linear velocity is greater than 10 ft/y (3 m/y)	Necessary to ensure that down-gradient water quality changes can be observed within the lifetime of this project.

To illustrate the use of this approach, aquifer characterization data and groundwater concentration data was collected down-gradient of the ESTCP-funded full-scale MTBE biobarrier project at NBVC (Port Hueneme, CA).

3.3 TEST SITE DESCRIPITION

The MTBE biobarrier PTB system shown in Figure 3-1 was installed at NBVC in August 2000 to fully treat a 500-ft (150 m) wide dissolved MTBE plume. The system was comprised of a line of gas injection wells designed to create a well-oxygenated zone spanning the width of the MTBE plume while still allowing unimpeded flow of groundwater through the system.

The dissolved MTBE plume emanates from a large gasoline-impacted source zone, that was created when gasoline leaked from underground piping at the NEX service station. Gasoline liquid flowed down to the shallow perched aquifer and then spread laterally down-gradient, resulting in a 9-acre gasoline source area. Free-product (mobile) gasoline has not been detected in any of the on-site wells in the source area, but trapped, residual gasoline is present and visible in soil cores collected from the upper 3-ft (1 m) of the aquifer throughout the source zone.

The biobarrier was installed just past the down-gradient edge of the gasoline-impacted source zone, and became operational in September 2000. Performance data presented in Figure 3-2 was collected through mid-2002. The biobarrier ultimately achieved a reduction of MTBE concentrations in groundwater to <5 ug/L within the well-oxygenated treatment zone.

The geology throughout the vadose zone and upper unconfined aquifer consists of unconsolidated sands, silts, and clays with minor amounts of gravel and fill material. Silty fill material extends from ground surface to about 7 - 9 ft (2.1 – 2.7 m) below ground surface (BGS). Below that, silty fine- to medium-grained sands transition to predominantly medium-grained sands which extend to approximately 20 ft (6.1 m) BGS, at which point a clay aquitard is encountered. Depth to the groundwater table is approximately 9 ft (3 m) BGS, with seasonal variations of approximately 1-ft (0.3 m). The gasoline-containing source zone soils are generally found in the sandy layer from about 9 - 12 ft (2.7 – 3.7 m) BGS. The dissolved MTBE groundwater plume of interest to this study was contained within this upper aquifer.

In general, groundwater within this aquifer flows to the southwest with gradients ranging from approximately 0.001 to 0.003 ft/ft (0.001 to 0.003 m/m). Transmissivity values ranging from 19,000 to 45,000 gal/day/ft have been reported, which correspond roughly to hydraulic conductivity estimates of 250 to 600 ft/d (0.088 to 0.21 cm/s), and groundwater flow velocity estimates ranging from 270 to 1,900 ft/y (80 to 580 m/y), assuming an effective porosity of 0.35 ft^3-H_2O/ft^3 (0.35 m^3-H_2O/m^3).

Tracer studies conducted in the vicinity of the field site demonstrated groundwater velocities ranging from about 280 to 560 ft/y (85 to 170 m/y), with the velocity increasing from the top to the bottom of the aquifer (Amerson and Johnson, 2003). An average linear groundwater velocity of about 300 ft/d (91 m/y) is consistent with the dissolved plume length and time since the gasoline release.

Figure 3-1. Large-scale Biobarrier PTB System at NBVC (Port Hueneme, California). The Fenced-in Area is Approximately 600-ft Long.

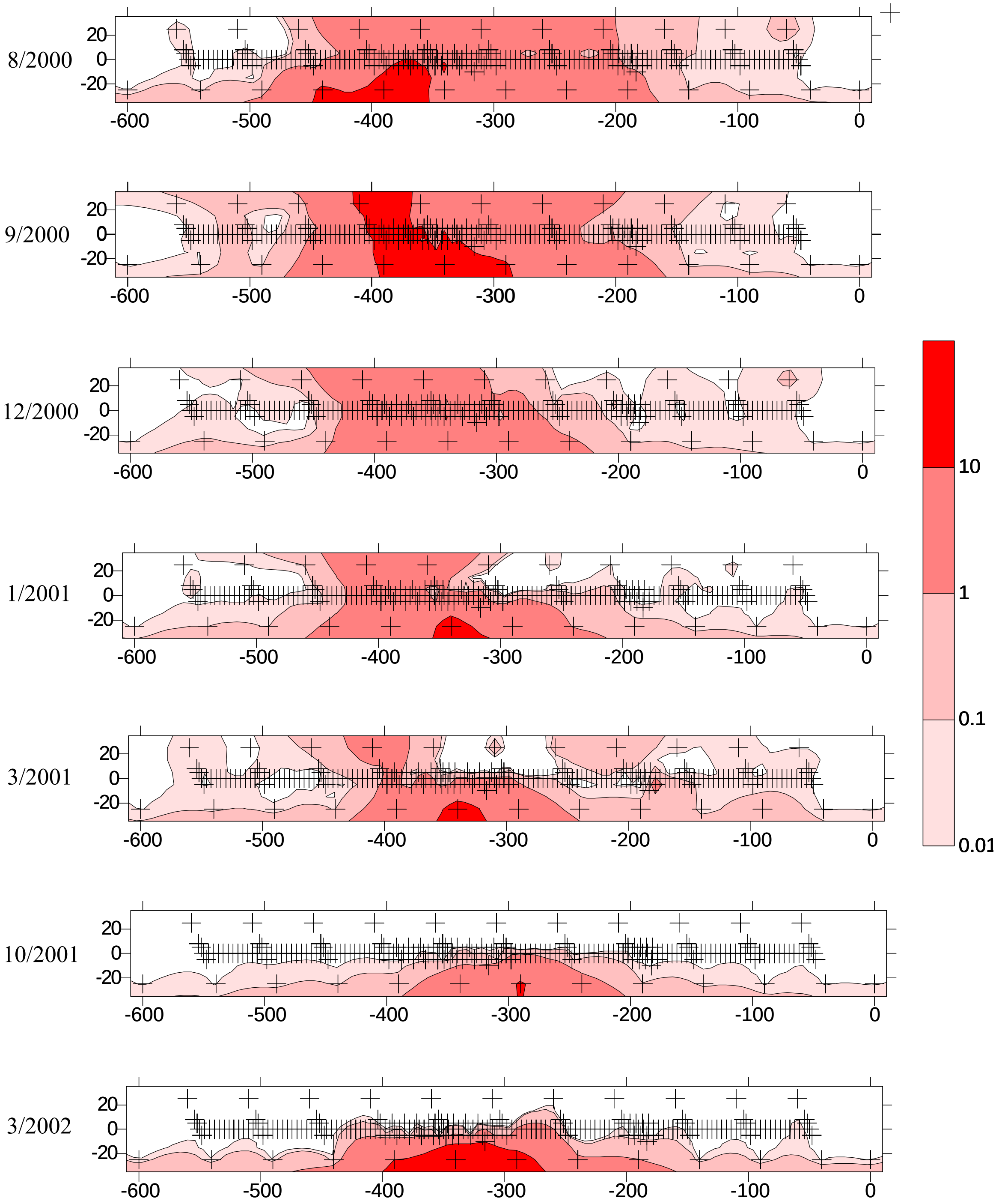


Figure 3-2. MTBE Concentration [mg/L] Plan-view Snapshots for the NBVC Biobarrier; Each "+" Marks the Location of a Monitoring or Gas Delivery Well. The Gas Delivery Wells are Found Along the High Well Density Line (0 ft vertical axis position)**. Groundwater Flows Roughly from the Bottom to the Top of Each Plot, so Treatment is Indicated by the Disappearance of MTBE with Time Down-gradient of the Biobarrier Wells** (i.e., the top of each snapshot plot)**. All Distances Shown on the Axes are in feet.**

3.4 PRE-DEMONSTRATION SAMPLING AND ANALYSIS

Pre-demonstration data is compiled in the final report produced from the ESTCP large-scale biobarrier demonstration project (ESTCP 2003). That report contains aquifer characterization data as measured during pump tests conducted on all biobarrier gas injection wells at the time of their installation. That report also contains dissolved MTBE concentrations in wells immediately up-gradient, within, and immediately down-gradient of the biobarrier system.

3.5 TESTING AND EVALUATION PLAN

3.5.1 Demonstration Installation and Start-Up

The only mobilization involved in this study was that of the Arizona State University (ASU) field laboratory analytical equipment and ASU personnel. Field equipment included peristaltic sampling pumps, dissolved oxygen (DO) and oxidation-reduction-potential (ORP) probes, and a portable gas chromatograph (GC) equipped with flame-ionization (FID) and photo-ionization (PID) detectors. An on-site Geoprobe direct-push rig was used for soil core and groundwater sample collection.

3.5.2 Period of Operation

This project was conducted over a two-year period. Soil/groundwater sampling and hydrogeologic characterization events occurred in April/May 2004, July/August 2004, and August 2005. For reference, this is 1226, 1324 and 1709 d, respectively, after the seeding of the biobarrier in December 2000 (oxygenation began in September 2000). Development of the calculation tool, testing, and refinement began following the second field event and extended throughout the remainder of the project.

3.5.3 Amount/Treatment Rate of Material to be Treated

This section is not applicable to this study.

3.5.4 Residuals Handling

Soil cores collected in this work were shipped to ASU for lab-scale permeameter testing. Because they were collected in the dissolved plume and were drained, the soils were not hazardous and were disposed of appropriately at ASU. Groundwater samples, sampling purge water, and discharge water from hydraulic conductivity testing was poured into designated containers and disposed of on-base according to NBVC established procedures for MTBE-impacted groundwater.

3.5.5 Operating Parameters for the Technology

This section is not applicable to this study.

3.5.6 Experimental Design

As previously discussed, the primary objectives of this work were to:

- Develop a practicable approach that can be used to project reasonable order-of-magnitude estimates of groundwater quality changes with time down-gradient of a PTB, with emphasis on modeling the migration of the treated water, and
- Illustrate the use of this approach for an existing PTB system.

Thus, the project-specific demonstration plan was developed to: (a) collect extensive characterization data from which one could, in hindsight, assess the minimum characterization data required to reasonably project the expected time vs. distance relationship for treated water migration down-gradient of the biobarrier PTB, and (b) to collect spatial "snapshots" of the dissolved MTBE groundwater plume at different times following the start-up of the biobarrier.

Implicit in this experimental design was the pre-test assumption that the time vs. distance behavior of treated water is largely reflective of predominantly horizontal flow and vertical variations in the horizontal groundwater velocity caused by vertical variations in the horizontal hydraulic conductivity.

3.5.7 Sampling Plan

This section provides an overview of the sampling operations. All sampling procedures were in compliance with the demonstration's Quality Assurance Project Plan included as Appendix C.

Field investigations occurred in April/May 2004, July/August 2004, and August 2005 and involved:

- the collection and analysis of over 680 groundwater samples collected from the top to the bottom of the shallow aquifer at one-foot vertical resolution at 37 locations;
- collection of 61 continuous soil cores from the top to the bottom of the shallow aquifer at 20 locations for lab permeameter testing;
- slug tests performed in eight conventional wells;
- 207 discrete-interval constant-flow specific-discharge tests conducted using 0.75-in (1.7 cm) diameter wells and a direct-push sampling tool created specifically for this work;
- 88 discrete-interval water-level recovery tests using a direct-push sampling tool created specifically for this work;

- three depth-to-water (groundwater elevation) measurement events; and

- a site survey of monitoring wells in which the depth-to-water measurements were conducted.

These activities are summarized in Table 3-2 and all sampling locations are shown in Figure 3-3.

Table 3-2. Summary of Field Sampling Activities at NBVC.

			Sampling Events		
			April/May ‘04	July/Aug. ‘04	Aug ‘05
Number of temporary GW sampling locations			33	18	37
Number of GW samples collected and analyzed (excluding QA/QC samples)			188	197	298
Aquifer characterization tests	Temporary GW locations	Constant drawdown pumping tests	74	66	---
		WL recovery tests	88	---	---
	Permanent wells	Constant drawdown pumping tests	---	67	---
		Slug tests	---	8	---
Number of soil cores collected for lab permeameter testing			---	61	---
Number of permeameter tests performed			---	245	---

Notes: *GW – groundwater*
WL – water level

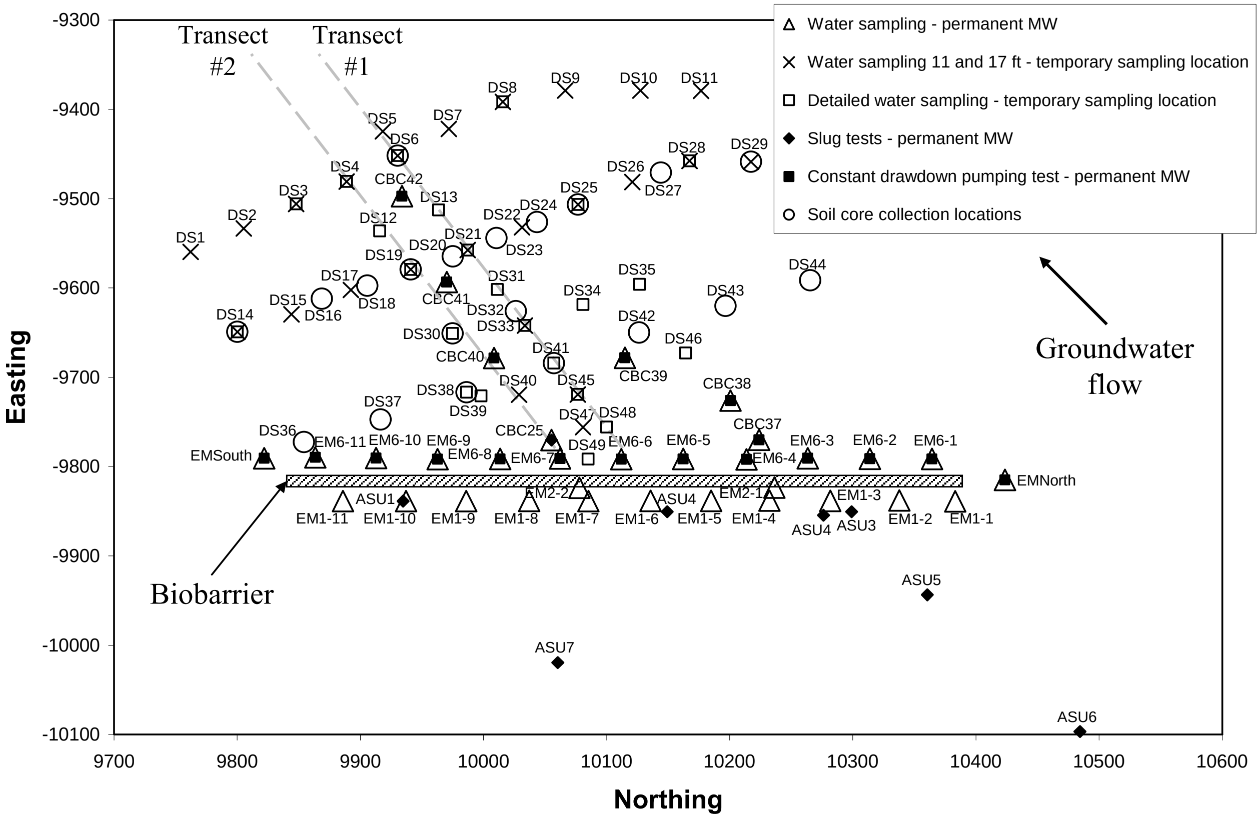


Figure 3-3. Sampling Locations Used in this Project. All Distances Along the Axes are in feet.

Year 2004 activities included the assessment of the horizontal and vertical distribution of MTBE in groundwater down-gradient of the PTB as well as the assessment of aquifer characteristics. Year 2005 activities focused primarily on groundwater sampling at the Year 2004 locations, with some additional hydraulic property characterization.

More specifically, the following were conducted:

Dissolved MTBE Plume Characterization and Assessment of the Horizontal/Vertical Distribution of MTBE in Groundwater Across the Site:

- Initial plume characterization: Discrete 1-ft (0.3 m) interval groundwater samples were collected at 11- and 17- ft (3.3- and 5.2-m) BGS at 25 locations to first define the dissolved plume axis and width down-gradient of the biobarrier. The samples were analyzed for MTBE, DO, and ORP.

- Definition of dissolved contaminant distribution horizontally/vertically across the site: Groundwater samples were collected at 23 locations on 1-ft (0.3 m) intervals throughout the 9 ft to 20 ft (2.7 m to 6.1 m) vertical extent of the aquifer. The groundwater samples were analyzed for MTBE, DO, and ORP.

- Water quality from permanent monitoring wells: Water samples were collected from 26 wells in 13 locations immediately down-gradient of the PTB to assess water quality discharging from the PTB. Water samples were also collected in 7 wells further down-gradient of the PTB across the area of interest. The samples were analyzed for MTBE, DO, and ORP.

Hydrogeologic Characterization:

- Soil core collection for quantitative permeameter testing and qualitative soil description: Continuous soil cores from 8 to 20 ft (2.4 to 6.1 m) bgs were collected using a 3-ft (1-m) long Geoprobe macro-core sampler. Samples were collected from 20 locations along 2 primary transects perpendicular to flow direction as shown in Figure 3-3. Sixty-one 3-ft (1-m) core sections were shipped to ASU where they were subdivided into 245 sections (on 1-ft = 0.3-m intervals or smaller based on visual differences in soil texture) and were then subjected to both constant- and falling-head permeameter testing.

- In-situ hydraulic conductivity measurements: Aquifer specific-capacity (constant draw-down pumping tests) tests were attempted at 1 ft (0.3 m) resolution across the 9 ft to 20 ft (2.7 m to 6.1 m) BGS vertical interval at 23 locations across the site. Tests were not successful at all depths at each location due to slow water recovery in the direct-push rod. In those cases, qualitative observations of conductivity were captured by recording water level recovery within the direct-push rod prior to collecting a groundwater sample.

- Slug tests were performed in eight conventional 2- and/or 4-in groundwater monitoring wells in the vicinity of the demonstration site.

- Aquifer specific-capacity (constant draw-down pumping tests) tests were performed in 31 wells at 19 locations across the site. Thirteen locations provided data for both shallow (10-15 ft = 3.0-4.6 m BGS) and deep (15-20 ft = 4.6-6.1 m BGS) intervals.

- Depth-to-water measurements were collected during three separate field events: July/August 2004, March 2005, and August 2005 for flow direction determination. A well survey was performed in March 2005 to ensure the accuracy of the groundwater flow direction determination. This survey included both a GPS survey for X, Y, and Z coordinates and a Spirit Level survey with loop closure for vertical (Z) coordinate confirmation.

Sampling Methods. Groundwater samples were collected as discussed below:

- Groundwater sample collection and hydraulic conductivity testing at direct-push sampling locations was conducted using the Geoprobe Groundwater Profiler modified for this project as discussed in Appendix D. This tool allowed successive discrete intervals to be sampled as the drive rods were pushed downward. At each target sampling depth, the six-inch stainless steel screened interval was exposed for groundwater withdrawal by pulling up on the external drive rod. This groundwater profiler would then retract during the advance downward to the next sampling interval.

- Groundwater samples were collected using slow-flow Masterflex peristaltic pumps. For permanent monitoring well installations, each well had a dedicated polyethylene drop tube and Norprene tubing was used in the pump head. The standard procedure was to purge the well for at least one well purge volume and until dissolved oxygen (DO) measurements stabilized (about 1 liter for the 0.75-in (1.9 cm)-diameter well completions) prior to sample collection and measurement of DO and ORP.

- For direct-push discrete interval sampling, samples were also collected using the slow-flow Masterflex peristaltic pumps, a polyethylene drop tube down the drive rod, and Norprene tubing in the pump head. The standard sampling procedure involved purging the sampler as possible, allowing the water level recover in the drive rod, performing an aquifer specific-capacity test (if water level recovery was sufficiently fast), sample collection, and measurement of DO and ORP.

- Two zero-headspace groundwater samples were collected in 40-ml VOA vials having Teflon-lined septum caps.

- Sample splits (duplicates) were collected at a frequency of 1-in-10.

- Sample vials were labeled by permanent marker with the well ID and are then placed in a cardboard box. The cardboard box is then hand-carried to the field analytical laboratory building, where the vials were placed on ice until analyzed.

Analytical Methods. Table 3-3 summarizes the analytical methods used.

Table 3-3. Analytical/Testing Methods.

Measurement	Description of Analyses
Dissolved oxygen (DO)	DO concentrations were measured using a flow-through cell and a YSI Model 550A DO meter with an accuracy of ±0.3 mg/L or ±2% of the reading, an air saturation range of 0 to 200% and a temperature range of -5° C to +45° C. DO concentrations were monitored until a stable reading was obtained and until a sufficient volume of water from the well or groundwater sampling point was purged (approximately 1 liter). Meter calibration was conducted by a one-point calibration in air as is standard for this instrument.
MTBE concentration in groundwater	Heated headspace method: 30 ml sample warmed in 40 ml VOA vial to 35ºC followed by 0.5 ml injection of headspace onto an SRI 8610C gas chromatograph (GC) equipped with a DB-1 type capillary column and photo-ionization (PID) and flame-ionization (FID) detectors. The GC was calibrated to known dissolved MTBE concentrations across the concentration range of interest (approximately 0.001 mg/l to 10 mg/l). A three- to five-point calibration was used, with at least one calibration concentration within each order of magnitude. The reporting level for this study was generally about 0.005 ug/l based on calibration data.
Oxidation reduction potential (ORP)	ORP was measured using an Orion Quikchek Model 108 ORP meter with a relative mV range/resolution: ±999mV/1mV and relative accuracy: ±5mV. ORP meter function was confirmed using an ORP standard solution. Due to the slow response time for the meter, it was determined in the field that the most stable ORP measurements were made when a static sample was collected and the meter was allowed to stabilize within the sample.
Specific Discharge	For 0.75-in (1.9 cm) diameter permanent monitoring wells and direct-push groundwater sampling locations, specific-discharge tests were conducted using an electronic water level indicator, a volumetric cylinder, a peristaltic pump, and a stop watch. First, the water level is measured in the well/drive-rod until stable. Then the polyethylene tubing inlet is lowered 3-in (7.6 cm) to 6-in (15 cm) below the stable water level and the peristaltic pump is run at a speed capable of drawing the water down to that level (this was apparent by slugs of air coming up in the tubing). At this point, the flow is measured by recording the time required to collect a specified volume of water.
Measurement	Description of Analyses
Slug Tests	Slug testing was performed in permanent monitoring well installations with well diameters 2-in (5.1 cm) or greater. Slug tests utilized either one or two 4-ft (1.2 m) long slugs to obtain a minimum 1-ft (0.3-m) displacement within each monitoring well. A submersible transducer/data-logger was used to monitor water level recovery during each test.
Laboratory Permeameter Tests	Laboratory hydraulic conductivity tests were conducted on all soil cores using both constant- and falling-head permeameters. Each core was cut into 1-ft (0.3-m) intervals or smaller, based on visual changes in the geology of the soil core. Each interval was then tested. Sections that took longer than 30 min to saturate were not analyzed. For these intervals, the hydraulic conductivity was assigned a value less than the lowest conductivity recorded for the laboratory methods (10^{-5} cm/s)

Experimental Controls. The concept of experimental controls is not relevant to this demonstration.

Data Quality Parameters. Sample density for this demonstration was extremely high; 680 groundwater samples were collected at 37 sampling locations. To ensure the quality of the data, the following were performed:

- A GC calibration check was performed after at least every 15 analyses.

- Sample duplicates (additional sample collected from same sampling location for analysis) were collected twice at each direct-push location and sample replicates (same sample analyzed more than once) were analyzed at a rate of one in ten samples.

- Duplicate sampling of select locations was also performed to ensure data gathered was representative. This included soil core locations as well as groundwater sampling and specific discharge measurement locations.

Data Quality Indicators. The measure of acceptability for GC analyses is typically about 20% variability in results from the duplicate and replicate analyses when more than an order of magnitude above the reporting limit for the analyses.

Calibration Procedures, Quality Control Checks, and Corrective Action. The quality assurance activities used in the project were selected to maintain the accuracy and the precision of the field analytical techniques. These activities included frequent equipment calibration checks, and in the case of GC analyses, sample duplicate and sample replicate analyses and field laboratory sample blanks. The quality assurance activities were designed to trigger corrective action activities and diagnose potential sources of error.

- Dissolved oxygen (DO): The YSI 550A DO probe membranes were changed at the beginning of each field event and as necessary during each sampling event. Meter calibration was a one-point calibration in air as per manufacturer's instructions. Meters were calibrated periodically throughout the day and every time they were powered on to ensure consistent results. If DO readings were slow to stabilize, probe membranes were cleaned or changed as necessary.

- Oxidation reduction potential (ORP): No calibration of the ORP meter was possible. As such, ORP readings were checked daily against a standard to confirm response and electrode tips were cleaned periodically to maintain response.

- MTBE Concentrations: The SRI 8610C GC was calibrated each day at five different concentrations spanning the concentration range of interest (e.g., 1, 10, 100, 1000, and 10,000 µg/L for dissolved MTBE concentrations). In addition, at least one calibration sample was re-analyzed every 20 samples to detect any instrument drift. If area counts from successive calibration analyses consistently deviated by more than 20% or if retention times varied by more than 0.2 minutes, then the equipment was checked for a leaking septum and/or a change in gas flows. If the equipment was not the source of error, then a new standard was made and analyzed. If necessary, recalibrating over the entire concentration range was repeated. Reporting levels of 1 ug/L for MTBE in groundwater were established based on the calibration results. Duplicate analyses were conducted at a frequency of not less than one in 15 samples, and replicate (split) water samples are also analyzed at a frequency of not less than one in ten samples

Original data recording retained all significant digits so that round-off errors would not be propagated through the calculations. Peer checks of data recording and data reduction were used to reduce errors.

3.5.8 Demobilization

Holes created by the direct push methods well backfilled with granular bentonite and the surface was repaired to original pavement conditions with cold-mix asphalt.

ASU sampling and analytical equipment was transported back to ASU after each sampling event.

3.6 SELECTION OF ANALYTICAL/TESTING METHODS

The analytical/testing methods are summarized above in Table 3-3. All GC-FID/PID analyses were conducted on a dedicated SRI Instruments Model 8610C gc housed in a dedicated building located approximately 200 ft (60 m) from the biobarrier. Based on over eight years of analysis experience at this site, no matrix or environmental interferences were expected during those analyses.

3.7 SELECTION OF ANALYTICAL/TESTING LABORATORY

All testing and analysis was conducted by ASU personnel. Due to the volume and sensitivity of the testing required for this demonstration, all water quality analyses were performed on-site. Soil cores were shipped to ASU for permeameter testing and qualitative characterization of geologic description.

PERFORMANCE ASSESSMENT

4.1 PERFORMANCE CRITERIA

This ESTCP project does not involve the demonstration of a technology; instead, it involves the development and demonstration of an approach for estimating groundwater quality improvements down-gradient of a PTB as discussed in Chapter 2. Consistent with that, the performance criteria established for this project are summarized in Table 4-1.

Table 4-1. Performance Criteria.

Performance Criteria	Description	Primary or Secondary
Data set collected at NBVC is useful for testing and revising predictive approach, and for use by others in developing more sophisticated tools	- Data set to include aquifer characterization data and MTBE concentration vs. distance down-gradient of biobarrier PTB at two different sampling times and at a spatial density much greater than typical PTB performance monitoring.	Primary
Utility of Approach	- Illustrate the use of a "practicable" approach that can be used to project estimates of groundwater quality changes with time down-gradient of a PTB. - Be able to project reasonable order-of-magnitude estimates of groundwater quality changes with time down-gradient of a PTB. - Predictive tool is useable by consultants, project managers, and regulators. - Utilize readily available aquifer and contaminant characterization data and supplemental data that does not significantly increase characterization and PTB remedy costs.	Primary

4.2 PERFORMANCE CONFIRMATION METHODS

Metrics associated with the performance criteria are presented below in Table 4-2.

Table 4-2. Performance Metrics.

Primary Performance Criteria (qualitative and quantitative)	Expected Performance Metric	Performance Confirmation Method	Actual
Data set collected at NBVC is useful for testing and revising approach for estimating down-gradient water quality changes with time, and for use by others in developing more sophisticated tools	Data set reasonably characterizes the changes in hydraulic conductivity with depth in the aquifer and includes sufficient flow direction and hydraulic gradient data	Summary tables of hydraulic property results and maps of groundwater elevations	See §4.3.1 and §4.3.2
	Data set shows concentration vs. distance and time behavior down-gradient of the PTB, ranging from very low (or non-detect) concentrations at the PTB to unaffected concentrations some distance down-gradient of the PTB	Plots of MTBE concentration vs. distance at different sampling times	See §4.3.3
Utility of Approach	Illustrate approach for estimating down-gradient water quality changes with time	Use data from NBVC site and present inputs and outputs	See §4.3.4, Appendix A, and Appendix B
	Comparison of projected and measured concentrations down-gradient of the PTB	Reasonable order-of-magnitude agreement.	
	Predictive tool incorporated in a spreadsheet.	Spreadsheet created and User's Guide written	
	Comparison of characterization requirements for the proposed approach and current characterization requirements.	Supplemental data collection does not increase typical characterization costs by more than 10 – 20%.	

4.3 DATA ANALYSIS, INTERPRETATION, AND EVALUATION

4.3.1 Hydrogeologic Characterization

Results from the measurement of hydraulic conductivity are summarized below in Table 4-3, and more details are archived in Appendix E.

Table 4-3. Hydraulic Conductivity Descriptive Statistics for NBVC Site.

Laboratory Permeameter Tests	Interval (ft bgs)	Hydraulic conductivity (cm/s)				
		Average	Adjusted Median*	Median	Minimum	Maximum
	8	2.0E-2	1.0E-5	1.0E-5	1.0E-5	4.0E-1
	9	2.2E-4	1.0E-5	1.0E-5	1.0E-5	4.2E-3
	10	7.9E-3	1.0E-5	1.0E-5	1.0E-5	8.2E-2
	11	6.9E-3	3.8E-3	9.0E-4	1.0E-5	8.2E-2
	12	1.0E-2	1.3E-2	8.5E-3	1.0E-5	3.5E-2
	13	1.6E-2	1.4E-2	1.3E-2	1.0E-5	6.8E-2
	14	2.3E-2	1.5E-2	7.5E-3	1.0E-5	2.1E-1
	15	3.8E-2	3.4E-2	2.8E-2	1.0E-5	1.1E-1
	16	3.9E-2	4.0E-2	1.9E-2	1.0E-5	2.0E-1
	17	3.6E-2	4.1E-2	3.1E-2	1.0E-5	1.3E-1
	18	5.1E-2	5.1E-2	4.2E-2	1.0E-5	1.4E-1
	19	7.6E-2	7.6E-2	5.6E-2	1.0E-5	3.7E-1
Discrete Interval Field Mini-Pump Tests at Direct-Push Locations	Interval (ft bgs)	Hydraulic conductivity (cm/s)				N
		Average	Adjusted Median*	Minimum	Maximum	
	8	---	---	---	---	---
	9	---	---	---	---	---
	10	1.1E-2	1.1E-2	1.1E-2	1.1E-2	2
	11	7.8E-3	3.1E-3	1.3E-3	2.1E-2	5
	12	6.4E-3	1.6E-3	6.9E-4	2.5E-2	5
	13	2.5E-2	9.3E-3	1.6E-3	7.3E-2	5
	14	7.3E-3	6.3E-3	1.6E-3	1.7E-2	5
	15	2.1E-2	5.2E-3	3.6E-3	4.9E-2	5
	16	4.0E-2	4.3E-2	4.8E-4	7.9E-2	5
	17	3.4E-2	1.7E-2	1.0E-3	7.9E-2	5
	18	3.2E-2	6.3E-3	5.1E-4	7.9E-2	5
	19	3.8E-2	2.4E-2	1.4E-3	7.9E-2	5
Field Slug Tests in Conventional Wells	Hydraulic conductivity (cm/s)					
	Interval (ft BGS)	Average	Median	Minimum	Maximum	N
Slug-out	9 – 20	0.20	0.16	4.0E-2	4.6E-1	8
Slug-In	9 - 20	0.12	0.11	1.9E-2	3.1E-1	8

* *"adjusted median" represents the median of values after the exclusion of values considered to be outliers for that layer.*

Overall, the data suggest hydraulic conductivities that are lowest at shallow intervals and highest at deeper intervals throughout the aquifer interval of interest. The range of hydraulic conductivity values for this study was consistent with previous findings including the Amerson and Johnson tracer study (2003) and estimates of hydraulic conductivity collected during the installation of the biobarrier in 2000.

The quantitative hydraulic conductivity data are generally in agreement with visual observations of the soils cores summarized in Table 4-4.

Table 4-4. Summary of Visual Observations from Soil Cores.

Depth Interval [ft BGS]	Geologic Description
0 - 8	Silt/fill material
8 - 10	Silty fine sands
10 - 14	Fine sands
14 - 20	Fine to coarse sands, with some gravel
>20	Clay aquitard

These findings were consistent with those from biobarrier installation studies which indicated that site stratigraphy was silty fill material from 7 to 9 ft BGS, medium grained sands and gravel for 9 to 20 ft BGS, at which point a clay aquitard was encountered (Bruce et al. 2003).

4.3.2 Groundwater Flow Direction and Hydraulic Gradient

Depth to groundwater across the site was approximately 8 ft, with seasonal fluctuations of up to 1 ft. Using depth-to-water measurements and survey data, groundwater elevations were calculated and were used to develop water level contour maps and to determine flow direction and hydraulic gradient across the site for each measurement event. Figures 4-1a and 4-1b present groundwater elevation contour maps for the August 2004 and August 2005 measurement events.

In both cases, groundwater flow is to the southwest (north is to the right of the page in both of these figures). The hydraulic gradient ranges from 0.003 ft/ft to 0.004 ft/ft. Using a range of hydraulic conductivities from 10^{-5} cm/s to 2.1×10^{-1} cm/s, a hydraulic gradient of 0.004 m/m, and a moisture content of 0.3 m^3-H_2O/m^3-soil, groundwater velocities at the site were estimated to range from 1.3×10^{-7} cm/s (3.8×10^{-4} ft/day) to 2.7×10^{-3} cm/s (7.9 ft/day).

Groundwater elevation data from this study are tabulated in Appendix F.

Figure 4-1a. Groundwater Elevation Contour Map for the August 2004 Event.

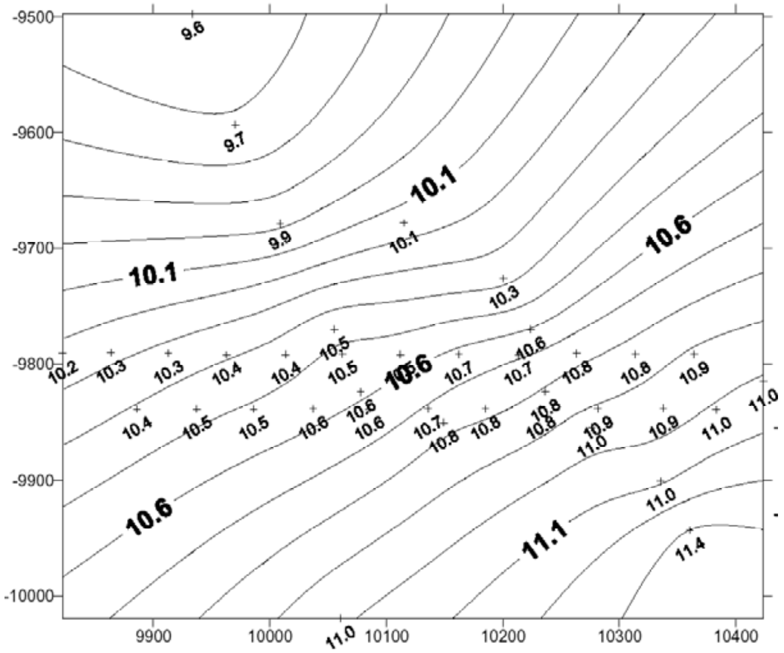


Figure 4-1b. Groundwater Elevation Contour Map for the August 2005 Event.

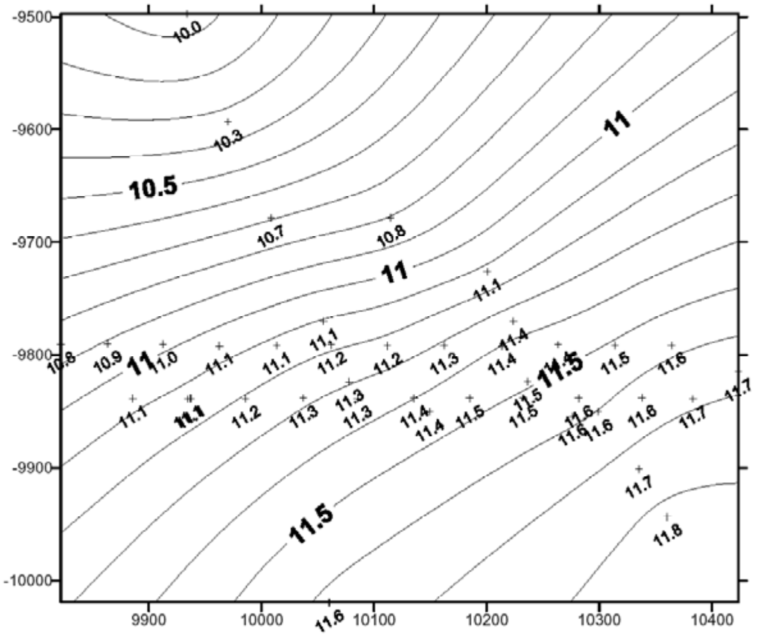


Figure 4-1. Groundwater Elevation Contour Maps for the August 2004 and August 2005 Measurement Events. The PTB is Oriented Horizontally Across this Figure at About -9975 ft on the Vertical Axis. Axis Units are [ft] **and Elevations are in** [ft above mean sea-level]**.**

4.3.3 Groundwater Quality Changes in Space and with Time

Pre-biobarrier PTB operation water quality data were obtained by Bruce et al. (2003) from 13 monitoring well locations in August of 2000. These data, collected at 15 ft and 20 ft BGS, indicated that dissolved MTBE concentrations were as high as 12000 ug/L in the core of the dissolved plume.

Figures 4-2 through 4-5 present contour plots of MTBE concentrations for the 2004 and 2005 sampling events (1324 and 1709 d after seeding of the biobarrier PTB, respectively). Figures 4-2 through 4-4 present plan-view concentration contour plots for sampling depths of 11, 13, and 17 ft BGS, respectively. Figure 4-5 presents data for a vertical slice along the direction of flow. The complete data set is given in Appendix G.

Statistical analysis of MTBE concentration data included maximum, minimum, mean, and median values for each depth interval for the 2004 and 2005 sampling events and are presented in Table 4-5.

Table 4-5. **MTBE Groundwater Concentration Statistics in Monitored Down-gradient Zone from the 2004 and 2005 Sampling Events** (1226 – 1324 d and 1709 d after biobarrier seeding, respectively).

Depth (ft BGS)	2004 MTBE concentrations (ug/L)			2005 MTBE concentrations (ug/L)		
	Minimum	Maximum	Median	Minimum	Maximum	Median
9	BDL	BDL	BDL	ND	ND	ND
10	ND	507	19.5	ND	63	3
11	ND	654	29	ND	170	3
12	ND	876	78	ND	176	9
13	ND	484	39.5	ND	102	5
14	BDL	480	18.5	BDL	52	3
15	BDL	67	13	ND	28	3
16	BDL	53	9	ND	8	3
17	BDL	226	10	ND	7	3
18	BDL	84	11	ND	9	3
19	1	111	13	ND	8	3

Notes: BDL - below detection limit
ND - non-detect
BGS - below ground surface

Analysis of water quality data reveals the following:

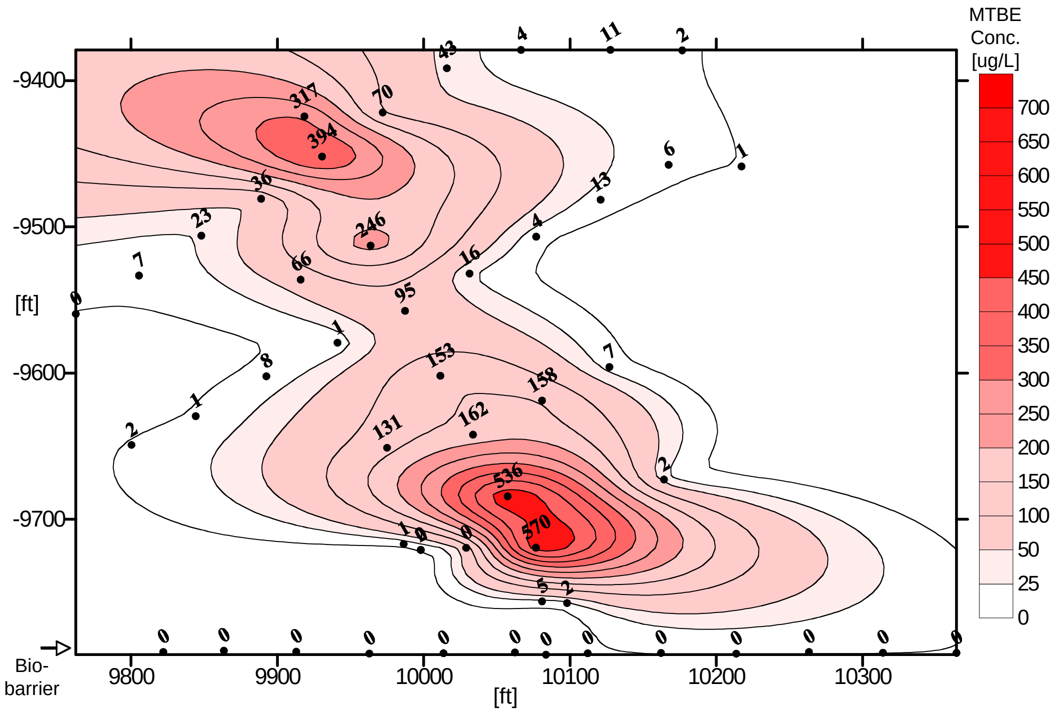
- Dissolved MTBE concentrations were typically greatest at shallower depths and decreased with increasing depth down to 20 ft BGS. The greatest dissolved MTBE concentrations were located along the plume’s central axis

- With time, treated water from the biobarrier can be seen to be migrating down-gradient, resulting in a decreasing trend in concentration.

- Changes in concentration with time occur more rapidly in the deeper and higher conductivity sections of the aquifer. Concentrations persist longer in the shallower and less conductive sections of the aquifer.

In reviewing these data, it is important to note that the NBVC site would typically be considered a relatively simple and homogeneous site. Using the average hydraulic conductivity value from conventional well slug tests (0.4 cm/s; Table 4-3), a gradient of 0.004 m/m, and an effective porosity of 0.3 m^3-H_2O/m^3-aquifer, the conventional expectation would be that all wells within about 2000 ft down-gradient of the biobarrier would have non-detect levels within a year of the start-up of the biobarrier. Yet, it is clear that MTBE persists in groundwater longer than this, and that the migration of clean water and persistence of MTBE are linked to the vertical variations in hydraulic conductivity.

a) 2004 data collected 1226 to 1324 days after biobarrier seeding.



b) 2005 data collected 1709 days after biobarrier seeding.

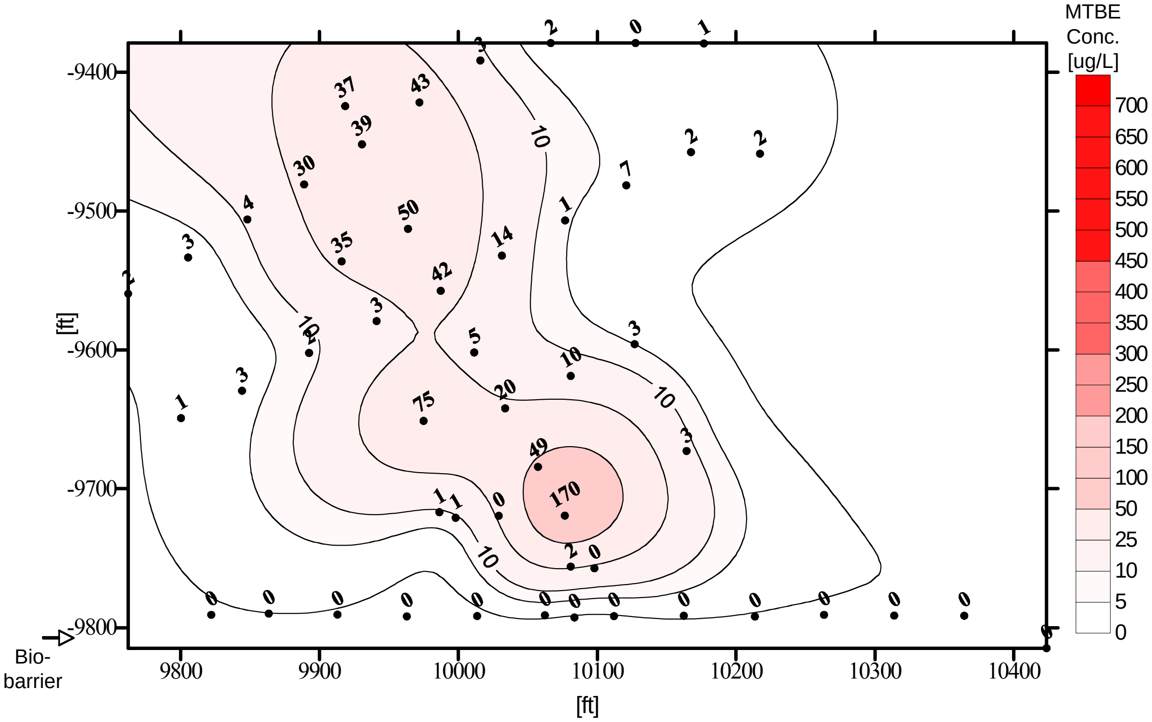
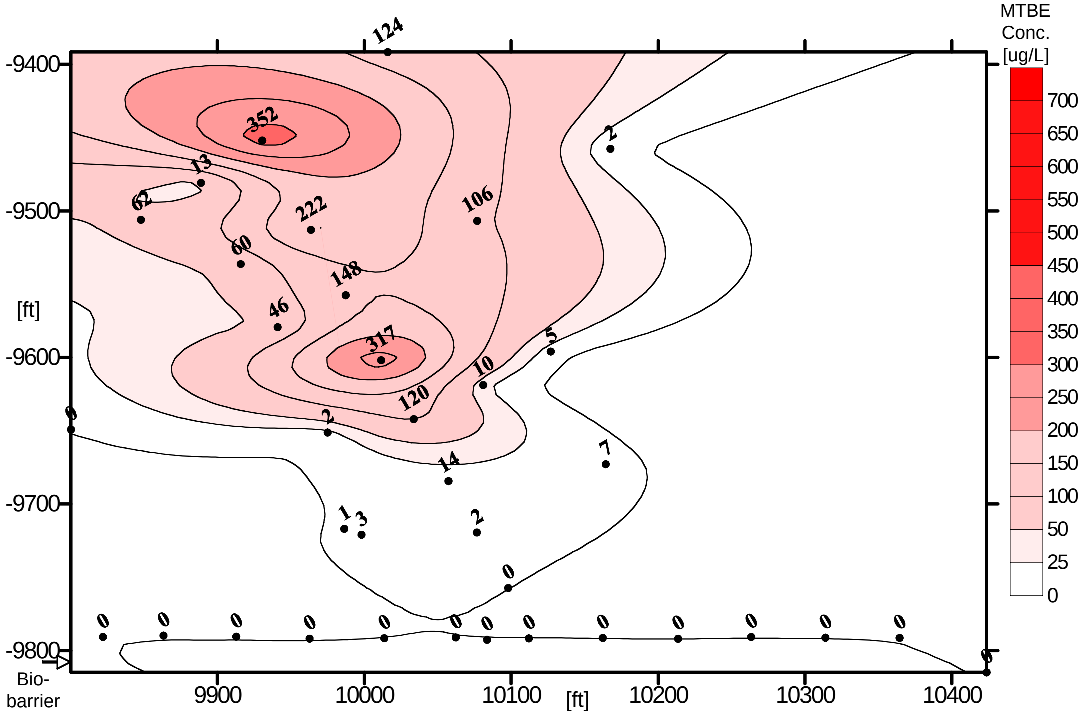


Figure 4-2. MTBE Concentrations in Groundwater at 11 ft BGS (average lab K=0.0069 cm/s)**.**

a) 2004 data collected 1226 to 1324 d after biobarrier seeding.



b) 2005 data collected 1709 d after biobarrier seeding.

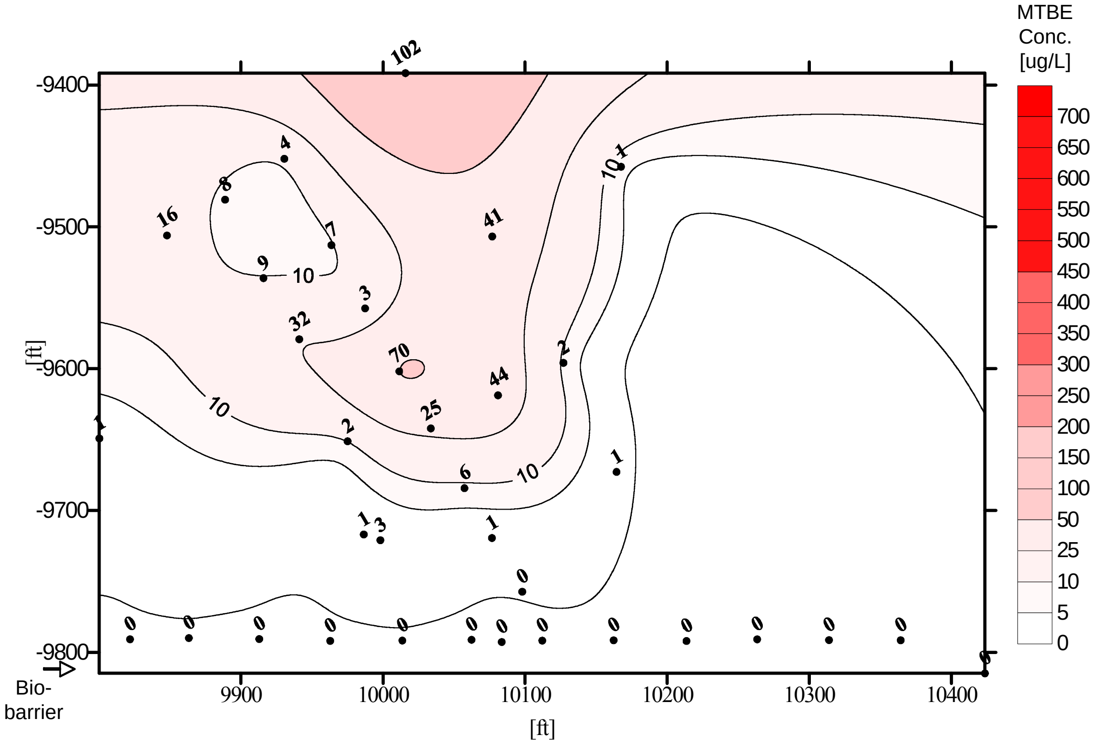
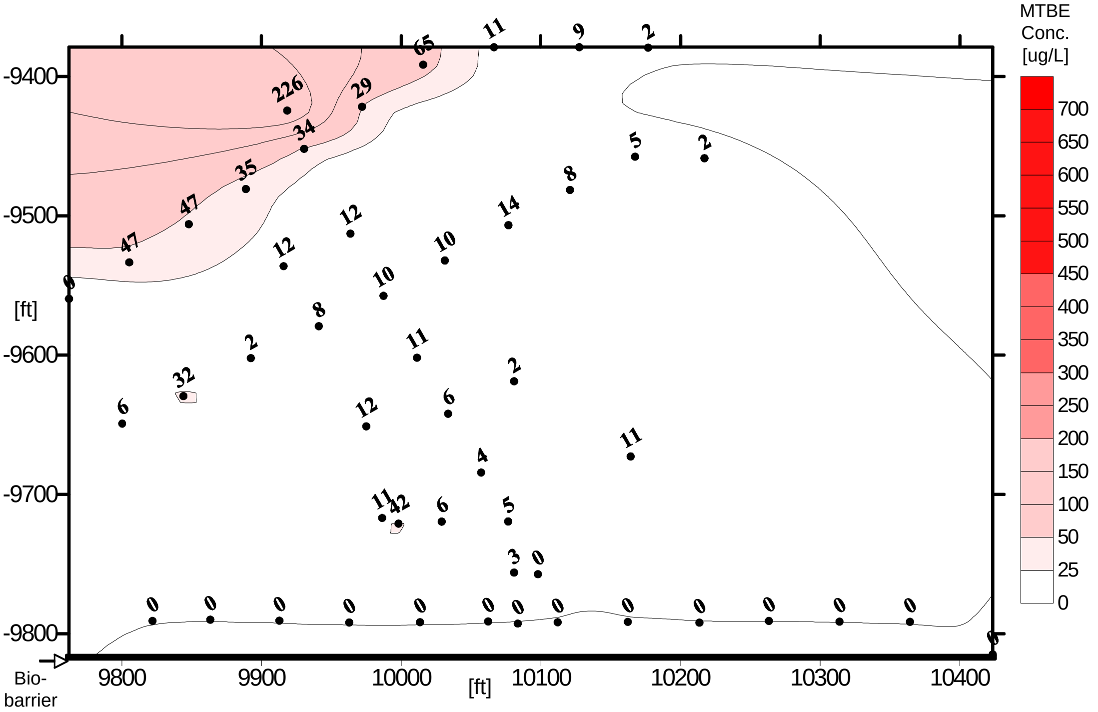


Figure 4-3. MTBE Concentrations in Groundwater at 13 ft BGS. (average lab K=0.016 cm/s).

a) 2004 data collected 1226 to 1324 d after biobarrier seeding.



b) 2005 data collected 1709 d after biobarrier seeding.

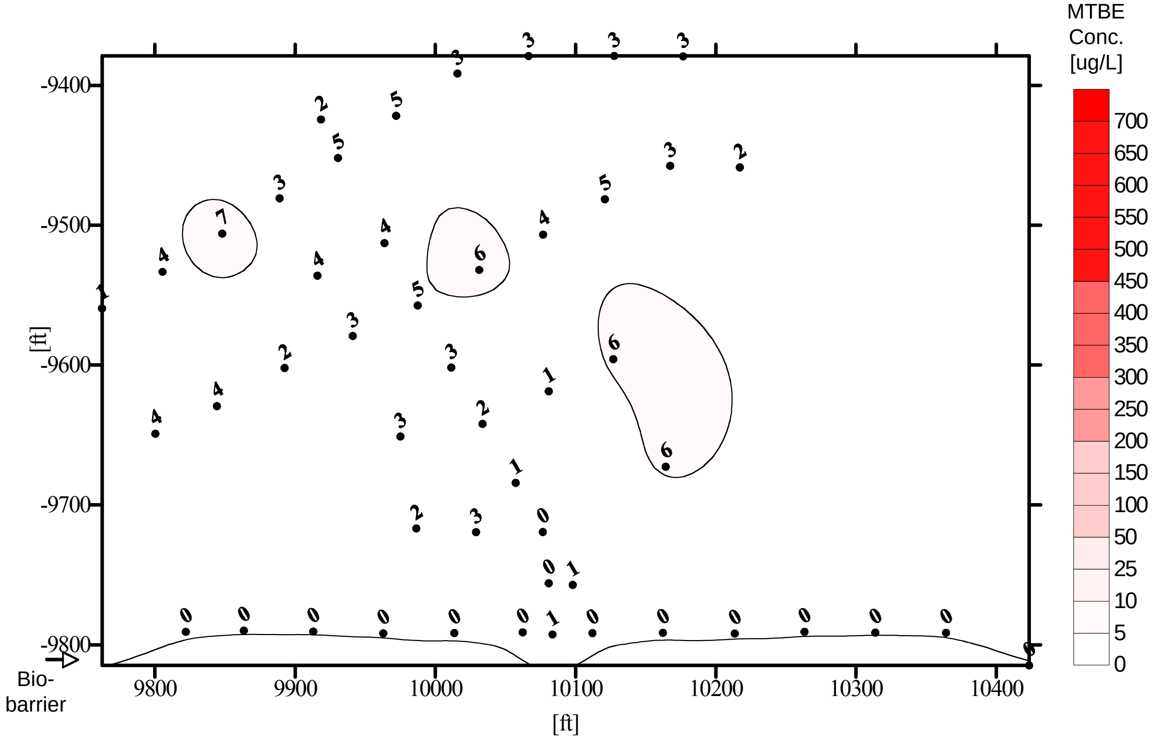
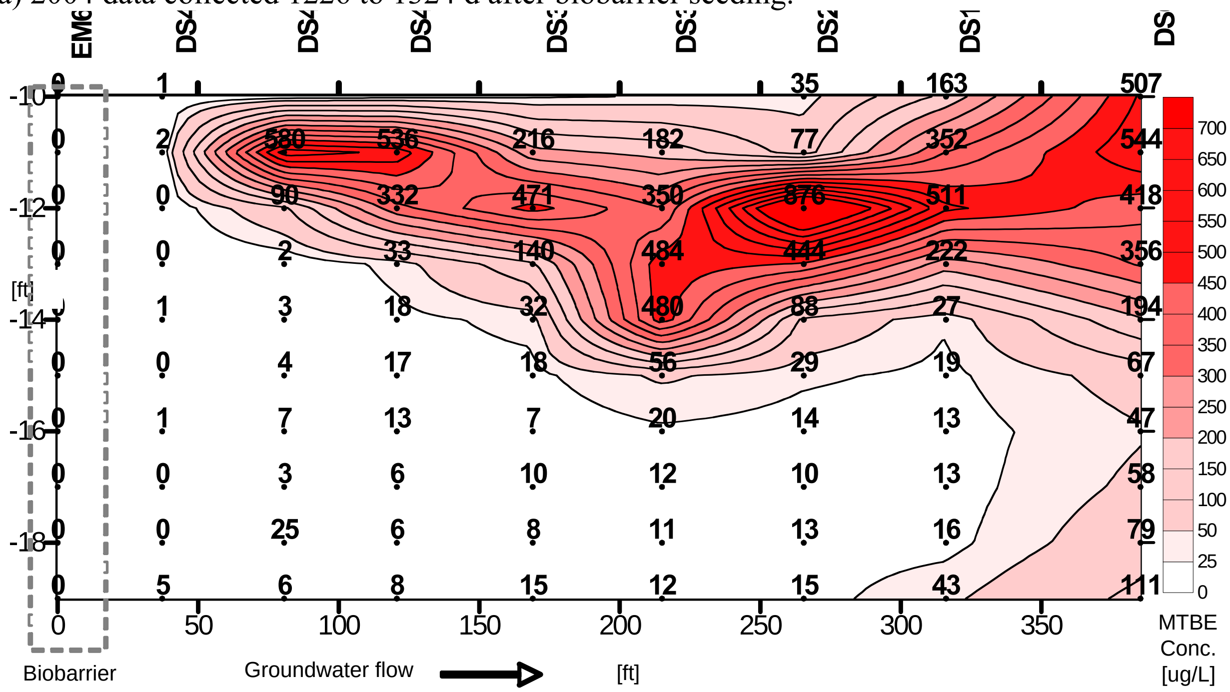


Figure 4-4. MTBE Concentrations in Groundwater at 17 ft BGS. (average lab K=0.036 cm/s).

a) 2004 data collected 1226 to 1324 d after biobarrier seeding.



b) 2005 data collected 1709 d after biobarrier seeding.

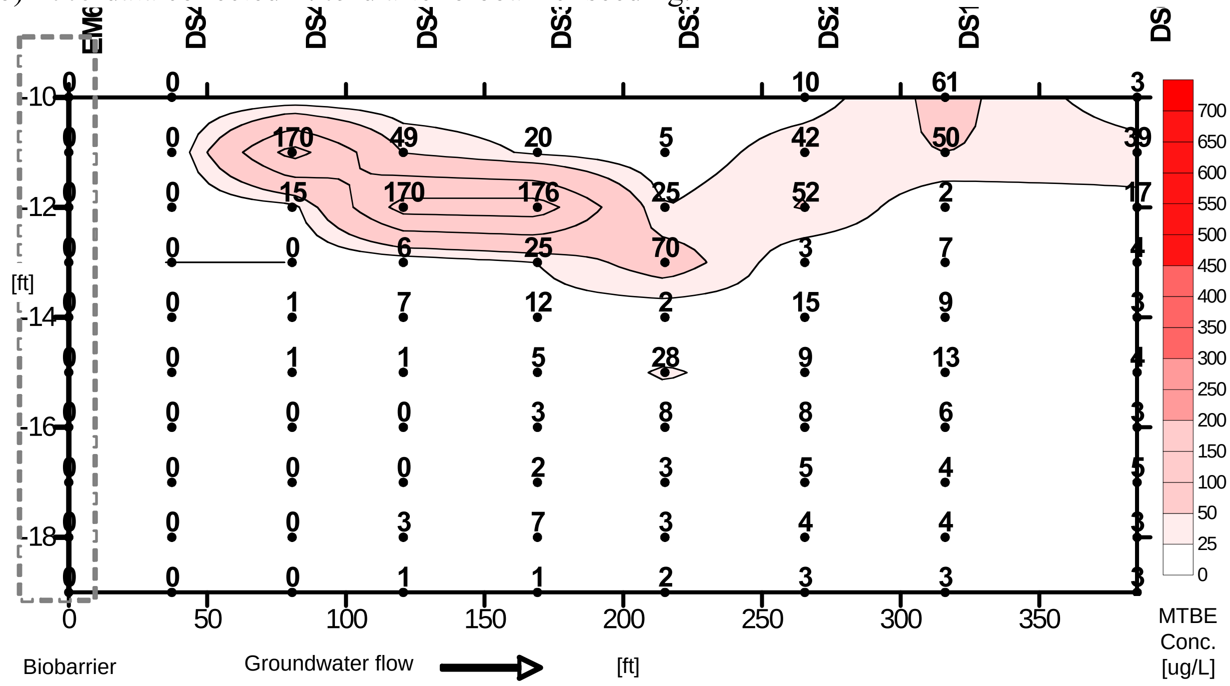


Figure 4-5. MTBE Concentrations – Vertical Cross-section Along Plume Centerline.

4.3.4 Estimating Groundwater Quality Changes Down-Gradient of PTB

Two groundwater flow and contaminant transport models were developed and applied using data collected down-gradient of the NBVC Port Hueneme MTBE biobarrier. The first was a user-friendly spreadsheet model (DGCHANGE v1.0) developed to estimate approximate time frames over which significant concentration reductions should be observed in near-field down-gradient monitoring wells. The second was a more sophisticated MODFLOW/MT3D-based model using Groundwater Vistas (Environmental Simulations Inc.) pre- and post-processing software.

4.3.4.1 DGCHANGE V1.0 Spreadsheet Model

DGCHANGE v1.0 is a spreadsheet based modeling tool developed to predict order-of – magnitude changes in groundwater quality with time down-gradient of a PTB. With this tool, the user enters aquifer characteristics and the output is presented graphically as: a) cross-section plots along the plume centerline showing concentration vs. depth and distance for user-specified times, b) changes with depth and time at fixed distances down-gradient, and c) expected concentrations vs. time in conventional wells located at selected distances down-gradient of the PTB. The governing equations and fundamental basis for DGCHANGE v1.0 are presented in Appendix A, and Appendix B contains the User's Guide for the spreadsheets. Its application to the NBVC site is discussed below.

4.3.4.2 Application of DGCHANGE V1.0 to the NBVC Biobarrier PTB Site

The aquifer or saturated region of interest was discretized into 1-ft thick intervals, an interval consistent with the available data density. Model inputs included the hydraulic conductivity measurements for each interval, the hydraulic gradient for the region studied, estimates of the initial MTBE concentrations, water filled porosity, soil bulk density, and the fraction of organic carbon in the soil.

While pre-biobarrier data downgradient of the biobarrier was limited, initial model input groundwater concentrations for the site were estimated from August 2000 pre-biobarrier operation water quality data summarized by Bruce et al. (2003) for the 13 shallow (10-15 ft bgs) and deep (15-20 ft bgs) monitoring well pairs immediately down-gradient of the NBVC biobarrier. MTBE concentrations ranged from approximately 12000 ug/L in the core of the 500 ft wide dissolved MTBE plume to non-detect at the outer edges. These concentrations were projected without change down-gradient along transects parallel to the groundwater flow direction. MTBE concentrations from the 10 – 15 ft sampling interval were applied uniformly to all model layers at depths <15 ft BGS. Similarly, known pre-biobarrier MTBE concentrations from the 15-20 ft sampling interval were applied uniformly to all model layers at depths 15- 20 ft BGS.

Hydraulic conductivities for each model layer were based on statistical analysis of all hydraulic conductivity data and professional judgment. Maximum, minimum, mean, and median values for each layer are presented in Table 4-3 for both field and laboratory based measurements. The "adjusted median" represents the median of values after the exclusion of values considered to be outliers for that layer. For example, at some depths there were bi-modal distributions of hydraulic conductivity representing both higher conductivity (sandy) materials and lower conductivity (silty/clayey) materials. For each depth, therefore, professional judgment was used to select the data that corresponded best with visual descriptions of the core material. The hydraulic gradient was calculated to be 0.004 [m/m] through interpretation of groundwater contour maps in Figure 4-1.

Quantities that were not measured and had to be estimated for NBVC included the water-filled porosity, soil bulk density, and the fraction of organic carbon in the soil. These were assigned values of 0.30 cm^3-H_2O/ cm^3-soil, 1.7 g-soil/ cm^3-soil, and 0.005 g-OC/g-soil respectively, based on professional judgment.

Figure 4-6 presents the DGCHANGE v1.0 **Inputs** worksheet showing a complete listing of input parameters.

Figures 4-7 through 4-10 present DGCHANGE v1.0 output for t=1, 1.5, 2, and 2.5 years. These figures show the progression of clean water (blue cells) which follow MTBE impacted water (red cells). Contaminant concentrations are also displayed in each cell. From this time sequence, it can be seen that the translation of clean water is slow in the silt and/or fine sand layers (9 to 13 ft BGS) where clean water moves less than 30 ft per 6 month increment. These time sequences also indicate that the translation of clean water is faster in the heterogeneous mix of fine/coarse sand layers (14 to 20 ft BGS), moving more than 60 ft per 6-month period.

Figures 4-11 and 4-12 show DGCHANGE v1.0 vertical cross-section snapshots at times corresponding to the NBVC sampling trips - 1,324 d (t=3.6 y) and 1,709 d (t=4.7 y) after seeding of the biobarrier. A comparison of model results with actual water quality data from field investigations (Figures 4-2 through 4-5) indicates that DGCHANGE v1.0 reasonably anticipated the distribution of clean and MTBE-impacted water; in particular:

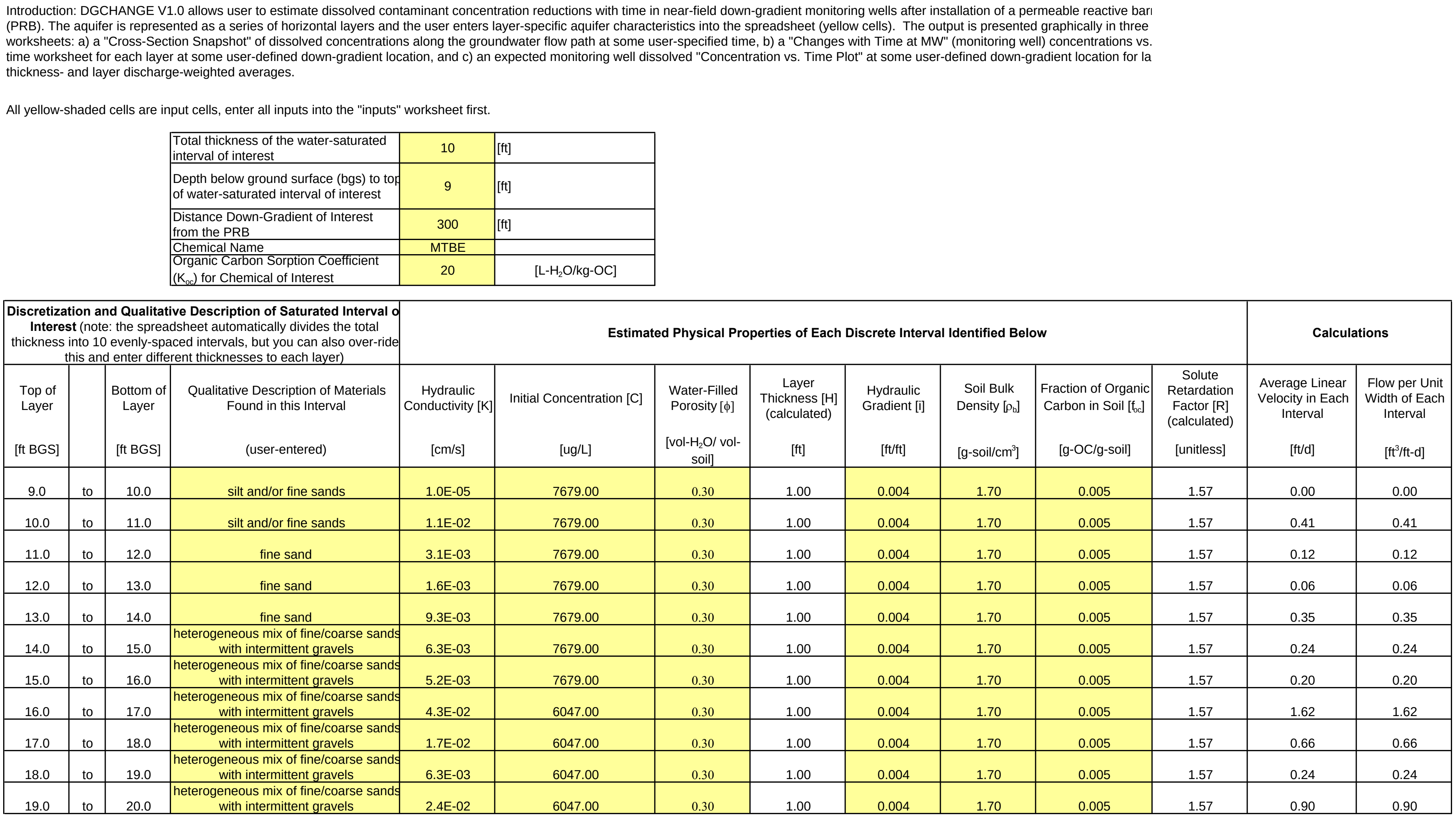
- MTBE-impacted groundwater was persistent at the shallowest depths from 9 to 12 ft BGS for both DGCHANGE v1.0 output and NBVC data.

- Clean water was found at all depth intervals from 0 to 30 ft down-gradient of the biobarrier for both DGCHANGE v1.0 output and NBVC data.

- MTBE concentrations were significantly reduced for both DGCHANGE v1.0 output and NBVC data from 15 to 20 ft bgs.

The time evolution of concentrations in a conventional monitoring well down-gradient of the biobarrier PTB can also be estimated using DGCHANGE v1.0. This can be seen in Figure 4-13 for a down-gradient distance of 50 ft over a t = 0 to t = 10 y time frame. This tabular output communicates how each layer’s concentrations are expected to change with time at a given distance down-gradient and reflects the differences in hydraulic conductivity and groundwater flow velocity between the model layers as anticipated by the progression shown in Figures 4-7 through 4-10.

Results in Figure 4-13 are used to calculate layer thickness- and layer discharge-weighted concentrations as shown in Figure 4-14. This figure indicates that while contaminant may persist in the less conductive zones within the aquifer, the flow-weighted average, or that which is likely detected in monitoring wells, can drop substantially due to the dominance or contributions from the higher conductivity zones. To evaluate the models capabilities from this aspect, concentration versus time curves were generated using DGCHANGE v1.0 for down-gradient CBC wells at NBVC. Concentration versus time curves were generated for the exact down-gradient distances for each of the CBC wells using initial concentrations based on concentrations from EM wells, projected down-gradient parallel to the flow axis. Actual concentration values for each of the CBC wells collected on NBVC sampling trips were then superimposed on to the concentration versus time curve and are shown in Figures 4-15 (a) through (g). The DGCHANGE v1.0 curve and actual monitoring data quantitatively agree with each other, both indicating significant reductions in concentrations between 1300 and 1700 d. However, due to the lack of actual data collected from time = 0 to 1300 d, no conclusions can made on the accuracy of DGCHANGE v1.0 for that period.



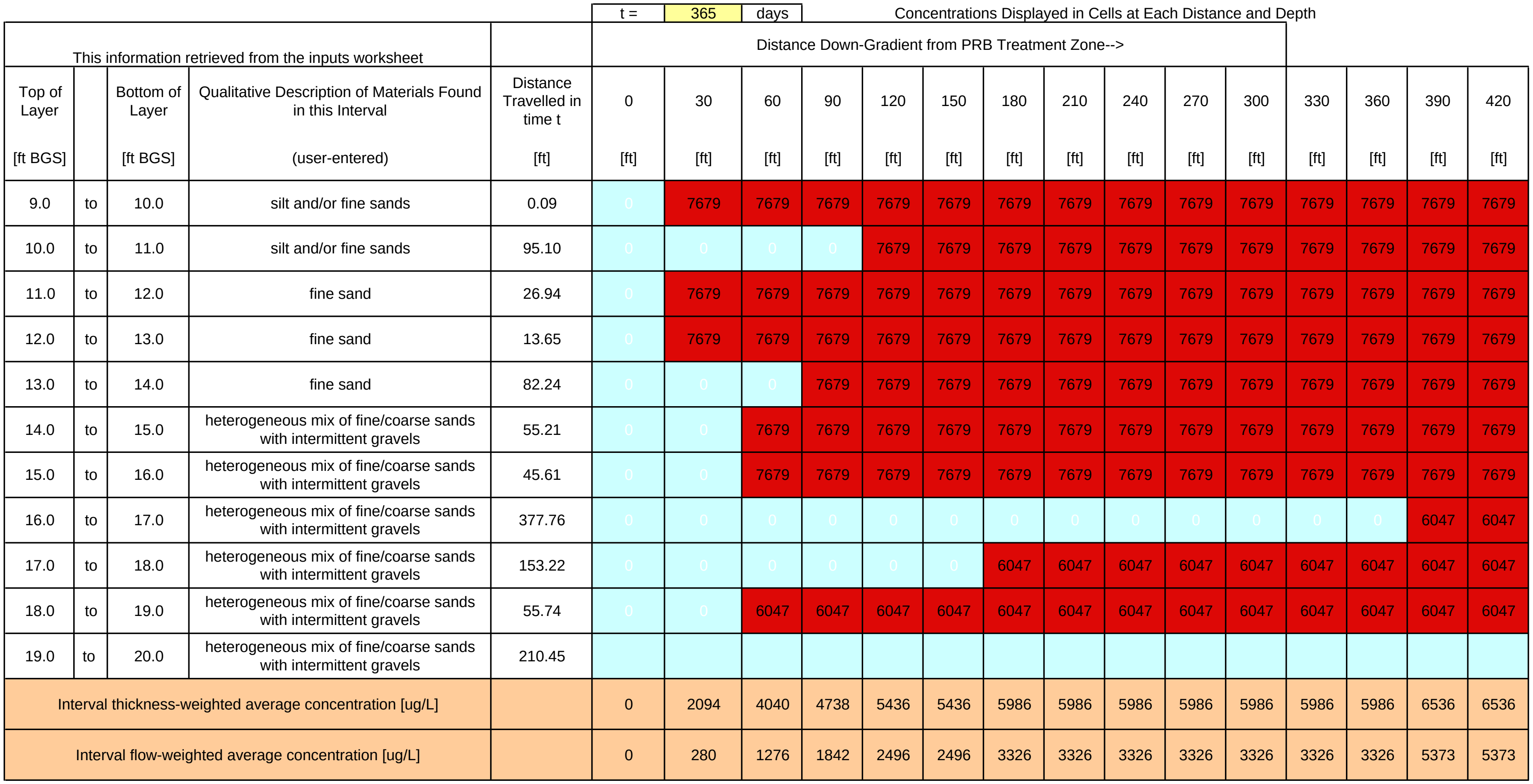
Introduction: DGCHANGE V1.0 allows user to estimate dissolved contaminant concentration reductions with time in near-field down-gradient monitoring wells after installation of a permeable reactive bari (PRB). The aquifer is represented as a series of horizontal layers and the user enters layer-specific aquifer characteristics into the spreadsheet (yellow cells). The output is presented graphically in three worksheets: a) a "Cross-Section Snapshot" of dissolved concentrations along the groundwater flow path at some user-specified time, b) a "Changes with Time at MW" (monitoring well) concentrations vs. time worksheet for each layer at some user-defined down-gradient location, and c) an expected monitoring well dissolved "Concentration vs. Time Plot" at some user-defined down-gradient location for la thickness- and layer discharge-weighted averages.

All yellow-shaded cells are input cells, enter all inputs into the "inputs" worksheet first.

Total thickness of the water-saturated interval of interest	10	[ft]
Depth below ground surface (bgs) to top of water-saturated interval of interest	9	[ft]
Distance Down-Gradient of Interest from the PRB	300	[ft]
Chemical Name	MTBE	
Organic Carbon Sorption Coefficient (K_{oc}) for Chemical of Interest	20	[L-H_2O/kg-OC]

Discretization and Qualitative Description of Saturated Interval o Interest (note: the spreadsheet automatically divides the total thickness into 10 evenly-spaced intervals, but you can also over-ride this and enter different thicknesses to each layer)				**Estimated Physical Properties of Each Discrete Interval Identified Below**								**Calculations**	
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Hydraulic Conductivity [K] [cm/s]	Initial Concentration [C] [ug/L]	Water-Filled Porosity [ϕ] [vol-H_2O/ vol-soil]	Layer Thickness [H] (calculated) [ft]	Hydraulic Gradient [i] [ft/ft]	Soil Bulk Density [ρ_b] [g-soil/cm^3]	Fraction of Organic Carbon in Soil [f_{oc}] [g-OC/g-soil]	Solute Retardation Factor [R] (calculated) [unitless]	Average Linear Velocity in Each Interval [ft/d]	Flow per Unit Width of Each Interval [ft^3/ft-d]
9.0	to	10.0	silt and/or fine sands	1.0E-05	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.00	0.00
10.0	to	11.0	silt and/or fine sands	1.1E-02	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.41	0.41
11.0	to	12.0	fine sand	3.1E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.12	0.12
12.0	to	13.0	fine sand	1.6E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.06	0.06
13.0	to	14.0	fine sand	9.3E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.35	0.35
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	6.3E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.24	0.24
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	5.2E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.20	0.20
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	4.3E-02	6047.00	0.30	1.00	0.004	1.70	0.005	1.57	1.62	1.62
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	1.7E-02	6047.00	0.30	1.00	0.004	1.70	0.005	1.57	0.66	0.66
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	6.3E-03	6047.00	0.30	1.00	0.004	1.70	0.005	1.57	0.24	0.24
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	2.4E-02	6047.00	0.30	1.00	0.004	1.70	0.005	1.57	0.90	0.90

Figure 4-6. NBVC-Specific User Inputs for DGCHANGE v1.0.



t = 365 days Concentrations Displayed in Cells at Each Distance and Depth

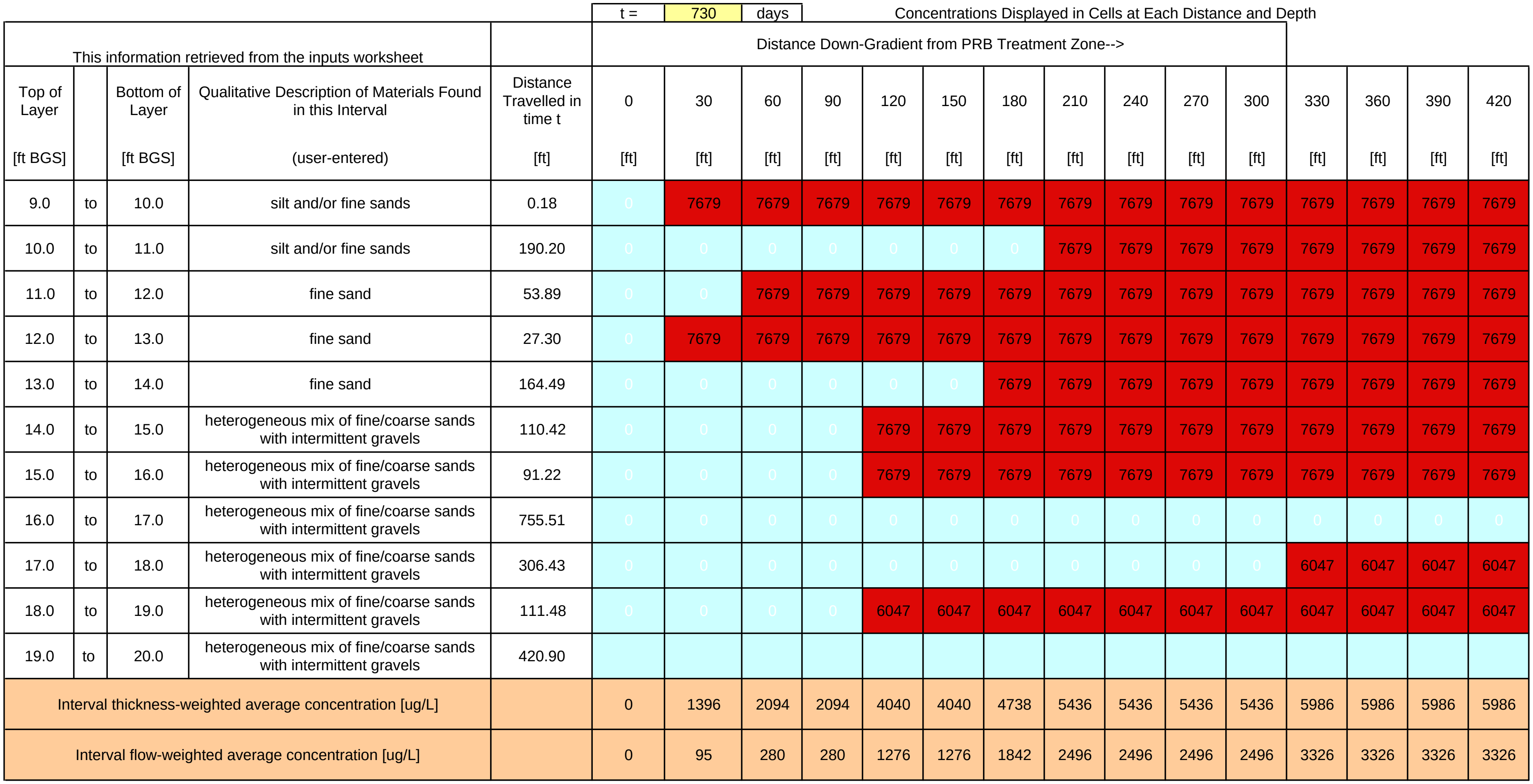
This information retrieved from the inputs worksheet					Distance Down-Gradient from PRB Treatment Zone-->														
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Distance Travelled in time t [ft]	0 [ft]	30 [ft]	60 [ft]	90 [ft]	120 [ft]	150 [ft]	180 [ft]	210 [ft]	240 [ft]	270 [ft]	300 [ft]	330 [ft]	360 [ft]	390 [ft]	420 [ft]
9.0	to	10.0	silt and/or fine sands	0.09	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
10.0	to	11.0	silt and/or fine sands	95.10	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
11.0	to	12.0	fine sand	26.94	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
12.0	to	13.0	fine sand	13.65	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
13.0	to	14.0	fine sand	82.24	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	55.21	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	45.61	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	377.76	0	0	0	0	0	0	0	0	0	0	0	0	0	6047	6047
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	153.22	0	0	0	0	0	0	6047	6047	6047	6047	6047	6047	6047	6047	6047
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	55.74	0	0	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	210.45															
Interval thickness-weighted average concentration [ug/L]					0	2094	4040	4738	5436	5436	5986	5986	5986	5986	5986	5986	5986	6536	6536
Interval flow-weighted average concentration [ug/L]					0	280	1276	1842	2496	2496	3326	3326	3326	3326	3326	3326	3326	5373	5373

Figure 4-7. DGCHANGE v1.0 Results for t=1.0 years: Vertical Cross-section Snapshot Aligned with Groundwater Flow.

t = 547.5 days Concentrations Displayed in Cells at Each Distance and Depth

This information retrieved from the inputs worksheet					Distance Down-Gradient from PRB Treatment Zone-->														
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Distance Travelled in time t [ft]	0 [ft]	30 [ft]	60 [ft]	90 [ft]	120 [ft]	150 [ft]	180 [ft]	210 [ft]	240 [ft]	270 [ft]	300 [ft]	330 [ft]	360 [ft]	390 [ft]	420 [ft]
9.0	to	10.0	silt and/or fine sands	0.13	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
10.0	to	11.0	silt and/or fine sands	142.65	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
11.0	to	12.0	fine sand	40.42	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
12.0	to	13.0	fine sand	20.47	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
13.0	to	14.0	fine sand	123.36	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	82.82	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	68.42	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	566.63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	229.82	0	0	0	0	0	0	0	0	6047	6047	6047	6047	6047	6047	6047
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	83.61	0	0	0	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	315.68															
Interval thickness-weighted average concentration [ug/L]					0	1396	2094	4040	4040	5436	5436	5436	5986	5986	5986	5986	5986	5986	5986
Interval flow-weighted average concentration [ug/L]					0	95	280	1276	1276	2496	2496	2496	3326	3326	3326	3326	3326	3326	3326

Figure 4-8. DGCHANGE v1.0 Results for t=1.5 years: Vertical Cross-section Snapshot Aligned with Groundwater Flow.

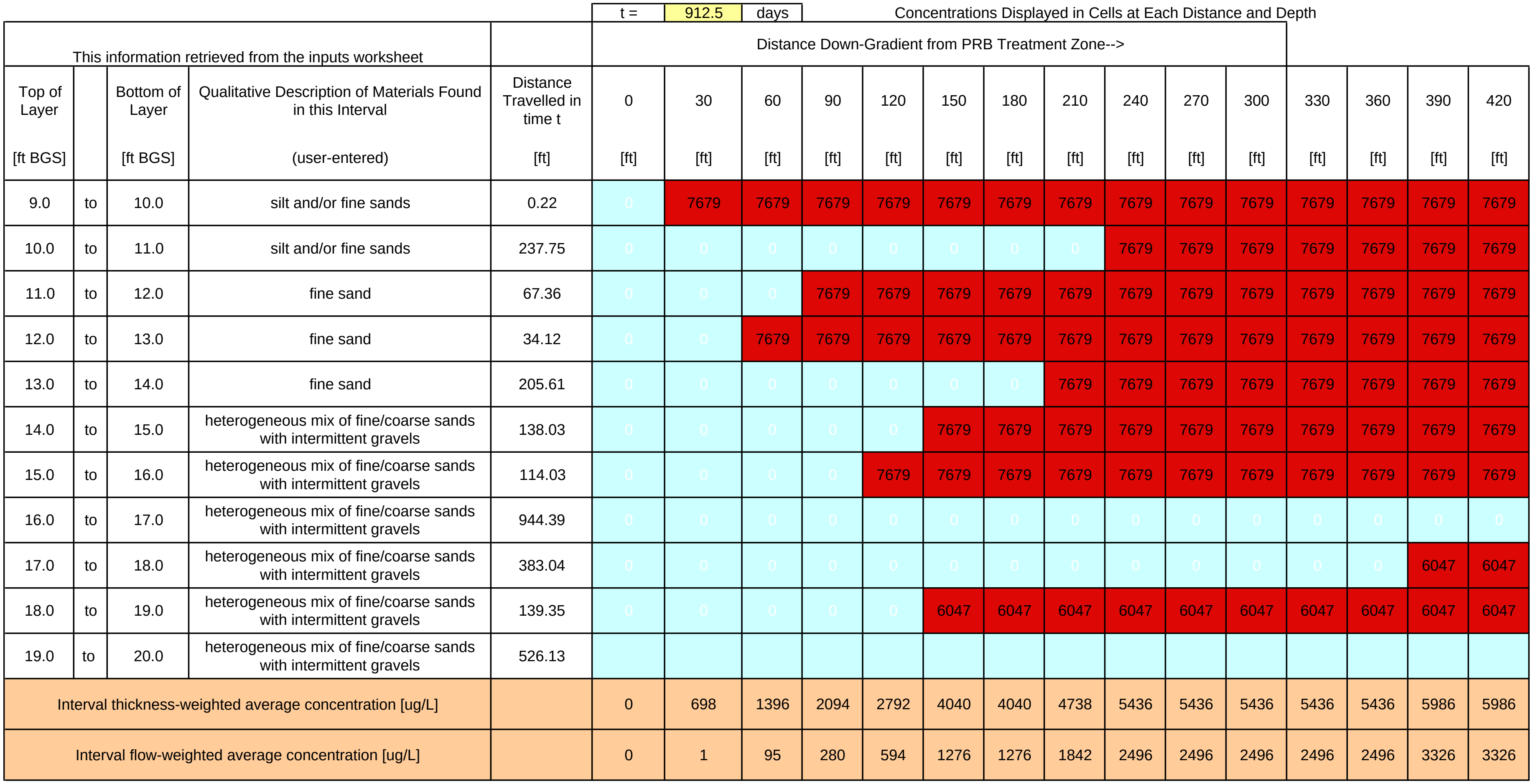


t = 730 days

Concentrations Displayed in Cells at Each Distance and Depth

This information retrieved from the inputs worksheet					Distance Down-Gradient from PRB Treatment Zone-->														
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Distance Travelled in time t [ft]	0 [ft]	30 [ft]	60 [ft]	90 [ft]	120 [ft]	150 [ft]	180 [ft]	210 [ft]	240 [ft]	270 [ft]	300 [ft]	330 [ft]	360 [ft]	390 [ft]	420 [ft]
9.0	to	10.0	silt and/or fine sands	0.18	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
10.0	to	11.0	silt and/or fine sands	190.20	0	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679
11.0	to	12.0	fine sand	53.89	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
12.0	to	13.0	fine sand	27.30	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
13.0	to	14.0	fine sand	164.49	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	110.42	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	91.22	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	755.51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	306.43	0	0	0	0	0	0	0	0	0	0	0	6047	6047	6047	6047
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	111.48	0	0	0	0	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	420.90															
Interval thickness-weighted average concentration [ug/L]					0	1396	2094	2094	4040	4040	4738	5436	5436	5436	5436	5986	5986	5986	5986
Interval flow-weighted average concentration [ug/L]					0	95	280	280	1276	1276	1842	2496	2496	2496	2496	3326	3326	3326	3326

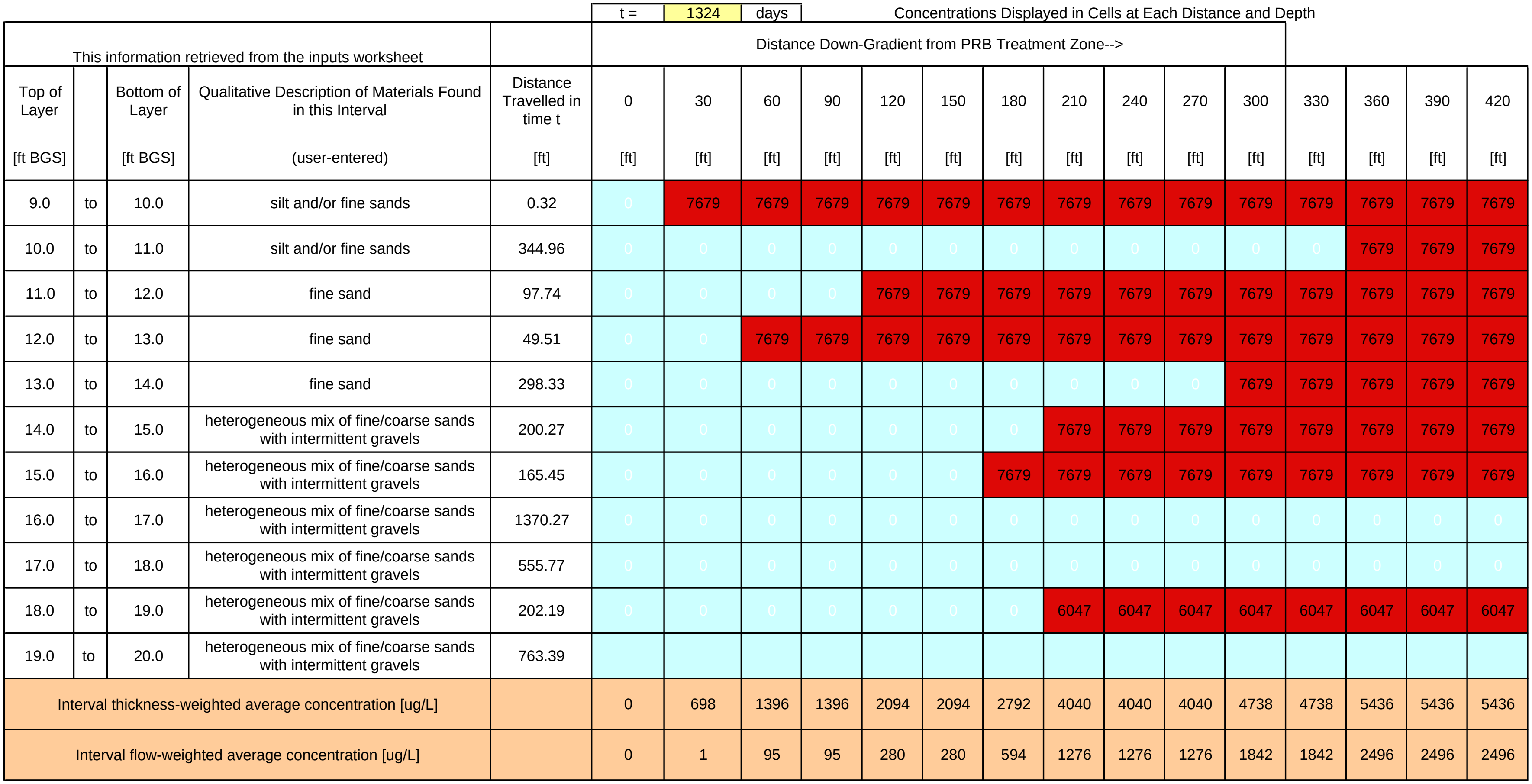
Figure 4-9. DGCHANGE v1.0 Results for t=2.0 years: Vertical Cross-section Snapshot Aligned with Groundwater Flow.



t = 912.5 days Concentrations Displayed in Cells at Each Distance and Depth

This information retrieved from the inputs worksheet					Distance Down-Gradient from PRB Treatment Zone-->														
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Distance Travelled in time t [ft]	0 [ft]	30 [ft]	60 [ft]	90 [ft]	120 [ft]	150 [ft]	180 [ft]	210 [ft]	240 [ft]	270 [ft]	300 [ft]	330 [ft]	360 [ft]	390 [ft]	420 [ft]
9.0	to	10.0	silt and/or fine sands	0.22	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
10.0	to	11.0	silt and/or fine sands	237.75	0	0	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679
11.0	to	12.0	fine sand	67.36	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
12.0	to	13.0	fine sand	34.12	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
13.0	to	14.0	fine sand	205.61	0	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	138.03	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	114.03	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	944.39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	383.04	0	0	0	0	0	0	0	0	0	0	0	0	0	6047	6047
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	139.35	0	0	0	0	0	6047	6047	6047	6047	6047	6047	6047	6047	6047	6047
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	526.13															
Interval thickness-weighted average concentration [ug/L]					0	698	1396	2094	2792	4040	4040	4738	5436	5436	5436	5436	5436	5986	5986
Interval flow-weighted average concentration [ug/L]					0	1	95	280	594	1276	1276	1842	2496	2496	2496	2496	2496	3326	3326

Figure 4-10. DGCHANGE v1.0 Results for t=2.5 years: Vertical Cross-section Snapshot Aligned with Groundwater Flow.

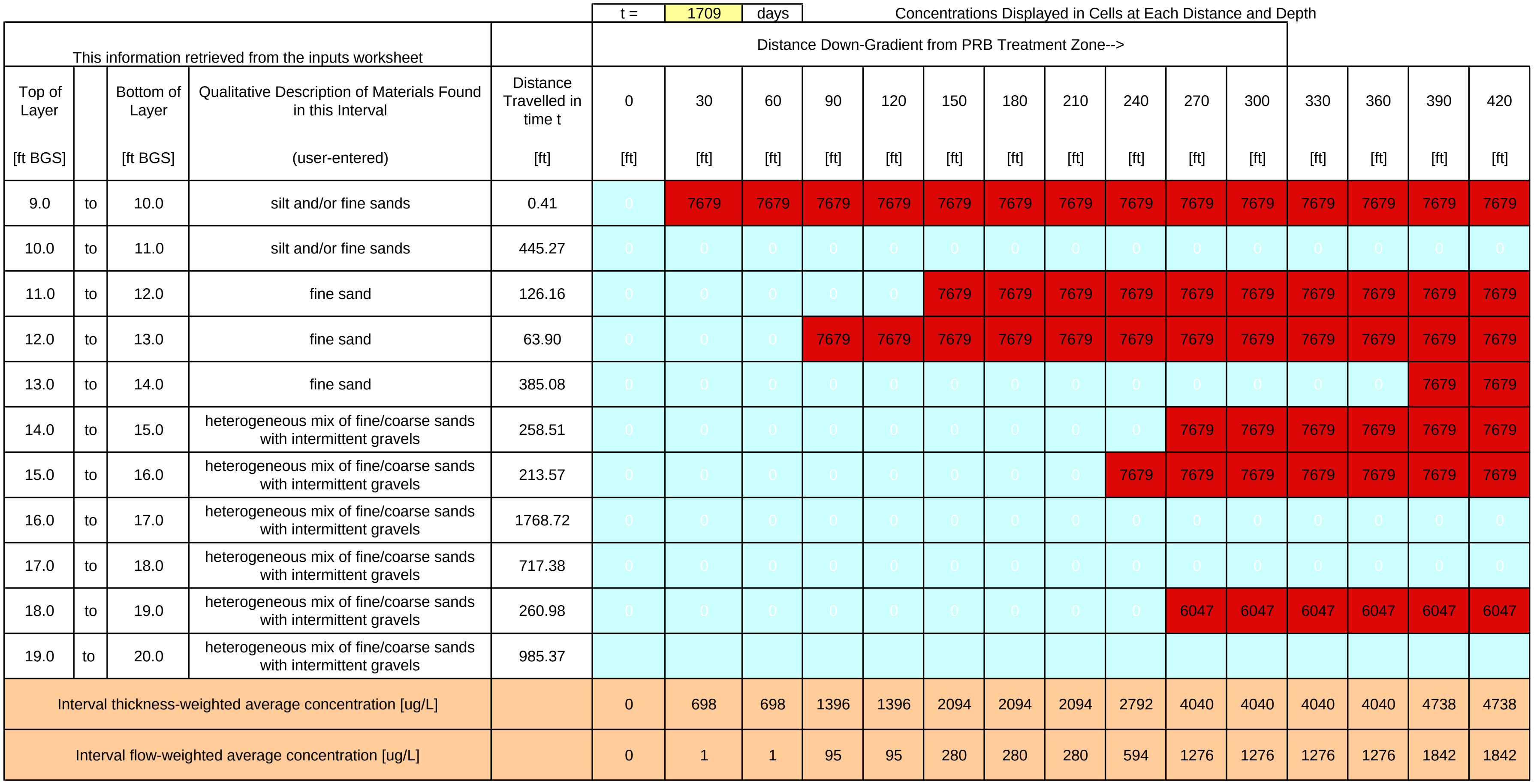


t = 1324 days

Concentrations Displayed in Cells at Each Distance and Depth

This information retrieved from the inputs worksheet					Distance Down-Gradient from PRB Treatment Zone-->														
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Distance Travelled in time t [ft]	0 [ft]	30 [ft]	60 [ft]	90 [ft]	120 [ft]	150 [ft]	180 [ft]	210 [ft]	240 [ft]	270 [ft]	300 [ft]	330 [ft]	360 [ft]	390 [ft]	420 [ft]
9.0	to	10.0	silt and/or fine sands	0.32	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
10.0	to	11.0	silt and/or fine sands	344.96	0	0	0	0	0	0	0	0	0	0	0	0	7679	7679	7679
11.0	to	12.0	fine sand	97.74	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
12.0	to	13.0	fine sand	49.51	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
13.0	to	14.0	fine sand	298.33	0	0	0	0	0	0	0	0	0	0	7679	7679	7679	7679	7679
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	200.27	0	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	165.45	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	1370.27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	555.77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	202.19	0	0	0	0	0	0	0	6047	6047	6047	6047	6047	6047	6047	6047
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	763.39															
Interval thickness-weighted average concentration [ug/L]					0	698	1396	1396	2094	2094	2792	4040	4040	4040	4738	4738	5436	5436	5436
Interval flow-weighted average concentration [ug/L]					0	1	95	95	280	280	594	1276	1276	1276	1842	1842	2496	2496	2496

Figure 4-11. DGCHANGE v1.0 Results for t=1324 d (t=3.6 yr): Vertical Cross-section Snapshot Aligned with Groundwater Flow.

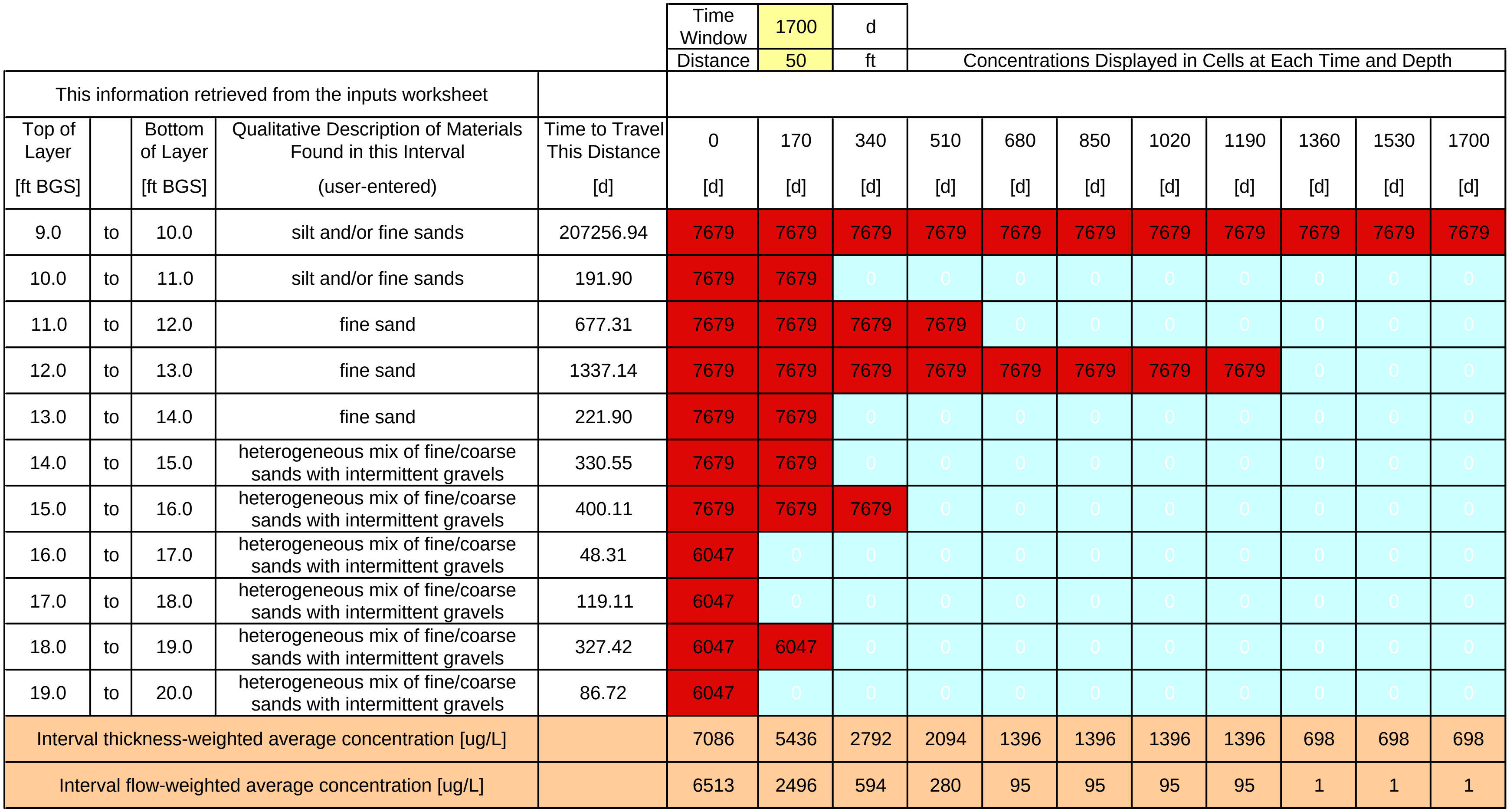


t = 1709 days

Concentrations Displayed in Cells at Each Distance and Depth

This information retrieved from the inputs worksheet					Distance Down-Gradient from PRB Treatment Zone-->														
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Distance Travelled in time t [ft]	0 [ft]	30 [ft]	60 [ft]	90 [ft]	120 [ft]	150 [ft]	180 [ft]	210 [ft]	240 [ft]	270 [ft]	300 [ft]	330 [ft]	360 [ft]	390 [ft]	420 [ft]
9.0	to	10.0	silt and/or fine sands	0.41	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
10.0	to	11.0	silt and/or fine sands	445.27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.0	to	12.0	fine sand	126.16	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
12.0	to	13.0	fine sand	63.90	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
13.0	to	14.0	fine sand	385.08	0	0	0	0	0	0	0	0	0	0	0	0	0	7679	7679
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	258.51	0	0	0	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	213.57	0	0	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	1768.72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	717.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	260.98	0	0	0	0	0	0	0	0	0	6047	6047	6047	6047	6047	6047
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	985.37															
Interval thickness-weighted average concentration [ug/L]					0	698	698	1396	1396	2094	2094	2094	2792	4040	4040	4040	4040	4738	4738
Interval flow-weighted average concentration [ug/L]					0	1	1	95	95	280	280	280	594	1276	1276	1276	1276	1842	1842

Figure 4-12. DGCHANGE v1.0 Results for t=1709 d (t=4.7 yr): Vertical Cross-section Snapshot Aligned with Groundwater Flow.



					Time Window	1700	d								
					Distance	50	ft	Concentrations Displayed in Cells at Each Time and Depth							
This information retrieved from the inputs worksheet															
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Time to Travel This Distance [d]	0 [d]	170 [d]	340 [d]	510 [d]	680 [d]	850 [d]	1020 [d]	1190 [d]	1360 [d]	1530 [d]	1700 [d]
9.0	to	10.0	silt and/or fine sands	207256.94	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
10.0	to	11.0	silt and/or fine sands	191.90	7679	7679	0	0	0	0	0	0	0	0	0
11.0	to	12.0	fine sand	677.31	7679	7679	7679	7679	0	0	0	0	0	0	0
12.0	to	13.0	fine sand	1337.14	7679	7679	7679	7679	7679	7679	7679	7679	0	0	0
13.0	to	14.0	fine sand	221.90	7679	7679	0	0	0	0	0	0	0	0	0
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	330.55	7679	7679	0	0	0	0	0	0	0	0	0
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	400.11	7679	7679	7679	0	0	0	0	0	0	0	0
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	48.31	6047	0	0	0	0	0	0	0	0	0	0
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	119.11	6047	0	0	0	0	0	0	0	0	0	0
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	327.42	6047	6047	0	0	0	0	0	0	0	0	0
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	86.72	6047	0	0	0	0	0	0	0	0	0	0
Interval thickness-weighted average concentration [ug/L]					7086	5436	2792	2094	1396	1396	1396	1396	698	698	698
Interval flow-weighted average concentration [ug/L]					6513	2496	594	280	95	95	95	95	1	1	1

Figure 4-13. DGCHANGE v1.0 Projected Changes with Time and Depth at a Location 50 ft Down-gradient of the Biobarrier PTB.

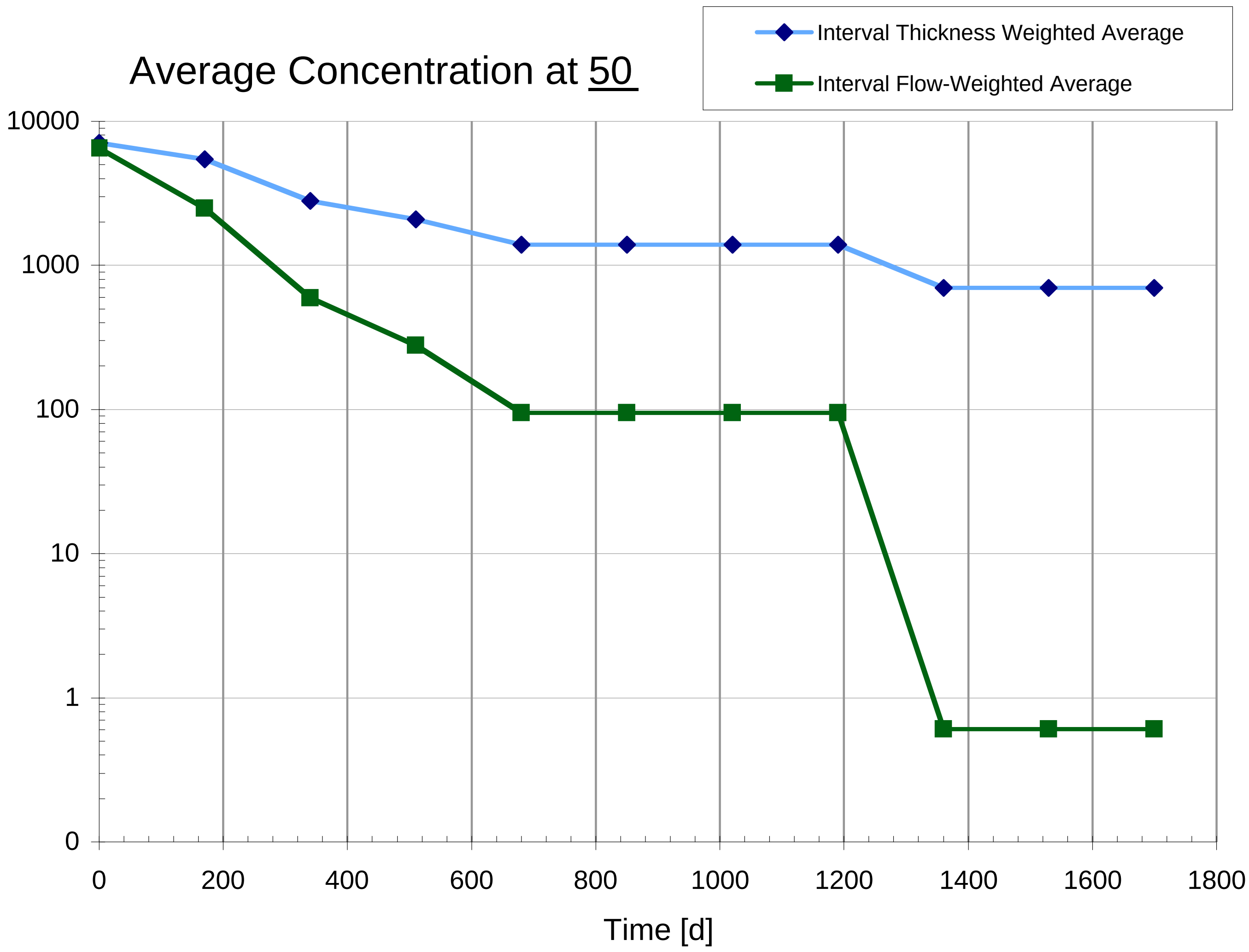
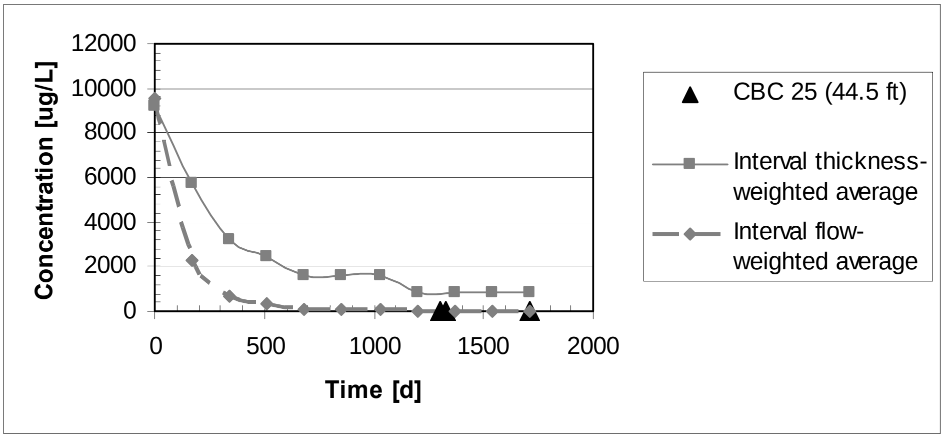
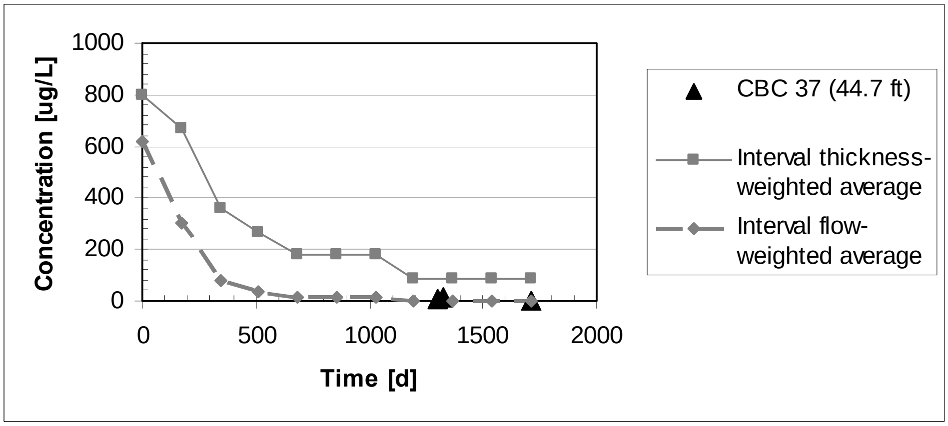


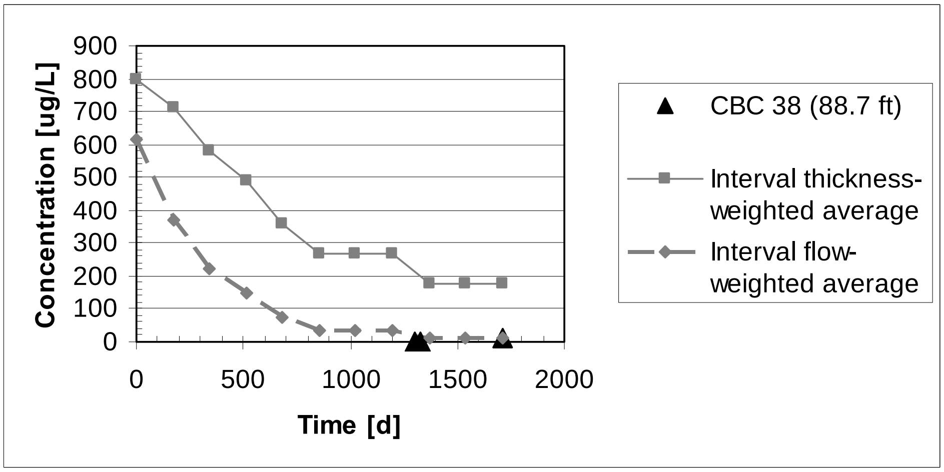
Figure 4-14. DGCHANGE v1.0 Projected Changes with Time in a Full-screened Monitoring Well 50 ft Down-gradient of the Biobarrier PTB.



a) CBC25

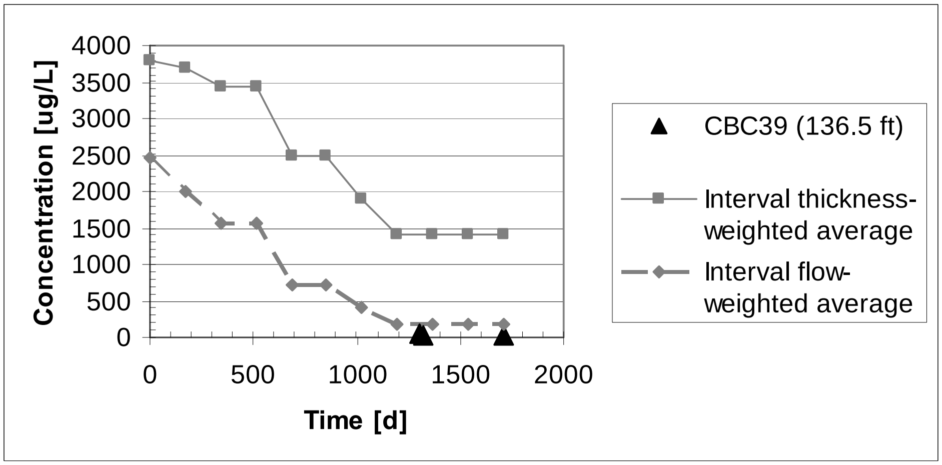


b) CBC37

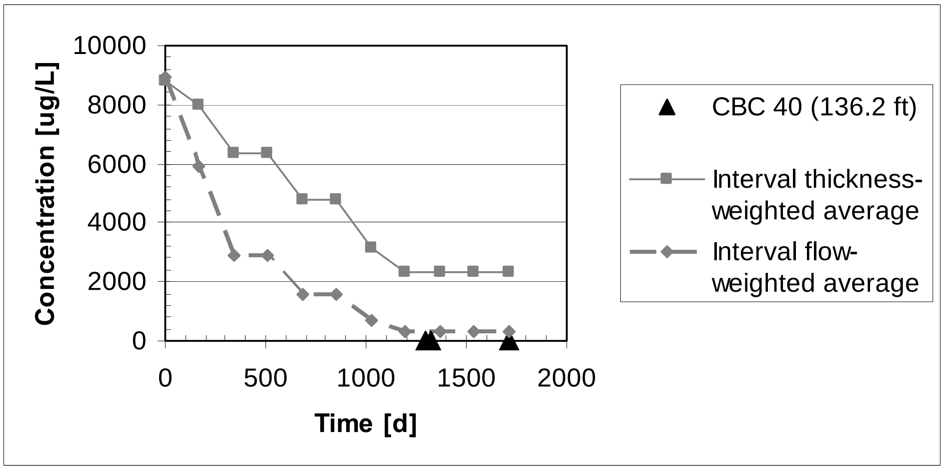


c) CBC38

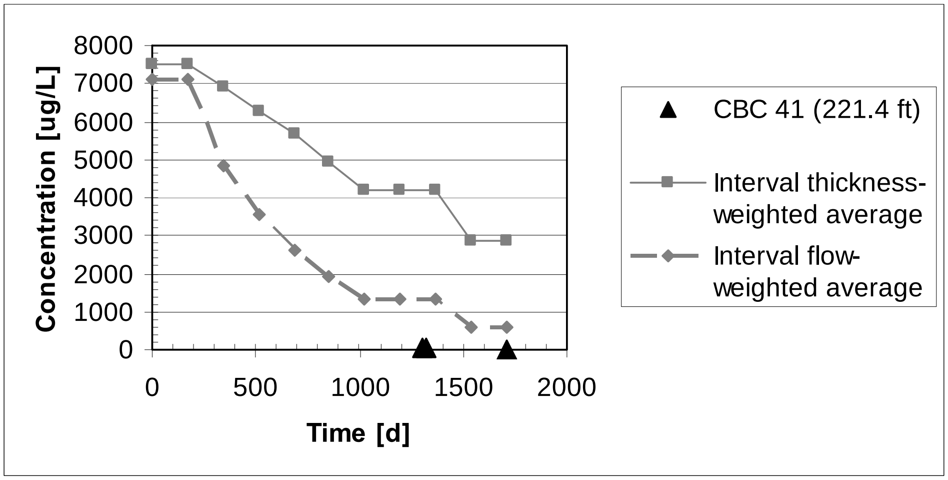
Figure 4-15. Projected Concentration Changes with Time and Measured Data for NBVC Monitoring Wells.



d) CBC39

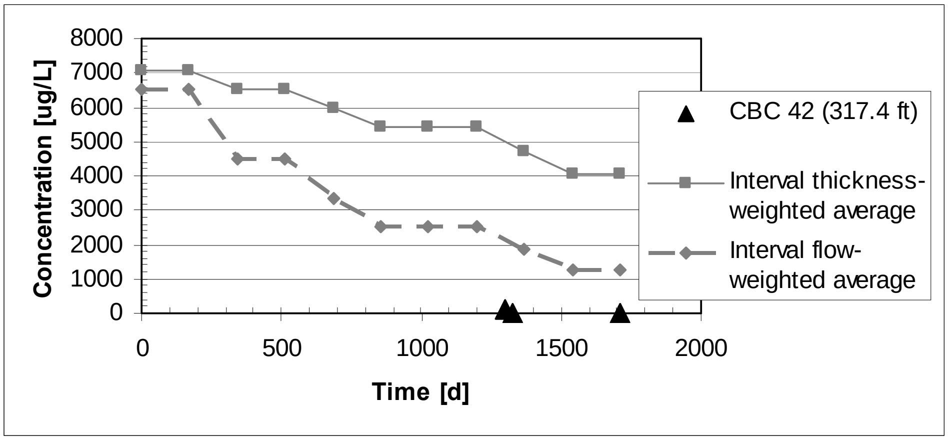


e) CBC40



f) CBC41

Figure 4-15. Projected Concentration Changes with Time and Measured Data for NBVC Monitoring Wells. (cont.)



g) CBC42

Figure 4-15. Projected Concentration Changes with Time and Measured Data for NBVC Monitoring Wells. (cont.)

In summary, use of the DGCHANGE v1.0 tool provides the following:

- Insight to clean water movement as depicted graphically in vertical cross-section view. The vertical cross section visually communicates the differences in speeds of horizontal movement of clean water (advection dominated translations) through each user-defined layer. Note that the model uses advection only, and does not account for movement between layers or reduction of chemicals through processes such as biodegradation.

- Insight to the anticipated time evolution of concentrations in each layer at a given location and the time evolution of groundwater concentrations measured when sampling a monitoring well at that location. The time evolution of concentrations in each layer at a fixed point down-gradient is presented graphically in tabular format. These results are then used to calculate layer thickness- and layer discharge-weighted concentrations anticipated in a well located at that distance down-gradient. Collectively, the table and graph output communicate how each layer's concentrations change with time at that point, and how those changes would be reflected in sampling from a conventional groundwater well.

4.3.4.3 MODFLOW/MT3D Model

Modeling of the down-gradient migration of clean water was also performed using MODFLOW-2000 and MT3D with a Groundwater Vistas graphical user interface. A complete description and discussion of that exercise can be found in Maass (2005), and only the key points are summarized below.

- The MODFLOW/MT3D model was run for two scenarios: “low dispersion” and “typical dispersion”. The former was selected to correspond with those conditions modeled using DGCHANGE v1.0. The latter was based on dispersion input parameters estimated from common rules-of-thumb for groundwater contaminant transport modeling (as dispersion coefficients are rarely measured and are typically estimated).

- Input parameters for Groundwater Vista modeling were the same as those used previously in DGCHANGE v1.0. Those included: the initial groundwater concentrations selected from pre-biobarrier-operation water quality data; site and depth specific hydraulic conductivity values; the site-wide hydraulic gradient; and. estimated values for water-filled porosity, soil bulk density, and the fraction of organic carbon in the soil. The model discretization was similar to that used in DGCHANGE v1.0.

- The low dispersion scenario produced the same results as those generated by DGCHANGE v1.0.

- The typical dispersion scenario resulted in complete vertical mixing across all layers, and were not consistent with field observations. The results from this scenario predicted a nearly clean aquifer 600 ft down-gradient of the biobarrier by t=1324 d, the time of the first sampling trip, and a clean aquifer by t=1709 d, the time of the second sampling trip. However, actual NBVC monitoring results revealed the presence of MTBE in lower-conductivity layers during both of those events.

Thus, a typical modeling approach would not have reasonably predicted the migration of clean water and the concentration vs. time changes anticipated at down-gradient monitoring wells.

Projections of how down-gradient concentrations will change with time in monitoring wells are usually based on a single site-wide value for groundwater velocity, or are obtained by using a more complex model utilizing estimated dispersivity values. For the NBVC site, neither the simple approach, nor the more complex, high dispersion model reasonably predicted the observed down-gradient concentration changes with time.

4.4 Summary of Key Activities and Findings

Detailed monitoring and characterization were conducted down-gradient of a well-understood full-scale MTBE biobarrier PTB at the Naval Base Ventura County (NBVC). This included discrete-depth groundwater sampling at 37 locations and analysis of over 680 groundwater samples during three sampling trips (1226, 1324, and 1709 d after the biobarrier treatment zone was well-oxygenated and seeded), conventional slug tests and constant drawdown pumping-tests conducted at existing full-length monitoring wells, water level measurements in monitoring wells, constant draw-down mini pump-tests conducted at 1-ft intervals during direct-push sampling, soil cores collected at 20 locations, and 245 laboratory permeameter tests with at least a 1-ft resolution on the soil cores.

From these data the following were observed:

- Horizontal hydraulic conductivity varied across the site from 1 x 10^{-5} cm/s to 3.7 x 10^{-1} cm/s. More specifically, variations with depth were as great as one order of magnitude over a change in depth of just 2 ft (60.9 cm). Overall, the least conductive zones were at the top of the aquifer and the most conductive zones were at the base of the aquifer.

- MTBE concentration snapshots from the sampling events illustrate the migration of clean water from the biobarrier PTB through the higher conductivity zones and persistence of MTBE in lower conductivity regions.

The proposed approach, which couples determination of horizontal hydraulic conductivity changes with depth, flow direction, and hydraulic gradient with a simplistic spreadsheet-based tool, appears practicable.

The spreadsheet tool DGCHANGE v1.0 was designed to be user-friendly and relatively easy to use. The user enters aquifer characteristics into the spreadsheet (hydraulic conductivity, initial contaminant concentrations, soil porosity, and the hydraulic gradient) and the spreadsheet estimates time frames over which significant concentration reductions should be observed in near-field down-gradient monitoring wells. The output visually communicates the variations in clean water movement with depth and how those variations might be reflected in conventional monitoring well data.

COST ASSESSMENT

5.1 COST REPORTING

This ESTCP project does not involve the demonstration of, and cost-tracking for a technology; however, users will be interested in the incremental costs associated with using the approach developed for estimating groundwater quality improvements down-gradient of a PTB.

Consistent with that, the cost assessment for this project involves the following:

- An estimate of the incremental increase in time and site characterization costs associated with collecting the required data.
- An estimate of the time and cost associated with using the predictive tool.

As stated previously, the recommendations for minimum data collection includes:

- Groundwater flow direction determination – this should already be a component of PTB selection and design activities.
- Hydraulic gradient determination - this should already be a component of PTB selection and design activities.
- Groundwater concentration measurements - this should already be a component of PTB selection and design activities.
- Determination of vertical variations in hydraulic conductivity – this may not currently be part of typical PTB selection and design activities, but PTB designers should be collecting soil cores as part of the design process, so the only additional effort here is the characterization of the core material. Also, as was done in this work, it may be relatively easy at some sites to measure hydraulic conductivity in situ via constant drawdown pumping tests at discrete depths while collecting groundwater samples with direct-push tools.

At most sites, the characterization of vertical variations in hydraulic conductivity at one to three locations should be sufficient, and it is unlikely that most aquifers will be conceptualized as having more than 10 distinct layers. Thus, the incremental data collection costs should be negligible in comparison with baseline site characterization and PTB design costs for most sites.

With respect to use of the predictive tool DGCHANGE v1.0, this involves at most a few hours once the site-specific data are available. Again, the incremental cost should be negligible in comparison with total project costs for most sites. The software is provided free with this report.

5.2 COST ANALYSIS

This section not applicable for this project.

IMPLEMENTATION ISSUES

6.1 ENVIRONMENTAL CHECKLIST

The field sampling required obtaining an on-site NBVC Digging Permit. No additional regulatory permits will be required as the sampling will be similar in procedure to other activities on Base.

6.2 OTHER REGULATORY ISSUES

The impact of this project will go beyond this particular test site to future technology selection and design efforts. The projection of down-gradient quality changes with time and distance of groundwater immediately impacted by the ESTCP biobarrier is not currently an issue with the local regulatory agency as there is another biobarrier installed at the leading-edge of the dissolved MTBE plume.

6.3 END-USER ISSUES

A manuscript for publication in *Ground Water Monitoring and Remediation* is being prepared.

This issue is of interest to the EPA, state regulatory agencies, and to the gasoline refining and marketing industry, all of which can be involved with PTB operations and to whom performance relative to down-gradient response would be of interest.

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APPENDIX A

Theoretical Basis for the Spreadsheet Tool DGCHANGE v1.0

APPENDIX A

THEORETICAL BASIS FOR THE SPREADSHEET TOOL DGCHANGE v1.0

DGCHANGE v1.0 was developed using a simplified form of the General Transport Equation (Fetter 1999) for cases of layered one-dimensional advection-dominated scenarios. Advective transport is the process by which dissolved constituents travel with flowing groundwater, and advection-dominated scenarios are ones for which the effects of dispersion, diffusion, and reaction are much less-significant than the effects of advection. In the case of one-dimensional flow, groundwater movement in each layer i can be characterized by an average linear velocity as described by Equation A.1:

$$v_i = (K_i/\theta_{m,i}) * (dh/dx) \tag{A.1}$$

where:

v_i = average linear velocity in layer i [cm/s]
K_i = horizontal hydraulic conductivity in layer i [cm/s]
$\theta_{m,i}$ = water-filled effective porosity in layer i [cm^3-H_2O/cm^3-soil]
(dh/dx) = horizontal hydraulic gradient in the direction of flow (dh/dx is the same in all layers because the flow is one dimensional) [cm/s]

The change in dissolved groundwater concentration in each layer C_i [g/cm^3-H_2O] with down-gradient distance x [cm] and time t [s] is described by:

$$\frac{\partial C_i}{\partial t} = -\frac{v_i}{R_i}\frac{\partial C_i}{\partial x} \tag{A.2}$$

where R_i is referred to as the retardation factor for layer i, and contains partitioning information:

$$R_i = 1 + \frac{H_c\,\theta_{v,i}}{\theta_{m,i}} + \frac{K_{s,i}\,\rho_{b,i}}{\theta_{m,i}} \tag{A.3}$$

and:

H_c = Henry's Law Constant [(mg/cm^3-vapor)/(mg/cm^3-H_2O)]
$\theta_{v,i}$ = vapor-filled porosity in layer i [cm^3-vapor/cm^3-soil]
$\theta_{m,i}$ = water-filled porosity in layer i [cm^3-H_2O/cm^3-soil]
$K_{s,i}$ = sorption coefficient to soil in layer i [(mg/g-soil)/(mg/cm^3-H_2O)] = $f_{oc}K_{oc}$

K_{oc} = sorption coefficient to organic carbon [(mg/g-OC)/(mg/cm^3-H$_2$O)]
$f_{oc,i}$ = fraction of organic carbon in soil in layer i [g-OC/g-soil]

For problems involving dissolved transport in aquifers, the first term on the right-hand-side of Equation (A.3) is typically negligible when $H_c < 0.1$ (mg/cm^3-vapor)/(mg/cm^3-H$_2$O).

For PTB problems, we can approximate the boundary condition and initial conditions as $C_i(x=0, t) = C_{treated}$ and $C_i(x, t=0) = C_i^o(x)$, and the solution to Equations (A.1) through (4.3) becomes:

$$C_i(x,t) = C_{treated,i} \text{ for } x \leq (K_i(dh/dx)t/\theta_i R_i)$$
$$C_i(x,t) = C_{io}(x - K_i(dh/dx)t/\theta_i R_i) \text{ for } x > (K_i(dh/dx)t/\theta_i R_i) \qquad \text{(A.4)}$$

For PTB scenarios with $C_i(x=0, t) = 0$ (total treatment) and $C_i(x, t=0) = C^o$ (uniform initial conditions Equations (A.4) becomes:

$$C_i(x,t) = 0 \text{ for } x \leq (K_i(dh/dx)t/\theta_i R_i)$$
$$C_i(x,t) = C^o \text{ for } x > (K_i(dh/dx)t/\theta_i R_i) \qquad \text{(A.5)}$$

Equations (A.4) and (A.5) apply to any horizontal plane with the x-axis aligned in the direction of groundwater flow.

Most groundwater samples are collected from monitoring wells screened over finite, but not small, intervals. For example, many groundwater monitoring well screen lengths are 3 – 5 m long. Thus, the sample represents a weighted average of groundwater entering the well at different depths spanned by the well screen. This weighted average likely represents something ranging from a layer thickness-weighted average to a layer discharge-weighted average as described in Equations (A.6) and (A.7), respectively:

$$\{C\} = \frac{\sum_i C_i H_i}{\sum_i H_i} \text{ (layer thickness-weighted average)} \qquad \text{(A.6)}$$

$$\{C\} = \frac{\sum_i C_i K_i H_i}{\sum_i K_i H_i} \text{ (layer discharge-weighted average)} \qquad \text{(4.7)}$$

where H_i = layer thickness [cm]

DGCHANGE v1.0 performs the calculations outlined above.

APPENDIX B

DGCHANGE v1.0 User's Manual

APPENDIX B

DGCHANGE V1.0 USER'S MANUAL

B.1 OVERVIEW

DGCHANGE v1.0 estimates dissolved contaminant concentration reductions with time in near-field monitoring wells down-gradient of permeable treatment barriers (PTB). In this spreadsheet-based tool the aquifer is represented as a series of horizontal layers and the user enters layer-specific aquifer characteristics. The output is presented graphically in three main formats: a) a cross-section snapshot of dissolved concentrations along the groundwater flow path at some user-specified time, b) a table of dissolved concentrations vs. time in each layer at some user-defined down-gradient location, and c) as a plot of expected monitoring well dissolved concentration vs. time at some user-defined down-gradient location for layer thickness- and layer discharge-weighted averages.

The underlying fundamental basis and governing equations upon which DGCHANGE v1.0 is based are described in Appendix A. This appendix provides a step-by-step user's manual for DGCHANGE v1.0 and is organized by each of the tool's four worksheets that focus on model inputs, a cross-section snapshot, and changes with time at a monitoring well.

B.2 DGCHANGE v1.0 INPUTS

The "**inputs**" worksheet is the first worksheet found in DGCHANGE v1.0, and the values input here are utilized in other worksheets. The **inputs** worksheet is color-coded, and the user may enter items into the yellow cells only; all other cells include either text or calculated values. The following steps should be taken as the user enters inputs into the inputs worksheet (see Figure B-1).

- Save the DGCHANGE v1.0 file with a new name (i.e. use the site name) so that you can easily reuse the original file.
- Enter the total thickness of the water-saturated interval of interest into column E, row 4.
- Enter the depth below ground surface (BGS) to the top of the water-saturated interval of interest into column E, row 5.
- Enter the distance down-gradient of interest from the permeable reactive barrier (PRB) into column E, row 6.
- Enter the chemical name of interest into column E, row 7.
- Enter the organic carbon sorption coefficient (K_{oc}) for the chemical of interest into column E, row 8. There are internet –accessible sources of information for this property (e.g., http://www.epa.gov/superfund/resources/soil/attachc.pdf)

- DGCHANGE v1.0 automatically divides the total thickness into ten evenly-spaced vertical intervals, if desired; you can over-ride these interval thicknesses by entering user-specified thicknesses into columns A and C, rows 13 thru 23.
- Enter qualitative descriptions of materials found in each interval into column D, rows 13 thru 23.
- Enter the hydraulic conductivity K for each layer in units of [cm/s] into column E, rows 13 thru 23. These values should derive from field data and should be consistent with the qualitative descriptions entered in Step 8.
- Enter the initial (time = 0) dissolved concentration C for each layer in units of [μg/l] into column F, rows 13 thru 23. These values should derive from field data.
- Enter the water-filled porosity ϕ for each layer in units of [vol-H2O/vol-soil] into column G, rows 13 thru 23. Typical values for granular materials are in the range 0.25 – 0.45 cm^3-H_2O/cm^3-soil.
- Enter the hydraulic gradient (dh/dx) for each layer in units of [cm/cm = m/m = ft/ft] into column I, rows 13 thru 23. Typically, the same value will be entered for each layer.
- Enter the soil bulk density ρ_b for each layer in units of [g-soil/cm^3] into column J, rows 13 thru 23. In the absence if site-specific data, a value of 1.7 g-soil/cm^3 is a reasonable estimate.
- Enter the fraction of organic carbon in soil f_{oc} for each layer in units of [g-OC/g-soil] into column K, rows 13 thru 23. Typical values for most granular materials fall in the range 0.005 – 0.02 g-OC/g-soil. Some feel that values less than 0.005 g-OC/g-soil will underestimate sorption, even if the f_{oc} value is less than 0.005 g-OC/g-soil.

Please note that all yellow cells must contain values for the tool to work correctly.

B.3 VERTICAL CROSS-SECTION SNAPSHOT VIEW

Once the **Inputs** worksheet contains data for all yellow colored cells, the “**Cross-Section Snapshot”** worksheet shown in Figure B-2 may be used.

To use this worksheet, enter the time (in units of days) for which a cross-section snapshot is desired into column G, row 2.

The resulting output is presented as a cross-section snapshot for the time entered, oriented along the direction of groundwater flow, and showing locations where clean water is expected to be found. The cross-section is displayed in columns F thru T, from rows 6 thru 16. This cross-section corresponds to a single time snapshot, as defined by the input in column G, row 2. Cells colored red indicate contaminated (non-treated) water (these cells are assigned the corresponding user-identified initial concentration). Cells colored light blue indicate clean water (water treated by the PRB; these cells are assigned a concentration of 0 μg/l).

Rows 17 and 18 indicate corresponding thickness-weighted average concentrations (Equation B.1 below) and layer discharge-weighted average concentrations (Equation B.2 below) at different distances down-gradient of the PTB. Equation B.2 assumes that the horizontal hydraulic gradient is the same in each layer i.

$$\{C\} = \frac{\sum_i C_i H_i}{\sum_i H_i} \text{ (layer thickness-weighted average)} \qquad \text{(B.1)}$$

$$\{C\} = \frac{\sum_i C_i K_i H_i}{\sum_i K_i H_i} \text{ (layer discharge-weighted average)} \qquad \text{(B.2)}$$

B.4 ESTIMATED DISSOLVED CONCENTRATION CHANGES WITH TIME AT MONITORING WELLS

Using the values in the **Inputs** worksheet, the expected changes in concentrations in each layer with time at a fixed distance down-gradient are calculated in the **Changes with time at MW** worksheet shown in Figure B-3.

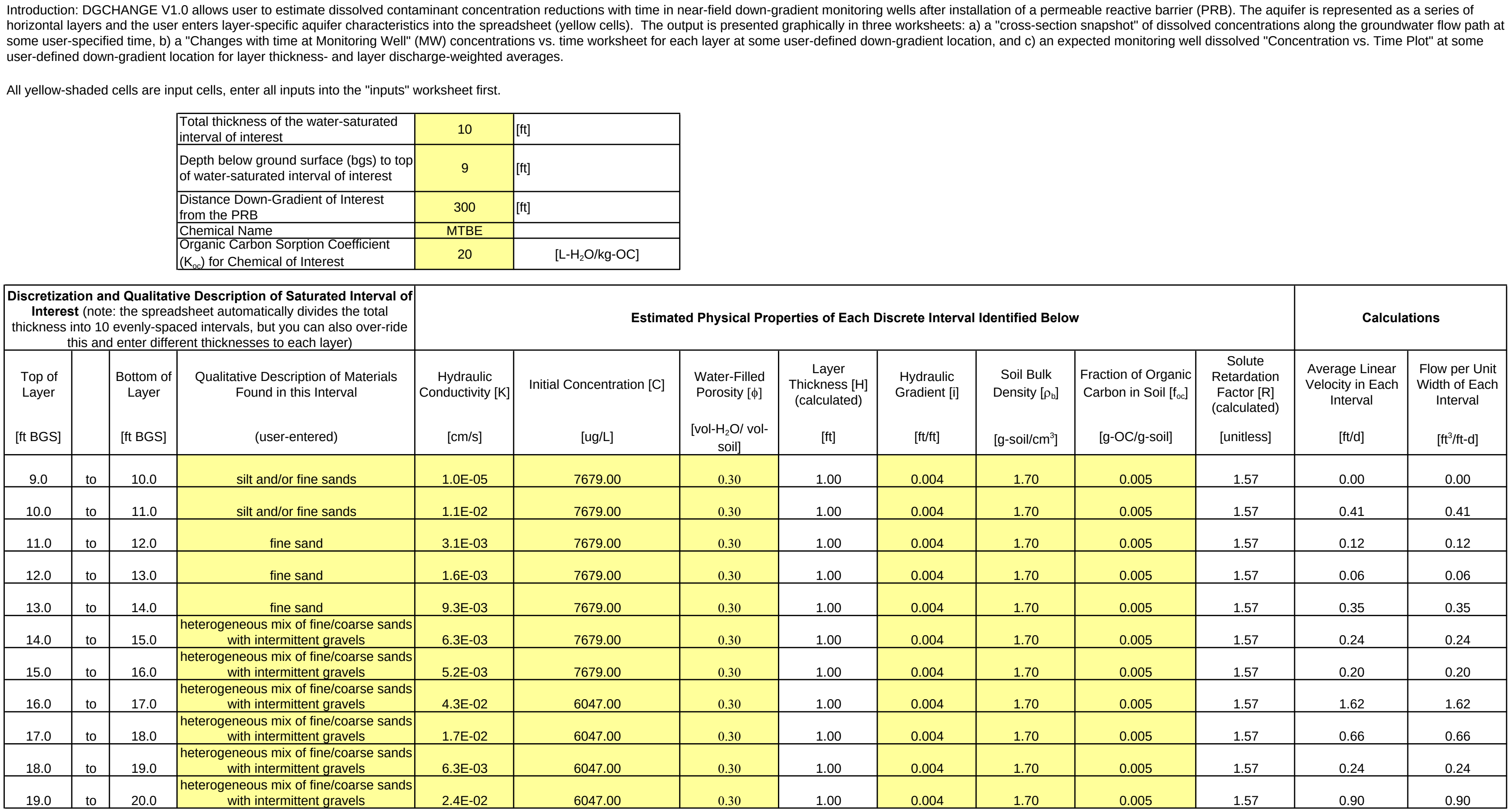
To use this worksheet, enter the time interval (in units of days) for which concentration vs. time projections are desired into column G, row 1. Next, enter the distance down-gradient of the PTB (in units of feet) where the monitoring well is to be located.

The resulting output is a tabular summary of the time evolution of treated water and contaminant concentrations in each layer, from the depths indicated in columns A and C, and over the time periods (in days) indicated in row 4. The time evolution is displayed in columns F thru P, from rows 6 thru 16. As in the cross-section worksheet, cells colored red indicate untreated water (these cells are assigned the corresponding user-identified initial concentration). Cells colored light blue indicate PRB-treated water (these cells are assigned a concentration of 0 µg/l).

Rows 17 and 18 present the corresponding thickness-weighted average concentrations (equation B.1) and layer discharge-weighted average concentrations (Equation B.2) for samples collected from a well at this location.

B.5 CONCENTRATION VS. TIME PLOT

The results calculated in the **Changes with time at MW** worksheet are used to generate the **Concentration vs. Time Plot** worksheet, which presents interval thickness-weighted average and the interval flow-weighted average concentrations as shown in Figure B-4.



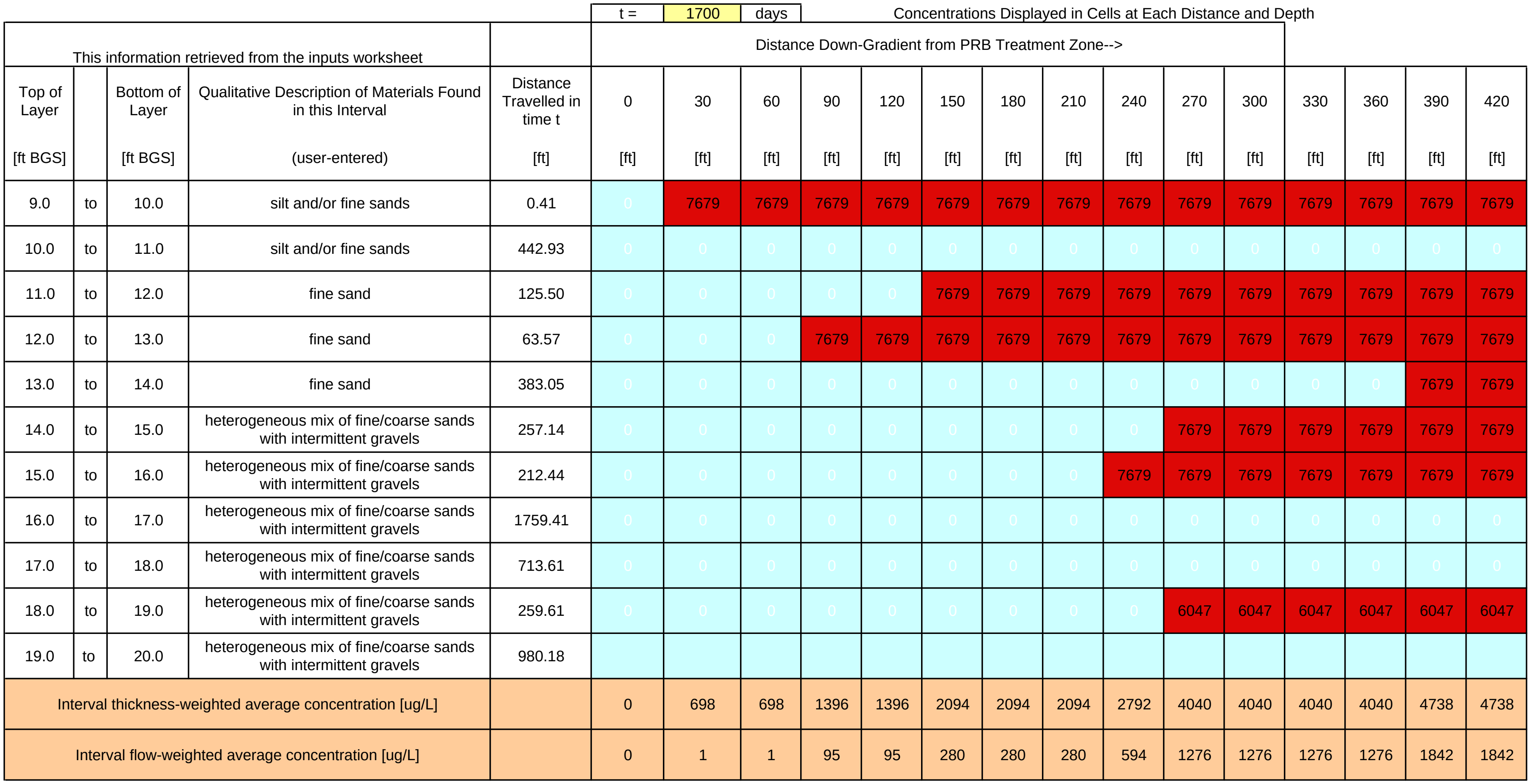
Introduction: DGCHANGE V1.0 allows user to estimate dissolved contaminant concentration reductions with time in near-field down-gradient monitoring wells after installation of a permeable reactive barrier (PRB). The aquifer is represented as a series of horizontal layers and the user enters layer-specific aquifer characteristics into the spreadsheet (yellow cells). The output is presented graphically in three worksheets: a) a "cross-section snapshot" of dissolved concentrations along the groundwater flow path at some user-specified time, b) a "Changes with time at Monitoring Well" (MW) concentrations vs. time worksheet for each layer at some user-defined down-gradient location, and c) an expected monitoring well dissolved "Concentration vs. Time Plot" at some user-defined down-gradient location for layer thickness- and layer discharge-weighted averages.

All yellow-shaded cells are input cells, enter all inputs into the "inputs" worksheet first.

Total thickness of the water-saturated interval of interest	10	[ft]
Depth below ground surface (bgs) to top of water-saturated interval of interest	9	[ft]
Distance Down-Gradient of Interest from the PRB	300	[ft]
Chemical Name	MTBE	
Organic Carbon Sorption Coefficient (K_{oc}) for Chemical of Interest	20	[L-H_2O/kg-OC]

Discretization and Qualitative Description of Saturated Interval of Interest (note: the spreadsheet automatically divides the total thickness into 10 evenly-spaced intervals, but you can also over-ride this and enter different thicknesses to each layer)				**Estimated Physical Properties of Each Discrete Interval Identified Below**								**Calculations**	
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Hydraulic Conductivity [K] [cm/s]	Initial Concentration [C] [ug/L]	Water-Filled Porosity [ϕ] [vol-H_2O/ vol-soil]	Layer Thickness [H] (calculated) [ft]	Hydraulic Gradient [i] [ft/ft]	Soil Bulk Density [ρ_b] [g-soil/cm^3]	Fraction of Organic Carbon in Soil [f_{oc}] [g-OC/g-soil]	Solute Retardation Factor [R] (calculated) [unitless]	Average Linear Velocity in Each Interval [ft/d]	Flow per Unit Width of Each Interval [ft^3/ft-d]
9.0	to	10.0	silt and/or fine sands	1.0E-05	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.00	0.00
10.0	to	11.0	silt and/or fine sands	1.1E-02	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.41	0.41
11.0	to	12.0	fine sand	3.1E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.12	0.12
12.0	to	13.0	fine sand	1.6E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.06	0.06
13.0	to	14.0	fine sand	9.3E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.35	0.35
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	6.3E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.24	0.24
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	5.2E-03	7679.00	0.30	1.00	0.004	1.70	0.005	1.57	0.20	0.20
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	4.3E-02	6047.00	0.30	1.00	0.004	1.70	0.005	1.57	1.62	1.62
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	1.7E-02	6047.00	0.30	1.00	0.004	1.70	0.005	1.57	0.66	0.66
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	6.3E-03	6047.00	0.30	1.00	0.004	1.70	0.005	1.57	0.24	0.24
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	2.4E-02	6047.00	0.30	1.00	0.004	1.70	0.005	1.57	0.90	0.90

Figure B-1. The Inputs Worksheet from DGCHANGE v1.0. The Sample Inputs in the Yellow-shaded Cells Represent Data from the NBVC MTBE Bio-barrier Site Discussed in Chapters 3 and 4.

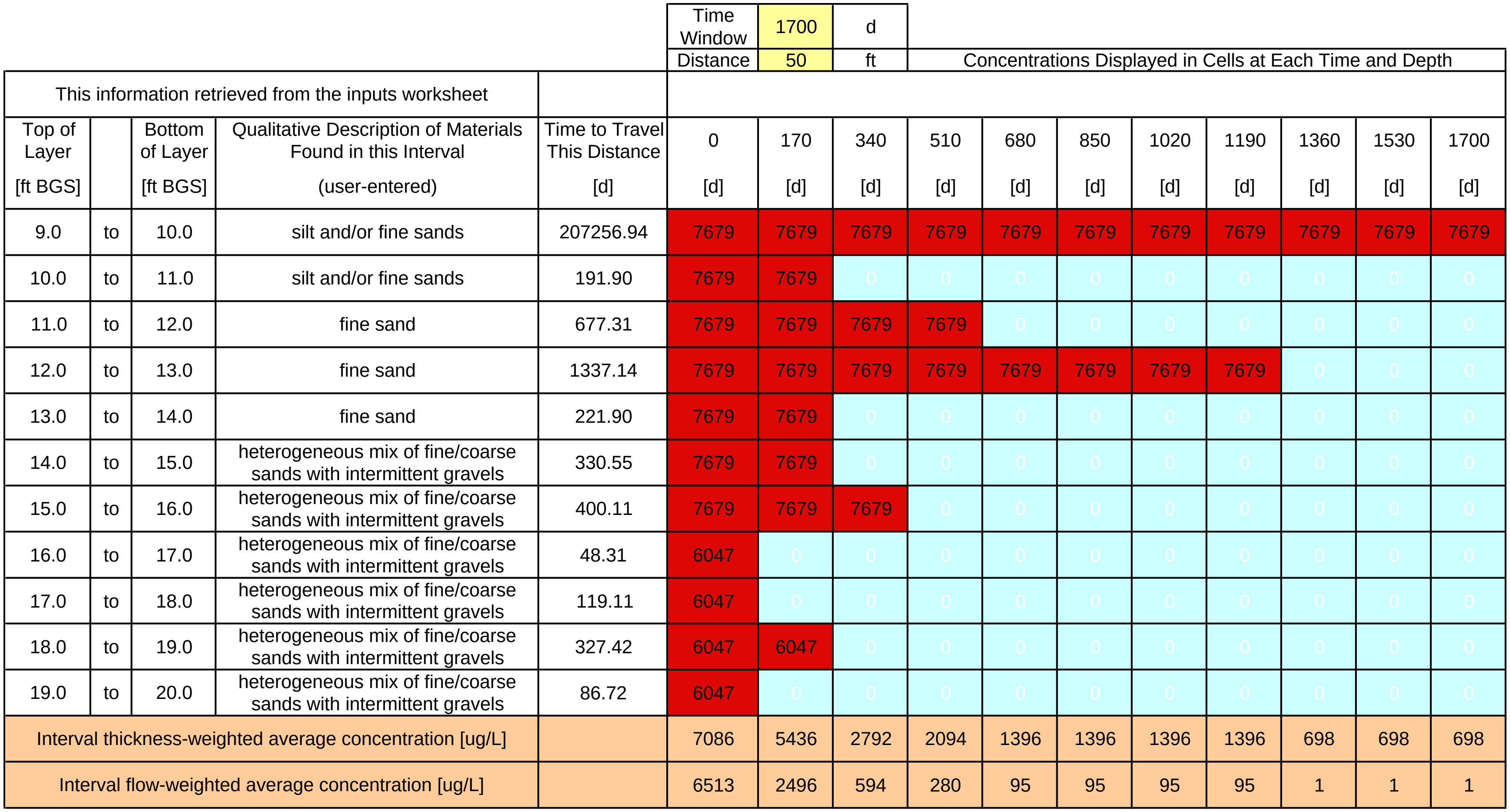


t = 1700 days

Concentrations Displayed in Cells at Each Distance and Depth

This information retrieved from the inputs worksheet					Distance Down-Gradient from PRB Treatment Zone-->														
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Distance Travelled in time t [ft]	0 [ft]	30 [ft]	60 [ft]	90 [ft]	120 [ft]	150 [ft]	180 [ft]	210 [ft]	240 [ft]	270 [ft]	300 [ft]	330 [ft]	360 [ft]	390 [ft]	420 [ft]
9.0	to	10.0	silt and/or fine sands	0.41	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
10.0	to	11.0	silt and/or fine sands	442.93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.0	to	12.0	fine sand	125.50	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
12.0	to	13.0	fine sand	63.57	0	0	0	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
13.0	to	14.0	fine sand	383.05	0	0	0	0	0	0	0	0	0	0	0	0	0	7679	7679
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	257.14	0	0	0	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	212.44	0	0	0	0	0	0	0	0	7679	7679	7679	7679	7679	7679	7679
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	1759.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	713.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	259.61	0	0	0	0	0	0	0	0	0	6047	6047	6047	6047	6047	6047
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	980.18															
Interval thickness-weighted average concentration [ug/L]					0	698	698	1396	1396	2094	2094	2094	2792	4040	4040	4040	4040	4738	4738
Interval flow-weighted average concentration [ug/L]					0	1	1	95	95	280	280	280	594	1276	1276	1276	1276	1842	1842

Figure B-2. The Cross-Section Snapshot Worksheet from DGCHANGE v1.0. Blue Shaded Areas Represent Distances and Depths Down-gradient Where Treated Water is Projected to Have Migrated to within the Time Entered at the Top of this Worksheet. Red Areas Represent Zones Still at their Initial Concentrations. Calculated Interval Thickness- and Flow-weighted Average Concentrations are Presented at the Bottom of the Table for Each Distance Down-gradient. The Sample Inputs Represent Data from the NBVC MTBE Bio-barrier Site Discussed in Chapters 3 and 4.



Time Window	1700	d	
Distance	50	ft	Concentrations Displayed in Cells at Each Time and Depth

This information retrieved from the inputs worksheet															
Top of Layer [ft BGS]		Bottom of Layer [ft BGS]	Qualitative Description of Materials Found in this Interval (user-entered)	Time to Travel This Distance [d]	0 [d]	170 [d]	340 [d]	510 [d]	680 [d]	850 [d]	1020 [d]	1190 [d]	1360 [d]	1530 [d]	1700 [d]
9.0	to	10.0	silt and/or fine sands	207256.94	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679	7679
10.0	to	11.0	silt and/or fine sands	191.90	7679	7679	0	0	0	0	0	0	0	0	0
11.0	to	12.0	fine sand	677.31	7679	7679	7679	7679	0	0	0	0	0	0	0
12.0	to	13.0	fine sand	1337.14	7679	7679	7679	7679	7679	7679	7679	7679	0	0	0
13.0	to	14.0	fine sand	221.90	7679	7679	0	0	0	0	0	0	0	0	0
14.0	to	15.0	heterogeneous mix of fine/coarse sands with intermittent gravels	330.55	7679	7679	0	0	0	0	0	0	0	0	0
15.0	to	16.0	heterogeneous mix of fine/coarse sands with intermittent gravels	400.11	7679	7679	7679	0	0	0	0	0	0	0	0
16.0	to	17.0	heterogeneous mix of fine/coarse sands with intermittent gravels	48.31	6047	0	0	0	0	0	0	0	0	0	0
17.0	to	18.0	heterogeneous mix of fine/coarse sands with intermittent gravels	119.11	6047	0	0	0	0	0	0	0	0	0	0
18.0	to	19.0	heterogeneous mix of fine/coarse sands with intermittent gravels	327.42	6047	6047	0	0	0	0	0	0	0	0	0
19.0	to	20.0	heterogeneous mix of fine/coarse sands with intermittent gravels	86.72	6047	0	0	0	0	0	0	0	0	0	0
Interval thickness-weighted average concentration [ug/L]					7086	5436	2792	2094	1396	1396	1396	1396	698	698	698
Interval flow-weighted average concentration [ug/L]					6513	2496	594	280	95	95	95	95	1	1	1

Figure B-3. The Changes with Time at MW Worksheet from DGCHANGE v1.0. Blue Shaded Areas Represent Time and Depth Combinations for the Appearance of Treated Water at a Fixed Monitoring Well Location Down-gradient of the PTB. Red Areas Represent Time and Depth Combinations Still at their Initial Concentrations. Calculated Interval thickness- and Flow-weighted Average Concentrations are Presented at the Bottom of the Table for each Time given. The Sample Inputs Represent Data from the NBVC MTBE Bio-barrier Site Discussed in Chapters 3 and 4.

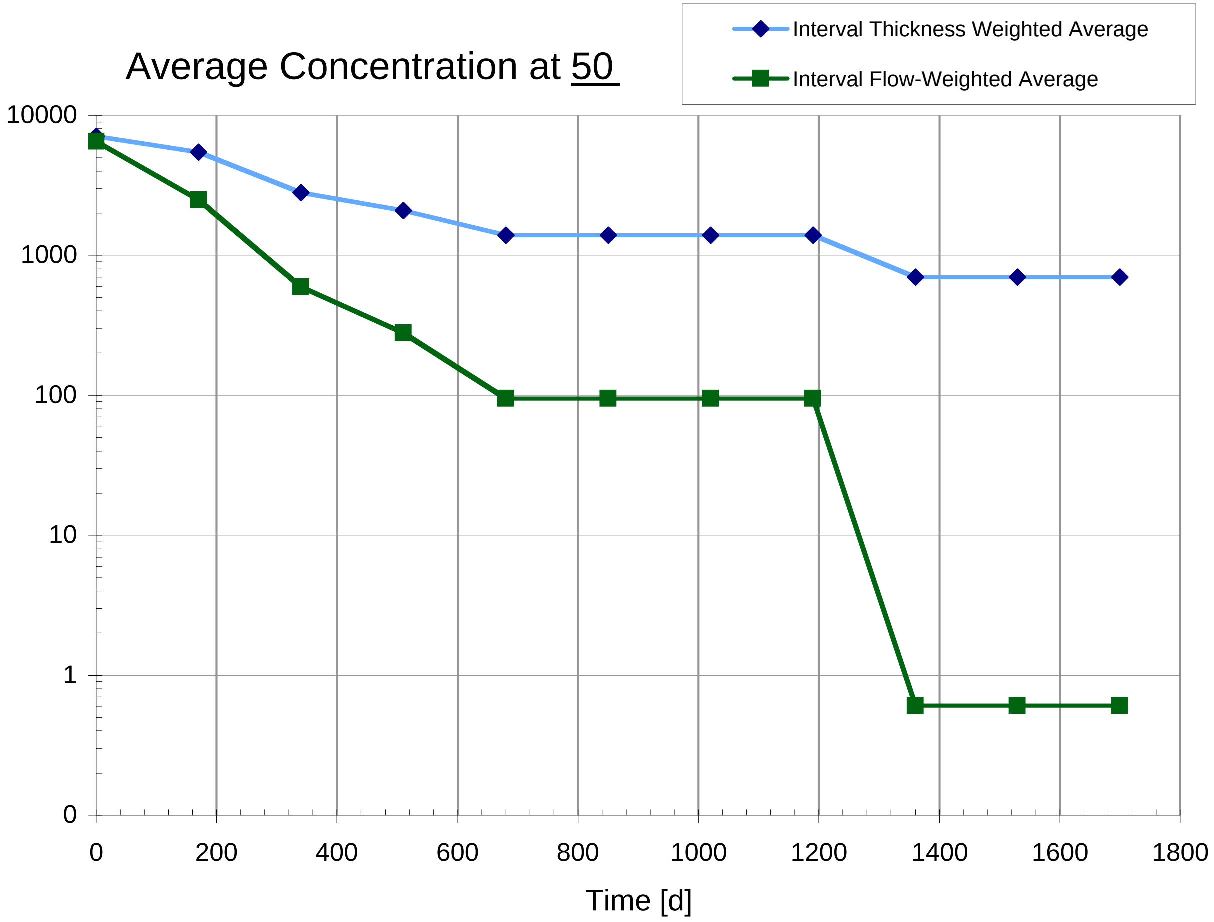


Figure B-4. The Concentration vs. Time Plot Generated from the Results in the Changes with Time at MW Worksheet in DGCHANGE v1.0. Calculated Interval Thickness- and Flow-weighted Average Concentrations are Plotted here. The Sample Inputs Represent Data from the NBVC MTBE Bio-barrier Site Discussed in Chapters 3 and 4.

APPENDIX C

Quality Assurance Project Plan (QAPP)

APPENDIX C

QUALITY ASSURANCE PROJECT PLAN
[Reproduced here from the Demonstration Plan]

C1.0 PURPOSE AND SCOPE OF PLAN

This Quality Assurance Project Plan (QAPP) establishes the quality assurance guidelines to be utilized during this project. This QAPP has been developed to address the DoD requirements for precision, accuracy, representativeness, completeness, and comparability of data collected and generated during this demonstration. The QAPP also provides the quality assurance requirements for data handling, manipulation, and reporting. It has been designed to ensure the quality of the data gathered and generated, as well as the conclusions and recommendations reached from the use of the data.

C2.0 QUALITY ASSURANCE RESPONSIBILITIES

Dr. Paul C. Johnson will be responsible for ensuring that the data collection activities conform to this QAPP. Arizona State University (ASU) will conduct the analysis of groundwater samples in the field with a laboratory-quality GC (SRI Model 3610C or equivalent). The ASU field laboratory will establish data quality objectives similar to those outlined below.

The quality assurance activities incorporated in the project will be used to maintain the accuracy and the precision of the system demonstration and the field analytical techniques. These activities include frequent equipment calibration, field blank samples (for shipment to the analytical laboratory), and field laboratory sample blanks. The quality assurance activities are designed to trigger corrective action activities and diagnose potential sources of error.

ASU will be responsible for summarizing the laboratory data and for data reduction and technology evaluation. Dr. Paul Johnson will be responsible for reviewing analytical data, identifying any deviations from the established protocols and data quality objectives, and then deciding how the data will be used, and what corrections, if any, need to be made to the field analytical procedures.

C3.0 PROJECT OBJECTIVES

The objectives of this demonstration are summarized below:

Type of Performance Objective	Primary Performance Criteria	Expected Performance Metric
Qualitative	Develop a "practicable" approach that can be used to project estimates of groundwater quality changes with time down-gradient of a PTB	- Data collection requirements utilize available technology and do not significantly increase characterization costs. - Calculation tool for projection of performance can be used by most environmental professionals, regulators, and project managers.
Semi-Quantitative	Be able to project reasonable order-of-magnitude estimates of groundwater quality changes with time down-gradient of a PTB	- Comparison of projected concentration vs. time and distance relationship with that observed at the NBVC site.
Quantitative	Collect data set for the NBVC site that can be used to illustrate the approach.	- The data satisfies data quality objectives and the density of samples is sufficient to be used to illustrate the approach being developed.

This Quality Assurance Project Plan (QAPP) focuses on the in-field data collection activities.

C4.0 EXPERIMENTAL MEASUREMENTS

The following section describes measurements to be made during this project; these are divided into categories focused on water quality changes and system hydraulic measurements.

C4.1 Groundwater Quality Measurement

Groundwater will be assessed for dissolved oxygen and MTBE concentrations.

Dissolved Oxygen: Dissolved oxygen concentrations will be measured using a flow-through system composed of a dissolved oxygen meter (YSI Model 550A Oxygen Probe or similar), a flow-through cell, and a variable-speed slow-flow peristaltic pump. Dissolved oxygen concentrations will be monitored until a stable reading is obtained and until a sufficient volume of water from the well or groundwater sampling point is purged (approx. 1-L for the proposed wells).

MTBE: Groundwater samples will be collected using the low-flow variable-speed peristaltic pump discussed above, and after the dissolved oxygen measurement is made, a sample will be collected 40-mL VOA vial with a septa-lined cap. Groundwater samples will be analyzed in the field for MTBE concentrations. Samples measured in the field will be analyzed using a headspace gas chromatography (GC) method. The GC used will be an SRI Series 8610C or similar equipped with flame ionization (FID) and photoionization (PID) detectors. The GC will be calibrated to known dissolved concentrations of these analytes.

C4.2 System Hydraulics Measurements

The following measurements relate to better understanding the groundwater flow system, and any changes to it caused by installation and operation of the biobarrier.

<u>Depth to groundwater:</u> The depth to groundwater will be measured with a standard electronic interface probe. Fore example, typical devices are comprised of an electronic sensor attached to the end of a 50- to 200-ft measuring tape marked with 0.01-ft increments.

<u>Aquifer Characterization Tests:</u> Specific capacity pump tests will be conducted as follows: a) an interface probe will locate the static water level in a small-diameter Geoprobe drive rod, b) tubing will be lowered so that the tubing intake is located a known distance below the static water level, c) a peristaltic pump will be operated at full speed with the hope that the pump rate is faster than the recharge rate to the well, so that the draw-down becomes the depth to the tubing intake, d) the flow rate is measured by the standard bucket-and-stopwatch approach, and e) the data is analyzed to determine hydraulic conductivity.

Slug tests will be conducted in conventional wells using a data logging pressure transducer and a slug capable of displacing about 2-ft of water. The slug is either lowered into, or pulled out of the well, and the water level response is monitored until it stabilizes at the pre-test level. The data is then analyzed by standard slug-test analysis methods.

Laboratory permeameter tests will be conducted using the constant-head technique whereby the flow through a vertical column is measured under conditions of a constant pre-set hydraulic head. The flow is measured by recording the time it takes to fill a 2-L volumetric flask and then the hydraulic conductivity is determined from the known column geometry, pre-set head, and measured flowrate.

C4.3 Sample Collection Techniques

Samples will be collected in a manner consistent with the sample matrix and the parameters being analyzed. Samples will be of groundwater or soil gas.

Groundwater samples will be collected using a variable-speed low-flow peristaltic pump and collected in a 40-mL VOA vial with a septa-lined cap. Analyses will be conducted in the field within 48-hours.
All sample collection devices will be cleaned and prepared in accordance to applicable U.S. EPA procedures prior to each use.

C4.4 Sample Identification Procedures

Each sample will be identified with a unique sample number coded to correlate to the sampling location and assigned by the sample collector at the time of collection. This code will be logged onto a master field data sheet indicating who collected the sample, where the sample was collected, and the date of sample collection.

Each sample will be logged in the Project Record Book (see section on Documentation) with the information recorded on the sample container label and a brief sample description. Any samples being shipped off-site for analysis will be logged on a chain-of-custody log sheet to be sent with the samples to document sample receipt.

C5.0 DATA QUALITY PARAMETERS

Precision will be based on the relative percent difference (RPD) of duplicate analysis of samples. Accuracy will be determined by the percentage of analyte recovered (percent recovery [%R]) from sample of known concentration. Laboratory QC will consist of analytical duplicates conducted for 10% of the total samples submitted for analysis. One laboratory control sample will be included for each 20 samples to ensure that the analytical equipment is operating properly. Laboratory controls will consist of standards of known concentrations. The calculation for each of these quantitative objectives is described in the following sections.

Accuracy: The percent accuracy is calculated from the general equation:

$$\%\ \text{Accuracy} = \frac{100\left(X - X_a\right)}{X_a} \qquad \text{(C-1)}$$

where X is the parameter measured

X_a is the parameter's known value

The accuracy claimed by each field instrument manufacturer will be compared with the percent accuracy as measured from standard samples. If the percent accuracy is less than the required accuracy then corrective action will be initiated.

Precision: Precision for the field laboratory analytical procedures will be assessed by the analytical laboratory on an on-going basis. ASU (Dr. Johnson) will review all analytical data to ensure that any questions concerning data validity are addressed at the earliest time possible.

Completeness: Percent completeness is defined by the general equation:

$$\%\,\text{Completeness} = 100\,\frac{D_o}{D_S} \qquad \text{(C-2)}$$

where D_o = quantity of data obtained
D_s = quantity of data scheduled to be obtained

Completeness in meeting the scheduled data recovery objectives will increase throughout the project as the experience base in equipment operation characteristics increases. The completeness objective for operations during this study is 90% for each test parameter.

C6.0 CALIBRATION CHECKS, QUALITY CONTROL CHECKS, AND CORRECTIVE ACTIONS

All GC-FID/PID analyses will be conducted on a dedicated SRI Instruments Model 8610C gas chromatograph using a DB-1 type capillary column. The instrument is housed in a dedicated building located approximately 200 ft from the site. The instrument will be calibrated each day at least three different concentrations spanning the concentration range of interest (e.g. 10, 100, 1000 ug/L for dissolved MTBE concentrations). In addition, at least one calibration sample is re-analyzed approximately two – to four-times during the day to detect any instrument drift. If area counts from successive calibration analyses consistently deviate by more than 20% or if retention times vary by more than 0.20 minutes, then the following routine checks are made to the equipment: a) leaking septum and b) change in gas flows. If these prove not to be the source of error, then a new standard is made and analyzed. If necessary, recalibration over the entire concentration range is repeated. Reporting levels will be established based on the calibration results. Based on experience with this instrument, reporting levels of about 1 – 5 ug/L are possible for MTBE in groundwater.

YSI DO meters are calibrated in air, at ambient temperature, according to the manufacturers specification.

Corrective action will be undertaken whenever circumstances arise that threaten the generation and quality of data. Much time and effort will be invested in designing and starting-up the biobarrier and there is need to operate this system over a relatively long period of time; therefore, extreme vigilance in recognizing the need for corrective action is critical. The responsibility for maintaining vigilance and initiating corrective action will be primarily with the system operators. Corrective action, however, may be initiated by the project officer.

The specific nature of all corrective actions and the operating limits that would trigger the need for corrective action for all aspects of the remediation system and analytical operations are to numerous to anticipate here. Most corrective actions will be empirical in nature as the following specific examples show.

Problem	Corrective Action
Analysis of standard indicates field GC accuracy has drifted outside established limits (calibration check every 20 samples).	- Perform replicate standard analysis. - Verify instrument parameters - Recalibrate instrument
DO meter does not calibrate properly, or is providing suspect data.	- Replace membrane - Recalibrate and re-test

C7.0 DOCUMENTATION AND RECORD-KEEPING

C7.1 Quality Assurance Reports

A chronological record of all field work associated with the project will be maintained in the Project Record Book. The record book will be used to record all activities and relevant observations during the field sampling events.

C7.2 Data Format

A summary of the sampling results for each sampling event will be produced within 30 days of the sampling event. The data will be presented with the following data fields:

- Sampling date
- Sampling time
- Location designation
- Position of sampling location relative to the biobarrier
- DO
- Temperature
- MTBE concentration
- Relevant notes for the collection and analysis of that sample

C7.3 Data Storage

All data and reports will be archived in both paper and electronic format. All electronic files will be backed-up on CDs at one-month intervals (minimum). All paper files (e.g., field log books) will be copied and archived in a project-specific file.

APPENDIX D

Modified Geoprobe® Groundwater Profiler

APPENDIX D

MODIFIED GEOPROBE® GROUNDWATER PROFILER

D. 1 OVERVIEW

As was discussed in Chapter 3, groundwater sampling was accomplished using Geoprobe® direct push-technology and a modified Geoprobe® Groundwater Profiler and a 2.125-in diameter rod cutting shoe assembly. The modified groundwater profiler and cutting shoe assembly was designed for this project and allowed for hydraulic conductivity testing and the collection of water samples from discrete intervals throughout the vertical extent of the aquifer within a single borehole. This appendix provides detail on both the design and function of the sampler.

D. 2 DETAILED DESIGN DESCRIPTION

D.2.1 Groundwater Profiler Components

Figures D-1a and D-1b provide photos of the modified groundwater sampler and cutting shoe assembly mentioned above. Individual components including the first three feet of drive rod are as follows:

- Part #1 – 1.25-in diameter drive tip (modified)
- Part #2 – Groundwater Profiler 6-in long center stem
- Part #3 – Groundwater Profiler drive head
- Part #4 - 1.25-in diameter x 24-in long hollow drive rod
- Part #5 - 1.25-in diameter threadless drive caps (modified)
- Part #6 – 6-in long Groundwater Profiler stainless steel screen
- Part #7 – 2.125-in diameter cutting shoe (modified)
- Part #8 – 2.125-in diameter x 36-in long drive rod
- Part #9 – 2.125-in diameter threaded drive cap

Part #1 through #6 include the groundwater sampler and the 1.25-in diameter internal drive column. The internal drive column nests with the 2.125-in diameter external drive column.

D.2.2 Profiler Modifications and Function

The modified tip assembly for the Groundwater Profiler and 2.125-in diameter cutting shoe are shown in Figure D-2, the modifications for which are detailed in Figures D-3 through D-5. Modifications include:

- Part #1 (Fig. D-1a) Increased outside diameter of drive tip with machined bevel to nest in tip of modified 2.125-in diameter cutting shoe (Figures D-2, -3, and -4);

- Part #7 (Fig. D-1a) The internal bore of the cutting shoe was increased to allow passage of the groundwater profiler screen and the cutting shoe tip was machined to accept modified drive tip (Figures D-2, -3, and -4)
- Part #5 (Fig. D-1a) The length of the 1.25-in diameter threadless drive caps were adjusted to accommodate the extended groundwater profiler design (Figure D-2 and -5)

The modifications shown allow the groundwater sampler (internal drive column) to be driven ahead of the 2.125-in diameter external drive column to expose the 6-in long sampler screen for hydraulic conductivity testing and groundwater sampling. To advance to the next sampling interval, the 2.125-in diameter external column is driven down over the 1.25-in diameter internal drive column until the 1.25-in diameter drive tip contacts the 2.125-in diameter cutting shoe. The complete assemblage can then be driven to the next sampling interval with the sampling screen protected within the external drive rod assembly. Groundwater was sampled and hydraulic conductivity tests were performed at each interval using a peristaltic pump (see Figure D-6).

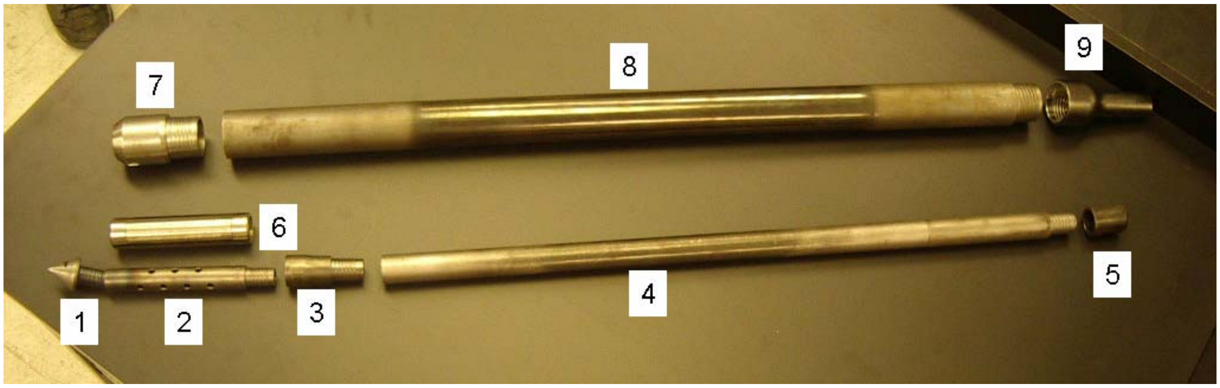


Figure D-1a. Modified Geoprobe® Groundwater Profiler - Components.

Figure D-1b. Modified Geoprobe® Groundwater Profiler – Assembled.

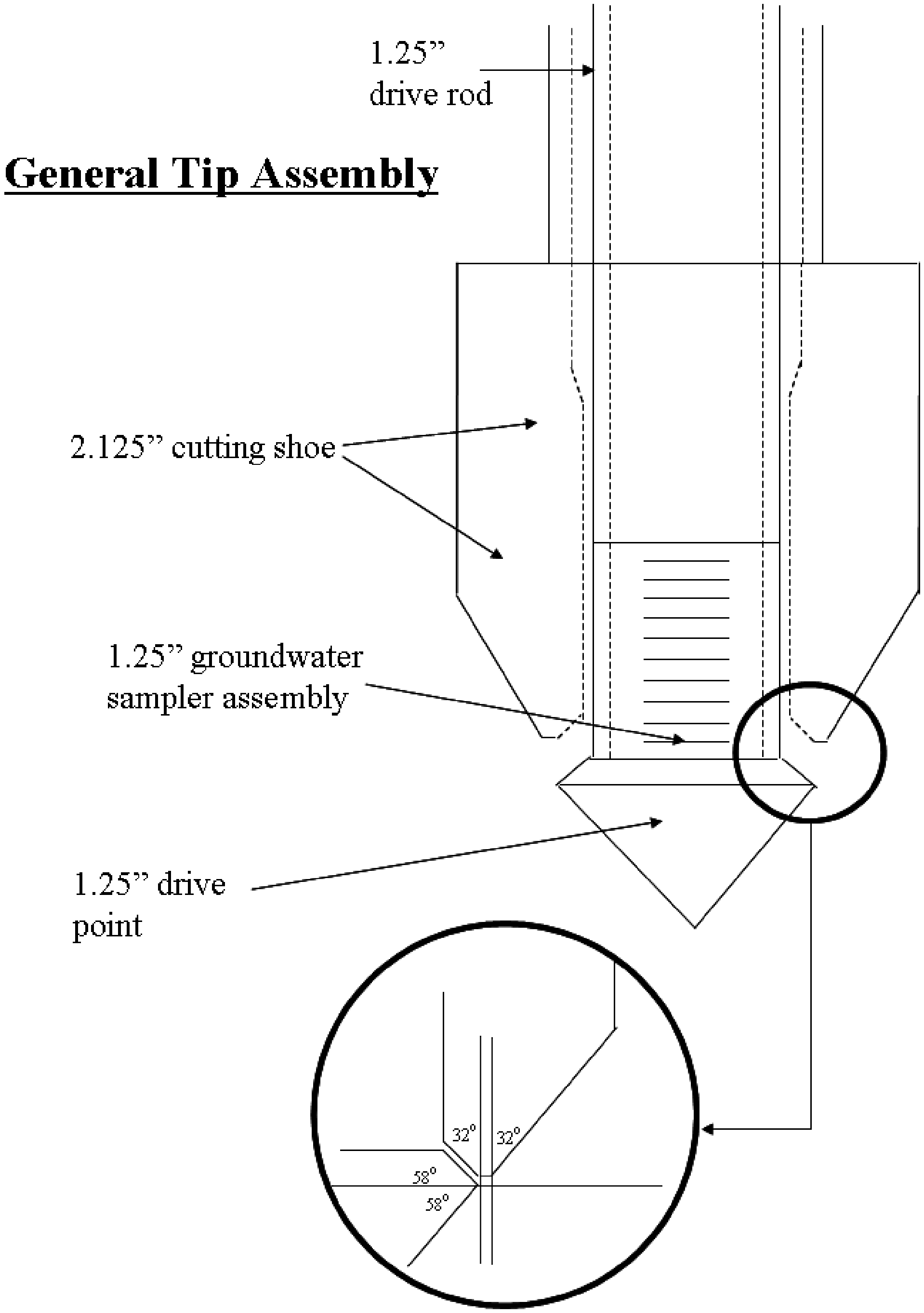


Figure D-2. Modified Geoprobe® Drive Tip/cutting Shoe Assembly.

1.25” Drive Tip Detail

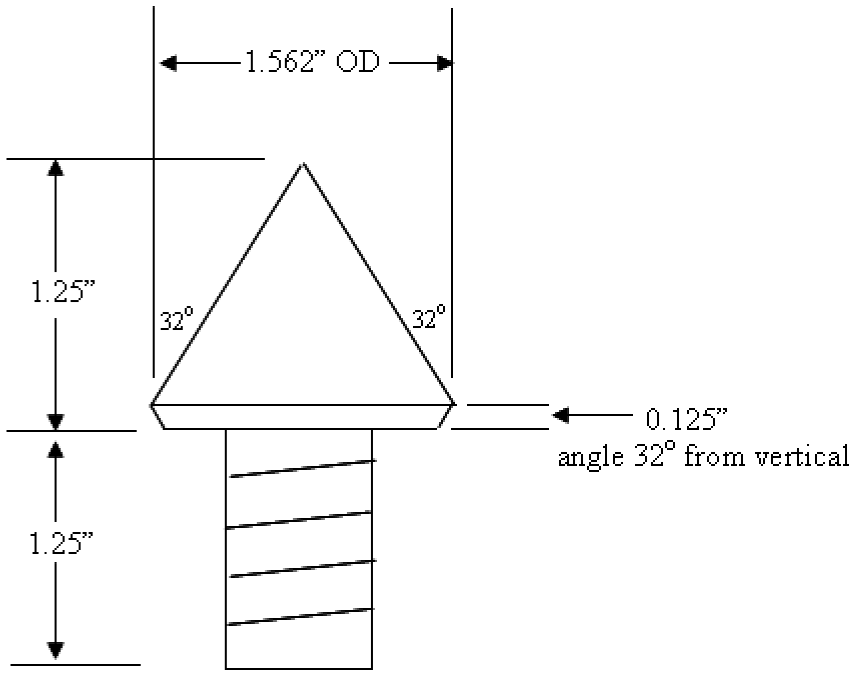


Figure D-3. Modified Geoprobe® Drive Tip.

2.125” Cutting Shoe Detail

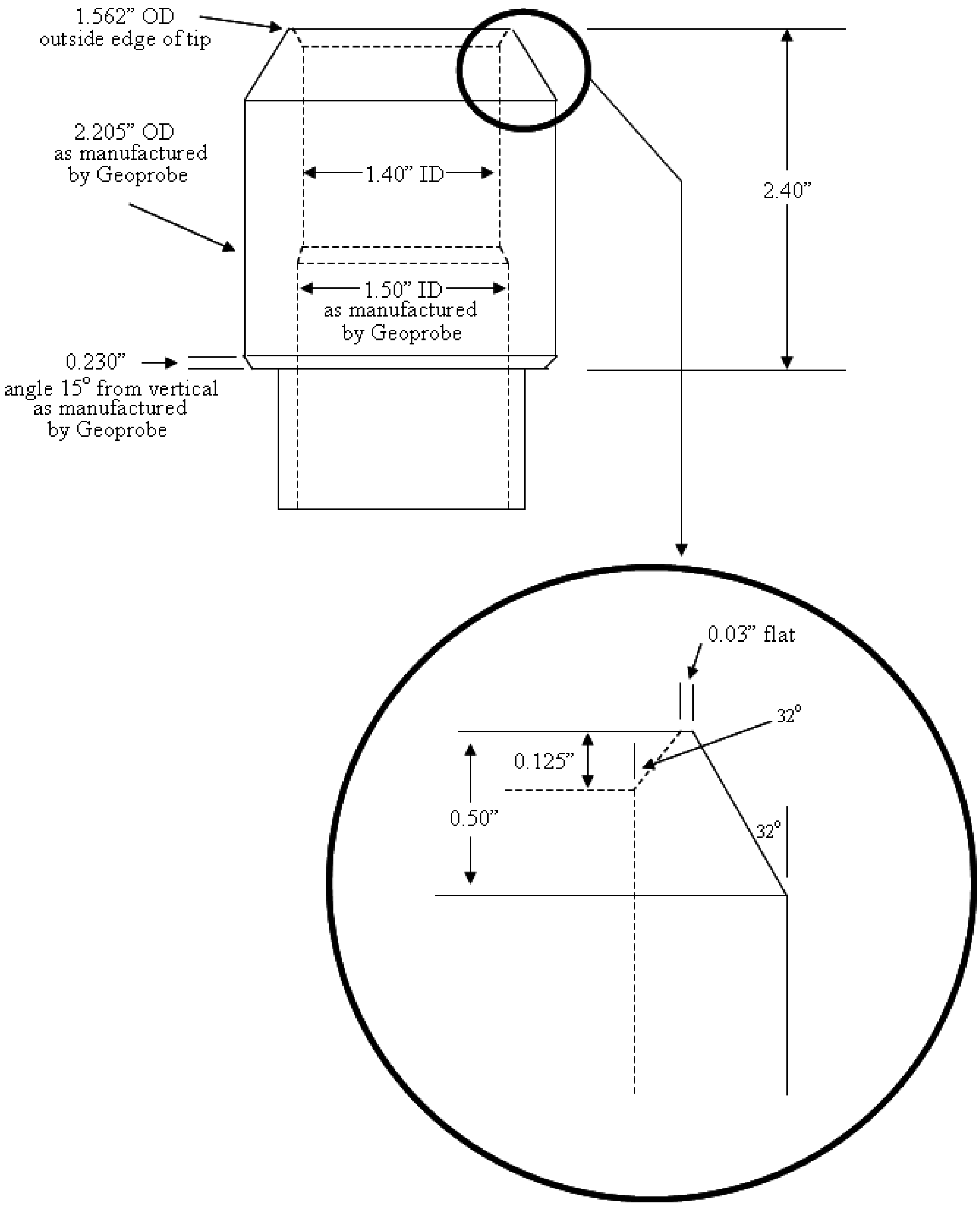


Figure D-4. Modified Geoprobe® Cutting Shoe.

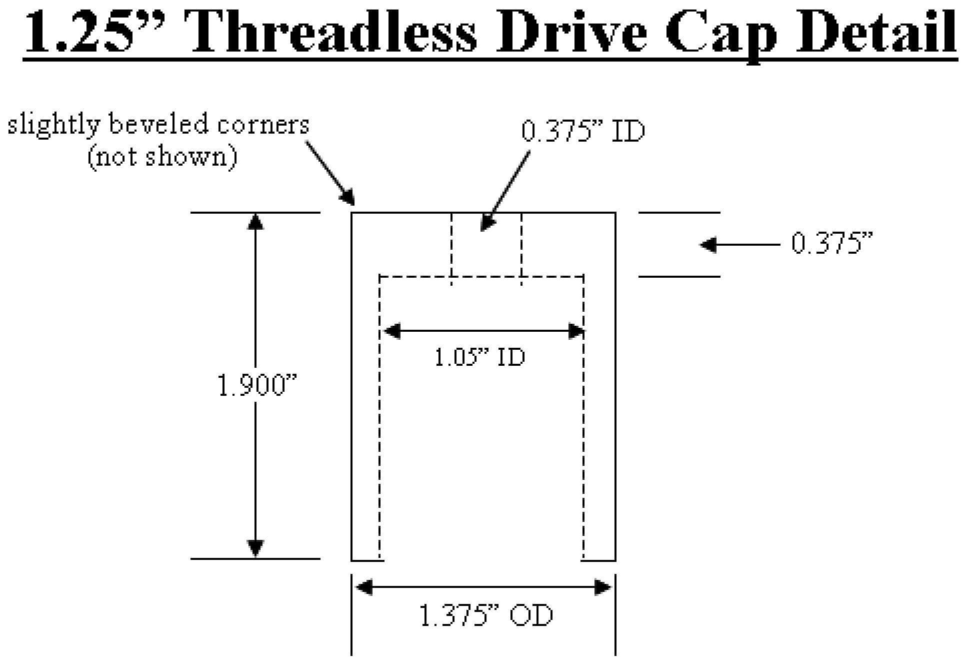


Figure D-5. Modified Geoprobe® Drive Cap.

Figure D-6. Groundwater sampling with Modified Geoprobe® Groundwater Profiler.

APPENDIX E

Hydraulic Conductivity Data from NBVC Site

APPENDIX E

Table E.1: Hydraulic Conductivity Data from Temporary Sampling Locations

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS6				
8	nm	nm	silt	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8				
8.9				
9	nm	nm	silt	nm
9.1				
9.2				
9.3				
9.4				
9.5				nm
9.6				
9.7				
9.8				
9.9				
10	nm	nm	silt	1.06E-02
10.1				
10.2				
10.3				
10.4				
10.5				nm
10.6				
10.7				
10.8				
10.9				
11	2.95E-03	3.38E-03	silt/fine sand	1.61E-03
11.1				
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	5.37E-03	6.22E-03	fine/coarse sand	1.55E-03
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9				
13	1.26E-02	1.25E-02	fine/coarse sand	9.34E-03
13.1				
13.2				
13.3				
13.4				
13.5				nm
13.6				
13.7				
13.8				
13.9				
14	2.11E-01	1.92E-01	medium/coarse sand	7.88E-03
14.1				
14.2				
14.3				
14.4				
14.5				nm
14.6				
14.7				
14.8				
14.9				
15	9.45E-02	1.17E-01	coarse	5.18E-03
15.1				
15.2				
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	5.66E-03	7.27E-03	fine/coarse sand	4.84E-04
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9				
17	9.93E-03	9.59E-03	fine/coarse sand	1.05E-03
17.1				
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7				
17.8				
17.9				
18	nm	nm	fine/coarse sand	1.05E-03
18.1				
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8				
18.9				
19	nm	nm	fine/coarse sand	1.40E-03
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS18				
8	nm	nm	silt/fine	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8				
8.9	nm	nm	silt/fine	
9				nm
9.1				
9.2				
9.3				
9.4				
9.5				nm
9.6				
9.7				
9.8				
9.9	nm	nm	silt	
10				nm
10.1				
10.2				
10.3				
10.4				
10.5				nm
10.6				
10.7				
10.8				
10.9	nm	nm	silt/fine	
11				nm
11.1				
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	8.59E-03	5.00E-03	fine	nm
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9	2.42E-02	1.29E-02	silt/fine	
13				nm
13.1				
13.2				
13.3				
13.4				
13.5				nm
13.6				
13.7				
13.8				
13.9	2.70E-02	1.03E-02	fine	
14				nm
14.1				
14.2				
14.3				
14.4				
14.5				nm
14.6				
14.7				
14.8				
14.9	2.28E-02	2.77E-02	fine	
15				nm
15.1				
15.2				
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	2.01E-01	1.52E-01	fine/coarse sand	nm
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9				
17	6.76E-02	7.92E-02	coarse	nm
17.1				
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7				
17.8				
17.9				
18	4.03E-02	1.72E-02	fine/coarse sand	nm
18.1				
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8				
18.9	4.88E-02	4.58E-02	fine	
19				nm
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.): **Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)	Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS14					**DS14 #2**				
8	nm	nm	fine	nm	8	3.00E-03	3.90E-03	fine	nm
8.1					8.1				
8.2					8.2				
8.3					8.3				
8.4					8.4				
8.5				nm	8.5				nm
8.6					8.6				
8.7					8.7				
8.8					8.8				
8.9					8.9				
9				nm	9	1.18E-03	2.20E-03	fine	nm
9.1					9.1				
9.2					9.2				
9.3	4.25E-03	4.69E-03	fine		9.3				
9.4					9.4				
9.5				nm	9.5				nm
9.6					9.6				
9.7					9.7				
9.8					9.8				
9.9					9.9				
10				nm	10	5.00E-03	9.90E-03	ne/coarse sar	nm
10.1					10.1				
10.2					10.2				
10.3					10.3				
10.4	nm	nm	fine		10.4				
10.5				nm	10.5				nm
10.6					10.6				
10.7					10.7				
10.8					10.8				
10.9					10.9				
11				nm	11	1.19E-02	1.60E-02	fine	nm
11.1					11.1				
11.2					11.2				
11.3	3.67E-03	5.38E-03	fine		11.3				
11.4					11.4				
11.5				nm	11.5				nm
11.6					11.6				
11.7					11.7				
11.8					11.8				
11.9					11.9				
12	1.97E-02	1.76E-02	coarse	nm	12	2.35E-02	3.10E-02	coarse	nm
12.1					12.1				
12.2					12.2				
12.3					12.3				
12.4					12.4				
12.5				nm	12.5				nm
12.6					12.6	3.30E-02	4.10E-02	coarse	
12.7					12.7				
12.8					12.8				
12.9					12.9				
13				nm	13				nm
13.1					13.1				
13.2					13.2				
13.3					13.3				
13.4					13.4				
13.5	4.70E-02	5.17E-02	coarse	nm	13.5	3.10E-02	3.30E-02	coarse	nm
13.6					13.6				
13.7					13.7				
13.8					13.8				
13.9					13.9				
14				nm	14				nm
14.1					14.1				
14.2					14.2				
14.3					14.3				
14.4					14.4				
14.5	1.91E-03	2.40E-03	fine/coarse sand	nm	14.5	1.43E-02	1.06E-02	fine	nm
14.6					14.6				
14.7					14.7				
14.8					14.8				
14.9					14.9				
15				nm	15				nm
15.1					15.1				
15.2					15.2	2.47E-02	1.35E-02	fine	
15.3	2.47E-02	2.88E-02	fine		15.3				
15.4					15.4				
15.5				nm	15.5				nm
15.6					15.6				
15.7					15.7				
15.8					15.8				
15.9					15.9				
16	3.89E-03	4.91E-03	coarse	nm	16	3.20E-03	4.10E-03	fine/coarse sand	nm
16.1					16.1				
16.2					16.2				
16.3					16.3				
16.4					16.4				
16.5				nm	16.5				nm
16.6					16.6				
16.7					16.7				
16.8					16.8				
16.9					16.9				
17	3.34E-03	4.15E-03	coarse	nm	17	4.90E-03	6.60E-03	coarse	nm
17.1					17.1				
17.2					17.2				
17.3					17.3				
17.4					17.4				
17.5				nm	17.5				nm
17.6					17.6				
17.7					17.7				
17.8					17.8				
17.9					17.9				
18	8.57E-03	9.98E-03	coarse	nm	18	6.50E-02	7.12E-02	coarse	nm
18.1					18.1				
18.2					18.2				
18.3					18.3				
18.4					18.4				
18.5				nm	18.5				nm
18.6					18.6				
18.7					18.7				
18.8					18.8				
18.9					18.9				
19	nm	nm	fine	nm	19	5.50E-03	5.90E-03	fine/coarse sand	nm
19.1					19.1				
19.2					19.2				
19.3					19.3				
19.4					19.4				
19.5				nm	19.5				nm
19.6					19.6				
19.7					19.7				
19.8					19.8				
19.9					19.9				
20					20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.): **Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS16				
8	nm	nm	silt	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8				
8.9	nm	nm	silt	
9				nm
9.1				
9.2				
9.3				
9.4				
9.5				nm
9.6	nm	nm	silt/fine sand	
9.7				
9.8				
9.9				
10				nm
10.1				
10.2				
10.3				
10.4				
10.5				nm
10.6				
10.7				
10.8				
10.9	4.96E-03	5.10E-03	fine	
11				nm
11.1				
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	1.75E-02	1.75E-02	fine	nm
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9				
13				nm
13.1	3.42E-02	1.16E-02	fine	
13.2				
13.3				
13.4				
13.5				nm
13.6				
13.7				
13.8				
13.9				
14	nm	nm	fine	nm
14.1				
14.2				
14.3				
14.4				
14.5				nm
14.6				
14.7				
14.8				
14.9				
15	nm	nm	fine	nm
15.1				
15.2				
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	1.36E-01	1.43E-02	fine/coarse sand	nm
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9	2.28E-02	3.06E-02	fine	
17				nm
17.1				
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7	3.82E-02	4.15E-02	fine	
17.8				
17.9				
18				nm
18.1				
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8	6.76E-02	9.60E-02	fine/coarse sand	
18.9				
19				nm
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS16#2				
8	nm	nm	fine	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8				
8.9				
9				nm
9.1				
9.2				
9.3				
9.4	nm	nm	fine	
9.5				nm
9.6				
9.7				
9.8				
9.9				
10				nm
10.1				
10.2	1.38E-02	1.20E-02	fine/coarse sand	
10.3				
10.4				
10.5				nm
10.6				
10.7				
10.8				
10.9				
11	2.40E-02	2.36E-02	fine	nm
11.1				
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	1.50E-02	1.70E-02	fine/coarse sand	nm
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9				
13				nm
13.1	1.19E-02	1.70E-02	fine	
13.2				
13.3				
13.4				
13.5				nm
13.6				
13.7				
13.8				
13.9				
14	1.10E-03	1.50E-03	fine	nm
14.1				
14.2				
14.3				
14.4				
14.5				nm
14.6				
14.7				
14.8				
14.9				
15	2.60E-03	2.90E-03	fine	nm
15.1				
15.2				
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	1.28E-02	2.10E-02	fine/coarse sand	nm
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9				
17	3.50E-02	4.20E-02	fine/coarse sand	nm
17.1				
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7				
17.8				
17.9				
18	1.33E-02	1.36E-02	fine/coarse sand	nm
18.1				
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8				
18.9				
19	6.89E-02	9.33E-02	fine/coarse sand	nm
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.): **Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)	Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS19					**DS19#2**				
8	nm	nm	fine	nm	8	nm	nm	fine	nm
8.1					8.1				
8.2					8.2				
8.3					8.3				
8.4					8.4				
8.5				nm	8.5				nm
8.6					8.6				
8.7					8.7				
8.8					8.8				
8.9					8.9				
9				nm	9	9.00E-03	5.00E-03	silt/fine sand	nm
9.1					9.1				
9.2					9.2				
9.3					9.3				
9.4					9.4				
9.5	nm	nm	clay	nm	9.5	nm	nm	clay	nm
9.6					9.6				
9.7					9.7				
9.8					9.8				
9.9					9.9				
10				nm	10	nm	nm	silt/fine sand	nm
10.1					10.1				
10.2					10.2				
10.3					10.3				
10.4					10.4				
10.5	nm	nm	fine	nm	10.5	nm	nm	fine	nm
10.6					10.6				
10.7					10.7				
10.8					10.8				
10.9					10.9				
11				2.05E-02	11				2.05E-02
11.1	6.07E-03	2.84E-03	silt/fine sand		11.1	3.10E-03	2.00E-03	fine	
11.2					11.2				
11.3					11.3				
11.4					11.4				
11.5				nm	11.5				nm
11.6					11.6				
11.7					11.7				
11.8					11.8				
11.9					11.9				
12	nm	nm	fine	6.89E-04	12	nm	nm	fine	6.89E-04
12.1					12.1				
12.2					12.2				
12.3					12.3				
12.4					12.4				
12.5				nm	12.5				nm
12.6					12.6				
12.7					12.7				
12.8					12.8				
12.9					12.9				
13				1.71E-03	13				1.71E-03
13.1	nm	nm	silt/fine sand		13.1	nm	nm	fine	
13.2					13.2				
13.3					13.3				
13.4					13.4				
13.5				nm	13.5				nm
13.6					13.6				
13.7					13.7				
13.8					13.8				
13.9					13.9				
14				6.27E-03	14	nm	nm	fine/coarse sand	6.27E-03
14.1					14.1				
14.2	2.38E-03	1.61E-03	fine/coarse sand		14.2				
14.3					14.3				
14.4					14.4				
14.5				nm	14.5				nm
14.6					14.6				
14.7					14.7				
14.8					14.8				
14.9					14.9				
15				4.08E-02	15	2.76E-01	3.22E-01	fine/coarse sand	4.08E-02
15.1					15.1				
15.2					15.2				
15.3	3.03E-02	5.16E-02	coarse		15.3				
15.4					15.4				
15.5				nm	15.5				nm
15.6					15.6				
15.7					15.7				
15.8					15.8				
15.9					15.9				
16	2.87E-02	3.70E-02	coarse	7.94E-02	16	3.46E-02	3.76E-02	fine/coarse sand	7.94E-02
16.1					16.1				
16.2					16.2				
16.3					16.3				
16.4					16.4				
16.5				nm	16.5				nm
16.6					16.6				
16.7					16.7				
16.8					16.8				
16.9	4.74E-02	3.26E-02	fine		16.9				
17				7.94E-02	17	1.34E-01	1.66E-01	coarse	7.94E-02
17.1					17.1				
17.2					17.2				
17.3	4.22E-02	4.38E-02	coarse		17.3				
17.4					17.4				
17.5				nm	17.5				nm
17.6					17.6				
17.7					17.7				
17.8					17.8				
17.9					17.9				
18				7.94E-02	18	3.58E-02	6.30E-02	coarse	7.94E-02
18.1					18.1				
18.2					18.2				
18.3					18.3				
18.4	1.36E-01	1.71E-01	coarse		18.4				
18.5				nm	18.5				nm
18.6					18.6				
18.7					18.7				
18.8					18.8				
18.9					18.9				
19				7.94E-02	19	7.26E-02	9.80E-02	coarse	7.94E-02
19.1					19.1				
19.2					19.2				
19.3	1.45E-01	1.56E-01	coarse		19.3				
19.4					19.4				
19.5				nm	19.5				nm
19.6					19.6				
19.7					19.7				
19.8					19.8				
19.9					19.9				
20					20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.): **Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)	Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS19#3					**DS24**				
8	nm	nm	fine	nm	8	nm	nm	clay	nm
8.1					8.1				
8.2					8.2				
8.3					8.3				
8.4					8.4				
8.5				nm	8.5				nm
8.6					8.6				
8.7					8.7				
8.8					8.8				
8.9					8.9				
9	nm	nm	fine	nm	9	nm	nm	silt/fine sand	nm
9.1					9.1				
9.2					9.2				
9.3					9.3				
9.4					9.4				
9.5				nm	9.5				nm
9.6					9.6				
9.7					9.7				
9.8					9.8				
9.9					9.9				
10	5.40E-03	4.30E-03	fine	nm	10	nm	nm	fine	nm
10.1					10.1				
10.2					10.2				
10.3					10.3				
10.4					10.4				
10.5				nm	10.5				nm
10.6					10.6				
10.7					10.7				
10.8					10.8	nm	nm	fine	
10.9					10.9				
11				2.05E-02	11				nm
11.1	8.80E-03	1.00E-02	fine		11.1				
11.2					11.2				
11.3					11.3				
11.4					11.4				
11.5				nm	11.5				nm
11.6					11.6				
11.7					11.7				
11.8					11.8				
11.9					11.9				
12	>44	>44	fine	6.89E-04	12	4.40E-03	5.20E-03	fine	nm
12.1					12.1				
12.2					12.2				
12.3					12.3				
12.4					12.4				
12.5				nm	12.5				nm
12.6					12.6				
12.7					12.7				
12.8					12.8				
12.9					12.9				
13				1.71E-03	13				nm
13.1	>70	>70	fine		13.1	8.94E-03	8.99E-03	fine	
13.2					13.2				
13.3					13.3				
13.4					13.4				
13.5				nm	13.5				nm
13.6					13.6				
13.7					13.7				
13.8					13.8				
13.9					13.9				
14	>30	>30	fine	6.27E-03	14				nm
14.1					14.1	>30	>30	fine	
14.2					14.2				
14.3					14.3				
14.4					14.4				
14.5	2.56E-02	3.44E-02	fine/coarse sand	nm	14.5				nm
14.6					14.6				
14.7					14.7				
14.8					14.8				
14.9					14.9				
15	9.90E-03	1.40E-02	coarse	4.08E-02	15				nm
15.1					15.1	5.15E-02	2.64E-02	fine	
15.2					15.2				
15.3					15.3				
15.4					15.4				
15.5				nm	15.5				nm
15.6					15.6				
15.7					15.7				
15.8					15.8				
15.9					15.9				
16					16	1.38E-02	1.81E-02	fine/coarse sand	nm
16.1					16.1				
16.2					16.2				
16.3					16.3				
16.4					16.4				
16.5					16.5				nm
16.6					16.6				
16.7					16.7				
16.8					16.8				
16.9					16.9				
17					17	7.49E-02	3.31E-02	fine/coarse sand	nm
17.1					17.1				
17.2					17.2				
17.3					17.3				
17.4					17.4				
17.5					17.5				nm
17.6					17.6				
17.7					17.7				
17.8					17.8				
17.9					17.9				
18					18				nm
18.1					18.1				
18.2					18.2				
18.3					18.3				
18.4					18.4				
18.5					18.5				nm
18.6					18.6				
18.7					18.7				
18.8					18.8	1.20E-01	1.34E-01	fine/coarse	
18.9					18.9				
19					19	>30	>30	fine/coarse sand	nm
19.1					19.1				
19.2					19.2				
19.3					19.3				
19.4					19.4				
19.5					19.5				nm
19.6					19.6				
19.7					19.7				
19.8					19.8				
19.9					19.9				
20					20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.): **Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)		Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS20						DS20#2				
8	nm	nm	silt	nm		8				
8.1						8.1				
8.2						8.2				
8.3						8.3				
8.4						8.4				
8.5				nm		8.5				
8.6						8.6				
8.7						8.7				
8.8						8.8				
8.9						8.9				
9	nm	nm	silt	nm		9				
9.1						9.1				
9.2						9.2				
9.3						9.3				
9.4						9.4				
9.5				nm		9.5				
9.6						9.6				
9.7						9.7				
9.8						9.8				
9.9						9.9				
10	nm	nm	fine	nm		10				
10.1						10.1				
10.2						10.2				
10.3						10.3				
10.4						10.4				
10.5				nm		10.5				
10.6						10.6				
10.7						10.7				
10.8						10.8				
10.9						10.9				
11				nm		11				
11.1						11.1				
11.2	nm	nm	fine			11.2				
11.3						11.3				
11.4						11.4				
11.5				nm		11.5				
11.6						11.6				
11.7						11.7				
11.8						11.8				
11.9						11.9				
12	3.80E-03	5.90E-03	fine	nm		12	4.28E-03	3.98E-03	fine	nm
12.1						12.1				
12.2						12.2				
12.3						12.3				
12.4						12.4				
12.5				nm		12.5				nm
12.6						12.6				
12.7						12.7				
12.8						12.8				
12.9	nm	nm	fine			12.9				
13				nm		13	2.80E-03	2.90E-03	fine	nm
13.1						13.1				
13.2						13.2				
13.3						13.3				
13.4						13.4				
13.5				nm		13.5				nm
13.6						13.6				
13.7						13.7				
13.8						13.8				
13.9						13.9				
14				nm		14	2.80E-02	3.20E-02	fine/coarse sand	nm
14.1						14.1				
14.2	3.54E-02	2.70E-02	fine/coarse sand			14.2				
14.3						14.3				
14.4						14.4				
14.5				nm		14.5				nm
14.6						14.6				
14.7						14.7				
14.8						14.8				
14.9						14.9				
15	4.80E-02	1.09E-02	fine/coarse sand	nm		15	4.70E-03	6.40E-03	fine/coarse sand	nm
15.1						15.1				
15.2						15.2				
15.3						15.3				
15.4						15.4				
15.5				nm		15.5				nm
15.6						15.6				
15.7						15.7				
15.8						15.8				
15.9						15.9				
16	5.26E-02	2.91E-02	fine	nm		16				
16.1						16.1				
16.2						16.2				
16.3						16.3				
16.4						16.4				
16.5				nm		16.5				
16.6						16.6				
16.7						16.7				
16.8						16.8				
16.9						16.9				
17	4.09E-02	4.54E-02	fine/coarse sand	nm		17				
17.1						17.1				
17.2						17.2				
17.3						17.3				
17.4						17.4				
17.5				nm		17.5				
17.6						17.6				
17.7						17.7				
17.8						17.8				
17.9						17.9				
18	5.08E-02	5.90E-02	fine/coarse sand	nm		18				
18.1						18.1				
18.2						18.2				
18.3						18.3				
18.4						18.4				
18.5				nm		18.5				
18.6						18.6				
18.7						18.7				
18.8						18.8				
18.9						18.9				
19	1.68E-01	1.51E-01	coarse	nm		19				
19.1						19.1				
19.2						19.2				
19.3						19.3				
19.4						19.4				
19.5				nm		19.5				
19.6						19.6				
19.7						19.7				
19.8						19.8				
19.9						19.9				
20						20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.)**: Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS22				
8	nm	nm	silt	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8				
8.9				
9	nm	nm	silt/fine sand	nm
9.1				
9.2				
9.3				
9.4				
9.5				nm
9.6				
9.7	nm	nm	fine	
9.8				
9.9				
10				nm
10.1				
10.2				
10.3				
10.4	2.83E-03	3.46E-03	fine	
10.5				nm
10.6				
10.7				
10.8				
10.9				
11				nm
11.1				
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	nm	nm	fine	nm
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9				
13				nm
13.1				
13.2				
13.3				
13.4	1.37E-02	1.41E-02	fine	
13.5				nm
13.6				
13.7				
13.8				
13.9				
14				nm
14.1				
14.2				
14.3				
14.4				
14.5	1.61E-02	2.06E-02	fine	nm
14.6				
14.7				
14.8				
14.9				
15				nm
15.1				
15.2	5.15E-02	6.82E-02	fine	
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	7.40E-03	5.55E-03	fine	nm
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9				
17	nm	nm	fine	nm
17.1				
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7				
17.8				
17.9				
18	3.41E-02	1.36E-02	fine	nm
18.1				
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8				
18.9				
19	6.29E-02	5.03E-02	fine/coarse sand	nm
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS22#2				
8				
8.1				
8.2				
8.3				
8.4				
8.5				
8.6				
8.7				
8.8				
8.9				
9.0				
9.1				
9.2				
9.3				
9.4				
9.5				
9.6				
9.7				
9.8				
9.9				
10.0				
10.1				
10.2				
10.3				
10.4				
10.5				
10.6				
10.7				
10.8				
10.9				
11.0	5.80E-03	5.80E-03	fine	nm
11.1				
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12.0	2.44E-02	2.76E-02	fine/coarse sand	nm
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9				
13.0	1.14E-02	1.19E-02	fine	nm
13.1				
13.2				
13.3				
13.4				
13.5				nm
13.6				
13.7				
13.8				
13.9				
14.0	5.60E-02	3.70E-02	fine	nm
14.1				
14.2				
14.3				
14.4				
14.5				nm
14.6				
14.7				
14.8				
14.9				
15.0				nm
15.1				
15.2				
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16.0	7.70E-03	9.70E-03	fine	nm
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9				
17.0				nm
17.1				
17.2				
17.3	1.70E-02	2.08E-02	fine/coarse sand	
17.4				
17.5				nm
17.6				
17.7				
17.8				
17.9				
18.0				nm
18.1	4.20E-02	7.40E-02	fine/coarse sand	
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8				
18.9				
19.0	2.05E-02	2.56E-02	fine/coarse sand	nm
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20.0				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.): **Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)	Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS25					**DS27**				
8	nm	nm	silt	nm	8	nm	nm	silt	nm
8.1					8.1				
8.2					8.2				
8.3					8.3				
8.4					8.4				
8.5				nm	8.5				nm
8.6					8.6				
8.7					8.7				
8.8					8.8				
8.9					8.9				
9	nm	nm	silt/fine sand	nm	9				nm
9.1					9.1				
9.2					9.2	nm	nm	silt	
9.3					9.3				
9.4					9.4				
9.5				nm	9.5				nm
9.6					9.6				
9.7					9.7				
9.8					9.8				
9.9					9.9				
10				nm	10				nm
10.1					10.1				
10.2					10.2				
10.3					10.3				
10.4					10.4	nm	nm	fine/coarse sand	
10.5	nm	nm	fine	nm	10.5				nm
10.6					10.6				
10.7					10.7				
10.8					10.8				
10.9					10.9				
11				1.24E-02	11				nm
11.1					11.1	nm	nm	fine	
11.2	1.80E-03	2.08E-03	fine		11.2				
11.3					11.3				
11.4					11.4				
11.5				nm	11.5				nm
11.6					11.6				
11.7					11.7				
11.8					11.8				
11.9					11.9				
12	7.90E-03	8.41E-03	fine/coarse sand	2.47E-02	12	1.21E-02	1.35E-02	fine/coarse sand	nm
12.1					12.1				
12.2					12.2				
12.3					12.3				
12.4					12.4				
12.5				nm	12.5				nm
12.6					12.6				
12.7					12.7				
12.8					12.8				
12.9					12.9				
13	2.86E-02	2.65E-02	fine/coarse sand	3.83E-02	13	1.66E-02	2.42E-02	fine/coarse sand	nm
13.1					13.1				
13.2					13.2				
13.3					13.3				
13.4					13.4				
13.5				nm	13.5				nm
13.6					13.6				
13.7					13.7				
13.8					13.8				
13.9					13.9				
14	5.62E-03	3.59E-03	fine/coarse sand	3.75E-03	14	1.06E-02	1.32E-02	coarse	nm
14.1					14.1				
14.2					14.2				
14.3					14.3				
14.4					14.4				
14.5				nm	14.5				nm
14.6					14.6				
14.7					14.7				
14.8					14.8				
14.9					14.9				
15	>81 min	>81min	fine	5.11E-03	15	3.37E-02	5.27E-02	fine	nm
15.1					15.1				
15.2					15.2				
15.3					15.3				
15.4					15.4				
15.5				nm	15.5				nm
15.6					15.6				
15.7					15.7				
15.8					15.8				
15.9					15.9				
16	4.70E-02	6.67E-02	fine/coarse sand	4.29E-02	16	2.78E-02	3.57E-02	coarse	nm
16.1					16.1				
16.2					16.2				
16.3					16.3				
16.4					16.4				
16.5				nm	16.5				nm
16.6					16.6				
16.7					16.7	1.56E-02	1.19E-02	coarse	
16.8					16.8				
16.9					16.9				
17	9.31E-02	1.11E-01	coarse	7.15E-02	17				nm
17.1					17.1				
17.2					17.2				
17.3					17.3				
17.4					17.4				
17.5				nm	17.5				nm
17.6					17.6	8.01E-02	2.24E-02	silt/fine sand	
17.7					17.7				
17.8					17.8				
17.9					17.9				
18	1.03E-02	4.65E-02	fine/coarse sand	7.15E-02	18				nm
18.1					18.1				
18.2					18.2				
18.3					18.3				
18.4					18.4	nm	nm	silt	
18.5				nm	18.5				nm
18.6					18.6				
18.7					18.7				
18.8					18.8				
18.9					18.9				
19	4.41E-02	3.82E-02	fine/coarse sand	7.15E-02	19				nm
19.1					19.1				
19.2					19.2				
19.3					19.3				
19.4					19.4				
19.5				nm	19.5				nm
19.6					19.6				
19.7					19.7				
19.8					19.8				
19.9					19.9				
20					20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.)**: Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS29				
8	4.03E-01	6.35E-01	silt/fine sand	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8				
8.9				
9	nm	nm	silt/fine sand	nm
9.1				
9.2				
9.3				
9.4				
9.5				nm
9.6				
9.7				
9.8				
9.9	nm	nm	silt/fine sand	
10				nm
10.1				
10.2				
10.3				
10.4				
10.5				nm
10.6				
10.7				
10.8				
10.9				
11	nm	nm	fine	nm
11.1				
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	3.49E-02	3.75E-02	fine/coarse sand	nm
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9				
13	1.27E-02	1.63E-02	fine/coarse sand	nm
13.1				
13.2				
13.3				
13.4				
13.5				nm
13.6				
13.7				
13.8				
13.9				
14	2.75E-02	1.82E-02	fine/coarse sand	nm
14.1				
14.2				
14.3				
14.4				
14.5				nm
14.6				
14.7				
14.8				
14.9				
15	6.66E-02	7.55E-02	fine/coarse sand	nm
15.1				
15.2				
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	nm	nm	fine/coarse sand	nm
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9				
17	6.09E-02	6.84E-02	fine/coarse sand	nm
17.1				
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7				
17.8				
17.9				
18	1.14E-01	1.10E-01	fine/coarse sand	nm
18.1				
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8				
18.9				
19	9.10E-02	1.04E-01	silt/fine sand	nm
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS30				
8	nm	nm	silt	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8				
8.9				
9				nm
9.1	nm	nm	silt	
9.2				
9.3				
9.4				
9.5				nm
9.6				
9.7				
9.8				
9.9				
10				nm
10.1				
10.2	nm	nm	silt	
10.3				
10.4				
10.5				nm
10.6				
10.7				
10.8				
10.9				
11				nm
11.1	nm	nm	fine	
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	2.05E-02	2.41E-02	fine	nm
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9	5.38E-03	4.57E-03	fine	
13				nm
13.1				
13.2				
13.3				
13.4				
13.5				nm
13.6				
13.7	4.64E-03	3.80E-03	fine	
13.8				
13.9				
14				nm
14.1				
14.2				
14.3				
14.4				
14.5				nm
14.6				
14.7	2.25E-02	1.20E-02	fine/coarse sand	
14.8				
14.9				
15				nm
15.1				
15.2				
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	5.14E-02	5.12E-02	fine/coarse sand	nm
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9	2.71E-02	1.16E-02	coarse	
17				nm
17.1				
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7				
17.8				
17.9	1.31E-02	1.91E-02	coarse	
18				nm
18.1				
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8				
18.9				
19	9.13E-02	1.15E-01	coarse	nm
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.)**: Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS32				
8 8.1 8.2 8.3 8.4	nm	nm	silt	nm
8.5 8.6 8.7 8.8 8.9				nm
9 9.1 9.2 9.3 9.4	nm	nm	silt	nm
9.5 9.6 9.7 9.8 9.9				nm
10 10.1 10.2 10.3 10.4	nm	nm	silt	nm
10.5 10.6 10.7 10.8 10.9				nm
11 11.1 11.2 11.3 11.4	1.50E-02	1.26E-02	fine	nm
11.5 11.6 11.7 11.8 11.9				nm
12 12.1 12.2 12.3 12.4	nm	nm	fine	nm
12.5 12.6 12.7 12.8 12.9				nm
13 13.1 13.2 13.3 13.4	nm	nm	fine	nm
13.5 13.6 13.7 13.8 13.9				nm
14 14.1 14.2 14.3 14.4	nm	nm	fine	nm
14.5 14.6 14.7 14.8 14.9				nm
15 15.1 15.2 15.3 15.4	nm	nm	fine	nm
15.5 15.6 15.7 15.8 15.9				nm
16 16.1 16.2 16.3 16.4	1.06E-02	1.32E-02	fine	nm
16.5 16.6 16.7 16.8 16.9				nm
17 17.1 17.2 17.3 17.4	2.54E-02	3.48E-02	fine	nm
17.5 17.6 17.7 17.8 17.9				nm
18 18.1 18.2 18.3 18.4	7.28E-02	1.04E-01	fine/coarse sand	nm
18.5 18.6 18.7 18.8 18.9				nm
19 19.1 19.2 19.3 19.4	7.84E-02	1.14E-01	fine	nm
19.5 19.6 19.7 19.8 19.9 20				nm

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS36				
8 8.1 8.2 8.3 8.4	nm	nm	fine	nm
8.5 8.6 8.7 8.8 8.9				nm
9 9.1 9.2 9.3 9.4	nm	nm	fine	nm
9.5 9.6 9.7 9.8 9.9				nm
10 10.1 10.2 10.3 10.4	2.90E-03	3.90E-03	fine	nm
10.5 10.6 10.7 10.8 10.9	1.20E-03	1.90E-03	fine	nm
11 11.1 11.2 11.3 11.4	1.43E-02	1.27E-02	fine	nm
11.5 11.6 11.7 11.8 11.9				nm
12 12.1 12.2 12.3 12.4	8.47E-03	6.79E-03	fine	nm
12.5 12.6 12.7 12.8 12.9				nm
13 13.1 13.2 13.3 13.4	8.73E-03	1.17E-02	fine	nm
13.5 13.6 13.7 13.8 13.9				nm
14 14.1 14.2 14.3 14.4	3.46E-02	2.25E-02	fine	nm
14.5 14.6 14.7 14.8 14.9				nm
15 15.1 15.2 15.3 15.4	5.74E-02	6.17E-02	fine	nm
15.5 15.6 15.7 15.8 15.9				nm
16 16.1 16.2 16.3 16.4	nm	nm	silt	nm
16.5 16.6 16.7 16.8 16.9				nm
17 17.1 17.2 17.3 17.4	nm	nm	silt/fine sand	nm
17.5 17.6 17.7 17.8 17.9				nm
18 18.1 18.2 18.3 18.4	1.05E-01	6.96E-02	fine	nm
18.5 18.6 18.7 18.8 18.9				nm
19 19.1 19.2 19.3 19.4	9.18E-02	5.88E-02	fine	nm
19.5 19.6 19.7 19.8 19.9 20				nm

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.)**: Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)		Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS37						**DS38**				
8	nm	nm	silt/fine sand	nm		8	nm	nm	fine	nm
8.1						8.1				
8.2						8.2				
8.3						8.3				
8.4						8.4				
8.5				nm		8.5				nm
8.6						8.6				
8.7						8.7				
8.8	nm	nm	fine			8.8				
8.9						8.9				
9				nm		9	nm	nm	fine	nm
9.1						9.1				
9.2						9.2				
9.3						9.3				
9.4	nm	nm	fine			9.4				
9.5				nm		9.5				nm
9.6						9.6				
9.7						9.7				
9.8						9.8				
9.9						9.9				
10				nm		10	nm	nm	fine	1.10E-02
10.1	5.20E-03	6.60E-03	fine			10.1				
10.2						10.2				
10.3						10.3				
10.4						10.4				
10.5				nm		10.5				nm
10.6						10.6				
10.7						10.7				
10.8						10.8				
10.9						10.9				
11	8.80E-03	8.60E-03	fine	nm		11	nm	nm	fine	3.06E-03
11.1						11.1				
11.2						11.2				
11.3						11.3				
11.4						11.4				
11.5				nm		11.5				nm
11.6						11.6				
11.7						11.7				
11.8						11.8				
11.9						11.9				
12	6.30E-03	8.70E-03	fine	nm		12	1.56E-02	9.99E-03	fine/coarse sand	3.78E-03
12.1						12.1				
12.2						12.2				
12.3						12.3				
12.4						12.4				
12.5				nm		12.5				nm
12.6						12.6				
12.7						12.7				
12.8						12.8				
12.9						12.9				
13	nm	nm	fine	nm		13	6.77E-02	5.32E-02	fine/coarse sand	7.34E-02
13.1						13.1				
13.2						13.2				
13.3						13.3				
13.4						13.4				
13.5				nm		13.5				nm
13.6						13.6				
13.7						13.7				
13.8						13.8				
13.9						13.9				
14				nm		14	nm	nm	fine	1.70E-02
14.1	1.45E-02	1.73E-02	fine			14.1				
14.2						14.2				
14.3						14.3				
14.4						14.4				
14.5				nm		14.5				nm
14.6						14.6				
14.7						14.7				
14.8						14.8				
14.9						14.9				
15	5.23E-03	4.68E-03	fine	nm		15	3.03E-02	2.67E-02	fine/coarse sand	4.92E-02
15.1						15.1				
15.2						15.2				
15.3						15.3				
15.4						15.4				
15.5				nm		15.5				nm
15.6						15.6				
15.7						15.7				
15.8						15.8				
15.9						15.9				
16	5.26E-02	6.55E-02	fine	nm		16	nm	nm	fine	7.15E-02
16.1						16.1				
16.2						16.2				
16.3						16.3				
16.4						16.4				
16.5				nm		16.5				nm
16.6						16.6				
16.7	5.25E-02	5.73E-02	fine/coarse sand			16.7				
16.8						16.8				
16.9						16.9				
17				nm		17	nm	nm	silt	2.39E-03
17.1						17.1				
17.2						17.2				
17.3						17.3				
17.4						17.4				
17.5	4.10E-02	4.17E-02	fine	nm		17.5	nm	nm	silt/fine sand	nm
17.6						17.6				
17.7						17.7				
17.8						17.8				
17.9						17.9				
18				nm		18	nm	nm	silt	5.11E-04
18.1						18.1				
18.2						18.2				
18.3	2.24E-02	1.78E-02	silt/fine sand			18.3				
18.4						18.4				
18.5				nm		18.5				nm
18.6						18.6				
18.7						18.7				
18.8	6.30E-03	5.90E-03	fine/coarse sand			18.8				
18.9						18.9				
19				nm		19	nm	nm	silt	2.39E-02
19.1						19.1				
19.2						19.2				
19.3						19.3				
19.4	3.42E-02	4.70E-02	fine/coarse sand			19.4				
19.5				nm		19.5				nm
19.6						19.6				
19.7						19.7				
19.8						19.8				
19.9						19.9				
20						20				
*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements *Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.						*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements *Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.				

Table E.1 (cont.)**: Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS41				
8	nm	nm	silt/fine sand	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8	nm	nm	silt/fine sand	
8.9				
9				nm
9.1				
9.2				
9.3				
9.4				
9.5				nm
9.6				
9.7	nm	nm	silt	
9.8				
9.9				
10				nm
10.1				
10.2				
10.3				
10.4				
10.5	nm	nm	silt/fine sand	nm
10.6				
10.7				
10.8				
10.9				
11				1.29E-03
11.1				
11.2				
11.3	nm	nm	fine	
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	nm	nm	fine	1.13E-03
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9				
13				1.59E-03
13.1				
13.2	nm	nm	fine/coarse sand	
13.3				
13.4				
13.5				nm
13.6				
13.7				
13.8	nm	nm	fine/coarse sand	
13.9				
14				1.61E-03
14.1				
14.2				
14.3	nm	nm	fine/coarse sand	
14.4				
14.5				nm
14.6				
14.7				
14.8				
14.9				
15				3.57E-03
15.1	2.46E-02	3.48E-02	coarse	
15.2				
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	1.79E-02	2.37E-02	fine	5.28E-03
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9				
17	1.93E-02	2.73E-02	fine/coarse sand	1.74E-02
17.1				
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7				
17.8	4.39E-02	4.86E-02	coarse	
17.9				
18				6.33E-03
18.1				
18.2				
18.3				
18.4				
18.5				nm
18.6	1.91E-01	2.55E-01	coarse	
18.7				
18.8				
18.9				
19				1.35E-02
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS42				
8	2.83E-03	3.35E-03	silt/fine sand	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8				
8.9	nm	nm	silt	
9				nm
9.1				
9.2				
9.3				
9.4				
9.5				nm
9.6				
9.7				
9.8				
9.9				
10				nm
10.1	nm	nm	fine	
10.2				
10.3				
10.4				
10.5				nm
10.6				
10.7				
10.8				
10.9	3.83E-03	2.56E-03	fine/coarse sand	
11				nm
11.1				
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	1.85E-03	1.61E-03	fine	nm
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9				
13				nm
13.1	nm	nm	fine	
13.2				
13.3				
13.4				
13.5				nm
13.6				
13.7				
13.8				
13.9				
14	2.14E-03	1.45E-03	fine/coarse sand	nm
14.1				
14.2				
14.3				
14.4				
14.5				nm
14.6				
14.7				
14.8				
14.9	nm	nm	fine/coarse sand	
15				nm
15.1				
15.2				
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	1.64E-02	3.41E-02	fine	nm
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9				
17	4.10E-02	3.36E-02	fine	nm
17.1				
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7				
17.8				
17.9	6.85E-02	6.16E-02	fine/coarse sand	
18				nm
18.1				
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8				
18.9	3.73E-01	5.06E-01	coarse	
19				nm
19.1				
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.): **Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)	Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS43					DS 43 Short				
8	nm	nm	silt	nm	8				
8.1					8.1				
8.2					8.2				
8.3					8.3				
8.4					8.4				
8.5				nm	8.5				
8.6					8.6				
8.7					8.7				
8.8					8.8				
8.9					8.9				
9				nm	9				
9.1					9.1				
9.2					9.2				
9.3					9.3				
9.4					9.4				
9.5				nm	9.5				
9.6	nm	nm	silt		9.6				
9.7					9.7				
9.8					9.8				
9.9					9.9				
10				nm	10				
10.1					10.1				
10.2					10.2				
10.3	1.51E-02	1.64E-02	fine		10.3				
10.4					10.4				
10.5				nm	10.5				
10.6					10.6				
10.7					10.7				
10.8					10.8				
10.9					10.9				
11				nm	11				
11.1	nm	nm	fine		11.1				
11.2					11.2				
11.3					11.3				
11.4					11.4				
11.5				nm	11.5				
11.6					11.6				
11.7					11.7				
11.8					11.8				
11.9					11.9				
12	nm	nm	fine	nm	12	2.70E-03	2.70E-03	fine	nm
12.1					12.1				
12.2					12.2				
12.3					12.3				
12.4					12.4				
12.5				nm	12.5				nm
12.6					12.6				
12.7					12.7				
12.8					12.8				
12.9	9.51E-03	9.50E-03	fine		12.9				
13				nm	13	2.60E-03	2.80E-03	fine	nm
13.1					13.1				
13.2					13.2				
13.3					13.3				
13.4					13.4				
13.5				nm	13.5				nm
13.6					13.6				
13.7	5.44E-02	6.08E-02	fine/coarse sand		13.7				
13.8					13.8				
13.9					13.9				
14				nm	14	3.90E-03	5.10E-03	fine/coarse sand	nm
14.1					14.1				
14.2					14.2				
14.3					14.3				
14.4					14.4				
14.5				nm	14.5				nm
14.6					14.6				
14.7	1.36E-02	1.68E-02	fine/coarse sand		14.7				
14.8					14.8				
14.9					14.9				
15				nm	15	6.20E-03	8.10E-03	fine/coarse sand	nm
15.1					15.1				
15.2					15.2				
15.3					15.3				
15.4					15.4				
15.5				nm	15.5				nm
15.6					15.6				
15.7					15.7				
15.8					15.8				
15.9					15.9				
16	2.00E-02	2.05E-02	fine	nm	16				
16.1					16.1				
16.2					16.2				
16.3					16.3				
16.4					16.4				
16.5				nm	16.5				
16.6					16.6				
16.7					16.7				
16.8					16.8				
16.9					16.9				
17	4.04E-02	4.15E-02	fine	nm	17				
17.1					17.1				
17.2					17.2				
17.3					17.3				
17.4					17.4				
17.5				nm	17.5				
17.6					17.6				
17.7					17.7				
17.8					17.8				
17.9					17.9				
18				nm	18				
18.1					18.1				
18.2					18.2				
18.3					18.3				
18.4					18.4				
18.5				nm	18.5				
18.6					18.6				
18.7					18.7				
18.8					18.8				
18.9	2.96E-02	3.57E-02	fine/coarse sand		18.9				
19				nm	19				
19.1					19.1				
19.2					19.2				
19.3					19.3				
19.4					19.4				
19.5				nm	19.5				
19.6					19.6				
19.7					19.7				
19.8	1.46E-02	1.54E-02	fine/coarse		19.8				
19.9					19.9				
20					20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements
*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

Table E.1 (cont.)**: Hydraulic Conductivity Data from Temporary Sampling Locations**

Borehole	K falling (cm/s)	K Constant (cm/s)	Description	Field K (cm/s)
DS44				
8	nm	nm	silt/fine sand	nm
8.1				
8.2				
8.3				
8.4				
8.5				nm
8.6				
8.7				
8.8				
8.9				
9				nm
9.1				
9.2	nm	nm	fine	
9.3				
9.4				
9.5				nm
9.6				
9.7				
9.8				
9.9				
10				nm
10.1	4.40E-03	5.20E-03	fine	
10.2				
10.3				
10.4				
10.5				nm
10.6				
10.7				
10.8				
10.9				
11				nm
11.1	nm	nm	fine	
11.2				
11.3				
11.4				
11.5				nm
11.6				
11.7				
11.8				
11.9				
12	nm	nm	fine	nm
12.1				
12.2				
12.3				
12.4				
12.5				nm
12.6				
12.7				
12.8				
12.9				
13				nm
13.1				
13.2				
13.3				
13.4				
13.5	2.66E-02	3.49E-02	fine/coarse sand	nm
13.6				
13.7				
13.8				
13.9				
14				nm
14.1				
14.2				
14.3				
14.4	nm	nm	fine	
14.5				nm
14.6				
14.7				
14.8				
14.9				
15				nm
15.1				
15.2	1.62E-02	1.19E-02	fine/coarse sand	
15.3				
15.4				
15.5				nm
15.6				
15.7				
15.8				
15.9				
16	nm	nm	fine/coarse sand	nm
16.1				
16.2				
16.3				
16.4				
16.5				nm
16.6				
16.7				
16.8				
16.9				
17				nm
17.1	nm	nm	fine/coarse sand	
17.2				
17.3				
17.4				
17.5				nm
17.6				
17.7				
17.8				
17.9				
18				nm
18.1	nm	nm	silt/fine sand	
18.2				
18.3				
18.4				
18.5				nm
18.6				
18.7				
18.8				
18.9				
19				nm
19.1	nm	nm	silt/fine sand	
19.2				
19.3				
19.4				
19.5				nm
19.6				
19.7				
19.8				
19.9				
20				

*NM-No Measurement:due to low conductivity(falling head and constant head tests), due to no sample for field measurements

*Field Measurement, K Value =7.15 E-02 corresponds with unable to drawdown, due too a high conductivity faster then 1000 ml in 1 min. 15 s.

APPENDIX E

Table E.2: Hydraulic Conductivity Data from Slug Testing of Permanent Monitoring Wells

Well Name	Slug Out	Slug In	t37 Slug Out	t37 Slug in	K Slug Out (cm/s)	K Slug In (cm/s)
ASU1	y=e-0.0632x	y=e-0.0295x	15.7	33.7	4.0E-02	1.9E-02
ASU2	y=e-0.7305x	y=e-0.4903x	1.4	2.0	4.6E-01	3.1E-01
ASU3	y=e-0.3376x	y=e-0.1673x	2.9	5.9	2.1E-01	1.1E-01
ASU4	y=e-0.2082x	y=e-0.1179x	4.8	8.4	1.3E-01	7.4E-02
ASU5	y=e-0.2438x	y=e-0.1687x	4.1	5.9	1.5E-01	1.1E-01
ASU6	y=e-0.4271x	y=e-0.1976x	2.3	5.0	2.7E-01	1.2E-01
ASU7	y=e-0.2606x	y=e-0.0801x	3.8	12.4	1.6E-01	5.0E-02
CBC25	y=e-0.2394x	y=e-0.2410x	4.2	4.1	1.5E-01	1.5E-01

APPENDIX E

Table E.3: Hydraulic Conductivity DataConstant Drawdown Pumping Tests in Permanent 3/4" Wells

Well	**Depth**	**Constant drawdown distance (ft)**	**Length of screen (ft)**	**Discharge**			**K (unconfined) (cm/sec)**	**K (unconfined) (ft/day)**	**Comments**
				Total time (sec)	**volume (mL)**	**QDischarge (cm3/sec)**			
EM1-1	S	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM1-2	S	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM1-3	S	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
	D	0.25	5	179	2000	11.17	2.60E-01	12.29	
EM1-4	S	0.25	5	165	2000	12.12	2.82E-01	13.34	
	D	0.25	5	126	2000	15.87	3.70E-01	17.47	
EM1-5	S	0.25	5	92	2000	21.74	5.06E-01	23.92	
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM1-6	S	0.25	5	214	800	3.74	8.71E-02	4.11	
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM1-7	S	0.25	5	140	800	5.71	1.33E-01	6.29	
	D	0.25	5	147	800	5.44	1.27E-01	5.99	
EM1-8	S	0.25	5	122	400	3.28	7.64E-02	3.61	
	D	0.25	5	149	1600	10.74	2.50E-01	11.82	
EM1-9	S	0.25	5	160	2000	12.50	2.91E-01	13.75	
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM1-10	S	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM1-11	S	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM2-1	S	0.25	5	167	1000	5.99	1.39E-01	6.59	
	D	0.25	5	110	2000	18.18	4.23E-01	20.01	
EM2-2	S	0.25	5	140	400	2.86	6.65E-02	3.14	
	D	0.25	5	153	1000	6.54	1.52E-01	7.19	
EM6-1	S	0.25	5	69	2000	28.99	6.75E-01	31.89	Unable to drawdown
	D	0.25	5	81	2000	24.69	5.75E-01	27.17	
EM6-2	S	0.25	5	187	800	4.28	9.96E-02	4.71	
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM6-3	S	0.25	5	183	2000	10.93	2.55E-01	12.03	
	D	0.25	5	73	2000	27.40	6.38E-01	30.15	
EM6-4	S	0.25	5	166	2000	12.05	2.81E-01	13.26	
	D	0.25	5	69	2000	28.99	6.75E-01	31.89	Unable to drawdown
EM6-5 (8/3/04)	S	0.25	5	203	2000	9.85	2.29E-01	10.84	
	D	0.25	5	69	2000	28.99	6.75E-01	31.89	Unable to drawdown
EM6-5 (8/17/04)	S	0.25	5	204	2000	9.80	2.28E-01	10.79	
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM6-6	S	0.25	5	231	2000	8.66	2.02E-01	9.53	
	D	0.25	5	69	2000	28.99	6.75E-01	31.89	Unable to drawdown
EM6-7 (8/3/04)	S	0.25	5	166	2000	12.05	2.81E-01	13.26	
	D	0.25	5	103	2000	19.42	4.52E-01	21.37	
EM6-7 (8/17/04)	S	0.25	5	160	2000	12.50	2.91E-01	13.75	
	D	0.25	5	124	2000	16.13	3.76E-01	17.75	
EM6-8	S	0.25	5	177	2000	11.30	2.63E-01	12.43	
	D	0.25	5	69	2000	28.99	6.75E-01	31.89	Unable to drawdown
EM6-9 (8/3/04)	S	0.25	5	69	2000	28.99	6.75E-01	31.89	Unable to drawdown
	D	0.25	5	154	2000	12.99	3.02E-01	14.29	
EM6-9 (8/17/04)	S	0.25	5	77	2000	25.97	6.05E-01	28.58	
	D	0.25	5	160	2000	12.50	2.91E-01	13.75	
EM6-10	S	0.25	5	138	2000	14.49	3.38E-01	15.95	
	D	0.25	5	78	2000	25.64	5.97E-01	28.21	
EM6-11 (8/3/04)	S	0.25	5	175	2000	11.43	2.66E-01	12.58	
	D	0.25	5	69	2000	28.99	6.75E-01	31.89	Unable to drawdown
EM6-11 (8/17/04)	S	0.25	5	175	2000	11.43	2.66E-01	12.58	
	D	0.25	5	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
EM North	S	0.25	5	69	2000	28.99	6.75E-01	31.89	Unable to drawdown
	D	0.25	5	69	2000	28.99	6.75E-01	31.89	Unable to drawdown
EM South	S	0.25	5	91	2000	21.98	5.12E-01	24.18	
	D	0.25	5	102	2000	19.61	4.57E-01	21.58	
ASU8	S	0.25	12	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
CBC37	S	0.25	12	74	2000	27.03	6.29E-01	29.74	Unable to drawdown
CBC38	S	0.25	12	121	2000	16.53	3.85E-01	18.19	
CBC39	S	0.25	12	210	2000	9.52	2.22E-01	10.48	
CBC40	S	0.25	12	82	2000	24.39	5.68E-01	26.84	
CBC41	S	0.25	12	79	2000	25.32	5.90E-01	27.86	
CBC42	S	0.25	12	74	2000	27.03	6.29E-01	29.74	Unable to drawdown

APPENDIX F

Groundwater Elevation Data

APPENDIX F

Table F.1: Groundwater Elevation Data

Well	Depth	TOC Well Elevation [ft amsl]	August 17 2004		March 18 2005		August 13 2005		Δ Water Level GW Elevation [ft amsl] (Aug. 04-Aug. 05)
			DTW BTOC [ft]	GW Elevation [ft amsl]	DTW BTOC [ft]	GW Elevation [ft amsl]	DTW BTOC [ft]	GW Elevation [ft amsl]	
EM2-1	S	18.90	8.09	10.81	6.18	12.72	7.41	11.49	-0.67
	D	18.96	8.16	10.80	6.26	12.70	7.49	11.47	-0.66
EM2-2	S	19.25	8.66	10.59	6.78	12.47	7.95	11.30	-0.71
	D	19.29	8.70	10.59	6.82	12.47	7.99	11.30	-0.72
EM1-1	S	19.07	8.07	11.00	6.25	12.82	7.38	11.69	-0.69
	D	19.08	8.08	11.00	6.24	12.84	7.40	11.68	-0.68
EM1-2	S	18.77	7.83	10.94	5.95	12.82	7.12	11.65	-0.71
	D	18.75	7.81	10.94	5.93	12.82	7.11	11.64	-0.70
EM1-3	S	18.64	7.76	10.88	5.82	12.82	7.06	11.58	-0.71
	D	18.74	7.86	10.88	5.92	12.82	7.16	11.58	-0.70
EM1-4	S	18.88	8.07	10.81	6.16	12.72	7.37	11.51	-0.70
	D	18.92	8.11	10.81	6.19	12.73	7.40	11.52	-0.70
EM1-5	S	19.30	8.55	10.75	6.64	12.66	7.83	11.47	-0.72
	D	19.30	8.54	10.76	6.64	12.66	7.84	11.46	-0.70
EM1-6	S	19.34	8.66	10.68	6.76	12.58	7.94	11.40	-0.73
	D	19.40	8.71	10.69	6.81	12.59	7.99	11.41	-0.72
EM1-7	S	19.29	8.68	10.61	6.77	12.52	7.96	11.33	-0.73
	D	19.36	8.75	10.61	6.94	12.42	8.02	11.34	-0.73
EM1-8	S	19.35	8.79	10.56	6.89	12.46	8.07	11.28	-0.73
	D	19.40	8.84	10.56	6.95	12.45	8.12	11.28	-0.72
EM1-9	S	19.36	8.86	10.50	6.98	12.38	8.16	11.20	-0.71
	D	19.38	8.86	10.52	6.99	12.39	8.17	11.21	-0.70
EM1-10	S	19.23	8.77	10.46	6.92	12.31	8.10	11.13	-0.67
	D	19.30	8.83	10.47	6.98	12.32	8.15	11.15	-0.67
EM1-11	S	19.32	8.92	10.40	7.10	12.22	8.24	11.08	-0.67
	D	19.34	8.92	10.42	7.10	12.24	8.26	11.08	-0.67
ASU-1		18.51	8.02	10.49	6.20	12.31	7.38	11.13	-0.64
ASU-2		19.09	8.37	10.72	6.46	12.63	7.65	11.44	-0.71
ASU-3		18.46	7.56	10.90	5.63	12.83	6.88	11.58	-0.68
ASU-4		17.57	6.73	10.84	4.80	12.77	5.99	11.58	-0.73
ASU-5		18.78	7.63	11.15	5.82	12.96	6.95	11.83	-0.68
ASU-6		20.75	9.15	11.60	4.11	16.64	8.47	12.28	-0.68
ASU-7		19.01	8.06	10.95	6.19	12.82	7.38	11.63	-0.68
ASU-8		18.95	7.92	11.03	6.05	12.90	7.20	11.75	-0.72
ASU-9		20.95	--	--	7.32	13.63	8.46	12.49	--
EM South	S	19.03	8.80	10.23	7.04	11.99	8.19	10.84	-0.62
	D	19.02	8.80	10.22	7.03	11.99	8.17	10.85	-0.64
EM6-1	S	18.71	7.77	10.94	5.98	12.73	7.12	11.59	-0.65
	D	18.68	7.74	10.94	5.94	12.74	7.11	11.57	-0.64
EM6-2	S	18.52	7.70	10.82	5.82	12.70	7.01	11.51	-0.69
	D	18.49	7.62	10.87	5.77	12.72	6.98	11.51	-0.64
EM6-3	S	18.54	7.74	10.80	5.85	12.69	7.09	11.45	-0.66
	D	18.49	7.70	10.79	5.80	12.69	7.05	11.44	-0.65
EM6-4	S	18.85	8.12	10.73	6.24	12.61	7.43	11.42	-0.69
	D	18.87	8.13	10.74	6.26	12.61	7.45	11.42	-0.67
EM6-5	S	19.01	8.36	10.65	6.50	12.51	7.69	11.32	-0.67
	D	18.98	8.33	10.65	6.47	12.51	7.65	11.33	-0.67
EM6-6	S	19.04	8.50	10.54	6.63	12.41	7.82	11.22	-0.68
	D	19.01	8.46	10.55	6.61	12.40	7.79	11.22	-0.68
EM6-7	S	19.11	8.43	10.68	6.75	12.36	7.93	11.18	-0.50
	D	19.09	8.33	10.76	6.73	12.36	7.90	11.19	-0.43
EM6-8	S	19.17	8.73	10.44	6.87	12.30	8.04	11.13	-0.69
	D	19.17	8.72	10.45	6.87	12.30	8.04	11.13	-0.68
EM6-9	S	19.19	8.78	10.41	6.95	12.24	8.13	11.06	-0.66
	D	19.12	8.72	10.40	6.89	12.23	8.06	11.06	-0.66

Table F.1 (cont.)**: Groundwater Elevation Data**

Well	Depth	TOC Well Elevation [ft amsl]	August 17 2004		March 18 2005		August 13 2005		Δ Water Level GW Elevation [ft amsl] (Aug. 04-Aug. 05)
			DTW BTOC [ft]	GW Elevation [ft amsl]	DTW BTOC [ft]	GW Elevation [ft amsl]	DTW BTOC [ft]	GW Elevation [ft amsl]	
EM6-10	S	19.11	8.78	10.33	6.97	12.14	8.13	10.98	-0.65
	D	19.10	8.76	10.34	6.95	12.15	8.13	10.97	-0.64
EM6-11	S	19.11	8.83	10.28	7.05	12.06	8.20	10.91	-0.63
	D	19.07	8.79	10.28	7.01	12.06	8.16	10.91	-0.63
EM NORTH	S	18.93	7.91	11.02	6.14	12.79	7.26	11.67	-0.66
	D	18.97	7.96	11.01	6.18	12.79	7.29	11.68	-0.67
CBC-25		18.54	8.14	10.40	6.22	12.32	7.42	11.12	-0.72
CBC-37		18.58	7.91	10.67	5.99	12.59	7.20	11.38	-0.71
CBC-38		18.68	8.22	10.46	6.41	12.27	7.58	11.10	-0.64
CBC-39		18.47	8.27	10.20	6.53	11.94	7.69	10.78	-0.58
CBC-40		18.48	8.39	10.09	6.64	11.84	7.79	10.69	-0.60
CBC-41		18.01	8.21	9.80	6.55	11.46	7.68	10.33	-0.52
CBC-42		17.55	7.96	9.59	6.40	11.15	7.52	10.03	-0.43

APPENDIX G

NBVC 2004 to 2005 Water Quality Data

APPENDIX G

Table G.1: NBVC 2004 to 2005 Water Quality Data

Well	Location		Depth (ft)	Water Quality							
	Feet South of North BB Well	Feet West of DG BB Wells		DO '04	ORP '04	MTBE (ug/L) May '04	MTBE (ug/L) July '04	MTBE (ug/L) Aug. '04	DO Aug. '05	ORP Aug.'05	MTBE (ug/L) Aug. '05
DS 1	9762	9839	11 to 11.5	<1	-10	ND	--	--	<1	-106	2
			17 to 17.5	<1	-160	BDL	--	--	<1	-4	1
DS 2	9805	9839	11 to 11.5	<1	--	7	--	--	<1	26	3
			17 to 17.5	<1	-80	47	--	--	<1	83	4
DS 3	9848	9824	11 to 11.5	<1	-190	29	--	--	--	--	--
			17 to 17.5	<1	--	72	--	--	--	--	--
DS3	9848	9824	9 to 9.5	--	--	--			--	--	--
			10 to 10.5	<1	--	--	--	11	<1	-228	4
			11 to 11.5	<1	-190	--	--	17	<1	-135	4
			12 to 12.5	<1	-210	--	--	38	<1	-84	7
			13 to 13.5	<1	-12	--	--	62	<1	-41	16
			14 to 14.5	<1	-44	--	--	24	<1	-58	10
			15 to 15.5	--	--	--	--	29	<1	-105	9
			16 to 16.5	--	--	--	--	--	<1	-31	8
			17 to 17.5	<1	-136	--	--	22	<1	12	7
			18 to 18.5	--	--	--	--	--	<1	-27	3
			19 to 19.5	<1	-120	--	--	27	<1	-97	3
DS 4	9889	9838	10 to 10.5	<1	--	152	--	--	--	--	--
			17 to 17.5	<1	--	56	--	--	--	--	--
DS 4	9889	9838	9 to 9.5	--	--	--			--	--	--
			10 to 10.5	<1	-157	--	--	83	<1	-61	44
			11 to 11.5	<1	-128	--	--	36	<1	-46	24
			12 to 12.5	<1	47	--	--	25	<1	-59	11
			13 to 13.5	<1	-118	--	--	13	<1	-55	7
			14 to 14.5	<1	-238	--	--	13	<1	-57	2
			15 to 15.5	<1	-183	--	--	11	<1	-35	2
			16 to 16.5	<1	-527	--	--	15	<1	-51	2
			17 to 17.5	<1	-224	--	--	14	<1	-49	2
			18 to 18.5	<1	-10	--	--	8	<1	-100	2
			19 to19.5	<1	-269	--	--	20	<1	-51	BDL
DS 4 Repeat	9889	9838	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	<1	-135	63
			11 to 11.5	--	--	--	--	--	<1	-71	30
			12 to 12.5	--	--	--	--	--	<1	-65	8
			13 to 13.5	--	--	--	--	--	<1	-78	8
			14 to 14.5	--	--	--	--	--	<1	-73	3
			15 to 15.5	--	--	--	--	--	<1	-85	3
			16 to 16.5	--	--	--	--	--	<1	-74	3
			17 to 17.5	--	--	--	--	--	<1	-75	3
			18 to 18.5	--	--	--	--	--	<1	-83	3
			19 to19.5	--	--	--	--	--	<1	66	2
DS 5	9918	9824	11 to 11.5	<1	-150	317	--	--	<1	-154	37
			17 to 17.5	<1	-50	226	--	--	<1	-129	2
DS 6	9930	9824	11 to 11.5	<1	-400	346	--	--	--	--	--
			17 to 17.5	<1	-100	79	--	--	--	--	--

Notes: BDL-Below Detection Limit; ND-Non Detect; "--" No Sample Collected

Table G.1 cont.: NBVC 2004 to 2005 Water Quality Data

Well	Location		Depth (ft)	Water Quality							
	Feet South of North BB Well	Feet West of DG BB Wells		DO '04	ORP '04	MTBE (ug/L) May '04	MTBE (ug/L) July '04	MTBE (ug/L) Aug. '04	DO Aug. '05	ORP Aug.'05	MTBE (ug/L) Aug. '05
DS6	9930	9824	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	-80	373	158	507	<1	-83	3
			11 to 11.5	<1	-120	544	267	513	<1	-49	39
			12 to 12.5	<1	-75	189	284	418	<1	-36	17
			13 to 13.5	<1	-26	356	235	352	<1	-38	4
			14 to 14.5	<1	-80	194	57	168	<1	-18	3
			15 to 15.5	<1	-58	67	43	33	<1	-57	4
			16 to 16.5	<1	-134	47	33	12	<1	-57	3
			17 to 17.5	<1	-85	58	30	13	<1	-90	5
			18 to 18.5	<1	-100	79	24	11	<1	-70	3
			19 to 19.5	<1	-80	111	16	10	<1	-17	3
DS 7	9972	9824	11 to 11.5	<1	-52	70	--	--	<1	130	43
			17 to 17.5	<1	-70	29	--	--	<1	-16	5
DS 8	10016	9791	11 to 11.5	<1	30	33	--	--	--	--	--
			17 to 17.5	<1	-30	50	--	--	--	--	--
DS8	10016	9791	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	335	4	28	--	<1	-57	4
			11 to 11.5	<1	240	39	67	--	<1	-18	3
			12 to 12.5	<1	240	209	112	--	<1	71	33
			13 to 13.5	<1	236	164	124	--	<1	117	102
			14 to 14.5	<1	17	63	141	--	<1	45	52
			15 to 15.5	<1	-25	25	56	--	<1	-21	16
			16 to 16.5	<1	-66	53	46	--	<1	-67	4
			17 to 17.5	<1	-515	99	59	--	<1	-81	3
			18 to 18.5	<1	-543	84	65	--	<1	-87	3
			19 to 19.5	<1	-540	86	103	--	<1	-104	4
DS 9	10066	9791	11 to 11.5	<1	--	4	--	--	<1	15	2
			17 to 17.5	<1	-50	11	--	--	<1	39	3
DS 10	10128	9790	11 to 11.5	<1	-460	11	--	--	<1	29	ND
			17 to 17.5	<1	-20	9	--	--	<1	47	3
DS 11	10177	9790	11 to 11.5	<1	-50	2	--	--	<1	94	1
			17 to 17.5	<1	-50	2	--	--	<1	-27	3
DS12	9916	9792	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	--	--	--
			11 to 11.5	<1	-510	--	--	66	<1	-87	35
			12 to 12.5	<1	-35	--	--	113	<1	-49	43
			13 to 13.5	<1	-42	--	--	60	<1	-32	9
			14 to 14.5	<1	64	--	--	50	<1	-56	9
			15 to 15.5	<1	82	--	--	21	<1	156	6
			16 to 16.5	<1	30	--	--	9	<1	-21	3
			17 to 17.5	<1	-84	--	--	12	<1	33	4
			18 to 18.5	<1	158	--	--	14	<1	-47	BDL
			19 to 19.5	<1	88	--	--	7	<1	-63	3

Notes: BDL-Below Detection Limit; ND-Non Detect; "--" No Sample Collected

Table G.1 cont.: NBVC 2004 to 2005 Water Quality Data

Well	Location		Depth (ft)	Water Quality							
	Feet South of North BB Well	Feet West of DG BB Wells		DO '04	ORP '04	MTBE (ug/L) May '04	MTBE (ug/L) July '04	MTBE (ug/L) Aug. '04	DO Aug. '05	ORP Aug.'05	MTBE (ug/L) Aug. '05
DS13	9964	9791	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	163	86	--	<1	-116	61
			11 to 11.5	<1	160	352	140	--	<1	-28	50
			12 to 12.5	<1	-131	511	482	--	<1	-148	2
			13 to 13.5	<1	-214	125	222	--	<1	-96	7
			14 to 14.5	<1	-118	21	27	--	<1	-6	9
			15 to 15.5	1.37	-143	19	15	--	<1	--	13
			16 to 16.5	<1	-48	9	13	--	<1	-10	6
			17 to 17.5	<1	-75	10	13	--	<1	-12	4
			18 to 18.5	<1	47	16	16	--	<1	-38	4
			19 to19.5	<1	163	43	17	--	<1	-32	3
DS 14	9800	9792	11 to 11.5	<1	-110	2	--	--	--	--	--
			17 to 17.5	<1	-40	6	--	--	--	--	--
DS 14	9800	9792	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	--	2	--	--	<1	-62	3
			11 to 11.5	<1	22	BDL	--	--	<1	-65	BDL
			12 to 12.5	<1	-71	1	--	--	<1	-34	BDL
			13 to 13.5	<1	-47	BDL	--	--	<1	24	BDL
			14 to 14.5	<1	2	2	--	--	<1	41	1
			15 to 15.5	<1	-90	5	--	--	<1	-15	2
			16 to 16.5	<1	-52	5	--	--	<1	-68	4
			17 to 17.5	<1	-176	4	--	--	<1	-134	4
			18 to 18.5	<1	-181	11	--	--	<1	-106	7
			19 to 19.5	<1	4	7	--	--	<1	-98	7
DS 15	9844	9792	11 to 11.5	<1	-100	1	--	--	<1	-126	3
			17 to 17.5	<1	25	32	--	--	<1	-96	4
DS 17	9892	9792	11 to 11.5	<1	42	8	--	--	<1	-6	2
			17 to 17.5	<1	-200	2	--	--	<1	58	2
DS 19	9941	9791	11 to 11.5	<1	-600	BDL	--	--	--	--	--
			17 to 17.5	<1	-340	7	--	--	--	--	--
DS 19	9941	9791	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	--	--	--	--	--	--	--
			11 to 11.5	<1	75	BDL	--	3	<1	-23	3
			12 to 12.5	<1	-172	--	--	4	<1	--	4
			13 to 13.5	<1	-94	--	--	46	<1	38	32
			14 to 14.5	<1	46	--	--	99	<1	-12	35
			15 to 15.5	<1	177	--	--	55	<1	14	9
			16 to 16.5	<1	203	--	--	10	<1	47	2
			17 to 17.5	<1	156	7	--	8	<1	34	3
			18 to 18.5	<1	66	--	--	8	<1	90	3
			19 to 19.5	<1	80	--	--	13	<1	55	3

Notes: BDL-Below Detection Limit; ND-Non Detect; "--" No Sample Collected

Table G.1 cont.: NBVC 2004 to 2005 Water Quality Data

Well	Location		Depth (ft)	Water Quality							
	Feet South of North BB Well	Feet West of DG BB Wells		DO '04	ORP '04	MTBE (ug/L) May '04	MTBE (ug/L) July '04	MTBE (ug/L) Aug. '04	DO Aug. '05	ORP Aug.'05	MTBE (ug/L) Aug. '05
DS 21	9987	9791	11 to 11.5	<1	165	114	--	--	--	--	--
			17 to 17.5	<1	-52	10	--	--	--	--	--
DS 21	9987	9791	9 to 9.5	--	--	--		--	--	--	--
			10 to 10.5	<1	-95	35	34	--	<1	214	10
			11 to 11.5	<1	-65	75	77	--	<1	160	42
			12 to 12.5	<1	-45	876	394	--	<1	186	52
			13 to 13.5	<1	-164	444	148	--	<1	98	3
			14 to 14.5	<1	27	88	80	--	<1	13	15
			15 to 15.5	<1	5	20	29	--	<1	-22	9
			16 to 16.5	<1	35	13	14	--	<1	-18	8
			17 to 17.5	<1	285	10	10	--	<1	-61	5
			18 to 18.5	<1	250	11	13	--	<1	-78	4
			19 to19.5	<1	230	15	14	--	<1	-77	3
DS 23	10031	9792	11 to 11.5	<1	0	16	--	--	<1	82	14
			17 to 17.5	<1	16	10	--	--	<1	-35	6
DS 25	10077	9791	11 to 11.5	<1	-15	3	--	--	--	--	--
			17 to 17.5	<1	-212	17	--	--	--	--	--
DS 25	10077	9791	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	--	--	--	--	<1	-70	BDL
			11 to 11.5	<1	-104	--	--	4	<1	-52	1
			12 to 12.5	<1	249	--	--	119	<1	-10	32
			13 to 13.5	<1	169	--	--	106	<1	21	41
			14 to 14.5	<1	-123	--	--	19	<1	-37	4
			15 to 15.5	<1	-109	--	--	5	<1	-61	3
			16 to 16.5	<1	-86	--	--	3	<1	-63	3
			17 to 17.5	<1	-60	--	--	10	<1	-51	4
			18 to 18.5	<1	-119	--	--	20	<1	-75	3
			19 to19.5	<1	-123	--	--	42	<1	-84	3
DS 26	10121	9791	11 to 11.5	<1	-115	13	--	--	<1	-122	7
			17 to 17.5	<1	-50	8	--	--	<1	-93	5
DS 28	10167	9790	11 to 11.5	<1	35	6	--	--	--	--	--
			17 to 17.5	<1	-20	5	--	--	--	--	--
DS 28	10167	9790	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	-150	4	--	--	<1	56	1
			11 to 11.5	<1	-54	6	--	--	<1	41	2
			12 to 12.5	<1	84	4	--	--	<1	115	2
			13 to 13.5	<1	27	2	--	--	<1	5	1
			14 to 14.5	<1	-27	2	--	--	<1	-54	1
			15 to 15.5	<1	-80	1	--	--	<1	-90	2
			16 to 16.5	<1	-220	11	--	--	<1	-131	3
			17 to 17.5	<1	-52	3	--	--	<1	-112	3
			18 to 18.5	<1	21	5	--	--	<1	-102	4
			19 to 19.5	--	--	25	--	--	<1	-179	2
DS 29	10217	9790	11 to 11.5	<1	2	1	--	--	--	--	2
			17 to 17.5	<1	-60	2	--	--	--	--	2

Notes: BDL-Below Detection Limit; ND-Non Detect; "--" No Sample Collected

Table G.1 cont.: NBVC 2004 to 2005 Water Quality Data

Well	Location		Depth (ft)	Water Quality							
	Feet South of North BB Well	Feet West of DG BB Wells		DO '04	ORP '04	MTBE (ug/L) May '04	MTBE (ug/L) July '04	MTBE (ug/L) Aug. '04	DO Aug. '05	ORP Aug.'05	MTBE (ug/L) Aug. '05
DS 30	9975	9651	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	--	--	--
			11 to 11.5	--	--	--	--	--	--	--	--
			12 to 12.5	<1	-48	8	--	--	--	--	--
			13 to 13.5	<1	-157	2	--	--	--	--	--
			14 to 14.5	<1	-52	2	--	--	--	--	--
			15 to 15.5	<1	117	4	--	--	--	--	--
			16 to 16.5	<1	-24	3	--	--	--	--	--
			17 to 17.5	<1	-55	10	--	--	--	--	--
			18 to 18.5	<1	-76	60	--	--	--	--	--
			19 to 19.5	<1	76	49	--	--	--	--	--
DS 30 Repeat	9975	9651	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	--	--	--
			11 to 11.5	--	-166	--	93	169	<1	136	75
			12 to 12.5	<1	22	--	10	4	<1	185	12
			13 to 13.5	<1	-258	--	7	2	<1	283	2
			14 to 14.5	--	--	--	5	1	<1	265	2
			15 to 15.5	<1	-51	--	5	4	<1	290	3
			16 to 16.5	<1	-213	--	8	4	<1	188	2
			17 to 17.5	<1	52	--	14	12	<1	172	3
			18 to 18.5	<1	-18	--	24	17	<1	190	4
			19 to 19.5	<1	-172	--	16	5	<1	20	3
DS 31	10011	9602	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	-234	BDL	6	--	--	--	--
			11 to 11.5	<1	-72	124	182	--	<1	78	5
			12 to 12.5	<1	-270	350	180	--	<1	-50	25
			13 to 13.5	<1	-363	484	317	--	<1	33	70
			14 to 14.5	<1	-587	415	480	--	<1	-21	2
			15 to 15.5	<1	-22	56	35	--	<1	129	28
			16 to 16.5	<1	-53	20	20	--	<1	50	8
			17 to 17.5	<1	-5	12	10	--	<1	-1	3
			18 to 18.5	<1	-138	11	9	--	<1	195	3
			19 to 19.5	<1	-55	11	12	--	<1	27	2
DS33	10034	9642	11 to 11.5	<1	-150	156	--	--	--	--	--
			17 to 17.5	<1	-55	4	--	--	--	--	--
DS33	10034	9642	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	--	--	--
			11 to 11.5	<1	--	119	216	--	<1	235	20
			12 to 12.5	<1	--	328	471	--	<1	107	176
			13 to 13.5	<1	-144	140	120	--	<1	66	25
			14 to 14.5	<1	-80	25	32	--	<1	214	12
			15 to 15.5	<1	-19	18	18	--	<1	185	5
			16 to 16.5	<1	-25	6	7	--	<1	202	3
			17 to 17.5	<1	-25	3	10	--	<1	114	2
			18 to 18.5	<1	-100	8	5	--	<1	-191	7
			19 to 19.5	<1	-207	15	7	--	<1	-72	1

Notes: BDL-Below Detection Limit; ND-Non Detect; "--" No Sample Collected

Table G.1 cont.: NBVC 2004 to 2005 Water Quality Data

Well	**Location**		**Depth (ft)**	**Water Quality**							
	Feet South of North BB Well	**Feet West of DG BB Wells**		**DO '04**	**ORP '04**	**MTBE (ug/L) May '04**	**MTBE (ug/L) July '04**	**MTBE (ug/L) Aug. '04**	**DO Aug. '05**	**ORP Aug.'05**	**MTBE (ug/L) Aug. '05**
DS 34	10081	9619	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	--	--	--
			11 to 11.5	<1	-204	--	--	158	<1	235	10
			12 to 12.5	<1	36	--	--	78	<1	81	80
			13 to 13.5	<1	-208	--	--	10	<1	-37	44
			14 to 14.5	<1	-59	--	--	11	<1	-61	13
			15 to 15.5	<1	-40	--	--	10	<1	-68	3
			16 to 16.5	<1	-70	--	--	4	<1	-78	1
			17 to 17.5	<1	-32	--	--	2	<1	-81	BDL
			18 to 18.5	<1	-180	--	--	6	<1	-83	1
			19 to 19.5	<1	-92	--	--	7	<1	-45	1
DS 35	10127	9596	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	<1	69	1
			11 to 11.5	--	--	--	--	7	<1	--	3
			12 to 12.5	<1	--	--	--	24	<1	192	9
			13 to 13.5	<1	--	--	--	5	<1	46	2
			14 to 14.5	<1	--	--	--	2	<1	-12	2
			15 to 15.5	<1	--	--	--	1	<1	-64	3
			16 to 16.5	--	--	--	--	--	<1	-76	8
			17 to 17.5	--	--	--	--	--	<1	-84	6
			18 to 18.5	--	--	--	--	--	<1	-86	6
			19 to 19.5	--	--	--	--	--	<1	-87	6
DS 38	9986	9717	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	-205	--	--	1	<1	-108	BDL
			11 to 11.5	<1	-100	--	--	1	<1	-113	BDL
			12 to 12.5	<1	-212	--	--	1	<1	-51	1
			13 to 13.5	<1	132	--	--	1	<1	--	BDL
			14 to 14.5	<1	98	--	--	2	<1	-22	1
			15 to 15.5	<1	12	--	--	1	<1	-70	1
			16 to 16.5	<1	-68	--	--	8	<1	96	1
			17 to 17.5	<1	-66	--	--	11	<1	-87	2
			18 to 18.5	<1	--	--	--	40	--	--	2
			19 to19.5	<1	60	--	--	13	<1	-93	4
DS39	9998	9721	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	-248	2	--	--	--	98	1
			11 to 11.5	<1	-274	2	--	--	<1	269	1
			12 to 12.5	<1	-428	BDL	--	--	<1	104	1
			13 to 13.5	<1	80	3	--	--	<1	59	3
			14 to 14.5	<1	-65	6	--	--	<1	48	4
			15 to 15.5	<1	-159	4	--	--	<1	36	1
			16 to 16.5	<1	-76	10	--	--	<1	69	2
			17 to 17.5	--	--	42	--	--	--	--	--
			18 to 18.5	<1	37	7	--	--	<1	50	3
			19 to 19.5	<1	-8	3	--	--	<1	96	2
DS 40	10029	9719	11 to 11.5	--	--	BDL	--	--	<1	-101	ND
			12 to 12.5	<1	-550	77	--	--	<1	165	3
			17 to 17.5	<1	-140	6	--	--	<1	-61	3

Notes: BDL-Below Detection Limit;   ND-Non Detect;   "--" No Sample Collected

Table G.1 cont.: NBVC 2004 to 2005 Water Quality Data

Well	Location		Depth (ft)	Water Quality							
	Feet South of North BB Well	Feet West of DG BB Wells		DO '04	ORP '04	MTBE (ug/L) May '04	MTBE (ug/L) July '04	MTBE (ug/L) Aug. '04	DO Aug. '05	ORP Aug.'05	MTBE (ug/L) Aug. '05
DS 41	10057	9684	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	--	--	--
			11 to 11.5	<1	--	--	536	--	--	--	49
			12 to 12.5	<1	-147	332	31	--	<1	-74	170
			13 to 13.5	<1	-461	33	14	--	<1	10	6
			14 to 14.5	<1	-146	18	14	--	<1	192	7
			15 to 15.5	<1	-30	2	17	--	<1	153	1
			16 to 16.5	<1	-5	4	13	--	<1	-68	BDL
			17 to 17.5	<1	55	1	6	--	<1	-54	BDL
			18 to 18.5	<1	-30	6	2	--	<1	-92	3
			19 to 19.5	<1	-39	8	6	--	<1	-28	1
DS 45	10077	9719	11 to 11.5	<1	-15	654	--	--	--	--	--
			17 to 17.5	<1	-140	6	--	--	--	--	--
DS 45	10077	9719	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	--	--	--
			11 to 11.5	<1	-580	390	580	--	<1	108	170
			12 to 12.5	<1	-209	90	27	--	<1	181	15
			13 to 13.5	<1	13	2	1	--	<1	189	BDL
			14 to 14.5	<1	-512	3	3	--	1.08	38	1
			15 to 15.5	<1	100	4	3	--	<1	152	1
			16 to 16.5	<1	-67	1	7	--	<1	130	ND
			17 to 17.5	<1	-361	2	3	--	<1	-10	ND
			18 to 18.5	<1	-109	4	25	--	--	16	ND
			19 to 19.5	<1	-74	5	6	--	<1	90	BDL
DS 46	10164	9673	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	--	--	--	--	--	--	--	--
			11 to 11.5	<1	-53	--	--	2	<1	12	3
			12 to 12.5	<1	5	--	--	BDL	<1	187	BDL
			13 to 13.5	<1	109	--	--	7	<1	26	1
			14 to 14.5	<1	184	--	--	7	<1	137	1
			15 to 15.5	<1	79	--	--	2	<1	87	1
			16 to 16.5	<1	-22	--	--	6	<1	-56	5
			17 to 17.5	<1	-64	--	--	11	<1	-70	6
			18 to 18.5	<1	-42	--	--	11	<1	-78	9
			19 to19.5	<1	-102	--	--	10	<1	-80	8
DS 47	10081	9756	11 to 11.5	<1	116	5	--	--	<1	-72	2
			17 to 17.5	<1	3	3	--	--	<1	-48	ND
DS 48	10098	9757	9 to 9.5	--	--	--	--	--	--	--	--
			10 to 10.5	<1	-233	1	--	--	1.79	170	ND
			11 to 11.5	<1	-65	2	--	--	<1	137	ND
			12 to 12.5	<1	-455	ND	--	--	<1	32	ND
			13 to 13.5	<1	-88	BDL	--	--	<1	6	ND
			14 to 14.5	<1	-14	1	--	--	<1	61	BDL
			15 to 15.5	<1	-83	BDL	--	--	<1	95	BDL
			16 to 16.5	<1	88	1	--	--	<1	57	ND
			17 to 17.5	<1	-330	BDL	--	--	<1	26	BDL
			18 to 18.5	<1	-85	BDL	--	--	<1	133	BDL
			19 to 19.5	<1	-419	5	--	--	<1	-160	ND

Notes: BDL-Below Detection Limit; ND-Non Detect; "--" No Sample Collected

Table G.1 cont.: NBVC 2004 to 2005 Water Quality Data

Well	Location		Depth (ft)	Water Quality							
	Feet South of North BB Well	Feet West of DG BB Wells		DO '04	ORP '04	MTBE (ug/L) May '04	MTBE (ug/L) July '04	MTBE (ug/L) Aug. '04	DO Aug. '05	ORP Aug.'05	MTBE (ug/L) Aug. '05
DS 49	10084	9793	9 to 9.5	--	--	BDL	--	--	2.03	17	ND
			10 to 10.5	<1	-110	ND	--	--	1.96	9	ND
			11 to 11.5	<1	40	BDL	--	--	3.95	76	ND
			12 to 12.5	2.3	--	ND	--	--	4	189	ND
			13 to 13.5	2.98	--	ND	--	--	4.08	208	ND
			14 to 14.5	4.99	86	BDL	--	--	3.41	198	BDL
			15 to 15.5	<1	-260	BDL	--	--	2.48	85	ND
			16 to 16.5	<1	-220	BDL	--	--	4.48	188	BDL
			17 to 17.5	4.14	58	BDL	--	--	4.69	240	BDL
			18 to 18.5	4.5	137	BDL	--	--	3.35	167	BDL
			19 to 19.5	4.55	202	1	--	--	<1	179	BDL
EM1-10 S	--	--	--	--	--	--	--	--	<1	222	6
EM1-10 D	--	--	--	--	--	--	--	--	<1	177	3
EM1-11 S	--	--	--	--	--	--	--	--	<1	335	5
EM1-11 D	--	--	--	--	--	--	--	--	<1	210	5
EM6-1 S	--	--	--	--	--	--	--	--	6.32	291	ND
EM6-1 D	--	--	--	--	--	--	--	--	3.17	305	ND
EM6-2 S	--	--	--	--	--	--	--	--	6.56	293	ND
EM6-2 D	--	--	--	--	--	--	--	--	7.03	313	ND
EM6-3 S	--	--	--	--	--	--	--	--	6.82	348	BDL
EM6-3 D	--	--	--	--	--	--	--	--	5.38	346	ND
EM6-4 S	--	--	--	--	--	--	--	--	4.87	354	BDL
EM6-4 D	--	--	--	--	--	--	--	--	6.81	361	ND
EM6-5 S	--	--	--	--	--	--	--	--	5.99	352	ND
EM6-5 D	--	--	--	--	--	--	--	--	<1	Not Recorded	BDL
EM6-6 S	--	--	--	--	--	--	--	--	4.85	349	BDL
EM6-6 D	--	--	--	--	--	--	--	--	5.31	342	BDL
EM6-7 S	--	--	--	--	--	--	--	--	4.95	356	ND
EM6-7 D	--	--	--	--	--	--	--	--	6.18	36	ND
EM6-8 S	--	--	--	--	--	--	--	--	1.53	356	BDL
EM6-8 D	--	--	--	--	--	--	--	--	6.07	362	ND
EM6-9 S	--	--	--	--	--	--	--	--	6.61	340	ND
EM6-9 D	--	--	--	--	--	--	--	--	4.9	347	ND
EM6-10 S	--	--	--	--	--	--	--	--	7.48	356	ND
EM6-10 D	--	--	--	--	--	--	--	--	3.5	358	ND
EM6-11 S	--	--	--	--	--	--	--	--	7.7	361	ND
EM6-11 D	--	--	--	--	--	--	--	--	6.77	369	ND
EM North S	--	--	--	--	--	--	--	--	<1	205	ND
EM North D	--	--	--	--	--	--	--	--	<1	185	ND
EM South S	--	--	--	--	--	--	--	--	<1	366	BDL
EM South D	--	--	--	--	--	--	--	--	<1	362	3

Notes: BDL-Below Detection Limit; ND-Non Detect; S-Shallow; D-Deep; "--" No Sample Collected

Table G.1 cont.: NBVC 2004 to 2005 Water Quality Data

Well	Location		Depth (ft)	Water Quality							
	Feet South of North BB Well	Feet West of DG BB Wells		DO '04	ORP '04	MTBE (ug/L) May '04	MTBE (ug/L) July '04	MTBE (ug/L) Aug. '04	DO Aug. '05	ORP Aug.'05	MTBE (ug/L) Aug. '05
ASU1	--	--	--	--	--	--	--	--	<1	206	1
CBC25	--	--	--	--	--	--	2	BDL	<1	289	BDL
CBC37	--	--	--	--	--	--	8	12	<1	161	BDL
CBC38	--	--	--	--	--	--	2	BDL	<1	168	13
CBC39	--	--	--	--	--	--	60	36	<1	104	18
CBC40	--	--	--	--	--	--	20	23	<1	176	5.7
CBC41	--	--	--	--	--	--	60	25	<1	185	15.6
CBC42	--	--	--	--	--	--	114	25	<1	161	2.6

Notes: BDL-Below Detection Limit; ND-Non Detect; S-Shallow; D-Deep; "--" No Sample Collected