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Final

Report for A Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at Naval Industrial Ordinance Plant Fridley, Minnesota

Prepared for

Naval Facilities Engineering Command
Southern Division
North Charleston, South Carolina

and

CH2M Hill Constructors Incorporated

Prepared By

PARSONS

November 2006

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November 29, 2006

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Subject: *Submittal of the Final Report for a Field Application to Enhance the In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at Naval Industrial Reserve Ordnance Plant (NIROP) Fridley, Minnesota*

Mr. Venkatesh,

Please find enclosed two electronic copies and two hard copies of the Final Report for a Field Application to Enhance the *In-Situ* Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at Naval Industrial Reserve Ordnance Plant (NIROP) Fridley, Minnesota. The final report was also submitted to recipients on the attached distribution list. This final report was prepared by Parsons for CH2M Hill Constructors Incorporated (CCI). If you have any questions or require additional information or additional copies of this report, please contact me at (303) 764-1940.

Sincerely,

PARSONS

Daniel R. Griffiths
Project Manager

cc: Dan Owens, Southern Division, Naval Facilities Engineering Command (2 copies)

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FINAL REPORT

FOR

A FIELD APPLICATION TO ENHANCE THE *IN-SITU* BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NAVAL INDUSTRIAL ORDNANCE PLANT (NIROP) FRIDLEY, MINNESOTA

November 2006

Prepared for:

NAVAL FACILITIES ENGINEERING COMMAND
SOUTHERN DIVISION
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EXECUTIVE SUMMARY

This report documents the results of a field feasibility study to evaluate the application of vegetable oil as an organic substrate to enhance the *in-situ* anaerobic reductive dechlorination of chlorinated aliphatic hydrocarbons (CAHs, or chlorinated solvents) in groundwater at Anoka County Park (ACP), Naval Industrial Reserve Ordinance Plant (NIROP) Fridley, Minnesota. Prior to the feasibility test, the distribution of the parent compound trichloroethene (TCE) and low concentrations of the degradation daughter product *cis*-1,2-dichloroethene (*cis*-1,2-DCE) in groundwater indicated that limited reductive dechlorination of chlorinated ethenes was occurring at the site. However, baseline geochemical data indicated that the process was electron donor (substrate) limited. Vegetable oil was selected as a slowly-soluble organic substrate to overcome the observed electron donor deficiency and to enhance anaerobic reductive dechlorination of chlorinated solvents in groundwater.

A field study consisting of the installation of injection and monitoring wells, baseline sampling, and vegetable oil injection was conducted during October, November, and December 2001. A total of 3,600 gallons of refined soybean oil and 7,200 gallons of native groundwater were injected into three injection wells in December 2001. Additional monitoring wells were installed and additional soil sampling was conducted in March and April of 2005. Process monitoring was conducted in February 2002, May 2002, August 2002, December 2002, April 2003, August 2003, April 2005, and November 2005.

ES.1 FIELD TEST RESULTS

Changes in geochemical conditions during process monitoring indicate that the addition of vegetable oil at ACP has induced environmental conditions conducive to reductive dechlorination. However, these changes are neither uniform nor widespread across the study area. Dissolved oxygen (DO) concentrations generally decreased below 0.2 mg/L at most of the monitoring well locations installed upgradient of PES-MW-5 after the February 2002 monitoring event. However, concentrations of DO rebounded during the December 2002 sampling event. DO concentrations remained elevated through April 2003, than began to decrease between April 2003 and November 2005.

Baseline oxidation-reduction potential (ORP) values exhibited a wide range of geochemical conditions with values ranging from a high of +115 millivolts (mV) to a low of -185 mV. ORP values varied substantially even within the treatment zone, which is suggestive of a high degree of heterogeneity in the natural geochemical conditions at the site prior to injection. After injection, ORP decreased to approximately -200 to -400 mV at most of the well locations installed upgradient of PES-MW-5 (with the exceptions of PES-MW-2 and PES-MW-4), indicating that geochemical conditions upgradient of PES-MW-5 became conducive to sulfate reduction and methanogenesis. At well locations downgradient of PES-MW-5 ORP conditions remained relatively oxidizing with ORP values ranging from approximately 0 to +300 mV. These observations indicate that the geochemical environment in the pilot test area upgradient of PES-MW-5 has been impacted by the injected vegetable oil and the geochemical conditions in this area have

become more reducing as a result. These observations also indicate that monitoring well locations downgradient of PES-MW-5 were not impacted significantly by the injected vegetable oil and that as a result the geochemical environment in this area has remained relatively aerobic.

Increases in methane concentration and decreases in sulfate concentration at several locations upgradient of PES-MW-5 indicate that sulfate reduction and methanogenesis are occurring in this area. Dissolved molecular hydrogen (H_2) concentration data further indicate that sulfate reduction and methanogenesis are the dominant terminal electron accepting processes (TEAPs) that have been stimulated at the site.

After vegetable oil injection, there was an overall decrease in TCE concentrations detected in groundwater. However, this decreasing trend is not uniform for all of the monitoring locations at ACP. The greatest decrease in TCE concentrations occurred at GWMS-46S, where contaminant concentrations have attenuated from 20,000 micrograms per liter (µg/L) to approximately 1,300 µg/L. Large decreases in TCE concentration were also observed in the injection wells and in monitoring wells MS-46S, PES-MW-1, PES-MW-2, PES-MW-3, PES-MW-4, PES-MW-6, PES-MW-7, PES-MW-8, and PES-MW-9. TCE concentrations in the remaining wells upgradient of PES-MW-5 increased initially, typically peaking in the May or August 2002 sampling rounds, than decreased between August 2002 and November 2005. Reductions in the concentration of TCE were often coupled with an increase in the concentration of DCE, the degradation daughter product of TCE. Overall increases in DCE (from baseline concentrations) were observed at locations PES-MW-1, PES-MW-2, PES-MW-3, PES-MW-4, PES-MW-6, PES-MW-7, and PES-MW-9. Low concentrations of the reductive dechlorination products vinyl chloride (VC) and ethene were also measured at the injection wells and at monitoring wells PES-MW-7 and PES-MW-9. Elevated concentrations of ethene at these locations indicate that complete reductive dechlorination of TCE has been stimulated at these locations.

Complete reductive dechlorination of chlorinated ethenes has been demonstrated by monitoring completed through November 2005 at only two well locations down gradient of the injection area (PES-MW-7 and PES-MW-9). Partial reductive dechlorination of TCE to DCE has also been observed at a number of monitoring wells upgradient of PES-MW-5.

Well locations where evidence of the complete reductive dechlorination of TCE has occurred exhibit the following characteristics:

- DO less than 1 milligrams per liter (mg/L);
- ORP less than -100 millivolts (mV);
- Carbon dioxide greater than 100 mg/L;
- Sulfate less than 50 mg/L;
- TOC equal to or greater than approximately 20 mg/L;

- Measurable quantities of volatile fatty acids (VFAs) equal to or greater than 50 mg/L;
- Ferrous iron concentration greater than 2 mg/L;
- Methane concentration greater than 1 mg/L; and
- Total biomass greater than approximately 50 picomoles of phospholipid fatty acids per milliliter (pmoles PLFA/mL).

These conditions have not been induced uniformly or widely across the treatment area, but were limited primarily to the injection area and the upper portion of the monitoring well network. This pilot test was designed with the assumption that there was significant horizontal advective groundwater flow within the pilot test area. Thus, the pilot test was designed to take advantage of this lateral flow as a means to distribute the dissolved components of the injected vegetable oil out of the injection area and into the monitoring well network. However, during the course of the pilot test very little advective groundwater flow was observed. This absence of lateral groundwater flow is believed to have resulted in limited substrate distribution outside of the injection area (with the exception of two well locations [PES-MW-7 and PES-MW-9]).

In order to stimulate reductive dechlorination, sufficient organic substrate is required to create environmental conditions sufficiently reducing for methanogenesis to occur while stimulating microbial growth of dechlorinating microorganisms. Therefore, the lack of wide spread reductive dechlorination within the pilot test area is primarily a function of inadequate substrate distribution. The observed lack of sufficient substrate distribution is likely related to the flat groundwater gradient (limited advective groundwater flow) and the variable groundwater flow conditions observed within the upper half of the pilot test area.

In addition, during the course of the pilot the United States Geological Survey (USGS) determined that there was a high potential for substantial vertical flow within the pilot test area. Based on the findings of the USGS, (USGS, 2003a) the vertical flow conditions are likely to be present throughout ACP and are currently only partially defined.

ES.2 RECOMMENDATIONS

Biologically mediated reductive dechlorination of TCE has been stimulated through the addition of vegetable oil at ACP. All of the requirements outlined by the data quality objectives (DQOs) were met and in most cases were exceeded. Therefore, the organic substrate addition technology has proven to be effective at destroying contaminant mass beneath ACP within a limited area. However, the pilot test results indicate that the dissolved organic carbon was not effectively distributed throughout the aquifer matrix. Therefore, the benefit of the vegetable oil injection was predominantly limited to a small area in the vicinity of the injection wells. Thus, this pilot test can only be considered a partial success in that reductive dechlorination was stimulated but only in a limited area. Because of the limited success of the pilot scale application, recommendations include continued monitoring of the pilot test area only.

The following recommendations are made for the consideration of the NIROP partnering team and are not necessarily required for future pilot-scale activities at ACP. Parsons suggests that the Navy continue to perform limited groundwater monitoring in the pilot test area in order to track the future progress of the pilot test and to define the life cycle of the injected substrate. Future sampling events should be combined with the base wide sampling events in order to decrease monitoring costs and to produce site wide sampling rounds that are internally comparable. The sampling locations and analytical parameters could be scaled back to only those locations and parameters important for tracking the progress of the pilot test (Section 5).

In addition it is recommended that a slightly expanded sampling program be implemented during the site wide sampling round immediately prior to a five year ROD review in order to prepare a more complete representation of "current" site conditions. Parsons recommends that PES-MW-1 and PES-MW-6 be added to the pre-ROD review sampling protocol in order to assess groundwater conditions immediately downgradient from the injection area (Section 5). Parsons also recommends that the B interval wells be added at well clusters PES-MW-10, PES-MW-12, and PES-MW-14 in order to assess water quality downgradient from and slightly below the injection area.

In the future the NIROP team will be required to make a series of decisions regarding the future of remedial activities at Anoka County Park. These decisions will be made based upon the results of the vegetable oil pilot test, research being conducted by the USGS with regard to the hydraulic system, and the impact of the extraction system currently operating on site. Enhanced bioremediation has been successful in enhancing the destruction of chlorinated solvent mass in the subsurface and has thus been successful in reducing the overall toxicity of the groundwater plume. Vegetable oil has also been shown to be effective at stripping contaminant mass from the soil matrix through its surfactant properties and immobilizing contaminant mass through its preferential partitioning properties (Parsons, 2004). Therefore, Parsons recommends that organic substrate addition in general and vegetable oil injection specifically be considered as a future remedial option at this site.

The NIROP Record of Decision (signed in 1990) specifies that contaminated groundwater located offsite and downgradient of the NIROP facility in Anoka County Park would be allowed to dissipate naturally (TTNUS, 2005). During the 1998 5-year ROD review it was determined that VOC concentrations in Anoka County Park were not decreasing as rapidly as expected and it was recommended that the Navy determine what could be done to reduce residual groundwater contamination in Anoka County Park (TTNUS, 2005). As a result of this recommendation the Navy embarked on this organic substrate addition pilot study program. In addition, the Navy started a groundwater extraction system expansion program in order to more fully capture the VOC plume emanating from the NIROP facility. Over the last several years of groundwater monitoring in Anoka County Park VOC concentrations at wells installed within and outside of the pilot testing area have been decreasing (TTNUS, 2006). The VOC concentration decreases observed outside of the pilot test area are likely a result of more complete capture afforded by the expanded extraction system and natural attenuation mechanisms active in the Park (TTNUS, 2006). Since VOC concentrations in Anoka County Park have been decreasing over the last several years, Parsons suggests that the Navy continue to monitor VOC concentrations at wells installed in the Park to determine

if the VOC concentration reductions are sustainable. If VOC concentrations continue to decrease in the Park then the tenants of the ROD should be fulfilled and active remediation in the Park may be unnecessary to be protective of identified potential contaminant receptors. In the event that VOC concentrations in the Park increase significantly over a significant period of time the NIROP partnering team could re-consider the need for more active remedial measures.

In the event that a more active approach becomes warranted, Parsons suggests that future active remedial activities at Anoka County Park be designed to reduce the potential impact to receptors and therefore reduce the environmental risk and impact associated with the contaminant mass remaining in the subsurface instead of attempting to remove or destroy all of the remaining contaminant mass. To this end Parsons suggests that the NIROP team limit future remedial activities at the site to defined contaminant hot spots or source areas instead of attempting to treat large low VOC concentration areas (for example attempting to treat an area within a particular interpreted VOC concentration contour). The control or elimination of contaminant mass present as hot spots will allow the environmental risk associated with the site to be reduced most significantly and most efficiently in terms of cost and in terms of impact to activities and access to the site.

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ACRONYMS AND ABBREVIATIONS

ACP	Anoka River Front County Park
bgs	below ground surface
^{12}C	Carbon-12
^{13}C	Carbon-13
CA	chloroethane
$CaCO_3$	calcium carbonate
CAH	chlorinated aliphatic hydrocarbon
cm/sec	centimeters per second
CCI	CH2M Hill Constructors Incorporated
CT	carbon tetrachloride
DCA	dichloroethane
DCE	dichloroethene
DGGE	denaturing gradient gel electrophoresis
DNA	deoxyribonucleic acid
DO	dissolved oxygen
DQO	data quality objective
FIG	Franconia/Ironton/Galesville Aquifer
ft/day	feet per day
ft/ft	feet per foot
ft/yr	feet per year
Fe (II)	ferrous iron
Fe (III)	ferric iron
H_2	molecular hydrogen
HRC™	Hydrogen Release Compound™
HSA	hollow stem auger
K_d	distribution coefficient
LNAPL	light non-aqueous phase liquid
MCL	Maximum Contaminant Level
MDH	Minnesota Department of Health
MDL	method detection limit
Mn(II)	manganese
MNA	monitored natural attenuation
MCES	Metropolitan Council for Environmental Services
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mL	milliliter
mV	millivolts
MHF	Mount Simon/Hinckley/Fond du Lac Aquifer
MPCA	Minnesota Pollution Control Agency
N	nitrogen
NAPL	nonaqueous phase liquid
nM	nanomole
GenBank	National Center for Biotechnology Information
NAVFAC	Naval Facilities Engineering Command
NIROP	Naval Industrial Reserve Ordinance Plant Fridley, Minnesota
NPDES	National Pollutant Discharge Elimination System
OU	Operable Unit
ORP	oxidation-reduction potential

ACRONYMS AND ABBREVIATIONS (Continued)

Parsons	Parsons Corporation
PC	Prairie du Chien/Jordan aquifer
PCE	tetrachloroethene
pmoles	picomoles
PLFA	phospholipid fatty acid
QAPP	quality assurance project plan
rDNA	ribosomal DNA
redox	oxidation/reduction
ROD	Record of Decision
RPD	relative percent difference
SDS	State Disposal System
TCA	trichloroethane
TCE	trichloroethene
TEAP	terminal electron accepting process
TOC	total organic carbon
TtNUS	Tetratech NUS
UDLP	United Defense Limited Partnership
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VC	vinyl chloride
VFA	volatile fatty acids
VOCs	volatile organic compounds
ZVI	zero valent iron

SECTION 1

INTRODUCTION

This report presents the results of a field-scale application to enhance *in-situ* bioremediation of chlorinated solvents via vegetable oil injection at Anoka County River Front Park (ACP), which is located downgradient from Naval Industrial Reserve Ordnance Plant (NIROP) Fridley, Minnesota. This report was prepared for CH2M Hill Constructors Incorporated (CCI) and Naval Facilities Engineering Command (NAVFAC) Southern Division by Parsons Corporation (Parsons).

1.1 TECHNOLOGY DESCRIPTION

Enhanced anaerobic bioremediation can be an effective method for degrading various forms of chlorinated compounds dissolved in groundwater. When anaerobic degradation of chlorinated aliphatic hydrocarbon (CAH) mass occurs naturally, it is considered to be a component of natural attenuation. Unfortunately, monitored natural attenuation (MNA) alone is not always sufficient to achieve remedial objectives in a timely manner at many sites contaminated with chlorinated compounds. The addition of an organic substrate to an aquifer has the potential to stimulate microbial growth and development, creating an anaerobic environment, which may greatly enhance rates of anaerobic degradation. Therefore, a variety of organic substrates have been applied to the subsurface to promote anaerobic degradation of CAHs to innocuous end products.

Advantages of enhanced anaerobic bioremediation include complete mineralization of the contaminants *in situ* with little impact on infrastructure or the need for secondary treatment trains. Enhanced *in situ* anaerobic bioremediation can generally be implemented at relatively low cost compared to more active remedial systems (e.g., groundwater extraction, air sparging, permeable reactive iron barriers, or chemical oxidation).

Biodegradation of an organic substrate depletes the aquifer of dissolved oxygen (DO) and lowers the oxidation-reduction potential (ORP), thereby stimulating conditions conducive to anaerobic biodegradation processes. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, manganese, ferric iron oxyhydroxides, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how biodegradation of CAHs may occur (Section 3). Reductive dechlorination has been demonstrated under nitrate-, iron-, and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994).

Anaerobic reductive dechlorination is the degradation process targeted by enhanced anaerobic bioremediation. Three general reactions may degrade CAHs by reductive dechlorination and include the following:

- **Direct Anaerobic Reductive Dechlorination**. A reaction in which bacteria gain energy and grow as one or more chlorine atoms on a chlorinated hydrocarbon compound are replaced with hydrogen in an anaerobic environment. In this reaction, the chlorinated compound serves as the electron acceptor and hydrogen serves as the direct electron donor. Molecular hydrogen (H_2) used in this reaction typically is supplied indirectly by the fermentation of organic substrates. This reaction may also be referred to as halorespiration or dehalorespiration (USEPA, 2000a).

- **Cometabolic Anaerobic Reductive Dechlorination**. A reaction in which chlorinated hydrocarbons are reduced by an enzyme or co-factor produced during microbial metabolism of another compound in an anaerobic environment. In such a case, biodegradation of the chlorinated compound does not yield any energy or growth benefit for the microbe mediating the reaction (USEPA, 2000a).

- **Abiotic or Chemical Reductive Dechlorination**. A chemical degradation reaction where a chlorinated hydrocarbon is reduced by a reactive compound that is not directly associated with biological activity. For example, this is the reaction targeted using zero-valent iron (ZVI) in permeable iron reactive walls. Addition of an organic substrate and creation of an anaerobic environment may create reactive compounds such as iron-monosulfides that can degrade CAHs (Butler and Hayes, 1999). In this case, substrate addition may indirectly cause abiotic reductive dechlorination.

In practice, it may not be possible to distinguish between these different reactions at the field scale. Adding an organic substrate to the subsurface provides organic carbon that can be fermented to produce hydrogen, which may directly or indirectly stimulate any of these reductive dechlorination reactions. Biodegradation of the organic substrate produces metabolic acids, primarily lactic, propionic, butyric, and acetic acids. Fermentation of these low-molecular-weight acids produces H_2, which is the primary electron donor used for reductive dechlorination of CAHs.

Anaerobic reductive dechlorination is typically based on the following generalized redox reaction:

$$H_2 + \text{R-C-Cl} \Rightarrow \text{R-C-H} + H^+ + Cl^-$$

where C-Cl represents a carbon-chloride bond in a chlorinated molecule and R represents a chlorinated molecule. In this reaction, H_2 is the electron donor, which is oxidized, and the chlorinated molecule is the electron acceptor, which is reduced. A few fermentation products (e.g., acetate) other than hydrogen have been identified which can also serve directly as electron donors. However, hydrogen appears to be the most important electron donor for reductive dechlorination (Maymo-Gatell *et al*., 1997; Fennell and Gossett, 1998).

In general, reductive dechlorination occurs by sequential removal of a chloride ion. For example, the chlorinated ethanes and ethenes are transformed sequentially as follows:

- **Chloroethanes:** 1,1,1-trichloroethane (TCA) to 1,1-dichlorethane (DCA) to chloroethane (CA) to acetate to carbon dioxide, water, and chloride.

- **Chloroethenes:** tetrachloroethene (PCE) to trichloroethene (TCE) to the dichloroethene (DCE) isomers (*cis*-1,2-DCE, *trans-1,2*-DCE, and 1,1-DCE) to vinyl chloride (VC) to ethene.

There are many organic carbon substrates that can be naturally fermented at chlorinated solvent sites and that result in the generation of hydrogen. Examples of easily fermentable organic substrates include carbohydrates and sugars, vegetable oils, and low-molecular-weight fatty acids. The substrates most commonly added for enhanced anaerobic bioremediation include lactate, molasses, Hydrogen Release Compound (HRC®), and vegetable oils (Parsons, 2002). Substrates utilized less frequently include ethanol, methanol, butyrate, high-fructose corn syrup, whey, bark mulch, and chitin. The physical nature of the substrate dictates the frequency of addition, the addition technique, and system configuration. Vegetable oil was selected for this pilot scale application because it is a slowly-soluble organic substrate. Thus, a single application of vegetable oil will likely provide organic carbon mass to the subsurface for several years.

1.2 PILOT TEST OBJECTIVES

This project is being conducted by NAVFAC in conjunction with Parsons and CCI to determine the effectiveness of organic substrate (vegetable oil) addition to enhance the *in-situ* bioremediation of chlorinated solvent mass dissolved in groundwater.

This pilot study was designed to provide indigenous microorganisms with an additional source of organic carbon in the form of commercially available, food-grade, non-hazardous vegetable oil. The addition of vegetable oil was designed to promote indigenous microbial population development and to support a larger microbial population. The stimulation of microbial activity was designed to bring about changes in subsurface conditions which will enhance the rates of sequential anaerobic dechlorination of PCE to TCE, DCE, VC, and finally to the innocuous reaction end product, ethene.

The results of this pilot test provide valuable data to support an evaluation of the restoration potential of ACP by providing direct evidence to demonstrate whether the organic substrate addition technology is capable of remediating groundwater contamination at ACP effectively, reliably, efficiently, and within a reasonable time frame. The results of this pilot test also provide valuable data that may be used to design a full scale vegetable oil application at ACP, and potentially in other areas of the NIROP Fridley facility, if this pilot test is deemed to be successful. The success of this pilot test is dependent upon meeting the project data quality objectives (DQOs) presented in the quality assurance project plan (QAPP) (Parsons, 2001a).

1.3 SCOPE OF WORK

Site-specific activities conducted at ACP in support of the field scale pilot test included:

- Installation of three vegetable oil injection wells and 15 groundwater monitoring wells using hollow stem auger (HSA) drilling technology;

- Baseline (i.e., pre-injection) sampling of groundwater at the newly-installed injection and monitoring wells, and existing monitoring wells GWMS-27S, GWMS-46S, and GWMS-47S, in accordance with revision 1 of the *Final Work Plan For Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents Via Vegetable Oil Injection at The Naval Industrial Reserve Ordnance Plant (NIROP), Fridley, Minnesota* (Parsons, 2001b), the *Final Quality Assurance Project Plan for Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents Via Vegetable Oil Injection at NIROP, Fridley, Minnesota* (Parsons, 2001a), and the *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* (United States Environmental Protection Agency [USEPA], 1998);

- Surveying of the newly installed injection and monitoring wells;

- Pre-injection aquifer testing (hydraulic conductivity) of three injection wells and six monitoring wells;

- Injection of 3,600 gallons of refined soybean oil emulsified with approximately 7,200 gallons of native groundwater;

- Post-injection aquifer testing (hydraulic conductivity) of three injection wells; and

- Post-injection sampling of groundwater and vegetable oil at the newly installed system monitoring and injection wells and existing monitoring wells GWMS-27S, GWMS-46S, and GWMS-47S, in February 2002, May 2002, August 2002, December 2002, April 2003, and August 2003.

The well installation activities, well development, soil sampling, baseline groundwater sampling, pre and post injection aquifer testing, and vegetable oil injection activities are documented in the *Project Completion Report (Revision 00), Pilot–Scale Study to Enhance In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at Anoka County Riverfront Park, Naval Industrial Reserve Ordnance Plant Fridley* (CCI, 2002).

This report describes the results of process monitoring activities completed 2, 5, 8, 12, 16, and 20 months after vegetable oil injection.

1.4 REPORT ORGANIZATION

This report consists of six sections, including this introduction, and three appendices. Section 2 is a brief summary of the history, geology, hydrogeology, and groundwater

quality of the site prior to vegetable oil injection. Section 3 is a description of the field system installation, substrate addition, and procedures followed for data collection. A discussion and evaluation of the results of the vegetable oil injection are presented in Section 4. Section 5 is a presentation of conclusions and recommendations, and Section 6 contains the references used in preparing this document. Appendix A contains laboratory analytical data collected from the pilot test area. Appendix B contains field sampling data and forms. Appendix C contains plots of contaminant concentrations and molar fractions over time for the system monitoring wells. Appendix D contains sample results for split samples collected by the Minnesota Pollution Control Agency (MPCA), the associated samples collected by CCI's subcontractor, and a calculated relative percent difference (RPD) between the two data sets. Appendix E contains an injection variance request letter and supporting product material data safety sheets (MSDS) that was prepared by the USGS to add colloidal iron and magnetite to the injection fluid. Comments that were submitted by the regulatory agencies on the draft report and responses to these comments are presented in Appendix F. The final May 2006 technical memorandum is included in Appendix G for reference.

SECTION 2

SUMMARY OF HISTORICAL SITE CHARACTERIZATION

This section summarizes the results of site characterization conducted by various contractors at ACP.

2.1 SITE HISTORY

The NIROP Facility and ACP are located in Fridley, Minnesota in the southern-most tip of Anoka County, just east of the Mississippi River. In September 1990 the Record of Decision (ROD) for the NIROP facility was signed by representatives of the U.S. Navy, USEPA Region 5, and the MPCA. The ROD specified hydraulic containment and recovery of all contaminated groundwater at the NIROP facility and the recovery, to the extent feasible, of contaminated groundwater downgradient of the NIROP facility. To achieve this, groundwater extraction wells were installed. The initial extraction system began operating in September 1992. Two additional extraction wells were constructed and placed into operation in June 1995. Another upgrade of the extraction system was completed in May 2001. Treatment of extracted groundwater involved a two-phase plan: Phase I involved discharging groundwater from the extraction system to an existing sanitary sewer with treatment provided at a local wastewater treatment facility; Phase II involved construction and operation of a groundwater treatment facility to provide long-term groundwater treatment. Groundwater treated by the Phase II treatment system is being discharged to the Mississippi River via a National Pollutant Discharge Elimination System (NPDES)/Metropolitan Council for Environmental Services (MCES) State Disposal System (SDS) storm sewer discharge permit. The Phase II treatment system began operating in December 1998. Under Phase II, the combined discharge from the extraction system is fed through a feed system and air stripping units for treatment before the effluent is discharged to the Mississippi River through outfall 020 (NPDES/SDS Permit MN0000710).

This two-phase approach originally specified that contaminated groundwater located offsite and downgradient of the NIROP Fridley facility in ACP would be allowed to naturally dissipate (TtNUS, 2002). However, discussions between Parsons, CCI, USEPA, MPCA, Anoka County Parks, TechLaw, Tetratech NUS (TtNUS), the Minnesota Department of Health (MDH), and Southern Division NAVFAC led to the decision to perform a pilot-scale test to determine if the organic substrate addition technology was a viable treatment option to accelerate the biodegradation of CAH mass located beneath ACP.

The investigation history of NIROP Fridley and ACP is discussed in more detail in TtNUS (2001) and CCI (2002).

2.2 SITE GEOLOGY

The site geology and hydrogeology sections presented below are summarized from TtNUS 2000, 2001, and 2006. More complete and in depth discussions of site geology and hydrogeology are presented in these documents.

Site subsurface geology generally consists of a relatively thick wedge of unconsolidated overburden consisting of fill materials, glacial-fluvial materials, and glacial drift materials overlying Ordovician-age Saint Peter Sandstone bedrock. The pilot test is being conducted exclusively in the shallow portion of the unconsolidated overburden. Therefore, the geology discussion is limited to this portion of the stratigraphic column. A detailed description of site geology is available in TtNUS (2006).

The unconsolidated overburden in the vicinity of the site was deposited during the Quaternary Period. These unconsolidated deposits consist of glacial drift (i.e., glacial outwash and till deposits) overlain by glacial-fluvial deposits and fill materials. The unconsolidated deposits extend from the ground surface down to the top of an intermediate aquitard, where it is present, and continue down to Ordovician-age bedrock where the intermediate aquitard is absent. The Quaternary aquifer zone deposits range in thickness from approximately 41 feet to 93 feet and primarily consist of fine, medium, and coarse sand and gravel with discontinuous and sporadically distributed fine-grained (i.e., silt and clay) interbeds (TtNus, 2000). The fine-grained interbeds range in thickness from 0 to 46 feet and generally increase in thickness with depth (TtNUS, 2000).

Generally, within the ACP, the subsurface material from ground surface to approximately 10 feet below ground surface (bgs) consists of fill. The fill material consists of re-worked natural material with variable amounts of wood, concrete, asphalt, and other debris. The fill layer is much thicker in the extreme southwestern end of ACP (south of the pilot test area), and contains large amounts of debris and rubble (sand, metal, plastic fragments, and cinders), and is related to tornado debris disposed of in this area.

The natural material located beneath the fill material consists predominantly of fine to medium sand, gravelly sand, and discontinuous silt to silty clay lenses.

The US Geological Survey (USGS) has interpreted the presence of an intermediate silt unit within the pilot test area. The intermediate silt unit is approximately 40 feet thick and the top of the unit is present at approximately 60 feet bgs (USGS, 2003a). This intermediate silt unit is interpreted to underlie the both the injection area and monitoring wells PES-MW-1, PES-MW-2, PES-MW-3, PES-MW-6, PES-MW-7, PES-MW-8, and PES-MW-9 (USGS, 2003a). The edge of the intermediate silt unit is interpreted to trend from southeast to northwest through the downgradient portion of the pilot test area somewhere between wells PES-MW-3 and PES-MW-5.

2.3 SITE HYDROGEOLOGY

The hydrogeology in the vicinity of the NIROP facility is consistent with the regional hydrogeology where four aquifers or aquifer zones govern groundwater movement

through the subsurface. These aquifers are, from shallow to deep, the unconsolidated Quaternary aquifer zone, the Prairie du Chien/Jordan (PC) aquifer, the Franconia/Ironton/Galesville (FIG) aquifer, and the Mount Simon/Hinckley/Fond du Lac (MHF) aquifer. Hydrogeologic details for the unconsolidated aquifer zone and the PC aquifer are provided in **Table 2.1**. More detailed site geology and hydrogeology discussions can be found in the Operable Unit (OU) 3 Remedial Investigation (RI) report (TtNUS, 1999), the Field Investigation Report (TtNUS, 2000), and the 2005 Annual Monitoring Report (AMR) (TtNUS, 2006). Because the vegetable oil injection pilot test was conducted in the shallow interval of the Quaternary aquifer system near well GWMS-46S, the remainder of this section will focus on this stratigraphic interval.

Depth to groundwater at the site ranges from approximately 25 to 33 feet bgs. The unconsolidated Quaternary aquifer zone consists of glacial drift (i.e., glacial outwash and till deposits) overlain by glacial-fluvial deposits. It is referred to as an aquifer zone because it consists of two poorly defined aquifers: a shallow unconfined aquifer (shallow drift aquifer) and a deep confined or semi-confined aquifer (deep drift aquifer). These aquifers consist of sand and gravel and are separated by a silty clay layer that ranges in thickness from 0 to 47 feet in the NIROP area. These two aquifers vary significantly in thickness and degree of hydraulic communication throughout the site. The shallow unconfined aquifer ranges in thickness from 41 to 93 feet, and the deep confined or semi-confined aquifer ranges in thickness from 19 to 55 feet across the site (TtNUS, 1999). Although monitoring wells installed in the shallow drift aquifer at the site have been designated as shallow and intermediate, there appears to be no or very little hydraulic separation between these monitored intervals; hence, both of these zones make up the shallow unconfined aquifer at the site. Cross-Section A-A' (Figure 2.1) illustrates the stratigraphic relationship between the shallow drift and deep drift aquifers in the pilot-study area.

2.3.1 Groundwater Flow Under Pumping Conditions

Groundwater flow conditions are discussed in detail in TtNUS (2006) and are summarized in this report.

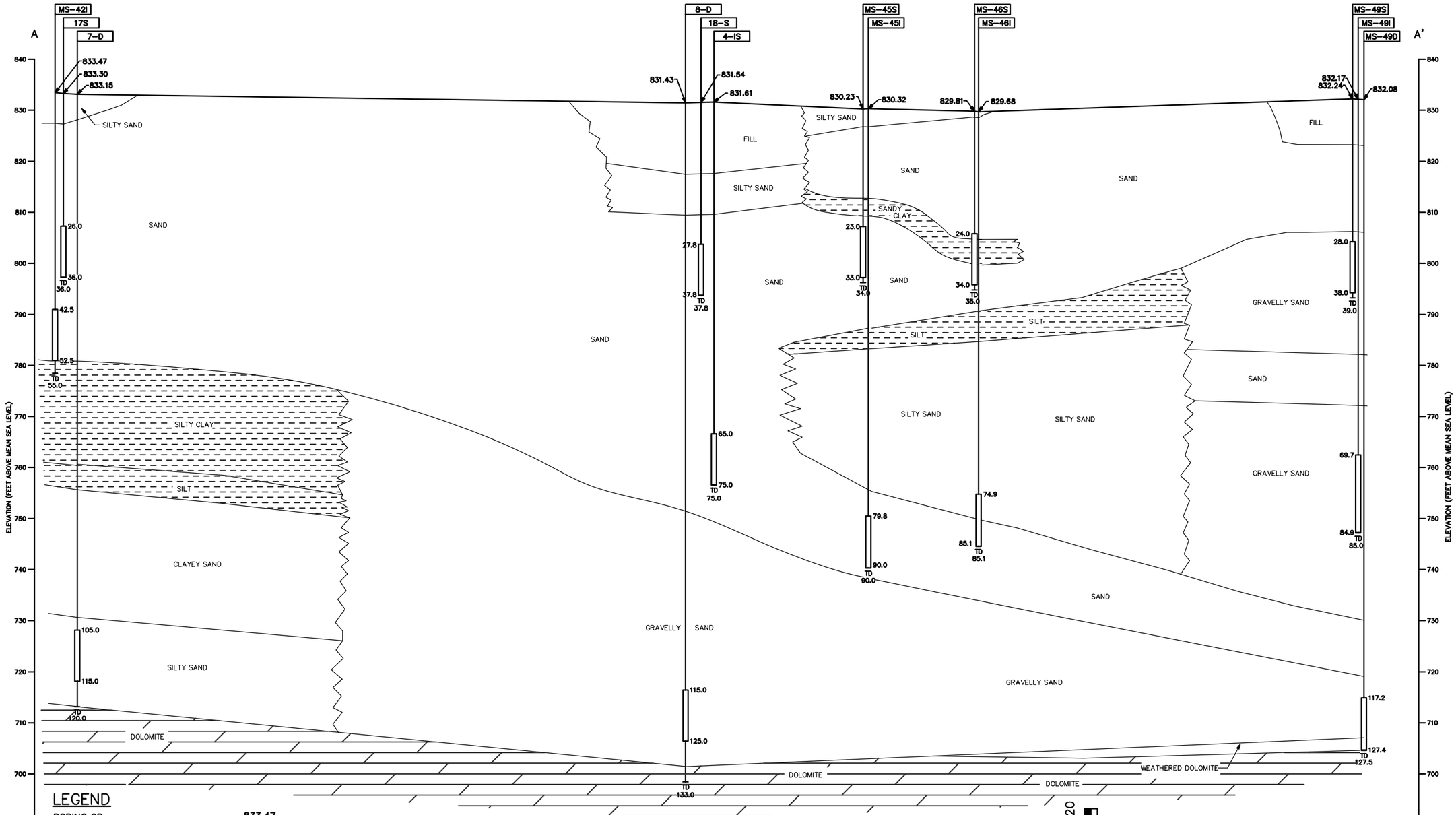
Under pumping conditions the horizontal groundwater flow direction across the NIROP site in the Quaternary aquifer zone is generally toward the southwest, toward the Mississippi River (Figure 2.2). Groundwater from the PC aquifer discharges to the Quaternary aquifer zone, which then discharges to the Mississippi River.

Groundwater flow directions in the Quaternary aquifer zone in the far western portion of the NIROP site (i.e., south end of ACP and western portion of the United Defense Limited Partnership [UDLP] area) are variable. In this area, a groundwater ridge is present within the Quaternary aquifer zone (Figure 2.2). This groundwater ridge is bounded by monitoring wells MS-41 (eastern edge), MS-36 and MS-44 (northern edge), MS-47 (southwestern edge), and MS-49 (southern edge) (TtNUS, 2006), and is clearly

TABLE 2.1
SUMMARY OF STRATIGRAPHIC INFORMATION
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Geologic Unit			Lithologic Description	Hydrogeologic Unit	Monitoring Interval	Approximate Thickness (Feet)
System	Group	Formation				
Quaternary			Sand and Gravel with Clay Interbeds	Shallow Unconfined Aquifer	Shallow Interval Intermediate Interval	41-93
			Silt and Clay	Leaky Aquitard	NS[a/]	0-47 Discontinuous and Sporadic
			Sand and Gravel with Clay Interbeds	Deep Confined or Semi-Confined Aguifer	Deep Interval	19-55
Ordovician	St. Peter	Sandstone	Sandstone	Leaky Aquitard	Bedrock Leaky Aquitard	0-65
	Praire du Chien (PC)	Shakopee Dolomite	dolomite	Confined Aquifer	Praire du Chien (PC) Aquifer	90-135
		Oneota Dolomite	dolomite			

Notes:
[a/] NS - not sampled
Source: Tetra Tech NUS, 2000a



LEGEND

BORING OR WELL NUMBER — MS-42I

GROUND SURFACE ELEVATION (ft.) — 833.47 — APPROXIMATE GROUND SURFACE

TOP OF MONITORED INTERVAL (ft bgs) — 42.5

BOTTOM OF MONITORED INTERVAL (ft bgs) — 52.5

LITHOLOGIC CONTACT

TOTAL DEPTH OF BORING OR WELL (ft bgs) — TD 55.0

NOTE: ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (FT AMSL)

UNCONSOLIDATED MATERIAL

CLAY, SILTY CLAY, SANDY CLAY, SILT, CLAYEY SILT AND SANDY SILT AS SHOWN ON THE CROSS-SECTION (UNCOLSOLIDATED MATERIAL HAVING A LOWER PERMEABILITY)

SAND, CLAYEY SAND, SILTY SAND, GRAVELY SAND, GRAVEL AND SANDY GRAVEL AS SHOWN ON CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A HIGH PERMEABILITY)

BEDROCK

DOLOMITE BEDROCK (PRAIRIE DU CHIEN GROUP)

NOTES:

1. LITHOLOGY SHOWN BETWEEN BORINGS WAS INTERPOLATED BASED ON THE BORING LOGS.
2. SAND SHOWN IN CROSS-SECTION RANGES FROM FINE TO COARSE SAND.

VERTICAL SCALE IN FEET: 0, 10, 20

HORIZONTAL SCALE IN FEET: 120, 60, 0

From: Tetra Tech NUS (2001)

FIGURE 2.1

CROSS-SECTION A-A'

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

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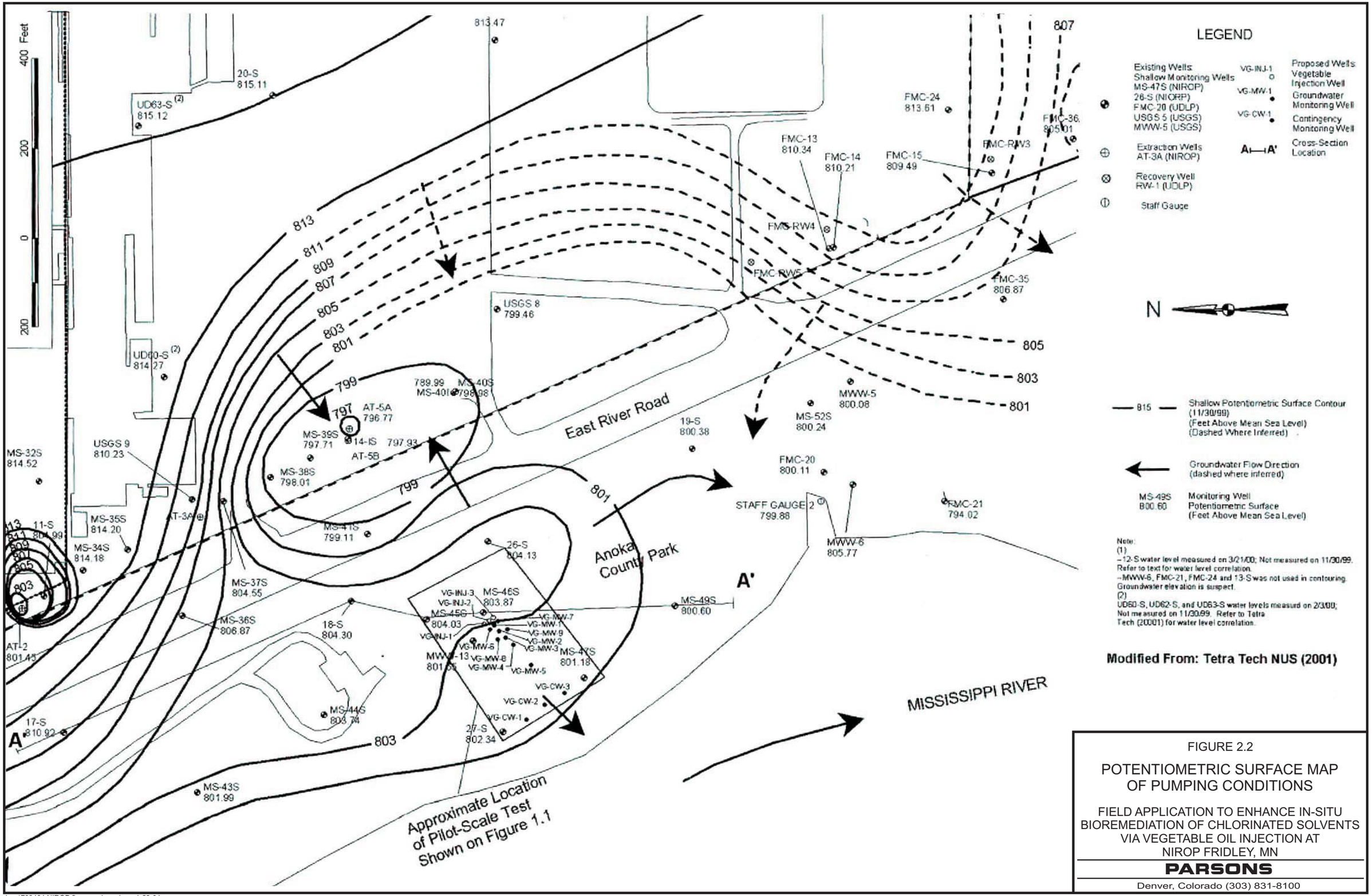

FIGURE 2.2

POTENTIOMETRIC SURFACE MAP OF PUMPING CONDITIONS

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

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discernable on the potentiometric surface contour map for pumping conditions (November 1999) for the shallow Quaternary aquifer (Figure 2.2). This groundwater ridge is also readily apparent in the potentiometric surface map developed from data collected in November 2005 (TtNUS, 2006 Figure 4-6). As a result of this ridge, groundwater (and dissolved contaminants) flow in a radial pattern both toward the Mississippi River and the NIROP Facility groundwater extraction wells (TtNUS, 2006). It is likely that the position of the groundwater ridge present beneath ACP controls local groundwater flow rates and directions within the pilot study area. The position of the groundwater ridge is likely controlled by seasonal fluctuations in precipitation and pumping rates in the extraction system. Thus, seasonal fluctuations in precipitation and any changes in the operation of the extraction system (periods of shutdown or partial shutdown) likely impact groundwater flow within the pilot study area.

It was recently determined that there is a component of upward vertical flow between the PC aquifer and the overlying unconsolidated aquifer system (USGS, 2003a). This vertical flow is interpreted to be significant beneath ACP and in close proximity to the river (TtNUS, 2006). Further evaluation by TtNUS as reported in the 2005 AMR indicates that under non-pumping conditions upward vertical flow appears to be most significant in the vicinity of the river where water from deeper aquifer units upwells to discharge to surface water (TtNUS, 2006).

2.3.2 Non-Pumping Conditions and Effect of Extraction Wells

The potentiometric surface contour map for non-pumping conditions (March 10, 2003) for the shallow Quaternary aquifer is presented as Figure 4.6 in the 2002 annual groundwater monitoring report (TtNUS, 2003). The entire extraction system was shut down on January 1, 2003 and remained down until at least March 10, 2003. The aquifer system was allowed to recover for over two months to reach static non-pumping water-level conditions. Under static (i.e., non-pumping) conditions, the groundwater flow direction across the site for the unconsolidated aquifers and the underlying PC bedrock aquifer is generally the same as under pumping conditions. The groundwater ridge observed under pumping conditions was present under non-pumping conditions as well, indicating that it is a natural hydrogeologic feature.

The direct impact of the extraction system on the pilot test area can be determined by comparing the water level within the pilot study area under pumping conditions with the water level under non-pumping conditions. On march 10th 2003 the groundwater extraction system was down and the groundwater elevation at MS-46S under non-pumping conditions was 806.04. The extraction system was restarted on March 18th 2003. On April 7th 2003 a round of water level data was collected as part of the April 2003 process monitoring event. During this sampling round the groundwater elevation at MS-46S was 804.81. Thus, the impact of the extraction system on MS-46S is likely to be a maximum of the difference between these sampling rounds or approximately 1.2 feet, assuming that seasonal fluctuations were minimal during this 17 day time period. The 1.2 foot drop in the water table in the vicinity of MS-46S due to the extraction system likely resulted in shallower groundwater potentiometric surface gradients within the pilot test area which would have effected the geochemical and contaminant conditions within the pilot test area.

2.3.3 Interaction Between the Aquifer System and the Mississippi River

The Mississippi River borders ACP to the west. It is expected that the Mississippi River and the underlying alluvium are hydraulically connected. The alluvium consists of sand and gravel (Schoenberg, 1994) and is estimated to be as much as 60 feet thick under the river (Lindgren 1990). To evaluate the interaction between the unconsolidated aquifer system and the Mississippi River, pressure transducers and data loggers were installed to record the rise and fall of water levels in the aquifers in relation to the rise and fall of the river stage of the Mississippi River (TtNUS, 2006). The hydraulic heads in the aquifer were found to be higher in all wells within 500 feet of the river compared to the river stage even during rapid changes in the river level. This head difference indicates that throughout the year (i.e., during all seasons) groundwater in the aquifer system flows toward and discharges into the Mississippi River. The data indicate that there were no bank storage effects, even at high river stages, during the data collection period and that the Mississippi River is a gaining river throughout the year (TtNUS, 2006).

2.4 GROUNDWATER QUALITY PRIOR TO VEGETABLE OIL INJECTION

Groundwater samples were collected and analyzed in the spring (April 19-22) and fall (November 2-5) of 1999. The results of these sampling events are described in more detail in the 2000 Annual Monitoring Report (TtNUS, 2001). The sampling round conducted in November 1999 represents a snapshot of site conditions prior to the injection of the vegetable oil. Consistent with historical observations, TCE was the most extensive contaminant encountered in groundwater at the NIROP and adjacent ACP sites. TCE was detected in 99 of 101 wells sampled in the fall 1999 sampling event. Detected concentrations of TCE ranged from 0.59 μg/L to 18,000 μg/L in the fall 1999 sampling round. Dissolved TCE is present at generally higher concentrations in the unconfined aquifer (up to 18,000 μg/L) than the deep semi-confined aquifer (up to 5,200 μg/L) (TtNUS, 2000). TCE concentrations in the PC aquifer are significantly lower than in shallow intervals (concentrations ranged from non-detect to 7.9 μg/L in 1999) (TtNUS, 2001). Generally, TCE in groundwater extends from north of the NIROP's northern boundary to the southwest, along the direction of groundwater flow, to the Mississippi River in the shallow, intermediate, and deep monitored intervals.

Based on the results of the NIROP/ACP field investigation in 1999 (TtNUS, 2000), TCE was present at elevated levels in the shallow aquifer in the southwestern portion of the NIROP and in ACP. A plan view isoconcentration map of the spatial distribution of TCE contamination in the shallow groundwater interval in the pilot study area near GWMS-46S is shown on Figure 2.3, based on groundwater samples collected in the fall of 1999. TCE concentrations are lower northeast of East River Road (ranging from 170 to 730 μg/L) than TCE concentrations present in the ACP (42 to 18,000 μg/L) (Refer to Figure 4-19 of TtNUS, 2000). More specifically, the concentrations in the central portion of the ACP were locally higher, ranging from 1,100 to 18,000 μg/L at well GWMS-46S. This zone of elevated concentrations generally corresponds to the location of a groundwater ridge (Figure 2.2), which may represent an area where contamination may have migrated around or through the groundwater extraction system through the shallow and/or intermediate aquifer zones. The primary reason for implementing the pilot scale

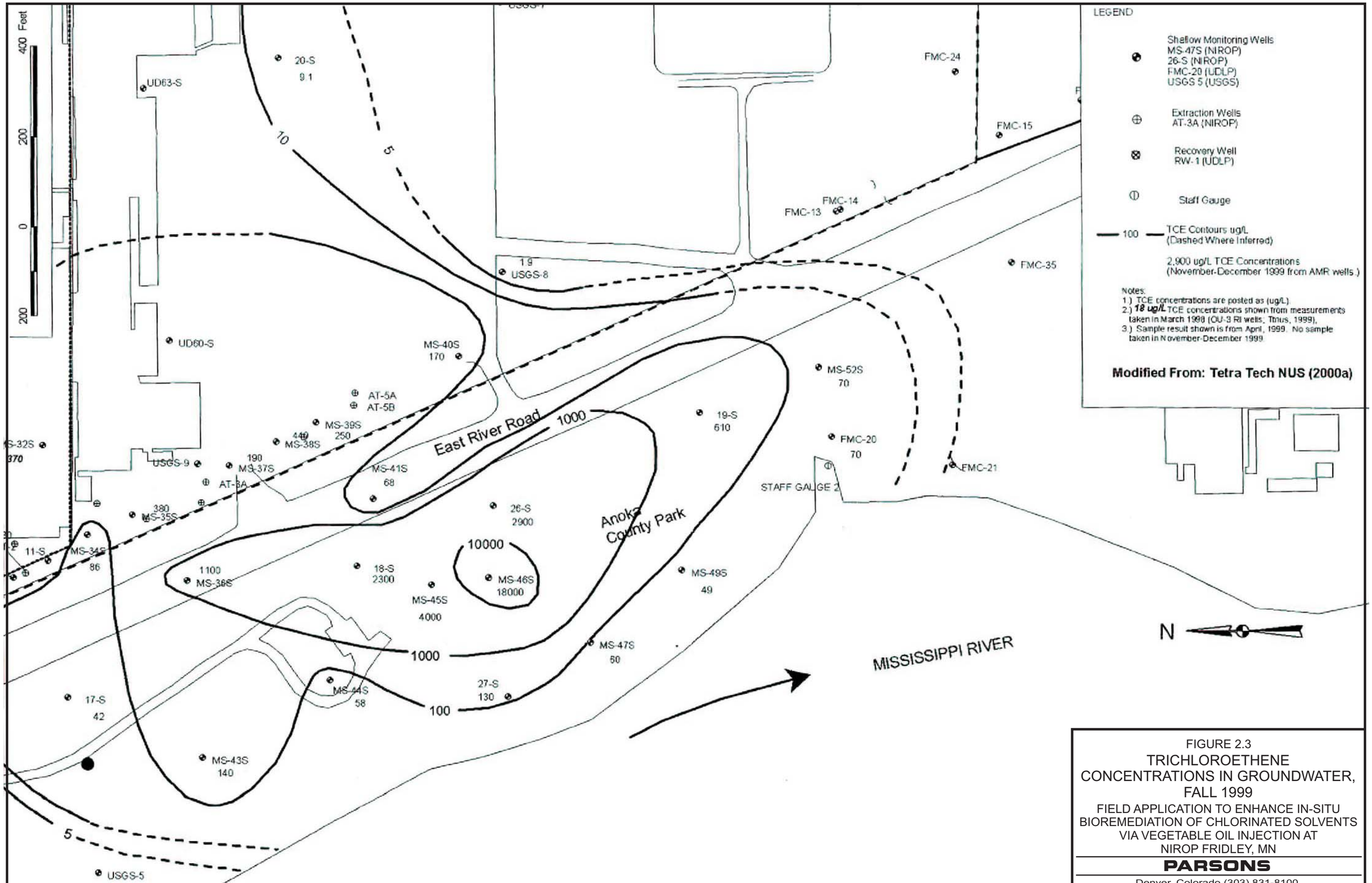

FIGURE 2.3
TRICHLOROETHENE CONCENTRATIONS IN GROUNDWATER, FALL 1999
FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

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vegetable oil injection study near well GWMS-46S was because this well exhibited the highest TCE concentration in the fall of 1999.

2.5 CHLORINATED ETHENES OVER TIME AT ANOKA COUNTY PARK

TCE and DCE (*cis*-1,2-DCE plus *trans*-1,2-DCE) concentration data over time is presented in the 2005 annual monitoring report (TtNUS, 2006). These trend data are summarized in this report in order to provide a background data set to compare the pilot test results to. Contaminant concentration trend plots were prepared by TtNUS (2006) for well locations in the vicinity of the vegetable oil pilot test area.

Prior to vegetable oil injection activities in December 2001, downward-trending TCE and DCE concentrations through time were observed at a number of shallow drift ACP monitoring well locations, while upward-trending TCE and DCE concentrations were observed at others. Monitoring well locations installed within ACP, within the shallow drift aquifer, and in the vicinity of the vegetable oil pilot test area that showed decreasing TCE concentration trends over time include wells GWMS-17S, GWMS-18S, GWMS-19S, GWMS-26S, GWMS-36S, and GWMS-45S; in contrast, increasing TCE concentration trends were observed at monitoring wells GWMS-41S, GWMS-43S, and GWMS-44S (TtNUS, 2001). Prior to vegetable oil injection, downward- trending DCE concentrations through time were observed at shallow drift ACP monitoring wells GWMS-17S and GWMS-18S, while increasing DCE concentration trends were observed at monitoring wells GWMS-26S, GWMS-41S, and GWMS-44S (TtNUS, 2001). TCE concentration trends were relatively stable at well GWMS-46S, while DCE concentration trends were relatively stable at wells GWMS-19S, GWMS-27S, GWMS-36S, GWMS-43S, and GWMS-46S.

During the course of the pilot test, groundwater sampling at wells outside of the pilot test area was limited to GWMS-17S, GWMS-19S, GWMS-27S, GWMS-36S, GWMS-41S, GWMS-43S, GWMS-44S, and GWMS-45S. During the course of the pilot test, TCE and DCE trends at these wells were variable. TCE and DCE concentrations decreased at monitoring wells GWMS-17S and GWMS-19S, while concentrations of these compounds increased at GWMS-41S, GWMS-43S, and GWMS-44S. At well GWMS-36S, TCE concentrations decreased substantially while DCE concentrations remained stable.

A Mann-Kendall trend analyses were conducted on the VOC data set to determine the direction of the concentration trend at each well location over time. The discussion of the methods and results of the Mann-Kendall trend analyses are presented in the 2005 AMR (TtNUS, 2006), and are summarized here for wells located in the vicinity of the pilot study area. For monitoring wells installed in the park 17 of the 28 wells sampled had statistically significant downward TCE concentration trends, 5 wells had upward trends, and the remaining 6 wells showed no statistically significant trend (TtNUS, 2006). Concentration trends for cis-1,2-DCE were very similar with 15 of the 28 wells having a downward trend, 7 having upward trends, and 8 having no trend. Monitoring well MS-18S and MS-45S, located up and cross gradient from the pilot test area, had downward trends in both TCE and cis-1,2-DCE concentrations while monitoring well MS-26S, also located up and cross gradient from the pilot test area had a statistically upward trend in TCE concentration and no trend in cis-1,2-DCE concentration. MS-41S, located

upgradient from the pilot test area had no identifiable trend for either TCE or cis-1,2-DCE.

The relative magnitude of the change in concentration between November 2001 and March 2003 was evaluated for each sampled well by computing the slope of the straight line between the 2001 and 2003 data points. The average slopes in the TCE and DCE concentration trends at wells outside of the pilot test area were approximately -3.2 and +1.1, respectively. The average TCE slope represents an average TCE concentration decrease of approximately 3.2 µg/L per month or 38.4 µg/L per year. The average DCE slope represents an average DCE concentration increase of approximately 1.1 µg/L per month or 13.2 µg/L per year. These concentration changes result from processes acting on ACP as a whole and thus will be considered during the evaluation of the pilot test. Wells GWMS-45S and GWMS-46S were likely impacted by the vegetable oil injection pilot test and are thus not included in this evaluation. GWMS-46S was directly impacted by vegetable oil during injection, and GWMS-45S and GWMS-53PC were likely accidentally impacted by vegetable oil back-flushing through groundwater extraction lines during substrate injection activities.

SECTION 3

VEGETABLE OIL INJECTION PILOT TEST IMPLEMENTATION

The installation of the pilot test system and the emplacement of the vegetable oil substrate are presented in detail in the Project Completion Report prepared by CCI (2002). Therefore, this section will be limited to discussion of the methods and techniques employed during the process monitoring events and a presentation of changes or departures from the project work plan (Parsons, 2001b).

3.1 PROCESS MONITORING ACTIVITIES

The final project work plan (Parsons, 2001b) called for the performance of a total of four process monitoring sampling events distributed over approximately 12 months following substrate injection. The project work plan also contained a provision for an additional 12 months of performance monitoring to be conducted by the performance of up to four additional performance monitoring events. Six performance monitoring events were conducted over a time period of 20 months.

3.1.1 Water Table Elevation Data Collection

Groundwater potentiometric surface elevation and vegetable oil non-aqueous phase liquid (NAPL) thickness measurements were collected during each process monitoring event, prior to the initiation of groundwater sampling. Groundwater elevation measurement data sets were used to qualitatively determine whether the vegetable oil injection activities affected groundwater flow over the course of the pilot test. Groundwater potentiometric surface maps were prepared for each sampling round and are presented in Section 4 of this report. Vegetable oil NAPL thicknesses were measured during each sampling round to determine if the NAPL migrated away from the initial injection area.

3.1.2 Hydraulic Conductivity Data Collection

Hydraulic conductivity of the aquifer matrix was calculated using slug test results from three injection wells and three monitoring wells (PES-MW-1, PES-MW-2, and PES-MW-3); the tests were performed during the December 2002, April 2003, and August 2003 sampling events. Post-injection hydraulic conductivity data collected during the process monitoring events was compared to hydraulic conductivity data collected from the same wells prior to vegetable oil injection to determine how the hydraulic conductivity of the aquifer matrix was impacted by vegetable oil injection. These results are presented in Section 4 of this report.

3.1.3 Groundwater Sample Collection

During each process monitoring event, groundwater samples were collected from three injection wells, nine pilot test monitoring wells, three contingency monitoring wells, and three pre-existing monitoring wells. At a minimum, each groundwater sample was analyzed for the following parameters:

- Volatile organic compounds (VOCs) using USEPA method 8260B;
- Methane, ethene, and ethane using USEPA method SW8015M and Microseeps, Inc. proprietary laboratory methods;
- Nitrate and nitrite using method USEPA E300.1;
- Total organic carbon (TOC) using method USEPA SW9060;
- DO, temperature, pH, ORP, and specific conductivity using field instrumentation; and
- Ferrous iron, manganese, hydrogen sulfide, sulfate, ammonia, alkalinity, chloride, and carbon dioxide in the field using various Hach® methods.

In addition, sample aliquots were collected from each well and analyzed for volatile fatty acids (VFAs), phospholipid fatty acids (PLFAs), and dissolved H_2 by internal laboratory procedures during the last five sampling rounds. Sample aliquots of vegetable oil NAPL were also collected during each process monitoring event from any well where the vegetable oil NAPL was present in sufficient quantity. The vegetable oil samples were analyzed for VOCs using method 8260B.

Sample aliquots collected from injection well PES-INJ-2 and monitoring wells GWMS-46S, PES-MW-1, PES-MW-2, PES-MW-3, and PES-MW-4 during the December 2002 sampling event were analyzed for isotope fractionation, denatured gradient gel electrophoresis (DGGE), and targeted gene detection through deoxyribonucleic acid (DNA) analysis. During the sampling rounds performed in 2003, sample aliquots were collected from the injection wells, existing well GWMS-46S, and the nine pilot test monitoring wells and analyzed for the same parameters. The isotope fractionation analyses were conducted to determine whether the chlorinated solvents at each well location were being degraded through microbially mediated processes. The DGGE and targeted gene detection analyses were conducted to determine the structure of the microbial community present at each well location. These results are presented in Section 4.

Groundwater samples were collected during baseline sampling and process monitoring events using a submersible bladder pump and Teflon®-lined tubing.

3.1.3.1 Data Quality Issues

During the February and May 2002 process monitoring events, 2-butanone and acetone were detected in samples collected from the injection wells and from monitoring

wells PES-MW-2, PES-MW-7, PES-MW-9, and GWMS-27S. Detected concentrations of both 2-butanone and acetone were relatively low during the first round of process monitoring, with maximum concentrations of 490 µg/L and 240 µg/L, respectively. During the second round of process monitoring both analytes were detected at slightly higher concentrations (maximum concentrations of 770 µg/L and 610 µg/L, respectively). None of the 2-butanone or acetone concentrations detected during the first two process monitoring rounds exceed the MPCA Health Risk Limits of 4,000 µg/L and 700 µg/L for 2-butanone and acetone, respectively. The source of these contaminants is unknown. However, it was suspected that they were contaminants introduced to the samples during sampling equipment decontamination or in the laboratory during sample analysis. This hypothesis was tested during the third process monitoring event (August 2002) by collecting additional rinse blanks to ensure that decontamination procedures were adequate and by using new sample collection tubing for sampling at PES-INJ-1.

However, during the August 2002 sampling event, high concentrations of 2-butanone and acetone were detected in samples collected from the injection wells and from monitoring wells PES-MW-7 and PES-MW-9. In addition, rinse blank samples that were collected following sample collection at wells containing high concentrations of TOC (and probably residual vegetable oil) contained significant concentrations of TCE, DCE, 2-butanone, and acetone. This indicated that the decontamination procedure in use was inadequate for wells that contain residual vegetable oil. Therefore, Parsons recommended that new tubing be used for sampling in wells PES-INJ-1, PES-INJ-2, PES-INJ-3, PES-MW-1, PES-MW-6, PES-MW-7, PES-MW-8, and PES-MW-9. Use of new tubing in these wells would significantly decrease the potential for cross contamination between wells and reduce the potential for introduction of decontamination solvents to samples and rinse blanks. Parsons also recommended that the sampling order be changed such that all other wells would be sampled prior to the eight above-listed wells. Monitoring wells PES-MW-2 and GWMS-46S would be sampled last, just prior to installing new tubing for well PES-MW-8.

The analytical data collected during the December 2002 event, performed following implementation of the revised procedures described in the previous paragraph, indicate the presence of 2-butanone and acetone in samples from wells PES-INJ-1, PES-INJ-3, PES-MW-7, and PES-MW-9 only. The spatial distribution of 2-butanone and acetone concentrations detected during the December 2002 sampling event indicate that the presence of these compounds are related to fermentation reactions within the injection area and in wells where there is significant organic carbon present. However, these compounds are highly degradable. Therefore, the presence of 2-butanone and acetone is dependent on the presence of high concentrations of organic carbon. The spatial distribution of these compounds confirmed that they were not migrating beyond the area of elevated organic carbon concentrations and bioactivity. The large decreases in TOC concentration observed in PES-MW-9 during the April and August 2003 events were coupled with large decreases in 2-butanone and acetone concentrations, supporting the hypothesis that the presence of these compounds is dependent on the presence of high concentrations of TOC.

The changes to sampling methodology adopted during the August 2002 and December 2002 process monitoring rounds were maintained during the 2003 process monitoring rounds.

3.1.4 Departures from the Final Project Work Plan

There were a number of minor departures from the Project Work Plan (Parsons, 2001b) that were adopted during the process monitoring phase of this project. In all cases, changes to the Project Work Plan were made to improve data quality and/or facilitate evaluation of the effects of vegetable oil injection . Departures from the Project Work Plan included:

- The addition of VFA, PLFA, DGGE, targeted gene detection, dissolved H_2, and isotopic fractionation analyses,
- Increased frequency of rinse blank sample collection and analysis;
- Use of dedicated tubing for sample collection at select well locations;
- Analysis for methane, ethene, and ethane using Microseeps Inc. internal standard operating procedures as well as analysis by USEPA Method SW8015M. The analysis of methane, ethene, and ethane by internal Microseeps Inc. procedures was conducted to obtain lower detection limits.
- The USGS added approximately 110 pounds of colloidal iron to the vegetable oil emulsion injected into PES-INJ-01 and approximately 7.8 pounds of dissolved magnetite to the vegetable oil emulsion injected into PES-INJ-03 (USGS, 2003). These iron products were added to the injected emulsion in order to track the emulsion in the subsurface following injection using geophysical techniques.

3.2 EXTENDED MONITORING ACTIVITIES

Extended process monitoring activities at the vegetable oil pilot test site were conducted in accordance with the final work plan addendum (January 6th 2005), the Final Work Plan (Parsons, 2001a), final Quality Assurance Project Plan (QAPP), (Parsons, 2001b), and guidance provided by the United States Environmental Protection Agency (USEPA (1998)).

The extended process monitoring activities were conducted in three phases. The first phase consisted of a membrane interface probe (MIP) survey within the pilot test area to investigate the stratigraphy and vertical distribution of volatile organic compound (VOC) mass from the ground surface to a total depth of approximately 60 to 70 feet below ground surface (bgs). The second phase used the data generated during the MIP survey to place eight new monitoring wells and ten soil borings within approximately 100 feet of the injection area. The third phase began after the new monitoring well clusters are installed and consisted of a groundwater sampling event at the newly installed wells, existing pilot test wells, and selected existing monitoring wells located outside of the pilot test area. A second groundwater sampling event was conducted approximately 7 months after the first event, in November 2005. The data collected during the field activities associated with the extending monitoring of the vegetable oil pilot test area are presented in the following subsections. Data collected during the extended monitoring activities has been incorporated into this final report and is presented in detail in the Final 2006 Technical Memorandum (Appendix G).

SECTION 4

RESULTS

Because CAH compounds are used as electron acceptors, there must be an appropriate source of electron donor to encourage microbial growth and to fulfill the electron requirement to drive reductive dechlorination. Potential electron donor sources include vegetable oil, fuel hydrocarbons, low-molecular-weight compounds (e.g., lactate, acetate, or methanol) present in natural organic matter, or less-chlorinated compounds such as VC or DCE. Vegetable oil was selected to remediate the CAH plume at ACP by overcoming the perceived electron donor limitation.

The separate-phase nature of vegetable oil allows for slow dissolution into groundwater, thus making it a slow-release carbon source. Vegetable oil is an inexpensive, innocuous, edible (i.e., food-grade) carbon source that is not regulated as an environmental contaminant by the USEPA. Because vegetable oil is a light NAPL (LNAPL), the potential exists that a single, low-cost injection could provide sufficient electron donor to drive reductive dechlorination for several years.

Vegetable oil was injected at ACP in December 2001 to create the redox and electron donor conditions necessary to promote the biologically mediated reductive dechlorination of the CAHs present in site groundwater and subsurface saturated soils. A secondary benefit of vegetable oil is that dissolved contaminants partition into the oil NAPL. This is beneficial because aqueous-phase CAH concentrations are lowered until steady-state conditions are reached, resulting in an initial attenuation of the dissolved-phase plume. Contaminants are then released from the oil back into groundwater at a rate dependent upon dissolution and/or degradation of the vegetable oil, and degradation of contaminants in the dissolved phase. In any event, contaminants are released back to groundwater within a zone characterized by the presence of adequate organic substrate and optimal conditions for reductive dechlorination. An extensive discussion of the processes by which vegetable oil enhances *in-situ* reductive dechlorination of CAHs can be found in the Project Work Plan (Parsons, 2001b).

4.1 GROUNDWATER FLOW

4.1.1 Groundwater Flow Direction

Table 4.1 presents groundwater elevation measurements collected during the baseline sampling and process monitoring events. Figure 4.1 depicts a groundwater potentiometric surface map developed from the baseline groundwater elevation data set. Figures 4.2 through 4.7 depict groundwater potentiometric surface maps developed for each of the six process monitoring events. The monitoring network for the pilot study

TABLE 4.1
SUMMARY OF GROUNDWATER ELEVATION DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well/Borehole Identification	Date	Elevation Datum (Feet amsl)[a/]	Depth to Water (Feet btoc)[b/]	Depth to Oil (Feet btoc)	Groundwater Elevation[c/] (Feet amsl)
MONITORING WELLS					
GWMS-27S	24-Oct-01	832.74	N.M. [d/]	N.E. [e/]	N.M.
	11-Feb-02		N.M.	N.E.	N.M.
	20-May-02		28.17	N.E.	804.57
	26-Aug-02		28.56	N.E.	804.18
	9-Dec-02		28.82	N.E.	803.92
	7-Apr-03		30.40	N.E.	802.34
	18-Jun-03		31.58	N.E.	801.16
	18-Aug-03		30.72	N.E.	802.02
GWMS-45S	24-Oct-01	832.13	28.00	N.E.	804.13
	11-Feb-02		N.M.	N.E.	N.M.
	20-May-02		N.M.	N.E.	N.M.
	26-Aug-02		N.M.	N.E.	N.M.
	9-Dec-02		N.M.	N.E.	N.M.
	7-Apr-03		27.11	N.E.	805.02
	18-Jun-03		24.54	N.E.	807.59
	18-Aug-03		26.63	N.E.	805.50
GWMS-46S	24-Oct-01	831.67	27.65	N.E.	804.02
	11-Feb-02		27.60	N.E.	804.07
	20-May-02		25.71	N.E.	805.96
	26-Aug-02		25.77	N.E.	805.90
	9-Dec-02		25.86	N.E.	805.81
	7-Apr-03		26.86	N.E.	804.81
	18-Jun-03		28.25	N.E.	803.42
	18-Aug-03		26.58	N.E.	805.09
GWMS-47S	24-Oct-01	834.83	33.75	N.E.	801.08
	11-Feb-02		33.83	N.E.	801.00
	20-May-02		31.09	N.E.	803.74
	26-Aug-02		31.70	N.E.	803.13
	9-Dec-02		31.97	N.E.	802.86
	7-Apr-03		33.57	N.E.	801.26
	18-Jun-03		31.87	N.E.	802.96
	18-Aug-03		33.98	N.E.	800.85
GWMS-49S	24-Oct-01	834.16	33.63	N.E.	800.53
	11-Feb-02		N.M.	N.E.	N.M.
	20-May-02		N.M.	N.E.	N.M.
	26-Aug-02		N.M.	N.E.	N.M.
	9-Dec-02		N.M.	N.E.	N.M.
	7-Apr-03		N.M.	N.E.	N.M.
	18-Jun-03		N.M.	N.E.	N.M.
	18-Aug-03		N.M.	N.E.	N.M.

TABLE 4.1 (Continued)
SUMMARY OF GROUNDWATER ELEVATION DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well/Borehole Identification	Date	Elevation Datum (Feet amsl)[a/]	Depth to Water (Feet btoc)[b/]	Depth to Oil (Feet btoc)	Groundwater Elevation[c/] (Feet amsl)
MWW-13	24-Oct-01	833.33	31.64	N.E.	801.69
	11-Feb-02		N.M.	N.E.	N.M.
	20-May-02		N.M.	N.E.	N.M.
	26-Aug-02		N.M.	N.E.	N.M.
	9-Dec-02		N.M.	N.E.	N.M.
	7-Apr-03		31.15	N.E.	802.18
	18-Jun-03		29.38	N.E.	803.95
	18-Aug-03		31.45	N.E.	801.88
PES-MW-1	24-Oct-01	832.49	28.52	N.E.	803.97
	11-Feb-02		28.36	N.E.	804.13
	20-May-02		26.40	N.E.	806.09
	26-Aug-02		26.51	N.E.	805.98
	9-Dec-02		26.67	N.E.	805.82
	7-Apr-03		27.77	N.E.	804.72
	18-Jun-03		25.39	N.E.	807.10
	18-Aug-03		27.50	N.E.	804.99
PES-MW-2	24-Oct-01	832.41	28.48	N.E.	803.93
	11-Feb-02		28.30	N.E.	804.11
	20-May-02		26.32	N.E.	806.09
	26-Aug-02		26.46	N.E.	805.95
	9-Dec-02		26.62	N.E.	805.79
	7-Apr-03		27.74	N.E.	804.67
	18-Jun-03		25.36	N.E.	807.05
	18-Aug-03		27.53	N.E.	804.88
PES-MW-3	24-Oct-01	832.80	29.66	N.E.	803.14
	11-Feb-02		29.34	N.E.	803.46
	20-May-02		27.39	N.E.	805.41
	26-Aug-02		27.66	N.E.	805.14
	9-Dec-02		27.66	N.E.	805.14
	7-Apr-03		28.61	N.E.	804.19
	18-Jun-03		26.43	N.E.	806.37
	18-Aug-03		28.38	N.E.	804.42
PES-MW-4	24-Oct-01	832.57	31.20	N.E.	801.37
	11-Feb-02		31.05	N.E.	801.52
	20-May-02		28.53	N.E.	804.04
	26-Aug-02		29.10	N.E.	803.47
	9-Dec-02		29.36	N.E.	803.21
	7-Apr-03		30.84	N.E.	801.73
	18-Jun-03		29.03	N.E.	803.54
	18-Aug-03		31.26	N.E.	801.31
PES-MW-5	24-Oct-01	832.60	31.23	N.E.	801.37
	11-Feb-02		31.12	N.E.	801.48
	20-May-02		28.58	N.E.	804.02
	26-Aug-02		29.14	N.E.	803.46
	9-Dec-02		29.41	N.E.	803.19
	7-Apr-03		30.90	N.E.	801.70
	18-Jun-03		29.14	N.E.	803.46
	18-Aug-03		31.30	N.E.	801.30

TABLE 4.1 (Continued)
SUMMARY OF GROUNDWATER ELEVATION DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well/Borehole Identification	Date	Elevation Datum (Feet amsl)[a/]	Depth to Water (Feet btoc)[b/]	Depth to Oil (Feet btoc)	Groundwater Elevation[c/] (Feet amsl)
PES-MW-6	24-Oct-01	832.41	28.46	N.E.	803.95
	11-Feb-02		28.46	N.E.	803.95
	20-May-02		26.37	N.E.	806.04
	26-Aug-02		26.45	26.44	805.97
	9-Dec-02		26.60	N.E.	805.81
	7-Apr-03		27.71	N.E.	804.70
	18-Jun-03		25.31	N.E.	807.10
	18-Aug-03		27.54	27.54	804.87
PES-MW-7	24-Oct-01	832.58	28.64	N.E.	803.94
	11-Feb-02		28.61	N.E.	803.97
	20-May-02		26.52	N.E.	806.06
	26-Aug-02		26.63	N.E.	805.95
	9-Dec-02		26.79	N.E.	805.79
	7-Apr-03		27.89	N.E.	804.69
	18-Jun-03		25.54	N.E.	807.04
	18-Aug-03		27.66	N.E.	804.92
PES-MW-8	24-Oct-01	832.64	28.72	N.E.	803.92
	11-Feb-02		28.63	N.E.	804.01
	20-May-02		26.70	N.E.	805.94
	26-Aug-02		26.77	N.E.	805.87
	9-Dec-02		26.93	N.E.	805.71
	7-Apr-03		28.05	N.E.	804.59
	18-Jun-03		25.71	N.E.	806.93
	18-Aug-03		27.77	N.E.	804.87
PES-MW-9	24-Oct-01	832.85	28.95	N.E.	803.90
	11-Feb-02		28.81	N.E.	804.04
	20-May-02		26.85	N.E.	806.00
	26-Aug-02		27.02	N.E.	805.83
	9-Dec-02		27.12	N.E.	805.73
	7-Apr-03		28.24	N.E.	804.61
	18-Jun-03		25.89	N.E.	806.96
	18-Aug-03		27.97	N.E.	804.88
PES-CW-1	24-Oct-01	832.01	30.30	N.E.	801.71
	11-Feb-02		N.M.	N.E.	N.M.
	20-May-02		27.91	N.E.	804.10
	26-Aug-02		28.39	N.E.	803.62
	9-Dec-02		28.66	N.E.	803.35
	7-Apr-03		30.18	N.E.	801.83
	18-Jun-03		28.56	N.E.	803.45
	18-Aug-03		34.34	N.E.	797.67
PES-CW-2	24-Oct-01	833.02	31.37	N.E.	801.65
	11-Feb-02		31.93	N.E.	801.09
	20-May-02		28.99	N.E.	804.03
	26-Aug-02		29.49	N.E.	803.53
	9-Dec-02		29.77	N.E.	803.25
	7-Apr-03		31.33	N.E.	801.69
	18-Jun-03		29.75	N.E.	803.27
	18-Aug-03		31.72	N.E.	801.30

TABLE 4.1 (Continued)
SUMMARY OF GROUNDWATER ELEVATION DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well/Borehole Identification	Date	Elevation Datum (Feet amsl)[a/]	Depth to Water (Feet btoc)[b/]	Depth to Oil (Feet btoc)	Groundwater Elevation[c/] (Feet amsl)
PES-CW-3	24-Oct-01	835.47	34.08	N.E.	801.39
	11-Feb-02		34.21	N.E.	801.26
	20-May-02		31.58	N.E.	803.89
	26-Aug-02		32.14	N.E.	803.33
	9-Dec-02		32.39	N.E.	803.08
	7-Apr-03		33.95	N.E.	801.52
	18-Jun-03		32.29	N.E.	803.18
	18-Aug-03		30.51	N.E.	804.96
PES-BG-1	24-Oct-01	832.75	28.68	N.E.	804.07
	11-Feb-02		N.M.	N.M.	N.M.
	20-May-02		N.M.	N.M.	N.M.
	26-Aug-02		26.67	N.E.	806.08
	9-Dec-02		26.83	N.E.	805.92
	7-Apr-03		27.89	N.E.	804.86
	18-Jun-03		25.55	N.E.	807.20
	18-Aug-03		25.54	N.E.	807.21
PES-BG-2	24-Oct-01	832.73	28.41	N.E.	804.32
	11-Feb-02		N.M.	N.M.	N.M.
	20-May-02		N.M.	N.M.	N.M.
	26-Aug-02		26.68	N.E.	806.05
	9-Dec-02		26.75	N.E.	805.98
	7-Apr-03		27.93	N.E.	804.80
	18-Jun-03		25.61	N.E.	807.12
	18-Aug-03		27.68	N.E.	805.05
PES-BG-3	24-Oct-01	832.56	28.52	N.E.	804.04
	11-Feb-02		N.M.	N.M.	N.M.
	20-May-02		N.M.	N.M.	N.M.
	26-Aug-02		26.50	N.E.	806.06
	9-Dec-02		26.67	N.E.	805.89
	7-Apr-03		27.75	N.E.	804.81
	18-Jun-03		25.42	N.E.	807.14
	18-Aug-03		27.49	N.E.	805.07
INJECTION WELLS					
PES-INJ-1	24-Oct-01	832.42	28.38	N.E.	804.04
	11-Feb-02		28.69	28.16	804.22
	20-May-02		26.55	N.E.	805.87
	26-Aug-02		26.42	26.41	806.01
	9-Dec-02		26.54	N.E.	805.88
	7-Apr-03		27.73	27.72	804.70
	18-Jun-03		25.29	N.E.	807.13
	18-Aug-03		27.48	N.E.	804.94
PES-INJ-2	24-Oct-01	832.87	28.86	N.E.	804.01
	11-Feb-02		31.24	28.62	804.04
	20-May-02		27.17	27.05	805.81
	26-Aug-02		26.99	26.92	805.94
	9-Dec-02		27.07	27.07	805.80
	7-Apr-03		28.23	28.14	804.72
	18-Jun-03		25.75	25.94	806.95
	18-Aug-03		27.96	27.96	804.91

TABLE 4.1 (Continued)
SUMMARY OF GROUNDWATER ELEVATION DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well/Borehole Identification	Date	Elevation Datum (Feet amsl)[a/]	Depth to Water (Feet btoc)[b/]	Depth to Oil (Feet btoc)	Groundwater Elevation[c/] (Feet amsl)
PES-INJ-3	24-Oct-01	832.71	28.74	N.E.	803.97
	11-Feb-02		30.44	28.51	804.05
	20-May-02		29.08	28.95	803.75
	26-Aug-02		31.42	26.41	805.90
	9-Dec-03		28.19	26.77	805.83
	7-Apr-03		N.M.	27.83	N.M.
	18-Jun-03		26.22	27.72	805.11
	18-Aug-03		27.71	27.71	805.00

[a/] Feet amsl indicates elevation in feet above mean sea level.
[b/] Feet btoc indicates depth in feet below top of casing.
[c/] Water elevations corrected for presence of oil using a specific gravity of 0.92.
[d/] N.M. = not measured.
[e/] N.E. = not encountered.

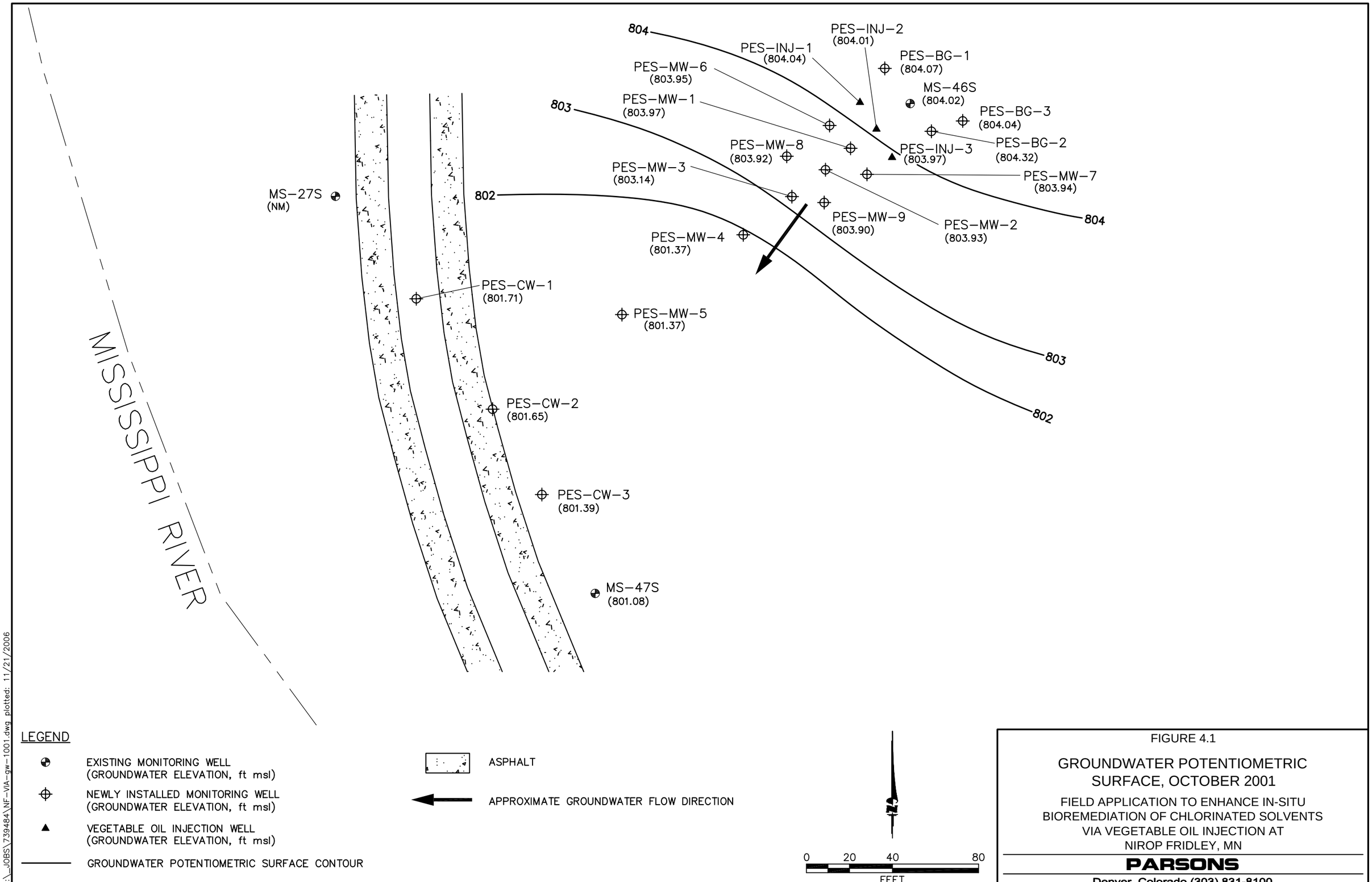


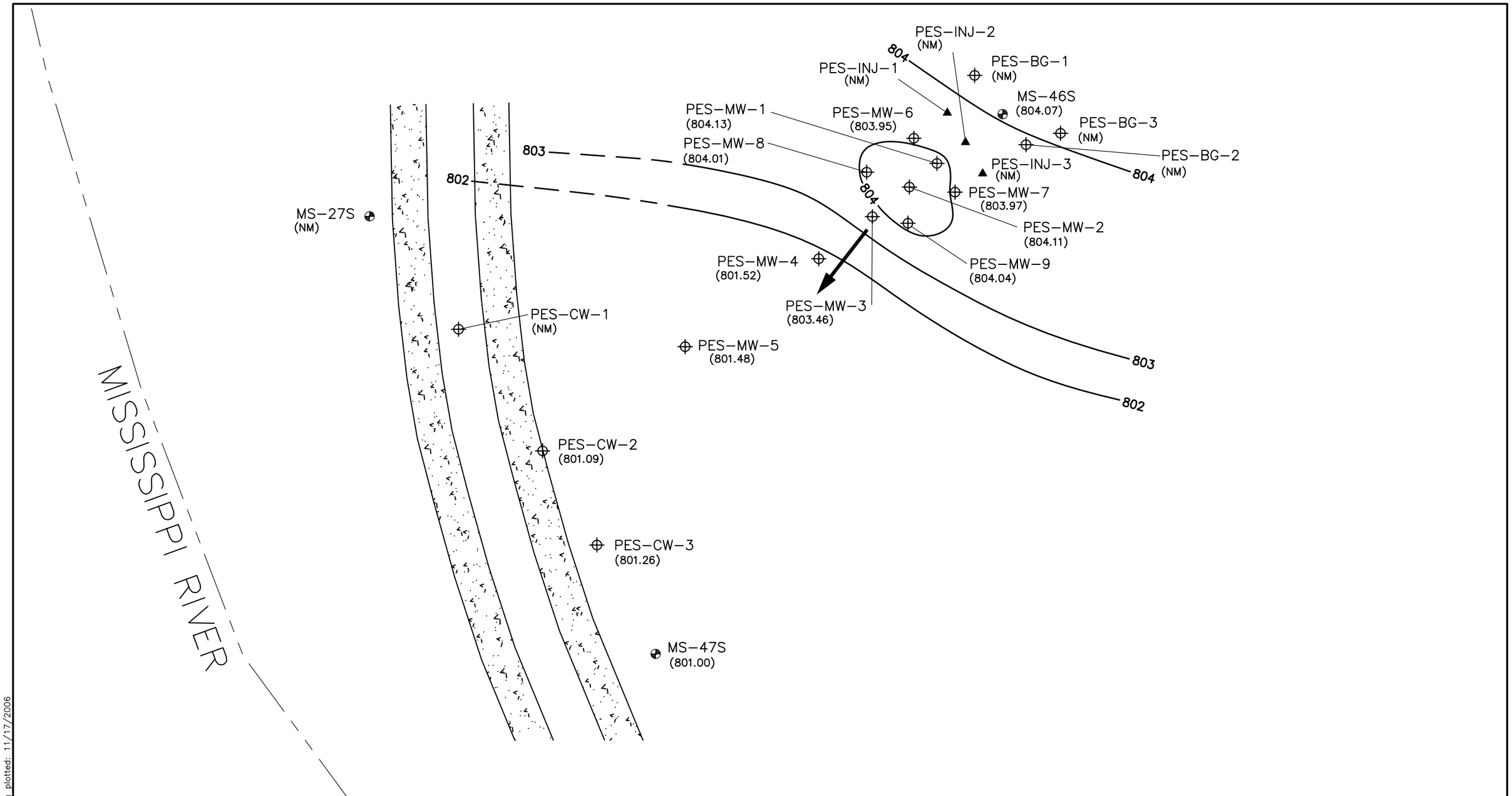
FIGURE 4.1

GROUNDWATER POTENTIOMETRIC SURFACE, OCTOBER 2001

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100



LEGEND

- EXISTING MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- NEWLY INSTALLED MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- VEGETABLE OIL INJECTION WELL (GROUNDWATER ELEVATION, ft msl)
- GROUNDWATER POTENTIOMETRIC SURFACE CONTOUR
- ASPHALT
- APPROXIMATE GROUNDWATER FLOW DIRECTION

N

0 20 40 80
FEET

FIGURE 4.2

GROUNDWATER POTENTIOMETRIC SURFACE, FEBRUARY 2002

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

C:_JOBS\739484\NF-VIA-gw-0202.dwg plotted: 11/17/2006

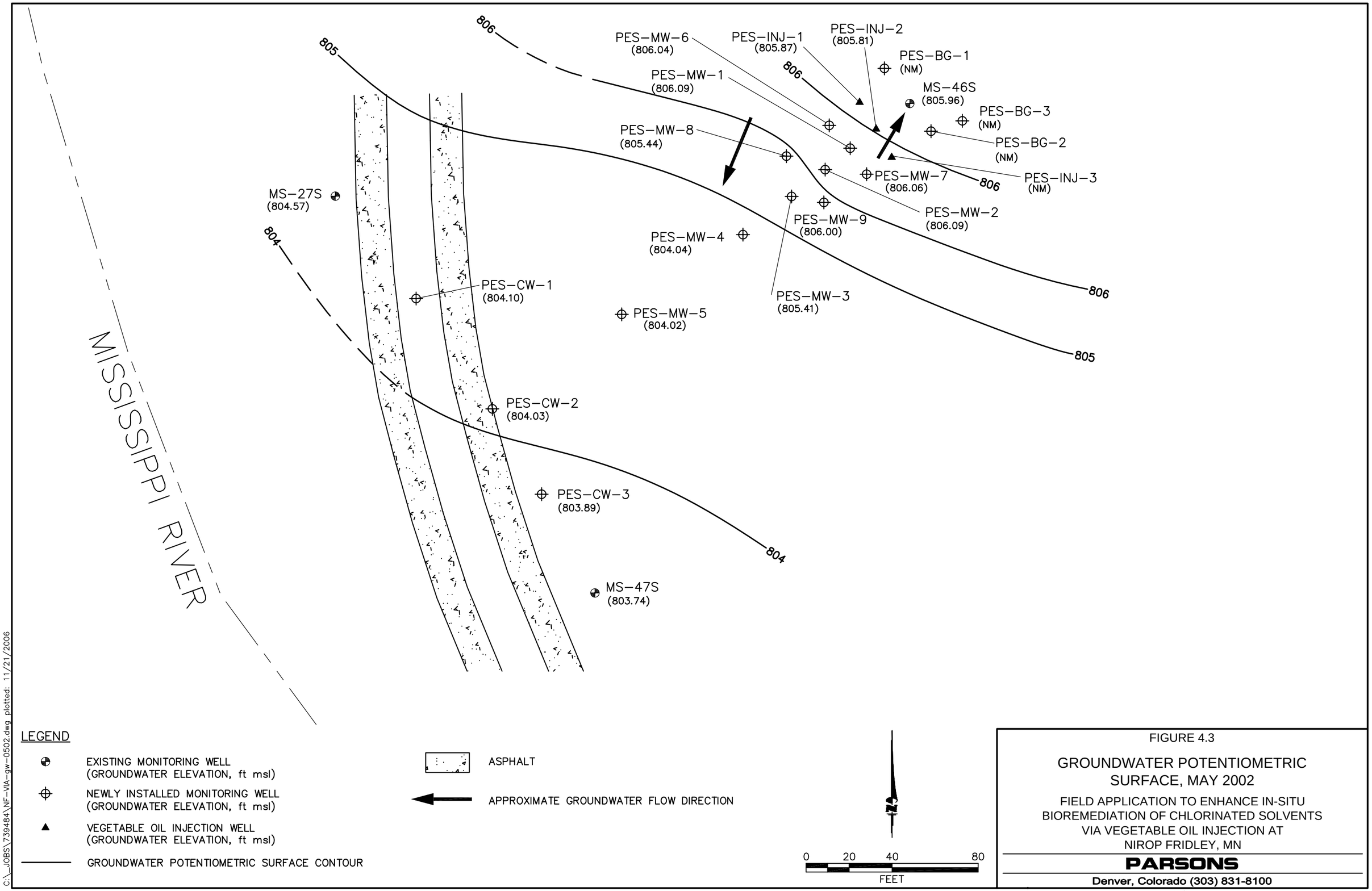


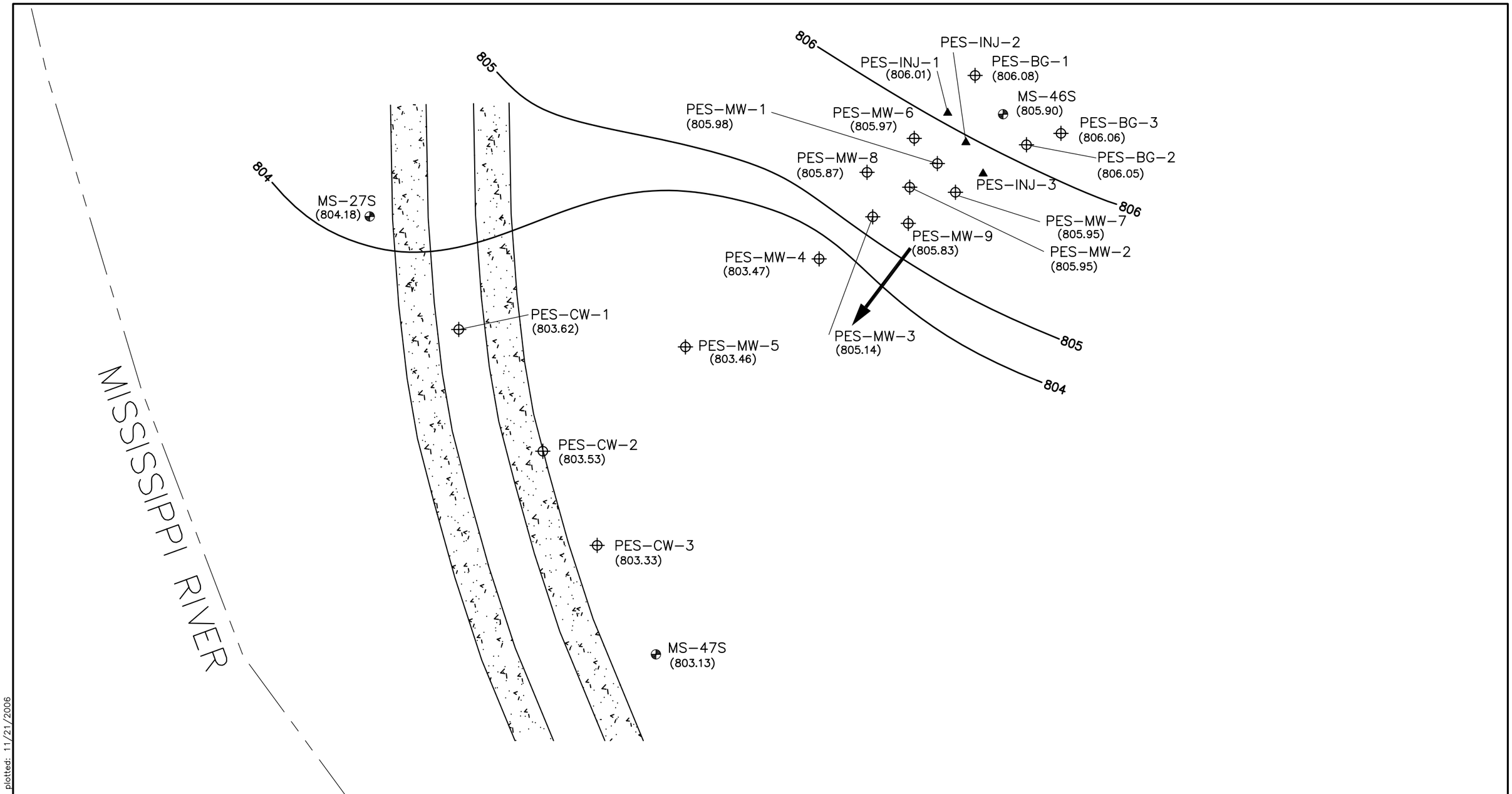
FIGURE 4.3

GROUNDWATER POTENTIOMETRIC SURFACE, MAY 2002

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100



LEGEND

- EXISTING MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- NEWLY INSTALLED MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- VEGETABLE OIL INJECTION WELL (GROUNDWATER ELEVATION, ft msl)
- GROUNDWATER POTENTIOMETRIC SURFACE CONTOUR
- ASPHALT
- APPROXIMATE GROUNDWATER FLOW DIRECTION

N

0 20 40 80
FEET

FIGURE 4.4

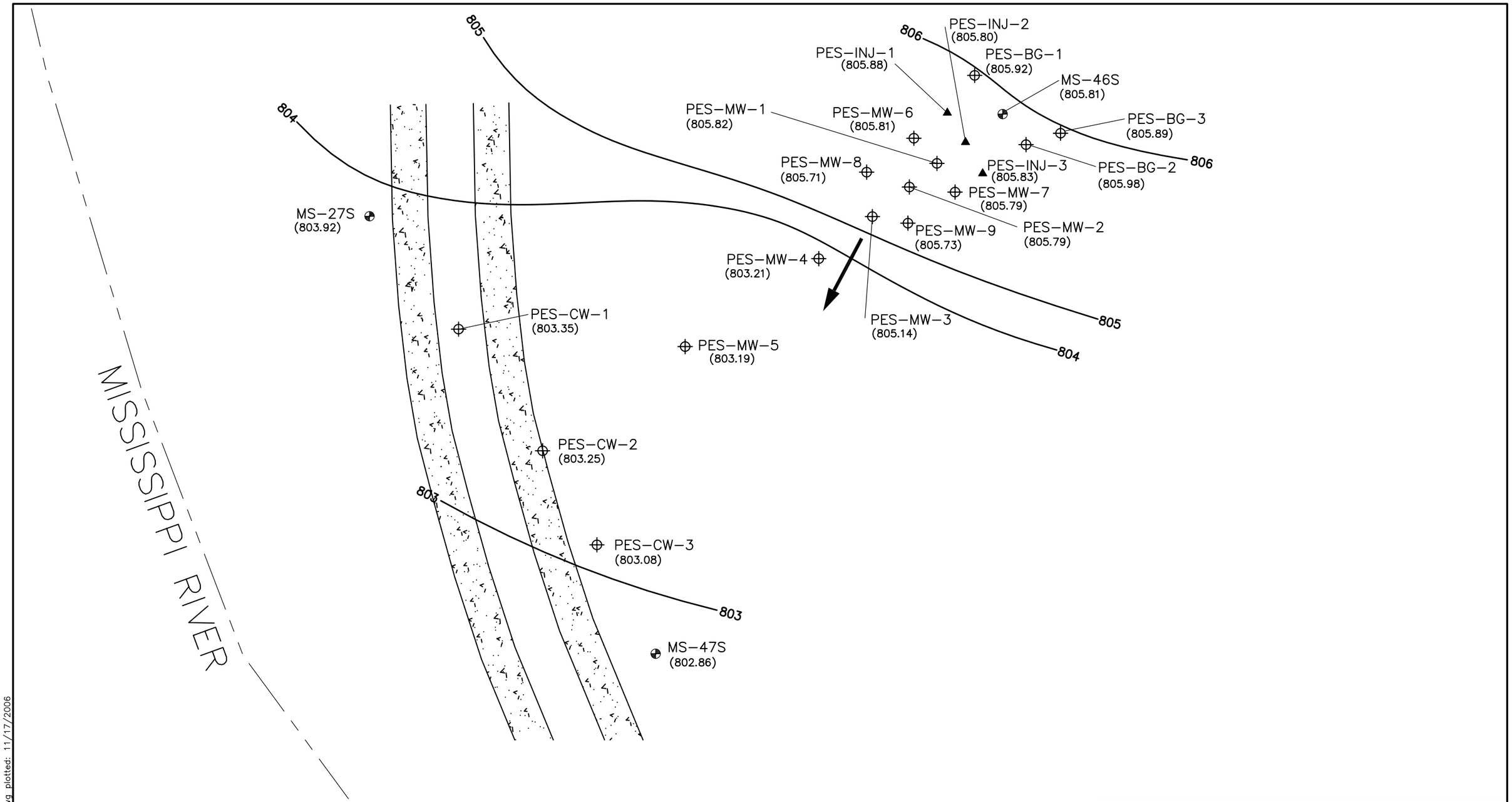
GROUNDWATER POTENTIOMETRIC SURFACE, AUGUST 2002

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

C:_JOBS\739484\NF-VIA-gw-0802.dwg plotted: 11/21/2006



LEGEND

- EXISTING MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- NEWLY INSTALLED MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- VEGETABLE OIL INJECTION WELL (GROUNDWATER ELEVATION, ft msl)
- GROUNDWATER POTENTIOMETRIC SURFACE CONTOUR
- ASPHALT
- APPROXIMATE GROUNDWATER FLOW DIRECTION

0 20 40 80
FEET

FIGURE 4.5

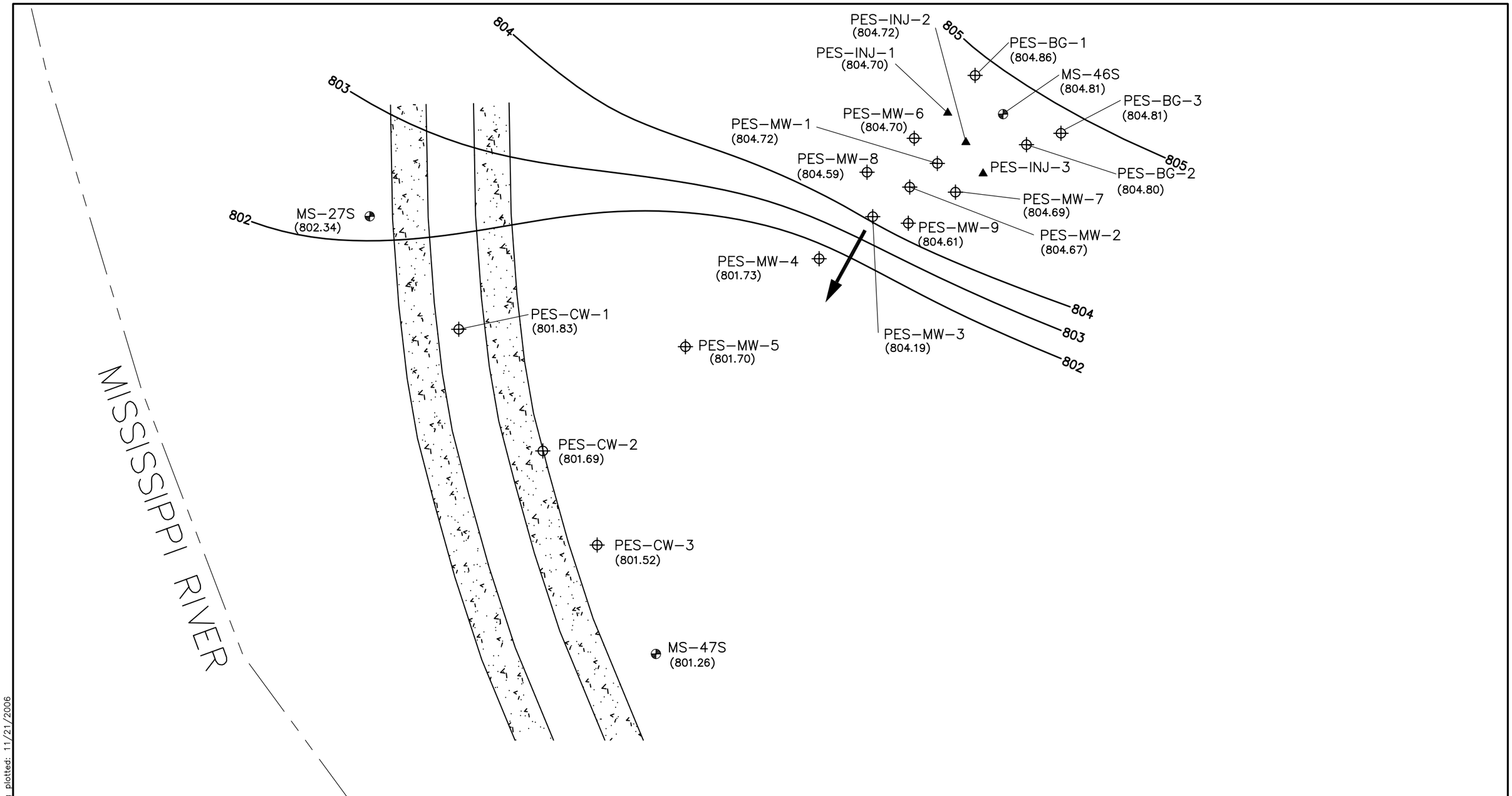
GROUNDWATER POTENTIOMETRIC SURFACE, DECEMBER 2002

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

C:_JOBS\739484\NF-VIA-gw-1202.dwg plotted: 11/17/2006



LEGEND

- EXISTING MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- NEWLY INSTALLED MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- VEGETABLE OIL INJECTION WELL (GROUNDWATER ELEVATION, ft msl)
- GROUNDWATER POTENTIOMETRIC SURFACE CONTOUR
- ASPHALT
- APPROXIMATE GROUNDWATER FLOW DIRECTION

N

0 20 40 80
FEET

FIGURE 4.6

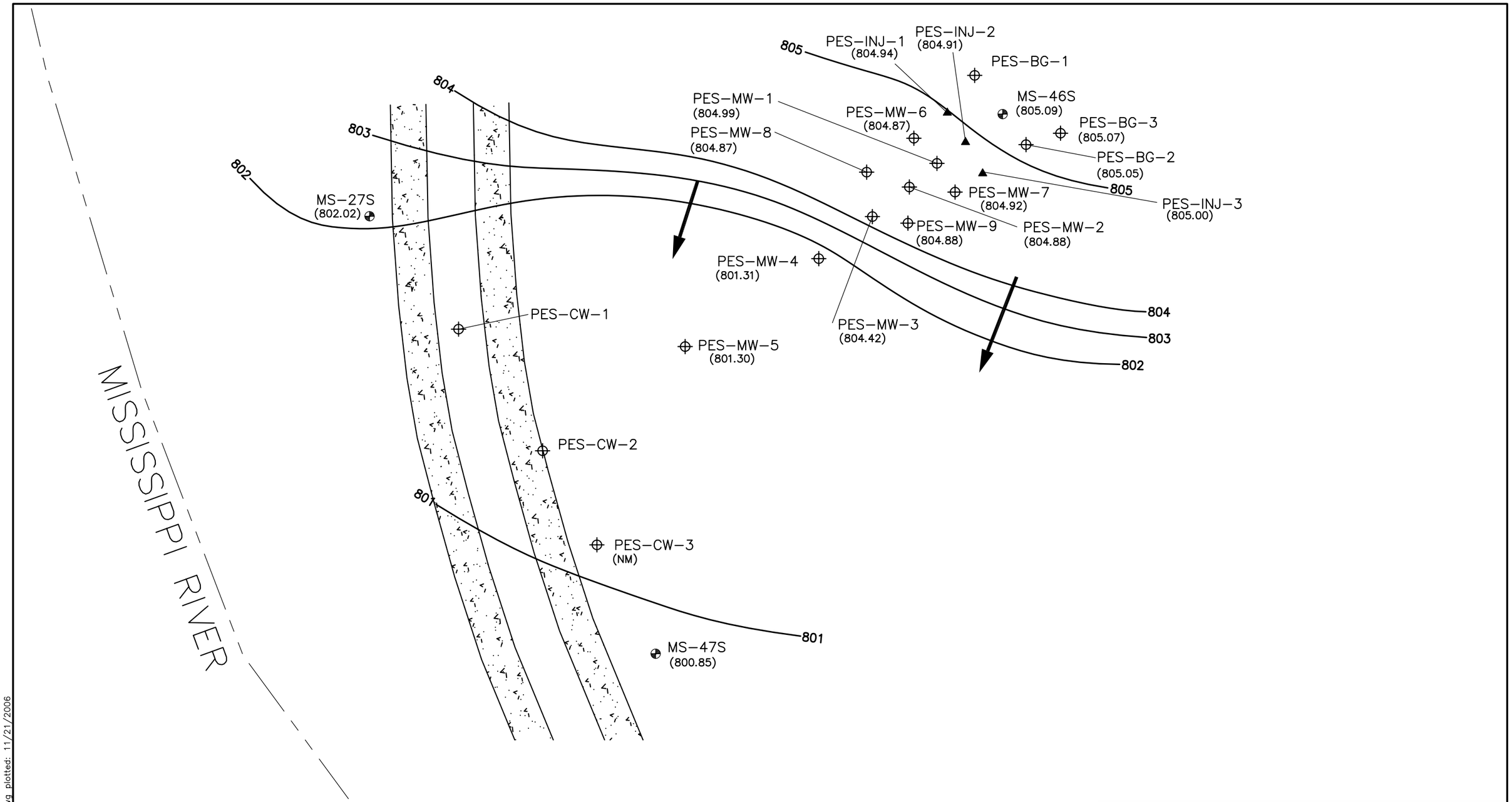
GROUNDWATER POTENTIOMETRIC SURFACE, APRIL 2003

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

C:_JOBS\739484\NF-VIA-gw-0403.dwg plotted: 11/21/2006



LEGEND

- EXISTING MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- NEWLY INSTALLED MONITORING WELL (GROUNDWATER ELEVATION, ft msl)
- VEGETABLE OIL INJECTION WELL (GROUNDWATER ELEVATION, ft msl)
- GROUNDWATER POTENTIOMETRIC SURFACE CONTOUR
- ASPHALT
- APPROXIMATE GROUNDWATER FLOW DIRECTION

0 20 40 80
FEET

FIGURE 4.7

GROUNDWATER POTENTIOMETRIC SURFACE, AUGUST 2003

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

C:_JOBS\739484\NF-VIA-gw-0803.dwg plotted: 11/21/2006

was designed assuming that groundwater flow was toward the west-southwest, toward the Mississippi River.

During the baseline sampling event, prior to vegetable oil injection, groundwater flow beneath the injection area was toward the southwest, toward the Mississippi River (Figure 4.1). Prior to the commencement of injection activities, the groundwater potentiometric surface was relatively flat in the area of the injection wells and downgradient as far as PES-MW-3. The horizontal gradient in the upgradient portion of the pilot test area was approximately 0.013 feet per foot (ft/ft). Immediately downgradient of monitoring well PES-MW-3 the hydraulic gradient appears to steepen. The hydraulic gradient between PES-MW-3 and PES-MW-4 was approximately 0.087 ft/ft. This zone coincides with the edge of the intermediate silt unit as interpreted by the USGS (2003a) (Section 2.3). Downgradient of PES-MW-4 the groundwater potentiometric surface is relatively flat and appears to slope toward the Mississippi River. During the February 2002 process monitoring event the groundwater flow throughout the pilot test area appeared to be toward the southwest and the Mississippi River (Figure 4.2). In the injection area and the upgradient portions of the monitoring well network (upgradient of PES-MW-4), groundwater potentiometric surface gradients were very similar to those observed during the baseline sampling event.

During the May 2002 process monitoring event the groundwater potentiometric surface was generally two to three feet higher across the entire pilot test area (Figure 4.3). Groundwater flow directions and horizontal hydraulic gradients were very similar to those observed during the baseline and February 2002 sampling events. However, the groundwater flow direction in the portion of the pilot test area upgradient of the injection wells appears to have reversed such that groundwater flow in this area was toward the northeast. This apparent reversal is evidenced by groundwater elevation data collected from the injection wells, MW-46S, PES-MW-1, PES-MW-6, and PES-MW-7. This groundwater flow direction reversal may be due to seasonal fluctuations in groundwater flow conditions or to the influence of extraction wells located across the road from ACP.

In August 2002 the groundwater potentiometric surface elevation was slightly lower than during the May 2002 event (Figure 4.4). Groundwater flow in the upgradient portion of the pilot test area was again toward the southwest; the groundwater flow reversal observed in this area in May 2002 was no longer present in August 2002.

In December 2002 the groundwater potentiometric surface was approximately two feet higher than in August 2002 and approximately four feet higher than in December 2001 (Figure 4.5). The groundwater flow directions in December 2002 were similar to those observed in August 2002 in that groundwater flow was toward the southwest in the majority of the pilot test area.

During the April and August 2003 sampling events (Figures 4.6 and 4.7) groundwater flow conditions were nearly identical to those observed during the December 2002 sampling round, except that the groundwater potentiometric surface during the 2003 sampling events was approximately 2 feet lower than during the December 2002 event.

Groundwater potentiometric surface maps that were prepared for sampling events after August 2003 are presented in various technical memoranda that have been submitted

under separate covers to USEPA and MPCA. The most recent potentiometric surface map that was prepared using data collected in November 2005 is presented in Appendix G, Figure 4.

4.1.2 Hydraulic Conductivity and Groundwater Flow Velocities

Table 4.2 presents the results of pre- and post-injection aquifer tests and estimates of groundwater seepage velocity. The geometric mean for hydraulic conductivity values measured in the upgradient portion of the injection area (upgradient of PES-MW-8 and PES-MW-9) was 176.6 feet per day (ft/day) (0.062 centimeters per second [cm/sec]). Hydraulic conductivity tests conducted in wells PES-MW3, PES-MW-8, and PES-MW-9 indicate that these wells are screened in a relatively low hydraulic conductivity zone. The geometric mean for hydraulic conductivity values measured PES-MW-3, PES-MW-8, and PES-MW-9 was 29.5 ft/day (0.010 cm/sec). The hydraulic conductivity calculated for well PES-CW-1, located in the northern portion of the site, was approximately 196 ft/day. Geometric mean groundwater flow velocities, calculated from data collected prior to injection, ranged from approximately 438 feet per year (ft/yr) to 2,545 ft/yr.

During each sampling round, separate vegetable oil thickness measurements were collected with an interface probe at each well location. Significant thicknesses of vegetable oil were detected in injection wells PES-INJ-2 and PES-INJ-3. Separate phase vegetable oil was also detected intermittently in PES-INJ-1. At each injection well the thickest layer of separate phase vegetable oil was detected during the February 2002 event (2 months after injection). During the successive sampling events vegetable oil thickness decreased rapidly to less than 0.01 foot in all three injection wells. The separate phase vegetable oil thickness decreased most rapidly in PES-INJ-1 (Table 4.1). Review of the data indicates that the separate phase vegetable oil thickness at all three injection wells is cyclical and likely related to the groundwater flow conditions(particularly at PES-INJ-3).

Comparison of the pre- and post-injection aquifer test data (Table 4.2) indicates that hydraulic conductivities measured in the injection wells immediately after injection (December 2002) are an order of magnitude lower than pre-injection hydraulic conductivities for the same wells. This decrease in hydraulic conductivity is likely due to the presence of large quantities of vegetable oil-in-water emulsion in these wells. As a result, the decrease in hydraulic conductivity observed in the injection wells is likely limited to the immediate area surrounding the injection wells. The observed impact to hydraulic conductivity is likely a long-term effect of the vegetable oil injection and will likely last until the vegetable oil and associated biomass have been depleted. The likely result is that shallow groundwater flow will be deflected to some extent around the injection area. However, the cross-sectional area of the volume of the aquifer impacted by the injection (perpendicular to groundwater flow) is relatively small (approximately 40 feet [USGS, 2003]). Thus, the impact of the injection on groundwater flow in ACP is likely to be very small and localized.

TABLE 4.2
PRE- AND POST-INJECTION HYDRAULIC CONDUCTIVITIES AND AVERAGE GROUNDWATER VELOCITIES
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Monitoring Well	Test Date	Rising or Falling Test	Screened Interval (ft bgs)[a/]	Casing Inside Diameter (inches)	Static Water Level (feet btoc)	Hydraulic Conductivity (K) (ft/day)[b/]	(cm/sec)[c/]	(gpd/ft^2)[d/]	Estimated Effective Porosity	Hydraulic Gradient (ft/ft)[e/]	Maximum Groundwater Velocity (ft/yr)[f/]
Pre-Injection Slug Tests in the Injection Area											
PES-INJ-1	12/7/01	Both	35-45	3.0	28.37	210	7.43E-02	1,574	0.25	0.002	522
PES-INJ-2	12/7/01	Both	40-50	3.0	28.84	221	7.79E-02	1,651	0.25	0.002	548
PES-INJ-3	12/7/01	Both	40-50	3.0	28.73	254	8.96E-02	1,898	0.25	0.002	630
PES-MW-1	12/7/01	Both	35-45	2.0	28.55	177	6.23E-02	1,321	0.25	0.002	438
GEOMETRIC MEAN						**214**	**7.54E-02**	**1,597**	**0.25**	**0.00**	**530**
Pre-Injection Slug Tests Down Gradient From the Injection Area											
PES-MW-3	12/6/01	Both	30-40	2.0	29.66	23	8.15E-03	173	0.25	0.059	1,988
PES-MW-4	12/6/01	Both	30-40	2.0	31.20	14	5.03E-03	107	0.25	0.059	1,228
PES-MW-8	12/7/01	Both	30-40	2.0	28.70	78	2.77E-02	587	0.25	0.059	6,754
GEOMETRIC MEAN						**30**	**1.04E-02**	**221**	**0.25**	**0.059**	**2,545**
PES-CW-1	12/6/01	Both	30-40	2.0	31.38	**196**	**6.92E-02**	**1,467**	**0.25**	**0.002**	**572**
December 2002 Post-Injection Slug Tests in the Injection Area											
PES-INJ-1	12/14/02	Both	35-45	3.0	28.73	11	3.87E-03	82	0.25	0.002	27
PES-INJ-2	12/14/02	Rise	40-50	3.0	28.82	7.9	2.79E-03	59	0.25	0.002	20
PES-INJ-3	12/14/02	Both	40-50	3.0	28.73	13	4.59E-03	97	0.25	0.002	32
GEOMETRIC MEAN						**10**	**3.67E-03**	**78**	**0.25**	**0.002**	**26**
December 2002 Post-Injection Slug Tests Down Gradient From the Injection Area											
PES-MW-1	12/16/02	Rise	35-45	2.0	26.67	83	2.93E-02	622	0.25	0.041	4,974
PES-MW-6	12/16/02	Rise	35-45	2.0	26.60	70	2.46E-02	522	0.25	0.041	4,179
PES-MW-7	12/16/02	Rise	40-50	2.0	26.79	110	3.87E-02	820	0.25	0.041	6,560
GEOMETRIC MEAN						**86**	**3.04E-02**	**643**	**0.25**	**0.04**	**5,147**
April 2003 Post-Injection Slug Tests in the Injection Area											
PES-INJ-1	4/5/03	Both	35-45	3.0	27.73	1.0	3.39E-04	7.2	0.25	0.002	2.4
PES-INJ-2	4/4/03	Both	40-50	3.0	28.23	8.4	2.96E-03	63	0.25	0.002	21
GEOMETRIC MEAN						**2.8**	**1.00E-03**	**21**	**0.25**	**0.00**	**7.0**
April 2003 Post-Injection Slug Tests Down Gradient From the Injection Area											
PES-MW-1	4/4/03	Both	35-45	2.0	27.77	124	4.36E-02	925	0.25	0.041	7,399
PES-MW-6	4/4/03	Both	35-45	2.0	27.71	68	2.40E-02	509	0.25	0.041	4,071
PES-MW-7	12/16/02	Both	40-50	2.0	26.79	85	2.99E-02	633	0.25	0.041	5,069
GEOMETRIC MEAN						**86**	**3.04E-02**	**644**	**0.25**	**0.041**	**5,156**
August 2003 Post-Injection Slug Tests in the Injection Area											
PES-INJ-1	8/28/03	Both	35-45	3.0	27.73	0.3	9.00E-05	1.9	0.25	0.002	0.6
PES-INJ-2	8/27/03	Both	40-50	3.0	28.23	2.7	9.60E-04	20	0.25	0.002	6.8
GEOMETRIC MEAN FOR POST-INJECTION TESTS						**0.8**	**2.94E-04**	**6.2**	**0.25**	**0.00**	**2.1**
August 2003 Post-Injection Slug Tests Down Gradient From the Injection Area											
PES-MW-1	8/27/03	Both	35-45	2.0	27.77	94	3.31E-02	702	0.25	0.020	2,741
PES-MW-6	8/27/03	Both	35-45	2.0	27.71	94	3.32E-02	704	0.25	0.023	3,159
PES-MW-7	8/27/03	Both	40-50	2.0	26.79	66	2.34E-02	496	0.25	0.012	1,161
GEOMETRIC MEAN FOR POST-INJECTION TESTS						**81**	**2.87E-02**	**607**	**0.25**	**0.018**	**2,094**

[a/] ft bgs = feet below ground surface.
[b/] ft/day = feet per day.
[c/] cm/sec = centimeters per second.
[d/] gpd/ft^2 = gallons per day per square foot.
[e/] ft/ft = foot per foot.
[f/] ft/yr = feet per year.
[g/] Pre-injection mean calculations are for wells upgradient of PES-MW8 and PES-MW9.
[h/] Pre-injection mean calculations are for wells PES-MW3, PES-MW8, and PES-MW9.
[i/] Pre-injection calculations are for well PES-CW1.

Hydraulic conductivity values calculated from data collected one year after injection (December 2002) are similar to those calculated from the pre-injection testing round (Table 4.2). This indicates that the decrease in hydraulic conductivity observed immediately after injection was a transient effect and that the hydraulic conductivity of the aquifer matrix in the vicinity of the first line of monitoring wells (PES-MW-1, PES-MW-6, and PES-MW-6) has returned to baseline conditions. Hydraulic conductivity data collected during the April and August 2003 sampling rounds indicate that the hydraulic conductivity in the vicinity of the first line of monitoring wells has remained at near baseline conditions since December 2002.

During the summer of 2003, a technical meeting was held to discuss groundwater flow data collected by the USGS. During the meeting it was determined that there was significant upward vertical groundwater flow within ACP from the PC aquifer to the unconsolidated aquifer system and that vertical and horizontal flow conditions within the park were not adequately defined (USGS, 2003). The pilot test was designed with the assumption that there was only horizontal flow within the pilot test area. The impact of significant vertical flow on the pilot test is difficult to determine because vertical flow within the park is not well-defined. However, it is likely that significant vertical groundwater flow within the pilot test area will impact the pilot test by introducing geochemical and contaminant concentration heterogeneity to the pilot test area. The likely result will be that groundwater geochemical and contaminant concentration data will be heterogeneous both spatially and temporarily, particularly if vertical flow varied over space and time within the timeframe of the test.

In addition, horizontal groundwater flow conditions are variable within ACP and the pilot test area, as evidenced by periodic groundwater flow reversals observed within the injection area and in the downgradient portions of the pilot test area. This variability is likely related to seasonal variations in precipitation and river stage, variations in vertical groundwater flow, and variations in groundwater extraction rates at the extraction wells installed upgradient of ACP. The result of the variable groundwater flow conditions is that geochemical and contaminant conditions within the pilot test area are also variable.

4.2 SOIL SAMPLING RESULTS

Soil analytical results collected during well installation activities are summarized in Table 4.3. The complete soil analytical data package is presented in Appendix C of the Project Completion Report (CCI, 2002).

4.2.1 Total Organic Carbon in Soil

A total of 13 soil samples were collected from 13 locations during the course of drilling and well installation activities at ACP and sent to Enchem, Inc. for TOC analysis using USEPA Method 9060. At each drilling location, soil samples were collected from the vertical interval where the monitoring well screens were to be placed in order to quantify concentrations of organic carbon within the soil matrix surrounding the screened interval. An additional 7 soil samples were collected in 2005 during the expanded monitoring program from areas that are unimpacted by vegetable oil and analyzed for TOC and VOCs. The complete TOC in soil data set is presented in Table 4.3.

TABLE 4.3

SUMMARY OF SOIL ANALYTICAL DATA

NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY

ANOKA COUNTY PARK

FRIDLEY, MINNESOTA

Sample Location	Sample Date	Sample Depth (feet bgs)[a/]	Stratigraphic Description	TCE[b/] (µg/kg)[c/]	*cis*-1,2-DCE[b/] (µg/kg)	*trans*-1,2-DCE (µg/kg)	Vinyl Chloride (µg/kg)	1,2-DCA[b/] (µg/kg)	Carbon Tetrachloride (µg/kg)	Acetone (µg/kg)	2-Butanone (µg/kg)	Bromomethane (µg/kg)	Total Organic Carbon (mg/kg)[d/]
PES-BG-1	17-Oct-01	37	Medium to coarse sand	**21**	< 1.3[e/]	< 1.3	< 2.2	< 1.4	< 1.4	< 6.4	< 1.8	< 1.3	**410**
PES-CW-1	5-Nov-01	35	Fine to medium sand	**48**	< 1.3	< 1.3	< 2.2	< 1.4	< 1.4	< 6.5	< 1.8	< 1.3	**1,100**
PES-CW-2	5-Nov-01	37	Medium sand	**51**	< 1.3	< 1.3	< 2.3	<1.4	< 1.4	**7.8**	< 1.9	< 1.4	**1,700**
PES-CW-3	2-Nov-01	35	Dense Clay	**43**	< 1.3	< 1.3	< 2.3	< 1.5	< 1.5	< 6.7	< 1.9	< 1.4	**7,100**
PES-MW-1	25-Oct-01	39	Fine sand	**41**	< 1.4	<1.4	< 2.4	< 1.5	< 1.5	< 6.9	< 2.0	< 1.4	**510**
PES-MW-2	30-Oct-01	41	Fine sand	**140**	< 1.4	< 1.8	< 2.3	**4.9**	**7.9**	< 6.8	**3.2J**[f/]	**2.3J**	**1,200**
PES-MW-3	1-Nov-01	35	Sandy silt	**200**	**3.1**	**4.4**	< 2.1	< 1.3	< 1.3	< 6.2	< 1.7	< 1.3	**570**
PES-MW-4	1-Nov-01	35	Lean sandy clay	**190**	**8.9**	**22**	< 2.2	<1.4	< 1.4	< 6.4	< 1.8	< 1.3	**590**
PES-MW-5	2-Nov-01	35	Lean sandy clay	**9.2**	**1.7**	< 1.3	< 2.3	< 1.5	< 1.5	< 6.7	< 1.9	< 1.4	**6,000**
PES-MW-6	29-Oct-01	40	Fine sand	**710**	**9.8**	**12**	< 12	< 7.9	< 7.9	< 36	< 10	**14J**	**320**
PES-MW-7	26-Oct-01	45	Fine sand	**2.5J**	< 1.3	< 1.4	< 2.3	< 1.5	< 1.5	< 6.8	< 1.9	< 1.4	**590**
PES-MW-8	31-Oct-01	35	Dense lean clay	**130**	**1.6**	**3.6**	< 2.1	<1.4	< 1.4	< 6.2	< 1.8	< 1.3	**1,400**
PES-MW-9	31-Oct-01	37	Medium sand	**100**	< 1.3	< 1.4	< 2.3	< 1.5	< 1.5	< 6.8	< 1.9	< 1.4	**500**
PES-MW-12B	5-Apr-05	62 - 63	Cohesive tight clay. no odor.	**190**	25 U	18 U	18 U	26 U	20 U	**140 J**	89 U	30 U	**5,900**
PES-MW-13A	28-Mar-05	26 [f/]	Sandy silt, no odor	**200**	22 U	16 U	16 U	23 U	18 U	64 U	80 U	27 U	**610**
	28-Mar-05	27	sandy silt, no odor	**89**	22 U	17 U	16 U	23 U	18 U	64 U	81 U	27 U	**460 J**
	28-Mar-05	42	Fine sand, no odor	**59**	23 U	17 U	17 U	24 U	19 U	66 U	84 U	28 U	**330 J**
PES-MW-14B	4-Apr-05	40 - 42	Sandy silt, no odor	**220**	**130**	16 U	16 U	23 U	18 U	63 U	79 U	27 U	**580**
	4-Apr-05	42	Sandy silt, no odor	**200**	**250**	**22 J**	16 U	23 U	18 U	64 U	81 U	27 U	**510**
	4-Apr-05	68 - 70	Fine sand, no odor	23 U	23 U	17 U	17 U	24 U	19 U	**360**	84 U	28 U	**370 J**

[a/] feet bgs = feet below ground surface.

[b/] TCE = trichloroethene; DCE = dichloroethene; DCA = dichloroethane.

[c/] µg/kg = micrograms per kilogram.

[d/] mg/kg = milligrams per kilogram.

[e/] <25 indicates that the analyte was not detected above the indicated method detection limit.

[f/] J indicates that the analyte was detected at a concentration above the method detection limit but below the reporting limit resulting in an estimated value.

TOC concentrations detected in soils at ACP ranged from 320 milligrams per kilogram (mg/kg) to 7,100 mg/kg. The average TOC concentration in soil samples collected upgradient of PES-MW-4 is approximately 677 mg/kg, while the average TOC concentration in soil samples collected downgradient from PES-MW-5 is approximately 3,975 mg/kg. The reason for this apparent increase in soil TOC detections in the direction of the river is likely related to organic material deposited by the river. In any case, the soil TOC data indicates that the subsurface soils beneath ACP are relatively rich in naturally-occurring organic carbon. Therefore, significant contaminant adsorption to the soil matrix, and consequent contaminant migration retardation, would be expected at ACP. Furthermore, contaminant retardation would be expected to increase near the river due to the observed increase in soil TOC concentrations.

Partitioning of a chemical from the dissolved phase to the solid phase is commonly referred to as soil sorption, and is quantified by the soil partition coefficient or distribution coefficient (K_d), which is the proportionality constant relating the amount of chemical sorbed to soil and dissolved in the groundwater. This description of the process assumes that partitioning between the sorbed and dissolved phases is completely reversible, and that the equilibrium isotherm relating the relative concentrations in the two phases is linear (Lyman *et al*., 1992). Organic matter in soil controls sorption where there is sufficient organic matter present (more than 0.1 percent organic carbon). This observation has been used as the basis for normalizing the linear partition coefficient to the concentration of TOC in the soil (Karickhoff *et al*., 1979; Karickhoff, 1981). If the organic carbon content of the soils at ACP can be characterized or estimated, these data can be used to evaluate chemical partitioning to the soil matrix. Specifically, the fraction of sorbed CAHs increases as the concentration of organic carbon in the soil increases.

Chemical sorption to the soil matrix is particularly important because sorption tends to slow or retard the advancement rate of the contaminant plume front. The retardation of contaminants is relative to the advective velocity of the groundwater and the amount of organic carbon present in the soil matrix. The retardation factor of a particular contaminant can be estimated by the following formula from EPA, 1998:

$$R = 1 + (\rho_0 K_d / n)$$

Where:
R = Retardation coefficient
ρ_0 = bulk density of the aquifer matrix
Kd = Contaminant distribution coefficient
n = total porosity of the aquifer matrix

Retardation coefficients were calculated based on the measurement of TOC concentrations (Table 4.3), an assumed bulk density of the more transmissive silty sand of 1.65 grams per cubic centimeter (typical for soils of this type), and conservative soil sorption coefficient factors for TCE, cis-1,2-DCE, and VC of 119, 45, and 2.5 respectively. The calculated retardation coefficients for TCE, cis-1,2-DCE, and VC are 1.46, 1.09. and 1.01 respectively (Table 4.4). As expected, the more highly chlorinated compound TCE is more heavily retarded than the less chlorinated compounds cis-1,2-DCE and VC.

TABLE 4.4
CONTAMINANT RETARDATION COEFFICIENTS
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Compound	K_{oc} (L/kg [a/])	Fraction Organic Carbon [b/]	Distribution Coefficient (L/kg)	Bulk Density (kg/L) [c/]	Total Porosity [d/]	Coefficient of Retardation	Average Pre-injection Groundwater Velocity (ft/yr) [e/]	Contaminant Velocity (ft/yr)
Silty fine to medium sand values								
TCE	119 [f/]	0.00079	0.094	1.72	0.35	1.46	1730	1183
cis-1,2-DCE	49 [f/]	0.00079	0.039	1.72	0.35	1.19	1730	1453
VC	2.5 [g/]	0.00079	0.002	1.72	0.35	1.01	1730	1714

[a/] L/kg = liters per kilogram.

[b/] The fraction of organic carbon for each soil type was calculated by averaging the TOC data set presented in Table 4.3.

[c/] kg/L = kilograms per liter.

[d/] Porosity values are from Fetter, 1994.

[e/] ft/yr = feet per year.

[f/] Howard, 1990 at 25 degrees centigrade.

[g/] Knox et. al., 1993.

4.2.2 Stratigraphic Data

The boring logs compiled during the most recent drilling activities completed in 2005 were combined with the historic boring logs and used to develop a fence diagram which depicts the stratigraphic data collected during drilling in three dimensions (Figure 3 of the final Technical Memorandum included as Appendix G). Review of the boring log data and the fence diagram indicates that the stratigraphy beneath the pilot test site is relatively consistent on a study area scale. The soil beneath the pilot test area consists predominantly of fine to medium sand and silty sand which extends from approximately 5 feet bgs to below the maximum drilling depth of 70 feet bgs. At approximately 30 feet bgs there is a fine grained of unit of variable thickness which consists predominantly of silt and clay. This fine grained unit ranges in thickness from less than one foot to a maximum of approximately 6 feet and is continuous throughout the pilot test area. There are also a number of smaller, less continuous, fine grained units present beneath the pilot test area. In particular, there appears to be a relatively large, thin silt/clay unit present at a depth of approximately 60 feet beneath and downgradient from the injection area. It is likely that these fine grained units impact and therefore to some extent control groundwater flow characteristics locally within the pilot test area.

The vegetable oil that was injected as part of this study was injected between 35 and 50 feet bgs, which would place it between the two observed silt units in the stratigraphic unit that appears to contain the highest contaminant concentrations.

4.2.3 Pre-Injection Extent of Chlorinated Aliphatic Hydrocarbons in Soil

Soil samples were collected at various intervals from a total of 13 newly-drilled boreholes and sent to Enchem, Inc. for VOC analysis using USEPA Method 8260B. The complete VOC analytical data package is presented in Appendix C of the Project Completion Report (CCI, 2002). VOC analytical results collected during this study indicate that there were a total of eight contaminants detected at concentrations above the associated analysis method detection limits (MDLs) (Table 4.3). All of the contaminants detected in soil, with the exception of TCE, were detected at relatively low concentrations (less than 100 micrograms per kilogram [μg/kg]).

TCE concentrations detected in soil ranged from 2.5 μg/kg to a maximum of 710 μg/kg detected at PES-MW-6. Detected soil TCE concentrations were significantly higher in the upgradient portions of the pilot test area (upgradient of PES-MW-5), with the exceptions of locations PES-BG-1, PES-MW-1, and PES-MW-7.

cis-1,2-DCE and/or *trans*-1,2-DCE were detected at low concentrations (less than 25 μg/kg) at monitoring wells PES-MW-3, PES-MW-4, PES-MW-5, PES-MW-6, and PES-MW-8. VC was not detected in any of the soil samples. The detection of low concentrations of the reductive dechlorination daughter product DCE in soil indicates that limited reductive dechlorination may have been occurring prior to vegetable oil injection at this site.

4.3 PRE-INJECTION EXTENT OF CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER

Groundwater samples from the 15 newly-installed injection and monitoring wells as well as three existing monitoring wells were collected prior to injection and analyzed for VOCs by Enchem, Inc., using USEPA Method 8260B. Analytical results for select VOCs in groundwater collected prior to injection are summarized in Table 4.5. The MPCA collected split samples in parallel with primary groundwater samples collected during the baseline sampling effort. The analytical results from the MPCA split samples and the analytical data from the associated primary samples are presented in Appendix D with an RPD calculated for each pair of results.

Baseline (pre-injection) groundwater sampling results indicate that TCE was detected at concentrations above the associated MDL at 14 of the 15 locations sampled, with a maximum concentration of 20,000 µg/L detected at location GWMS-46S. Other VOCs detected during the baseline sampling event (and the maximum concentration) include PCE (0.92 µg/L; *cis*-1,2-DCE (160 µg/L); *trans*-1,2-DCE (220 µg/L); 1,1-DCA (0.89 µg/L); acetone (3.3 µg/L); and benzene (12 µg/L). The detection of the common CAH degradation byproducts *cis*-1,2-DCE and *trans*-1,2-DCE indicate that some reductive dechlorination is or was occurring at ACP prior to the injection of the vegetable oil. The single detection of benzene indicates that fuel hydrocarbons may have been released in localized portions of at this site in the past. The 2-butanone and acetone detections are likely laboratory-introduced contaminants as these analytes were detected at only one location and at low concentrations.

During the baseline sampling event the highest concentrations of TCE in groundwater were detected upgradient of PES-MW-4, with the maximum TCE concentration detected in GWMS-46S. The average TCE concentration detected upgradient of PES-MW-4 was approximately 4,100 µg/L, while the average TCE concentration downgradient of PES-MW-4 is approximately 210 µg/L.

4.4 POST-INJECTION PROFILE OF CHLORINATED ALIPHATIC HYDROCARBONS

4.4.1 Chlorinated Ethenes Over Time

Reductions in contaminant concentrations and changing molar fractions (i.e., declining mass fraction of TCE and increasing mass fraction of daughter products such as *cis*-1,2-DCE) of dissolved constituents over time can be indicative of biodegradation. The overall plume appears to be relatively stable, with slightly lower concentrations of TCE in November 2005 with respect to the TCE concentrations detected during the baseline sampling round. Contaminant concentrations measured in the injection wells exhibit a dramatic decline over time. The maximum concentration of TCE measured for the injection wells was 1,400 µg/L at PES-INJ-1 prior to injection, while the maximum concentration of TCE for the injection wells detected during the April 2005 sampling round was 10 µg/L in the same well. The decline in TCE concentrations in the injection wells was not accompanied by a significant increase in concentrations of DCE or VC, indicating that the decline in dissolved TCE concentration is likely due to preferential partitioning of VOC mass into the vegetable oil NAPL. However, elevated

TABLE 4.5
SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Date	PCE[a/] (µg/L)[b/]	TCE[a/] (µg/L)	*cis-* 1,2-DCE[a/] (µg/L)	*trans* 1,2-DCE[a/] (µg/L)	1,1-DCE[a/] (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA[a/] (µg/L)	1,1-DCA[a/] (µg/L)	1,2-DCA[a/] (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Bromodichloro -methane (µg/L)	2-Butanone (µg/L)	Acetone (µg/L)	Benzene (µg/L)	Toluene (µg/L)
MONITORING WELLS																	
18-S	18-Apr-05	0.45 U	**400**	**96**	**27**	**0.87 J**	**0.37 J**	0.90 U	**0.89 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**39**	0.41 U	0.67 U
MS-26S	15-Apr-05	**0.63 J**	**230**	**48**	**2.7**	**0.61 J**	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
GWMS-27S	12-Nov-01	0.39 U[c/]	0.44 U	0.99 U	0.38 U	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	**3.3**	**12**	0.42 U
	11-Feb-02	0.39 U	**0.76 J**[d/]	**2.4**	0.38 U	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	21-May-02	0.39 U	**89**	**12**	**0.97**	0.47 U	0.17 U	0.53 U	**1.2**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.39 U	**170**	**50**	**5.1**	**0.62 J**	0.17 U	0.53 U	**0.62 J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	9-Dec-02	0.25 U	**54**	**33**	**0.99 J**	**0.58 J**	0.30 U	0.23 U	**0.94 J**	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	7-Apr-03	0.24 U	**140 J**	**10**	**1.5**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	18-Aug-03	**0.30 J**	**290**	**45**	**6.4**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	**23**	0.11 U	0.11 U
MS-36S	22-Apr-05	0.45 U	**21**	**270**	**51**	0.57 U	**1.7**	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
MS-44S	18-Apr-05	0.45 U	**77**	**19**	**2.3**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**4.0 J**	0.41 U	0.67 U
GWMS-45S	18-Apr-05	0.45 U	**180**	**550**	**62**	**2.3**	**0.28 J**	0.90 U	**1.5**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**5.7**	0.41 U	0.67 U
GWMS-46S	19-Nov-01	78 U	**20,000**	200 U	**200**	94 U	34 U	110 U	94 U	0.52 U	0.54 U	0.47 U	0.42 U	210 U	330 U	88 U	84 U
	18-Feb-02	39 U	**14,000**	**120**	**140**	47 U	17 U	53 U	47 U	52 U	54 U	47 U	42 U	100 U	160 U	44 U	42 U
	22-May-02	1.9 U	**5,600**	**55**	**61**	**4.6**	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	28-Aug-02	0.78 U	**4,900**	**29**	**29**	**2.5**	**0.92 J**	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.8 U	2.1 U	**5.0 J**	0.88 U	0.84 U
	11-Dec-02	1.2 U	**7,200**	**65**	**73**	**6.4**	1.5 U	1.2 U	1.0 U	1.7 U	1.4 U	0.95 U	1.6 U	4.3 U	10 U	1.0 U	1.1 U
	9-Apr-03	0.24 U	**2,600**	**24**	**32**	**2.6**	**0.6 J**	0.23 U	**1.0**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	20-Aug-03	0.24 U	**4,500**	**57**	**85**	**3.5**	**1.3 J**	0.23 U	**1.8**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	18-Apr-05	0.45 U	**1,700**	**55**	**51**	**1.7**	**0.45 J**	0.90 U	**1.8**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
	17-Nov-05	0.45 U	**1,300**	**35**	**36**	**2.0**	**0.43 J**	0.90 U	**1.7**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
GWMS-47S	14-Nov-01	**0.92**	**44**	**22**	**1.1**	0.47 U	0.17 U	0.53 U	**0.89**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	12-Feb-02	**1.1 J**	**180**	**9.9**	**2.1**	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	21-May-02	**0.60**	**220**	**9.3**	**3.3**	**0.50**	0.17 U	0.53 U	**1.1**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.39 U	**120**	**6.6**	**3.3**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	10-Dec-02	**0.64 J**	62 U	**25**	**1.4**	0.26 U	0.30 U	0.23 U	0.20 U	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	8-Apr-03	**1.5**	66 U	**20**	1.4 U	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	19-Aug-03	**1.1**	**57**	**14**	**1.2**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	11-Apr-05	**0.87 J**	**42**	**4.1**	0.89 U	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
MS-53PC	11-Apr-05	0.45 U	**0.83 J**	0.83 U	0.19 U	0.75 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.7 U	0.41 U	0.67 U
PES-MW-1	16-Nov-01	3.9 U	**1,100**	**14**	**15**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.40 U	4.7 U	4.2 U	10 U	16 U	4.4 U	4.2 U
	15-Feb-02	7.8 U	**1,100**	20 U	**20 J**	9.4 U	3.4 U	11 U	9.4 U	10 U	11 U	9.4 U	8.4 U	21 U	33 U	8.8 U	8.4 U
	22-May-02	0.78 U	**3,200**	**450**	**75**	**4.5**	0.34 U	1.1 U	**1.6**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	28-Aug-02	0.39 U	**2,600**	**630**	**39**	**3.8**	**1.3 J**	0.53 U	**1.5**	0.52 U	0.54 U	0.47 U	0.42 U	12 U	8.2 U	0.44 U	0.42 U
	12-Dec-02	0.50 U	**1,700**	**230**	**26**	**2.5**	0.6 U	0.46 U	**1.4 J**	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	1.0 U	0.40 U	**4.1**
	10-Apr-03	0.24 U	**1,300**	**370**	**30**	**2.0**	0.17 U	0.23 U	**1.2**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	21-Aug-03	0.24 U	**1,200**	**1100**	**79**	**3.2**	**1.4 J**	0.23 U	**2.3**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	15-Apr-05	0.45 U	**380**	**210**	**16**	**0.99 J**	0.18 U	0.90 U	**1.0**	0.36 U	0.49 U	0.37 U	0.56 U	4.30 U	**2.5 J**	0.41 U	0.67 U
PES-MW-2	15-Nov-01	7.8 U	**2,100**	**22**	**27**	9.4 U	3.4 U	11 U	9.4 U	10 U	11 U	9.4 U	8.4 U	21 U	33 U	8.8 U	8.4 U
	14-Feb-02	20 U	**3,600**	50 U	**68**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
	22-May-02	0.78 U	**2,200**	**62**	**39**	**3.1**	**0.59**	1.1 U	**1.7**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	**9.3**	0.88 U	0.84 U
	28-Aug-02	0.78 U	**3,200**	**21**	**26**	**2.0 J**	0.34 U	1.1 U	**1.3 J**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	11-Dec-02	0.50 U	**2,600**	**24**	**32**	**3.0**	0.60 U	0.5 U	**1.4 J**	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	4.0 U	0.40 U	0.44 U
	9-Apr-03	0.24 U	**2,900**	**46**	**55**	**2.7**	**0.53 J**	0.23 U	**1.6**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	20-Aug-03	0.24 U	**2,000**	**27**	**57**	**2.2**	**0.39 J**	0.23 U	**2.0**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	14-Apr-05	0.45 U	**930**	**45**	**18**	**1.5**	0.18 U	0.90 U	**0.93 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-3	14-Nov-01	20 U	**5,000**	**73**	**110**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
	13-Feb-02	20 U	**6,100**	**120**	**170**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
	21-May-02	1.9 U	**6,200**	**220**	**160**	**5.3**	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	27-Aug-02	1.9 U	**5,900**	**390**	**95**	**4.7 J**	**2.2 J**	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	10-Dec-02	1.2 U	**5,000**	**260**	**120**	**5.7**	1.5 U	1.2 U	1.0 U	1.7 U	1.4 U	0.95 U	1.6 U	4.3 U	10 U	1.0 U	1.1 U
	8-Apr-03	0.24 U	**3,800**	**300**	**130**	**3.7**	**1.1 J**	0.2 U	**2.3**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	20-Aug-03	0.24 U	**2,400**	**320**	**110**	**3.0**	**0.90 J**	0.23 U	**2.8**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	14-Apr-05	0.45 U	**830**	**170**	**51**	**1.8**	**0.34 J**	0.90 U	**1.4**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-4	14-Nov-01	7.8 U	**3,300**	**83**	**120**	9.4 U	3.4 U	11 U	9.4 U	10 U	11 U	9.4 U	8.4 U	21 U	33 U	8.8 U	8.4 U
	12-Feb-02	7.8 U	**3,300**	**88**	**110**	9.4 U	3.4 U	11 U	9.4 U	10 U	11 U	9.4 U	8.4 U	21 U	33 U	8.8 U	8.4 U
	21-May-02	0.78 U	**4,200**	**140**	**190**	**4.1**	0.34 U	1.1 U	**3.5**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	27-Aug-02	0.78 U	**3,100**	**56**	**67**	**2.2**	0.34 U	1.1 U	**1.7 J**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	10-Dec-02	0.50 U	**2,100**	**72**	**82**	**2.6**	0.60 U	0.46 U	**1.9 J**	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	4.0 U	0.40 U	0.44 U
	8-Apr-03	0.24 U	**2,300**	**80**	**100**	**2.1**	0.17 U	0.23 U	0.17 U	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	19-Aug-03	**0.73 J**	**2,600**	**130**	**160**	**2.8**	**0.86 J**	0.23 U	**3.2**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	12-Apr-05	0.45 U	**820**	**200**	**86**	**1.5**	**0.33 J**	0.90 U	**2.2**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**180**	0.41 U	0.67 U
	14-Nov-05	0.45 U	**1,000**	**140**	**76**	**1.9**	0.18 U	0.90 U	**2.0**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U

TABLE 4.5 (Continued)
SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Date	PCE[a/] (µg/L)[b/]	TCE[a/] (µg/L)	*cis-* 1,2-DCE[a/] (µg/L)	*trans* 1,2-DCE[a/] (µg/L)	1,1-DCE[a/] (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA[a/] (µg/L)	1,1-DCA[a/] (µg/L)	1,2-DCA[a/] (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Bromodichloro -methane (µg/L)	2-Butanone (µg/L)	Acetone (µg/L)	Benzene (µg/L)	Toluene (µg/L)
PES-MW-5	14-Nov-01	0.39 U	**75**	**29**	**1.8**	0.47 U	0.17 U	0.53 U	**0.76**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	12-Feb-02	0.39 U	**77**	**32**	**2.1**	0.47 U	0.17 U	0.53 U	0.74 **J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	21-May-02	0.39 U	**82**	**34**	**1.8**	0.47 U	0.17 U	0.53 U	**0.67**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	27-Aug-02	0.39 U	**1,000**	**21**	**21**	**1.0**	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	10-Dec-02	0.25 U	120 U	**94**	**4.4**	0.26 U	0.3 U	0.23 U	**2.8**	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	8-Apr-03	0.24 U	**780**	**53**	**17**	0.22 U	0.17 U	0.23 U	**0.97 J**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	19-Aug-03	**0.28 J**	**880**	**28**	**30**	**1.7**	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	12-Apr-05	0.45 U	**38**	**8.7**	**0.92 J**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**9.1**	0.41 U	**0.73 J**
PES-MW-6	15-Nov-01	20 U	**6,200**	**88**	**140**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
	15-Feb-02	20 U	**5,800**	**100**	**150**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	4.2 U
	23-May-02	1.9 U	**5,100**	**84**	**130**	**3.2**	**1.7**	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	28-Aug-02	1.9 U	**6,600**	**87**	**83**	**3.2 J**	**1.4 J**	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	**17 J**	2.2 U	2.1 U
	12-Dec-02	0.50 U	**3,800**	**240**	**71**	**3.9**	0.60 U	0.46 U	**1.6 J**	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	4.0 U	0.4 U	0.44 U
	10-Apr-03	0.24 U	**3,000**	**180**	**100**	**2.7**	**0.77 J**	0.23 U	**2.5**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.1 U	0.11 U
	21-Aug-03	0.24 U	**2,000**	**97**	**61**	**2.8**	**0.59 J**	0.23 U	**2.1**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	15-Apr-05	0.45 U	**700**	**170**	**27**	**1.7**	**0.27 J**	0.90 U	**0.87 J**	0.36 U	0.49 U	0.37 U	0.91 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-7	16-Nov-01	0.78 U	**300**	**5.2**	0.78 U	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	14-Feb-02	1.9 U	**540**	**7.9**	**7.4**	2.3 U	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	**74**	8.2 U	2.2 U	2.1 U
	22-May-02	0.39 U	**980**	**14**	**18**	**2.2**	**0.36**	0.53 U	**1.6**	0.52 U	0.54 U	0.47 U	0.42 U	**130**	**340**	0.44 U	0.42 U
	28-Aug-02	**0.48 J**	**1,300**	**65**	**11**	**2.1**	**0.42 J**	0.53 U	**0.98 J**	0.52 U	0.54 U	0.47 U	0.42 U	**66**	**55**	0.44 U	0.42 U
	12-Dec-02	0.25 U	**350 J**	**180**	**8.3**	**2.0**	0.53 U	0.23 U	**1.0**	0.34 U	0.29 U	0.19 U	0.32 U	**320**	2.0 U	0.20 U	**4.5**
	10-Apr-03	0.24 U	12 U	**270**	**5.5**	**0.99 J**	**0.69 J**	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.32 U	**1,800**	**65**	0.11 U	0.11 U
	21-Aug-03	0.24 U	**2.1**	**410**	**7.2**	0.22 U	**0.90 J**	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	**89**	**14**	0.11 U	0.11 U
	15-Apr-05	0.45 U	**4.1**	**130**	**4.7**	0.57 U	**0.29 J**	0.90 U	**0.89 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**4.9 J**	0.41 U	0.67 U
	17-Nov-05	0.45 U	**1.0**	**150**	**2.7**	0.57 U	**0.80 J**	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	**0.88 J**
PES-MW-8	15-Nov-01	20 U	**6,700**	**160**	**220**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	10 U	82 U	22 U	21 U
	14-Feb-02	20 U	**4,700**	**150**	**200**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	10 U	82 U	22 U	21 U
	22-May-02	1.9 U	**5,400**	**180**	**210**	**4.8**	**2.2**	2.6 U	**4.0**	2.6 U	2.7 U	23 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	27-Aug-02	1.9 U	**5,700**	**130**	**130**	**4.0 J**	**1.8 J**	2.6 U	**3.8 J**	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	**19 J**	2.2 U	2.1 U
	12-Dec-02	1.2 U	**5,500**	**70**	**73**	1.3 U	1.5 U	1.2 U	1.0 U	1.7 U	1.4 U	0.95 U	1.6 U	4.3 U	10 U	1.0 U	1.1 U
	9-Apr-03	0.2 U	**3,000**	**120**	**130**	**3.0**	**0.81 J**	0.23 U	**2.8**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	21-Aug-03	**0.32 J**	**2,200**	**76**	**96**	**3.3**	0.17 U	0.23 U	**1.9**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	14-Apr-05	0.45 U	**1,100**	**90**	**57**	**1.6**	**0.34 J**	0.90 U	**1.5**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-9	15-Nov-01	3.9 U	**1,400**	**15**	**20**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	52 U	16 U	4.4 U	0.42 U
	13-Feb-02	3.9 U	**1,300**	**17**	**20**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	52 U	16 U	4.4 U	4.2 U
	22-May-02	0.78 U	**410**	**1,800**	**63**	**8.2**	**1.2**	1.1 U	**1.5**	1.0 U	1.1 U	0.94 U	0.84 U	**91**	**150**	0.88 U	0.84 U
	27-Aug-02	1.9 U	**120**	**3,000**	**67**	**9.6**	**12**	2.6 U	2.3 U	2.6 U	2.7 U	2.30 U	2.1 U	**290**	**180**	2.2 U	2.1 U
	11-Dec-02	0.50 U	20 U	**1,500**	**33**	**6.8**	**5.7**	0.46 U	0.4 U	0.68 U	0.58 U	0.38 U	0.64 U	**180**	**68**	0.4 U	0.44 U
	9-Apr-03	0.24 U	**2,300**	**180**	**42**	**2.7**	0.17 U	0.23 U	**1.3**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	20-Aug-03	0.24 U	**2,200**	**370**	**110**	**3.2**	**0.71 J**	0.23 U	**2.8**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	13-Apr-05	2.2 U	**490**	**270**	**30**	**1.0**	0.90 U	4.5 U	**0.77 J**	1.8 U	2.40 U	1.8 U	2.8 U	22 U	12 U	2.0 U	3.4 U
	16-Nov-05	0.45 U	**28**	**500**	**18**	**3.2**	0.18 U	0.90 U	**1.0**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-CW-1	13-Nov-01	1.9 U	**630**	**12**	**7.5**	2.3 U	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	11-Feb-02	0.78 U	**170**	**9.5**	**2.4**	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	20-May-02	0.39 U	**170**	**8.2**	**2.3**	0.47 U	0.17 U	0.53 U	**0.86**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.89 **J**	**61**	**39**	**3.8**	0.47 U	0.17 U	0.53 U	**0.65 J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	9-Dec-02	**0.53 J**	**250 J**	**9.6**	**2.9**	**0.67** J	0.30 U	0.23 U	**0.99 J**	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	7-Apr-03	**1.5**	**54**	**9.6**	**0.93 J**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	18-Aug-03	**2.0**	**67**	**8.9**	**0.97 J**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
PES-CW-2	13-Nov-01	1.9 U	**290**	**7.3**	1.9 U	2.3 U	0.85 U	2.6 U	2.3 U	2.3 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	11-Feb-02	0.78 U	**350**	**9.0**	**4.8**	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	20-May-02	0.39 U	**210**	**7.0**	**2.1**	**0.71**	0.17 U	0.53 U	**1.4**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.39 U	**200**	**14**	**3.7**	**0.47 J**	0.17 U	0.53 U	**0.73 J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	9-Dec-02	0.25 U	**230 J**	**6.4**	**1.5**	0.26 U	0.30 U	0.23 U	1.0 U	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	7-Apr-03	**0.75 J**	**100**	**11**	**1.1**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	**0.75 J**
	19-Aug-03	**1.3**	**87**	**14**	**1.5**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	11-Apr-05	0.45 U	**110**	**4.9**	0.89 U	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**12**	0.41 U	0.67 U
	14-Nov-05	**0.66 J**	**63**	**6.4**	0.89 U	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U

TABLE 4.5 (Continued)
SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Date	PCE[a/] (µg/L)[b/]	TCE[a/] (µg/L)	*cis-* 1,2-DCE[a/] (µg/L)	*trans* 1,2-DCE[a/] (µg/L)	1,1-DCE[a/] (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA[a/] (µg/L)	1,1-DCA[a/] (µg/L)	1,2-DCA[a/] (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Bromodichloro -methane (µg/L)	2-Butanone (µg/L)	Acetone (µg/L)	Benzene (µg/L)	Toluene (µg/L)
PES-CW-3	13-Nov-01	0.78 U	**240**	**5.7**	0.76 U	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	12-Feb-02	0.78 U	**330**	**6.5**	**2.3**	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	20-May-02	0.39 U	**200**	**7.0**	**1.3**	**0.77**	0.17 U	0.53 U	**1.4**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.39 U	**230**	**5.8**	**2.9**	0.47 U	0.17 U	0.53 U	**0.88 J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	10-Dec-02	0.25 U	**220 J**	**6.0**	**0.98 J**	**0.58 J**	0.30 U	0.23 U	**1.0**	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	8-Apr-03	0.24 U	190 U	4.7 U	0.25 U	0.22 U	0.17 U	0.23 U	**0.72 J**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	19-Aug-03	0.24 U	**160**	**8.6**	**1.2**	0.22 U	0.17 U	0.23 U	**0.76 J**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	11-Apr-05	0.45 U	**120**	**4.5**	0.89 U	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
	14-Nov-05	0.45 U	**140**	**6.0**	**1.1**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-10A	15-Apr-05	0.45 U	**6.8**	**180**	**4.8**	0.57 U	**0.67 J**	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	**870**	**66**	0.41 U	0.67 U
	16-Nov-05	0.45 U	**1.2**	**81**	**1.4**	0.57 U	**0.56 J**	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	**250**	**9.7**	0.41 U	0.67 U
PES-MW-10B	14-Apr-05	**3.5**	**48**	**3.7**	0.89 U	0.57 U	0.18 U	0.90 U	**0.83 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**2.4 J**	0.41 U	0.67 U
	15-Nov-05	**3.9**	**49**	**4.1**	0.89 U	0.57 U	0.18 U	0.90 U	**0.77 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-11A	13-Apr-05	0.45 U	**100**	**110**	**6.5**	0.57 U	0.18 U	0.90 U	**1.1**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**3.7 J**	0.41 U	0.67 U
	15-Nov-05	0.45 U	**48**	**28**	0.89 U	0.57 U	0.18 U	0.90 U	**1.1**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-12A	12-Apr-05	0.45 U	**80**	**20**	**3.0**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	**1.3**	0.56 U	**11**	**24**	0.41 U	**0.79 J**
	15-Nov-05	0.90 U	**350**	**13**	**5.0**	1.1 U	0.36 U	1.8 U	1.5 U	0.72 U	0.98 U	0.74 U	1.1 U	8.6 U	4.6 U	0.82 U	1.3 U
PES-MW-12B	20-Apr-05	1.1 U	**330**	**22**	**8.7**	1.4 U	0.45 U	2.2 U	1.9 U	1.9 U	1.2 U	0.92 U	1.4 U	11 U	5.8 U	1.0 U	1.7 U
	15-Nov-05	0.90 U	**290**	**12**	**6.3**	1.1 U	0.36 U	1.8 U	1.5 U	0.72 U	0.98 U	0.74 U	1.1 U	8.6 U	4.6 U	0.82 U	1.3 U
PES-MW-13A	22-Apr-05	0.45 U	**380**	**8.1**	**6.2**	0.57 U	0.18 U	0.90 U	**1.2**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
	16-Nov-05	1.1 U	**230**	**5.8**	**5.0**	1.4 U	0.45 U	2.2 U	1.9 U	1.9 U	1.2 U	0.92 U	1.4 U	11 U	5.8 U	1.0 U	1.7 U
PES-MW-14A	12-Apr-05	0.45 U	**87**	**490**	**25**	**1.0**	**0.85 J**	0.90 U	**0.81 J**	0.36 U	0.49 U	**1.8**	0.56 U	4.3 U	**190**	0.41 U	**0.74 J**
	15-Nov-05	2.2 U	**87**	**510**	**12**	2.8 U	**1.3 J**	4.5 U	3.8 U	1.8 U	2.4 U	1.8 U	2.8 U	22 U	12 U	2.0 U	3.4 U
PES-MW-14B	20-Apr-05	0.45 U	**110**	**1.3**	**5.6**	0.57 U	0.18 U	0.90 U	**1.4**	0.36 U	0.49 U	**0.38 J**	0.56 U	4.3 U	**3.1 J**	0.41 U	0.67 U
	16-Nov-05	0.45 U	**110**	**5.5**	**1.2**	0.57 U	0.18 U	0.90 U	**1.4**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
INJECTION WELLS																	
PES-INJ-1	19-Nov-01	3.9 U	**1,400**	**16**	**20**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	10 U	16 U	4.4 U	4.2 U
	18-Feb-02	3.9 U	**70**	**15**	3.8 U	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	**340**	16 U	4.4 U	4.2 U
	23-May-02	0.39 U	**47**	**13**	**2.7**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**420**	**360**	0.44 U	**1.1**
	29-Aug-02	0.39 U	**29**	**9.6**	**2.3**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**370**	**270**	0.44 U	0.42 U
	13-Dec-02	0.25 U	**37 J**	**19**	**2.6**	**0.64**	**0.83**	0.23 U	0.20 U	0.34 U	0.29 U	0.19 U	0.32 U	**360**	**130**	0.20 U	0.7 U
	10-Apr-03	0.24 U	**66**	**16**	**2.0**	0.22 U	**0.63 J**	0.23 U	0.22 U	0.17 U	0.25 U	0.19 U	0.32 U	**320**	**66**	0.11 U	0.11 U
	22-Aug-03	0.24 U	**20**	**17**	**1.8**	0.22 U	**0.7 J**	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	**450**	**170**	0.11 U	**0.9 J**
	19-Apr-05	1.80 U	**10**	**11**	3.6 U	2.30 U	0.72 U	3.60 U	3.0 U	1.40 U	2.00 U	1.50 U	2.20 U	**1,900**	**640**	1.60 U	**2.7** U
PES-INJ-2	19-Nov-01	1.90 U	**630**	**8.6**	**7.9**	2.3 U	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	15-Feb-02	3.9 U	**45**	9.90 U	3.8 U	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	**390**	16 U	4.4 U	4.2 U
	23-May-02	0.39 U	**25**	**3.8**	**2.9**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**670**	**150**	0.44 U	**0.45**
	29-Aug-02	0.39 U	**16**	**3.4**	**2.4**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**590**	**160**	0.44 U	0.42 U
	13-Dec-02	0.25 U	**18 J**	**3.4**	**2.7**	0.34 U	0.30 U	0.23 U	0.20 U	0.34 U	0.34 U	0.19 U	0.32 U	**1,200**	**320**	0.20 U	**9.4**
	11-Apr-03	0.24 U	**16**	**3.1**	**2.2**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.32 U	**870**	**92**	0.11 U	**3.8**
	22-Aug-03	0.24 U	**13**	**3.0**	**2.1**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	**1,100**	**170**	0.11 U	**2.4**
	19-Apr-05	0.45 U	**14**	**2.9**	**1.9**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	**820**	**150**	0.41 U	**1.1**
Veg. Oil	12-Feb-02	1,100 U	**6,200**	680 U	850 U	800 U	1,000 U	480 U	620 U	800 U	610 U	670 U	660 U	940 U	650 U	590 U	**2,000 J**
PES-INJ-3	16-Nov-01	3.9 U	**760**	9.9 U	**9.1**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	10 U	16 U	4.4 U	4.2 U
	18-Feb-02	3.9 U	**29**	9.9 U	3.8 U	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	**490**	**240**	4.4 U	4.2 U
	23-May-02	0.39 U	**21**	**3.7**	0.39 U	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**770**	**610**	0.44 U	0.42 U
	29-Aug-02	3.90 U	**10**	9.9 U	3.8 U	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	**440**	**710**	4.4 U	4.2 U
	13-Dec-02	0.25 U	**12 J**	**3.8**	**2.8**	0.26 U	0.30 U	0.23 U	0.20 U	0.34 U	0.29 U	0.19 U	0.32 U	**560**	**680**	0.20 U	0.22 U
	11-Apr-03	0.24 U	**9.8**	**3.1**	**2.2**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.32 U	**900**	**400**	0.11 U	0.11 U
	22-Aug-03	0.24 U	**10**	**3.5**	**2.4**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	**1,200**	**470**	0.11 U	0.11 U
	19-Apr-05	0.45 U	**8.7**	**3.3**	**1.9**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	**960**	**480**	0.41 U	0.67 U
	17-Nov-05	9.0 U	**15.0 J**	17 U	18 U	11 U	3.6 U	18 U	15 U	7.2 U	9.8 U	7.4 U	11 U	**1,500**	**2,600**	8.2 U	**24**
Veg. Oil	12-Feb-02	1,100 U	**7,800**	680 U	850 U	800 U	1,000 U	480 U	620 U	720 U	610 U	670 U	660 U	940 U	650 U	590 U	770 U
Veg. Oil	29-Aug-02	570 U	**4,900**	550 U	560 U	620 U	940 U	520 U	530 U	610 U	610 U	540 U	470 U	**3,300**	**2,800**	470 U	640 U
Veg. Oil	9-Dec-02	1,100 U	**3,500**	680 U	850 U	800 U	1,000 U	480 U	620 U	720 U	610 U	670 U	660 U	**4,000**	**1,600 J**	590 U	**4,800**
PRE-INJECTION OIL SAMPLES																	
PES-INJ-2A-OIL	11-Dec-02	1,000 U	920 U	670 U	840 U	790 U	1,000 U	470 U	610 U	710 U	600 U	650 U	650 U	880 U	640 U	580 U	750 U
PES-INJ-2-OIL	11-Dec-02	1,000 U	950 U	670 U	840 U	790 U	1,000 U	470 U	610 U	710 U	600 U	650 U	650 U	900 U	640 U	580 U	750 U

[a/] PCE = tetrachloroethene; TCE = trichloroethene; DCE = dichloroethene; TCA = trichloroethane; DCA = dichloroethane.

[b/] µg/L = micrograms per liter.

[c/] U = Analyte was not detected at a concentration above the method detection limit.

[d/] J = Analyte was detected at a concentration above the method detection limit and below the reporting limit.

concentrations of ethene detected at the injection well locations indicate that complete reductive dechlorination is occurring in the injection area.

A significant decrease in TCE concentrations detected in GWMS-46S was observed during the process monitoring rounds following vegetable oil injection. The geochemical data from MS-46S and PES-BG-1 indicate that MS-46S may have been impacted by vegetable oil during or immediately after injection. Geochemical evidence of organic carbon impact to MS-46S includes: TOC concentrations increased an order of magnitude after vegetable oil injection, dissolved oxygen concentrations decreased from 0.6 mg/L to non-detect, and oxidation reduction potential decreased from -82 to -276. In addition, non-aqueous phase vegetable oil was observed at PES-BG-1, which is located cross-gradient from MS-46S, during the May 2002 sampling round indicating that non-aqueous phase vegetable oil is present as far upgradient as BG-1. Thus, vegetable oil has not been directly observed at MS-46S, but vegetable oil has been observed at a location very close to and cross gradient from MS-46S. This data indicates that at least a portion of the TCE concentration decrease observed at MS-46S may be related to the vegetable oil injection activities, despite that fact that it is located approximately 20 feet upgradient of the injection wells. During successive monitoring events TCE concentrations decreased from a baseline concentration of 20,000 µg/L to 4,900 µg/L in August 2002, increased to 7,200 µg/L in December 2002, than decrease again to 4,500 µg/L in August 2003. TCE concentrations continued to decrease through the most recent sampling event collected in November of 2005 when a TCE concentration of 1,300 µg/L was detected at this location. It is likely that a combination of mechanisms including the extraction system, natural attenuation, and degradation induced by the vegetable oil pilot are responsible for the VOC concentration decreases observed at MS-46S.

TCE and *cis*-1,2-DCE concentrations over time in all of the monitoring wells are plotted on Figures 4.8 and 4.9, respectively. The groundwater VOC analytical data collected in each sampling round are presented in Table 4.5. The maximum pre-injection concentration of TCE was 20,000 µg/L at location GWMS-46S, while the maximum TCE concentration measured in November 2005 was 1,300 µg/L at the same location. The maximum pre-injection concentration of *cis*-1,2-DCE was 160 µg/L at location PES-MW-8, while the maximum *cis*-1,2-DCE concentration measured in November 2005 was 510 µg/L at location PES-MW-14A. VC was not detected at any of the monitoring locations during baseline sampling, while the maximum VC concentration measured after injection was detected in August 2002 was 12 µg/L at location PES-MW-9. The lack of high concentrations of VC in the monitoring wells indicates that either VC is not being generated at a significant rate, or that it is being degraded as fast as it is generated.

Review of groundwater analytical data (Table 4.5) collected during the process monitoring events indicates that TCE concentrations detected in groundwater during the November 2005 sampling event were substantially lower than TCE concentrations detected during the baseline sampling event at nine monitoring well locations (MS-46S, PES-MW-1, PES-MW-2, PES-MW-3, PES-MW-4, PES-MW-6, PES-MW-7, PES-MW-8, and PES-MW-9). TCE concentrations in the wells located upgradient of PES-MW-5 increased initially, typically peaking in the May or August 2002 sampling rounds, than decreased between August 2002 and November 2005. Reductions in the concentration of TCE were often coupled with an increase in the concentration of *cis*-1,2-DCE, the reductive dechlorination daughter product of TCE. Overall increases in *cis*-1,2-DCE

FIGURE 4.8A
CONCENTRATIONS OF TCE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

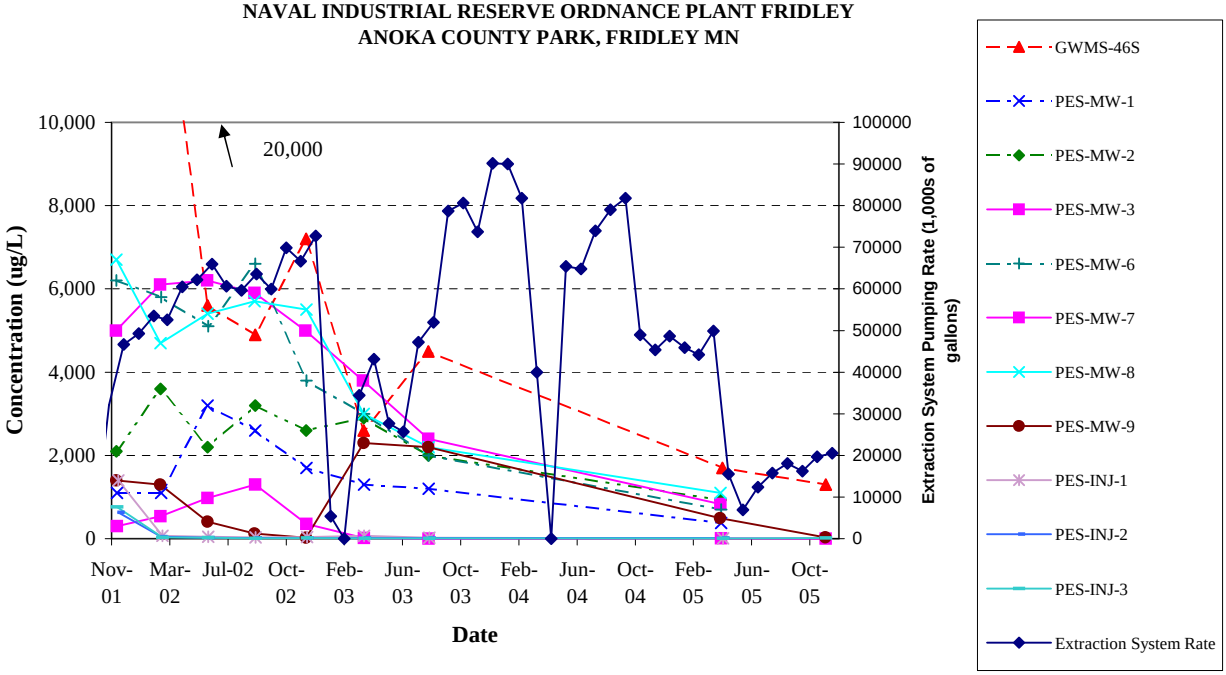


FIGURE 4.8B
CONCENTRATIONS OF TCE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

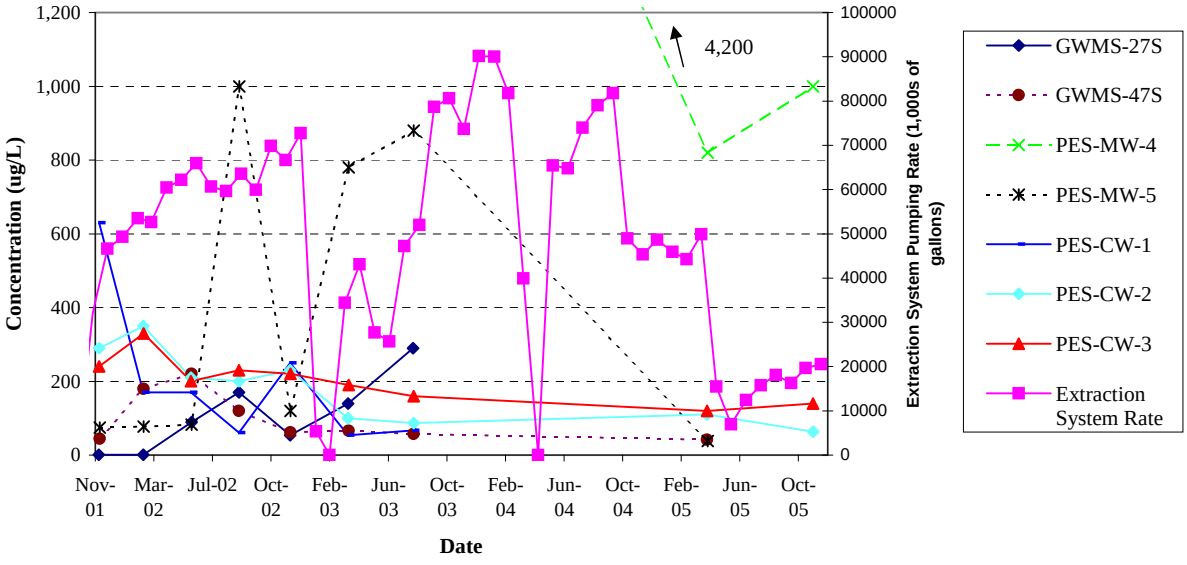


FIGURE 4.9A
CONCENTRATIONS OF *cis* -1,2-DCE Plus *trans* -1,2-DCE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

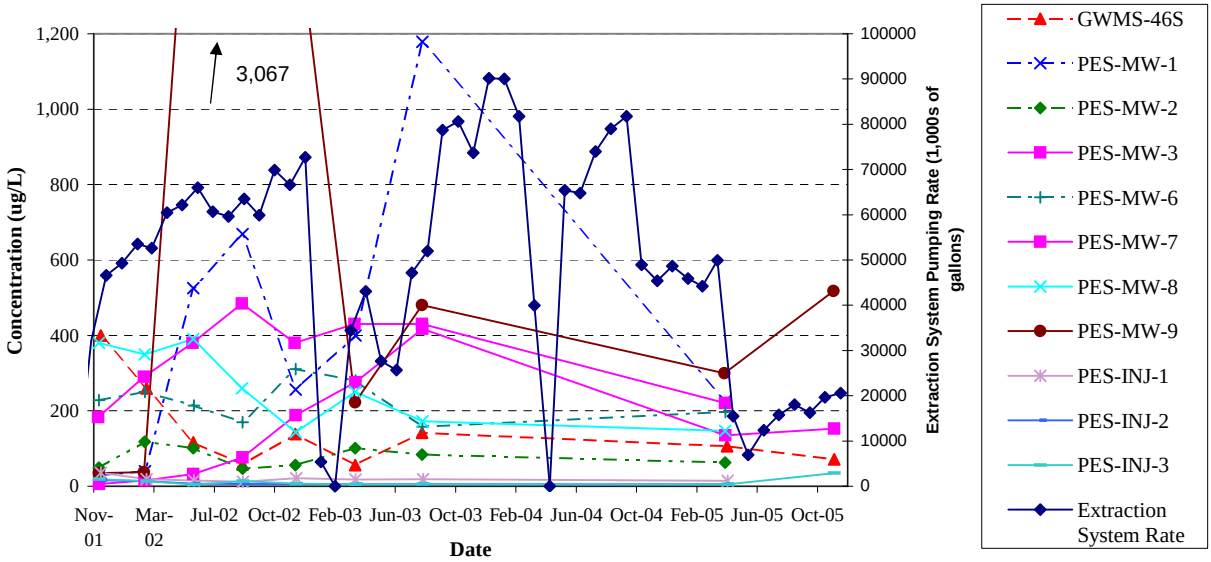
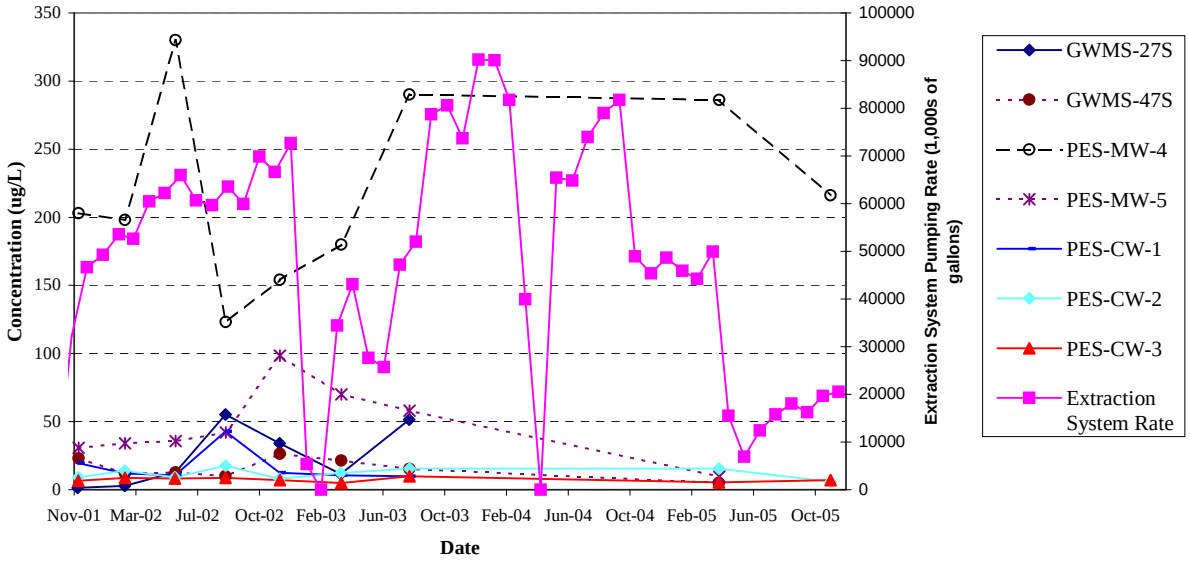


FIGURE 4.9B
CONCENTRATIONS OF *cis* -1,2-DCE Plus *trans* -1,2-DCE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



(from baseline concentrations) were observed for locations PES-MW-1, PES-MW-3, PES-MW-4, PES-MW-6, PES-MW-7, and PES-MW-9, indicating that TCE is being reductively dechlorinated in the vicinity of these locations.

At location PES-MW-9, TCE concentrations decreased dramatically and consistently from the baseline TCE concentration of 1,400 µg/L to the December 2002 TCE concentration of less than 30 µg/L (Figure 4.10A). This decrease in TCE concentration was accompanied by a large increase in *cis*-1,2-DCE from the baseline concentration of 15 µg/L to a maximum concentration of 3,000 µg/L detected in the August 2002 sampling event. VC and ethene concentrations also peaked during the August 2002 sampling event at 12 µg/L and 13 µg/L, respectively. Between the August and December 2002 sampling events, TCE, *cis*-1,2-DCE, VC, and ethene concentrations all declined. This pattern of decreasing TCE concentrations accompanied with increasing and then decreasing *cis*-1,2-DCE and VC concentrations and increasing ethene concentrations is indicative of reductive dechlorination. Between December 2002 and April 2003 the TCE concentration at PES-MW-9 increased to 2,300 µg/L. During the same time period *cis*-1,2-DCE, VC, and ethene concentrations decreased substantially. Between April 2003 and November 2005 the TCE concentration at PES-MW-9 decreased to 28 µg/L while *cis*-1,2-DCE concentrations increased and VC concentrations remained at or below the detection limit. These concentration trends may be due to the variable groundwater flow conditions at this location.

At monitoring well PES-MW-7, TCE concentrations increased substantially through the first three rounds of process monitoring from a baseline concentration of 300 µg/L to a maximum concentration of 1,300 µg/L detected in August 2002 (Figure 4.11A). Between August 2002 and November 2005 the TCE concentration at PES-MW-7 decreased from the maximum concentration of 1,300 µg/L to 1.0 µg/L. During the same period the *cis*-1,2-DCE concentration at PES-MW-7 increased from 65 µg/L to 410 µg/L, than decreased to 150 µg/L. VC was also detected at low estimated, but increasing, concentrations between August 2002 and November 2005. The observed increases in *cis*-1,2-DCE and VC concentrations coincident with a large decrease in TCE concentration indicates that the TCE mass is being reductively dechlorinated to *cis*-1,2-DCE and VC. It is apparent that contaminant trends observed at PES-MW-7 are following the same pattern observed at PES-MW-9, prior to April 2003.

The reductive dechlorination signature that was observed at PES-MW-7 and PES-MW-9 is also evident, in a less developed form, at monitoring wells PES-MW-1, PES-MW-3, and PES-MW-6. TCE concentrations at these wells decreased over at least two sampling rounds, while *cis*-1,2-DCE concentrations increased over at least two sampling rounds, and VC was detected at least once. TCE and molar fraction plots have been prepared for each well and are included in Appendix C.

Significant TCE concentration decreases were observed in the injection wells immediately after vegetable oil injection. However, these decreases were not accompanied by increases in *cis*-1,2-DCE, VC, or ethene concentrations, suggesting that they were due to partitioning of the TCE mass into the vegetable oil and/or dilution. During the course of process monitoring events the TCE concentrations detected in each injection well continued to decline. At the same time, concentrations of *cis*-1,2-DCE and VC in all three of the injection wells were stable, and concentrations of ethene in

FIGURE 4.10A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW9
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

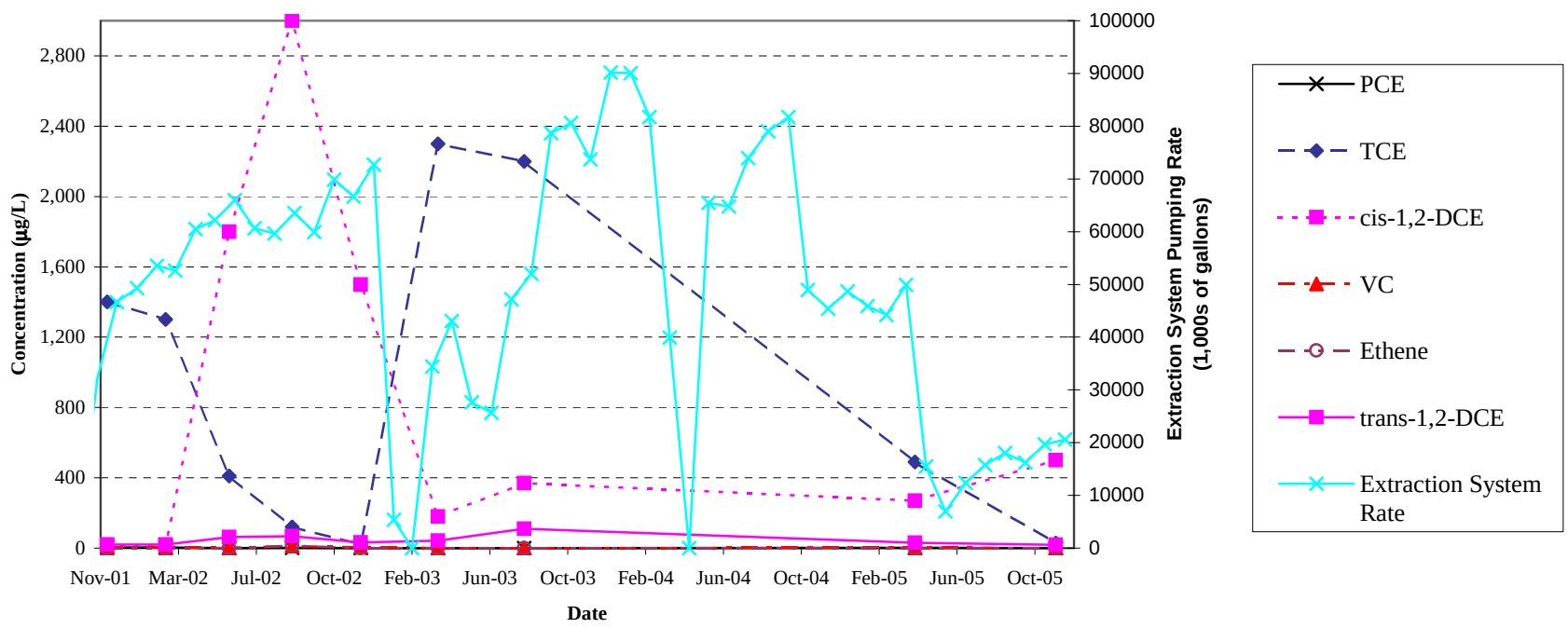


FIGURE 4.10B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW9
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

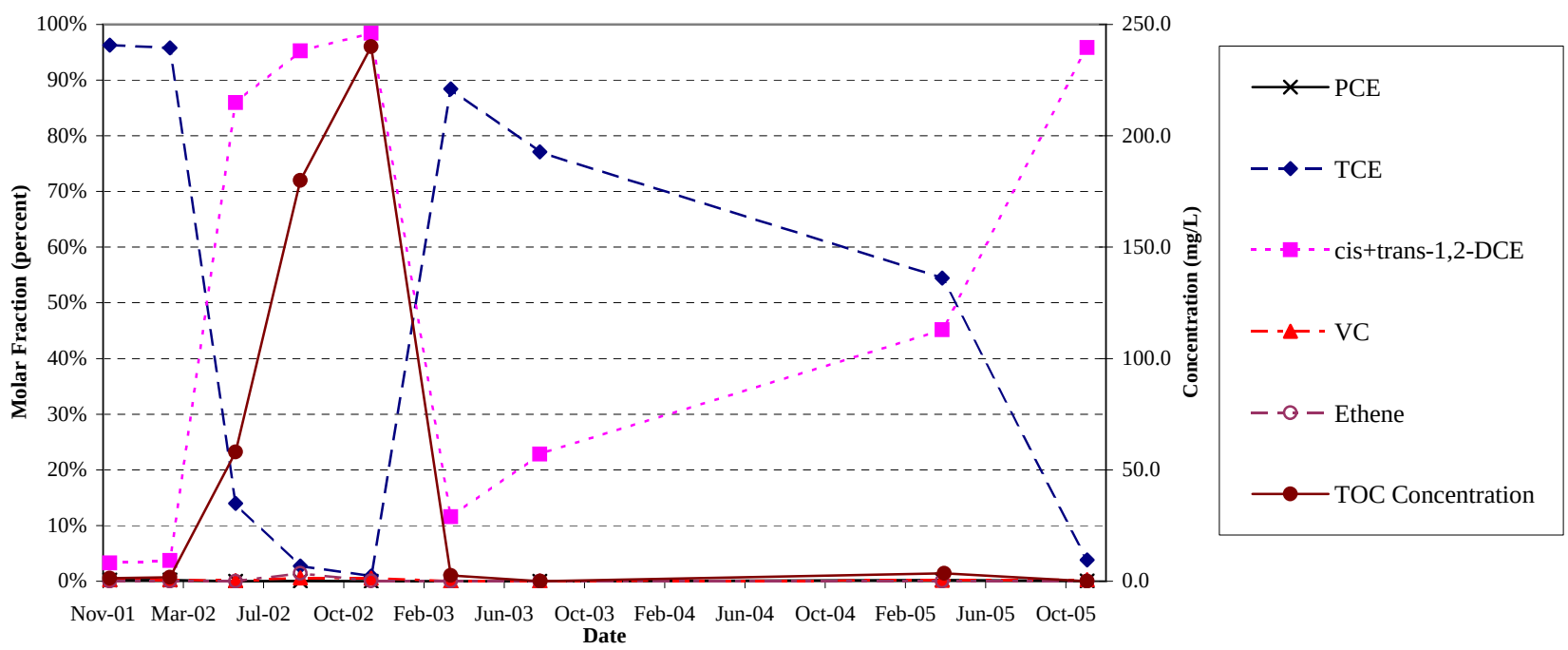


FIGURE 4.10C
MOLAR CONCENTRATION OF SELECT CHLORINATED ETHENES OVER TIME
AT WELL PES-MW9
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

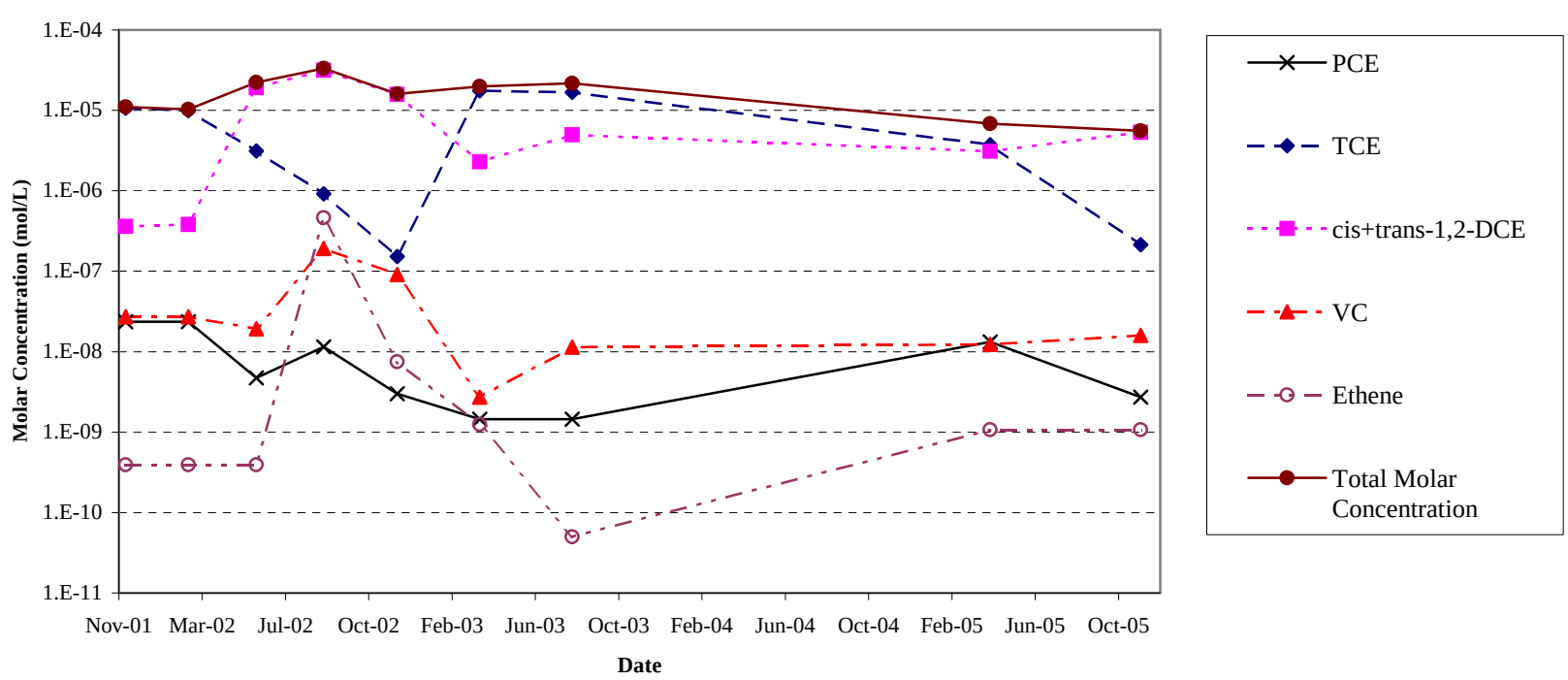


FIGURE 4.11A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW7
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

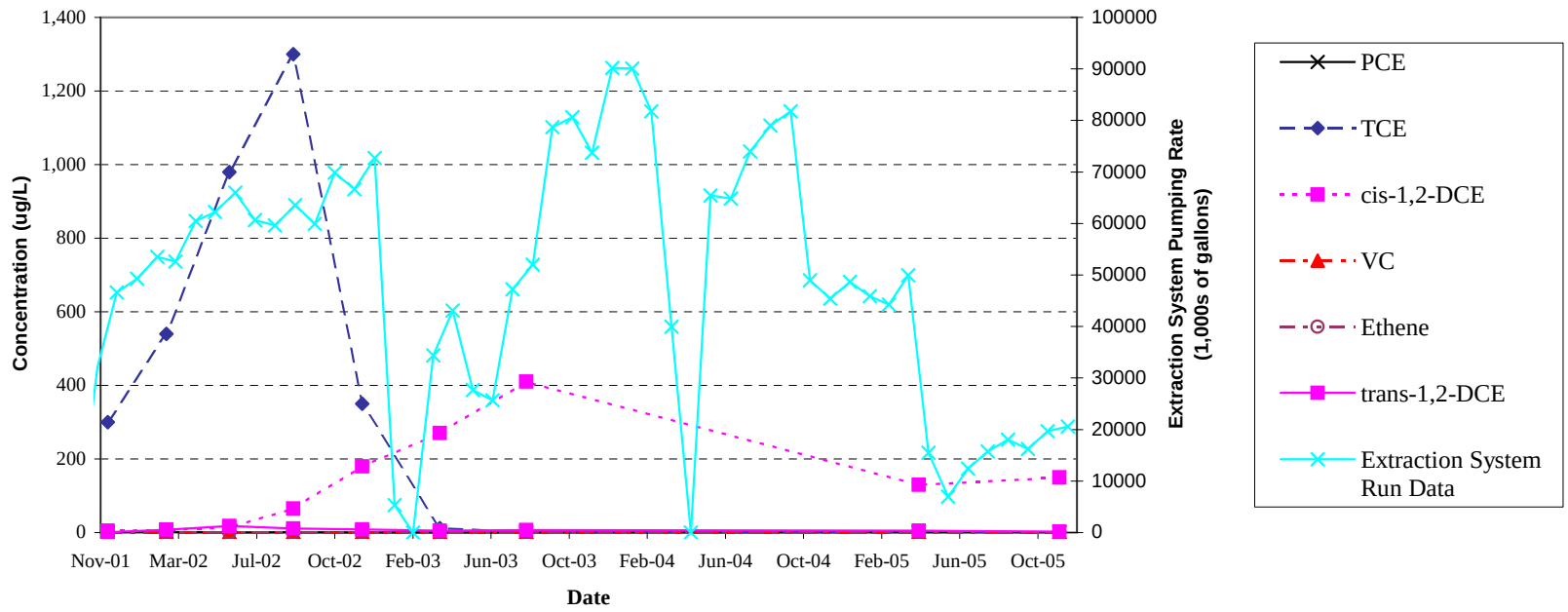


FIGURE 4.11B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW7
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

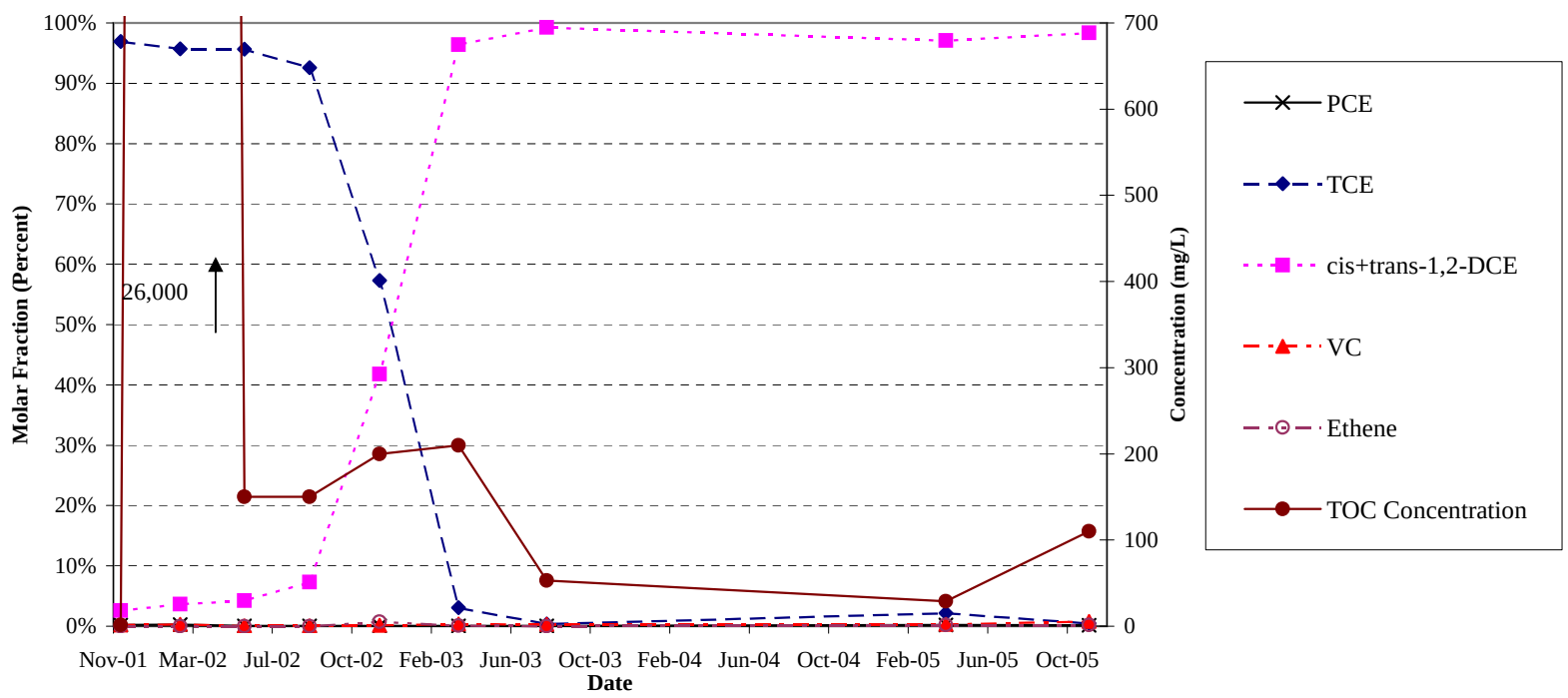
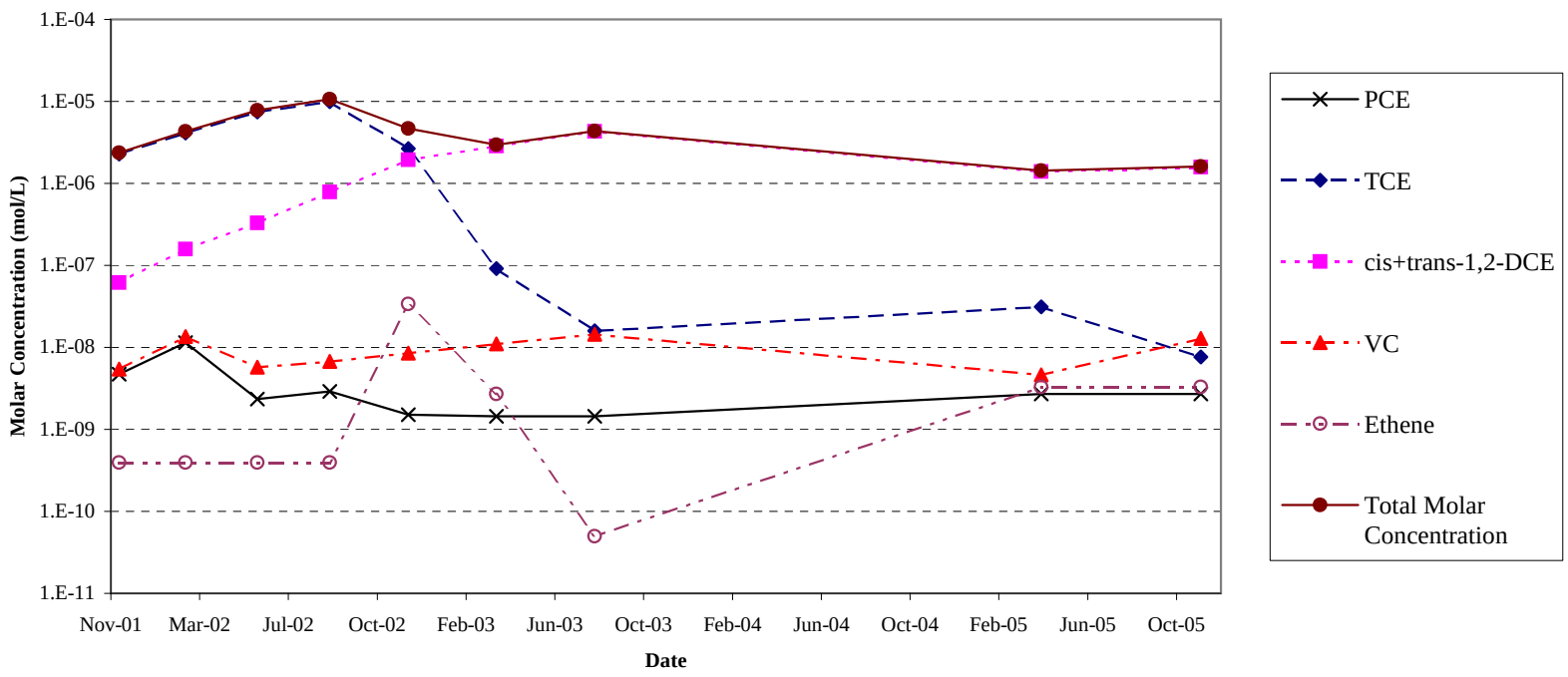


FIGURE 4.11C
MOLAR CONCENTRATION OF SELECT CHLORINATED ETHENES OVER TIME
AT WELL PES-MW7
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



PES-INJ-1 and PES-INJ-2 increased. These dissolved phase concentration trends were also accompanied by decreasing concentrations of TCE in the vegetable oil (Table 4.5). These data suggest that TCE is being released into the groundwater from the vegetable oil and that released TCE mass is being rapidly reductively dechlorinated to ethene.

4.4.2 Presence of Daughter Products and CAH Ratios

The presence of daughter products that were not used in NIROP operations, particularly *cis*-1,2-DCE, VC, ethene, and ethane provides strong evidence that PCE and TCE have been and/or are being reductively dechlorinated at this site. Progressive transformation of PCE and TCE to ethene can be demonstrated by computing the molar ratios of parent compounds to daughter products at a specific location. For example, because reductive dechlorination proceeds in only one direction (i.e., TCE to *cis*-1,2-DCE and not vice versa), the molar ratio of TCE to *cis*-1,2-DCE would decrease where reductive dechlorination of TCE dominates the contaminant attenuation process. Similarly, the sequential reduction of 1,1-DCA to chloroethane to ethanol or acetate and of carbon tetrachloride (CT) to chloroform to methylene chloride to chloromethane, also would indicate progressive transformation by reductive dechlorination.

Chlorinated ethene concentration plots, molar fraction plots, and molar concentration plots over time for all monitoring well locations are included in Appendix C. The following discussion includes an evaluation of chlorinated ethene data for select monitoring locations at the site.

The molar fraction of chlorinated ethenes at PES-MW-9 (Figure 4.10B) changed dramatically from a TCE-dominated system during the baseline sampling event to a DCE- (*cis* plus *trans*) dominated system by the May 2002 sampling event. Between May and December 2002, DCE continued to dominate the system and the molar fraction of VC increased slightly. The decrease in TCE molar fraction and accompanying increase in the DCE molar fraction was coincident with a dramatic increase in the TOC concentration as a result of the vegetable oil injection. Between December 2002 and April 2003 the system reverted back to a TCE-dominated system. This reversion indicates that new TCE mass was introduced to the system, presumably as a result of changing groundwater flow conditions. Between April and November 2005 the molar fraction of TCE decreased to nearly zero, the molar fraction of DCE increased, and the molar fraction of VC remained virtually unchanged. These sequential changes in molar fractions are indicative of partial reductive dechlorination of TCE to *cis*-1,2-DCE.

Review of the chlorinated ethene molar concentration data through time at PES-MW-9 (Figure 4.10C) indicates that the TCE molar concentration decreased at this location through December 2002, increased between December 2002 and August 2003, than decreased through August 2003. The DCE molar concentration increased from February through August 2002, decreased between August 2002 and April 2003, than increased through August 2003. The molar concentration of VC followed a similar pattern. These molar concentration trends are identical to the concentration trends discussed in Section 4.4.1. The molar concentration data also indicate that the DCE molar concentration increased to a maximum that was higher than the maximum TCE molar concentration. This indicates that additional TCE mass was added to the system in the immediate vicinity of PES-MW-9 and reductively dechlorinated to DCE or that additional DCE

mass was added to the system. The additional TCE or DCE contaminant mass likely migrated into the vicinity of PES-MW-9 by temporary shifts in groundwater flow conditions.

The chlorinated ethene molar fraction and concentration data collected at PES-MW-7 are presented on Figures 4.11B and 4.11C, respectively. The molar concentration data collected from PES-MW-7 indicates that the progression of reductive dechlorination at this location is following a pattern similar to that observed at PES-MW-9, except that reductive dechlorination progress at PES-MW-7 was delayed until the August sampling event and PES-MW-7 did not experience the concentration trend reversals observed at PES-MW-9. The TCE-dominated system observed at PES-MW-7 during the baseline event was replaced by a DCE-dominated system in December 2002. The TCE mass fraction continued to decline through 2005 while the DCE and VC molar fractions continued to increase through the same time period (Figure 4.11B). During the August 2005 sampling event the chlorinated ethene composition at PES-MW-7 was 0.5% TCE mass, 98.6% DCE mass, and 0.9% VC mass.

The chlorinated ethene molar fraction and molar concentration data from the remaining wells indicate that some of the wells are showing signs of potential reductive dechlorination (PES-MW-1, PES-MW-3, PES-MW-5, and PES-MW-6). However the data from these wells indicate that reductive dechlorination is not progressing as quickly or as completely as at PES-MW-7 and PES-MW-9.

Based on the ratio of the molar fraction of the parent compound TCE to the daughter products DCE, VC, and ethene in the pilot test monitoring wells, biodegradation has been stimulated by vegetable oil injection at some locations (most notably PES-MW-7 and PES-MW-9). Although significant concentrations of VC were not detected, the concentration and molar fraction of DCE increased at PES-MW1, PES-MW3, PES-MW-5, PES-MW-6, PES-MW-7, and PES-MW-9, and ethene concentrations increased in PES-MW-9 and the injection wells.

These data provide direct evidence that reductive dechlorination of TCE to DCE has been stimulated to some degree across the site and that the reductive dechlorination of DCE to VC and then to ethene has been stimulated in at least two locations (PES-MW-7 and PES-MW-9). Thus, the addition of vegetable oil has been successful in increasing rates of reductive dechlorination at ACP. However, the degree of stimulation is very heterogeneous within the pilot test area.

In summary, while trends in chlorinated ethene concentrations have varied from sampling event to sampling event, chlorinated ethene data indicate an overall reduction of maximum contaminant concentrations.

4.4.3 Chlorinated Aliphatic Hydrocarbons in Vegetable Oil

In addition to CAHs in groundwater, CAH concentrations in vegetable oil also were analyzed in samples collected from locations PES-INJ-2 (February 2002 sampling round) and PES-INJ-3 (February, August, and December 2002 sampling rounds). Unfortunately, the analyte-specific MDLs for VOCs in vegetable oil (550 to 1,000 μg/L)

are elevated due to interference of the vegetable oil sample matrix and the dilutions required for calibration.

TCE was detected at a concentration of 6,200 µg/L in the single sample collected from PES-INJ-2 in February 2002 (Table 4.5). The TCE concentration in groundwater at PES-INJ-2 during the February 2002 sampling event was approximately 18 µg/L, compared to 630 µg/L approximately three months earlier during the baseline sampling event. These data indicate that the majority (97 percent) of the TCE mass at this location was partitioned into the vegetable oil.

At injection well PES-INJ-3 the TCE concentration in groundwater detected during the baseline event was 760 µg/L. During the process monitoring events TCE concentrations in groundwater ranged from a maximum of 29 µg/L (February 2002), to a minimum of 10 µg/L (August 2003). TCE concentrations detected in vegetable oil ranged from 3,500 µg/L to 7,800 µg/L (Table 4.5). As in the case of PES-INJ-2, the TCE concentration in vegetable oil was two orders of magnitude higher than TCE concentrations in groundwater detected during the process monitoring events and approximately 1 order of magnitude higher than the TCE concentration detected in groundwater during the baseline event. This discrepancy suggests that additional TCE mass was stripped from the soil matrix shortly after vegetable oil injection and that the majority of the TCE mass in the system has partitioned into the vegetable oil NAPL. It is also important to note that the TCE concentration in vegetable oil declined from a maximum concentration of 7,800 µg/L (February 2002) to 3,500 µg/L (December 2002). This decline in TCE concentrations in vegetable oil without an associated increase in TCE concentrations in groundwater indicates that the released TCE mass is being rapidly degraded. The lack of significant detections of DCE or VC coupled with elevated concentrations of ethene in the injection wells indicates that the TCE mass is being degraded completely to ethene.

4.5 SUBSTRATE DISTRIBUTION

Addition of vegetable oil as an organic substrate provides a source of carbon for microbial growth. The evaluation of analytical data for TOC, VFAs, and PLFAs provides an indication of the extent to which groundwater has been impacted by addition of the vegetable oil and whether microbial growth has been stimulated.

4.5.1 Total Organic Carbon as an Indicator of Substrate Addition and Area of Influence

Groundwater samples collected from each of the wells during baseline sampling and process monitoring were analyzed for TOC to determine the lateral extent of dissolved vegetable oil. TOC is used to determine the approximate zone of influence of the vegetable oil injection in the glacio-fluvial deposits aquifer. Analytical results for TOC in groundwater are presented in Table 4.6. The USGS also performed radius of influence testing by injecting colloidal iron and a commercial product called FerroFluid™ and tracking the distribution of each of these products using geophysical techniques. The results of the radius of influence testing conducted by the USGS are presented in detail in the draft USGS report (USGS, 2003) and are summarized in Section 4.5.4 of this report.

TABLE 4.6
SUMMARY OF GROUNDWATER GEOCHEMICAL DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Methane (µg/L)[a/]	Ethane (µg/L)	Ethene (µg/L)	TOC [b/] (mg/L) [c/]	Dissolved Oxygen (mg/L)	Dissolved Hydrogen (nM)[d/]	Nitrate (mg/L)	Nitrite (mg/L)	Ferrous Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Ammonia (mg/L)	Total Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Chloride (mg/L)	Redox Potential (mV)[e/]	pH (SU)[f/]	Temperature (°C) [g/]	Specific Conductivity (µs/cm) [h/]
MONITORING WELLS																					
18-S	4/18/2005	NM[j/]	NM	NM	3.8	R[l/]	NM	NM	NM	1.44	2.0	180	0.01	NM	NM	35	NM	-87	7.49	11.9	1,238
MS-26S	4/15/2005	NM	NM	NM	2.2	R	NM	NM	NM	0.19	0.9	160	0.06	NM	NM	25	NM	-96	7.52	12.8	1,309
MS-27S	12-Nov-01	46 J[i/]	1.6 U	1.4 U	3.7	0.34	Na[l/]	<0.2[k/]	<0.2	0.05	0.1	19	<0.01	0.12	119	1.25	20	-123	9.81	12.5	1,136
	11-Feb-02	36	1.6 U	1.4 U	1.4	0.02	Na	<0.13	<0.077	0.22	<0.6	43	0.02	0.06	163	18	75	-371	8.06	11.4	575
	21-May-02	2.0 U	1.6 U	1.4 U	<1.7	0.33	3.3	<0.13	<0.077	0.90	<0.6	170	0.02	0.02	340	35	55	-315	7.00	10.8	1,068
	26-Aug-02	2.7 J	1.6 U	1.4 U	9.9	0.06	2.2	<0.13	<0.077	0.83	<0.6	170	<0.01	0.01	425	60	70	-85	6.36	12.8	1,052
	9-Dec-02	4.3	0.064	0.036	16	0.26	3.0	<0.057	<0.018	0.73	<0.6	170	<0.01	0.05	357	45	60	60	7.17	9.8	645
	7-Apr-03	2.6	0.022	0.023	2.8	0.23	5.2	<0.058	<0.018	0.82	<0.6	150	0.03	0.01	272	30	60	-77	7.24	10.4	1,011
	18-Aug-03	4.5	0.033	0.056	1.2 J	1.34	2.4	<0.058	<0.018	0.86	1.1	140	0.01	0.02	340	55	75	-47	NM	15.4	142
MS-36S	22-Apr-05	NM	NM	NM	3.4	R	NM	NM	NM	0.05	0.1	60	0.51	NM	NM	15	NM	-184	8.18	15.1	1,538
MS-44S	18-Apr-05	NM	NM	NM	0.4	R	NM	NM	NM	0.17	2.2	170	<0.01	NM	NM	25	NM	-50	7.07	11.5	1,380
GWMS-45S	18-Apr-05	20	0.095	0.071	7.0	R	NM	NM	NM	1.08	1.4	160	0.06	NM	NM	25	NM	-94	7.59	11.2	1,130
GWMS-46S	19-Nov-01	2.0 U	1.6 U	1.4 U	1.8	0.57	Na	<0.2	<0.2	2.2	1.9	210	0.01	0.07	391	50	15	-82	7.04	10.1	1,134
	18-Feb-02	2.0 U	1.6 U	1.4 U	3.6	0.96	Na	<0.13	<0.077	1.9	1.0	340	0.01	0.09	85	10	25	-276	6.95	10.7	1,048
	22-May-02	2.0 U	1.6 U	1.4 U	2.3	<0.01	1.1	<0.13	<0.077	1.4	1.4	180	<0.01	0.08	323	30	55	-276	7.30	13.1	1,132
	28-Aug-02	6.0	1.6 U	1.4 U	10	<0.01	2.0	<0.13	<0.077	1.2	1.3	170	0.01	0.06	340	40	50	-229	7.13	12.9	1,045
	11-Dec-02	2.0 U	0.014	0.069	18	0.12	1.2	<0.057	<0.018	1.7	1.1	210	<0.01	0.09	357	35	40	R	7.37	10.0	564
	9-Apr-03	4.2	0.007	0.030	1.0 J	1.52	1.6	<0.058	<0.018	1.7	1.8	190	0.01	0.09	323	35	45	-58	7.31	10.6	1,137
	20-Aug-03	18	0.010	0.046	<1.0	3.9	1.8	<0.058	<0.018	2.4	1.9	190	0.01	0.07	306	35	45	-95	7.18	16.3	1,094
	18-Apr-05	30	0.071	0.080	3.7	R	NM	NM	NM	1.1	2.0	210	<0.01	NM	NM	25	NM	-115	7.45	12.0	1,132
	17-Nov-05	NM	NM	NM	3.7J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	7.40	9.3	979
GWMS-47S	14-Nov-01	2.0 U	1.6 U	1.4 U	1.7	1.7	Na	1.3	<0.2	<0.01	1.8	70	0.13	<0.01	459	134	50	115	6.82	12.9	1,102
	12-Feb-02	2.0 U	1.6 U	1.4 U	1.6	8.8	Na	<0.13	<0.077	<0.01	<0.6	160	<0.01	<0.01	442	50	65	-14	7.21	10.7	1,092
	21-May-02	2.0 U	1.6 U	1.4 U	<1.1	6.1	2.6	0.59	<0.077	0.01	<0.6	140	<0.01	0.01	340	35	50	-31	7.10	12.0	1,078
	26-Aug-02	2.0 U	1.6 U	1.4 U	11	3.7	3.0	0.45	<0.077	0.04	<0.6	100	0.03	0.03	340	45	55	149	6.94	13.9	1,054
	10-Dec-02	2.0 U	0.007	0.013	38	2.4	3.1	2.5	<0.018	<0.01	<0.6	111	<0.01	<0.01	476	65	95	265	7.09	10.4	818
	8-Apr-03	0.32	0.005 U	0.010	1.1	1.0	1.8	1.1	<0.018	0.02	<0.6	170	<0.01	0.02	442	40	75	112	7.02	9.9	1,283
	19-Aug-03	0.46	0.006 U	0.001 U	1 J	2.3	3.2	1.1	<0.018	0.00	0.6	100	<0.01	<0.01	408	65	95	208	6.88	20.9	1,227
	11-Apr-05	NM	NM	NM	3.8	R	NM	NM	NM	0.04	<0.6	170	0.01	NM	NM	65	NM	16	7.11	11.6	1,405
MS-53PC	11-Apr-05	NM	NM	NM	110	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NA	NA	NA
PES-MW-1	16-Nov-01	2.0 U	1.6 U	1.4 U	1.0	1.3	Na	<0.2	<0.2	0.02	0.6	100	<0.01	0.03	255	15	55	-50	8.29	11.0	873
	15-Feb-02	2.0 U	1.6 U	1.4 U	30	1.1	Na	<0.13	<0.077	0.91	1.2	290	0.18	0.04	408	40	50	-324	7.25	10.5	1,032
	22-May-02	2.9	1.6 U	1.4 U	3	<0.01	2.3	<0.13	<0.077	0.37	0.6	200	0.02	0.05	374	40	45	-245	7.40	11.9	1,217
	28-Aug-02	170	1.6 U	1.4 U	14	<0.01	2.1	<0.13	<0.077	1.3	1.1	140	0.18	0.06	357	50	55	-299	7.06	12.8	1,084
	12-Dec-02	380	0.014	0.079	12	R	3.9	<0.057	<0.018	1.2	0.6	200	0.16	0.05	425	45	45	R	7.42	10.6	R
	10-Apr-03	2,000	0.002 J	0.050	< 1.0	1.23	1.7	<0.058	<0.018	3.0	1.6	180	<0.01	0.07	374	45	50	-241	7.30	11.7	1,154
	21-Aug-03	0.16	0.004 J	0.013	1.4 J	0.49	1.5	<0.058	<0.018	2.4	1.9	160	0.52	0.05	374	45	50	-164	7.28	14.3	1,098
	15-Apr-05	4,600	0.095	0.120	3.0	R	NM	NM	NM	3.1	7.6	220	0.09	NM	NM	35	NM	-132	7.23	11.6	1,158
PES-MW-2	15-Nov-01	2.0 U	1.6 U	1.4 U	1.7	0.39	Na	0.2	<0.2	0.17	<0.6	190	<0.01	0.09	1,700	50	60	-185	11.66	11.5	1,181
	14-Feb-02	2.0 U	1.6 U	1.4 U	3.2	0.74	Na	<0.13	<0.077	0.04	<0.6	340	<0.01	0.05	340	25	50	-188	7.82	10.3	1,005
	22-May-02	2.0 U	1.6 U	1.4 U	2.5	0.07	1.8	<0.13	<0.077	0.03	<0.6	230	0.02	0.06	323	30	45	-160	7.40	13.8	1,139
	28-Aug-02	2.5 J	1.6 U	1.4 U	12	0.19	2.9	<0.13	<0.077	0.11	1.2	220	0.08	0.06	340	45	45	-176	6.98	12.7	1,091
	11-Dec-02	150	0.008	0.054	6.5	0.03	1.4	<0.057	<0.018	0.02	0.6	200	0.01	0.07	374	30	40	R	7.45	10.3	589
	9-Apr-03	1,700	0.001 U	0.025	< 1.0	1.60	1.3	<0.058	<0.018	0.04	1.5	230	0.01	0.07	347	30	45	-26	7.37	10.8	1,180
	20-Aug-03	0.3	0.007	0.023	1.0 J	0.48	1.8	<0.058	<0.018	0.02	1.5	210	<0.01	0.03	340	30	55	-1	7.27	15.6	1,095
	14-Apr-05	11	0.022	0.070	1.9	R	NM	NM	NM	0.03	1.1	200	0.01	NM	NM	35	NM	-57	7.29	11.5	1,071
PES-MW-3	14-Nov-01	2.0 U	1.6 U	1.4 U	1.6	0.35	Na	<0.2	<0.2	0.48	0.9	150	<0.01	0.02	340	40	45	-76	7.05	12.1	1,078
	13-Feb-02	2.0 U	1.6 U	1.4 U	0.2	0.46	Na	<0.13	<0.077	1.3	1.4	200	<0.01	0.05	391	40	45	-288	7.09	10.3	1,092
	21-May-02	2.0 U	1.6 U	1.4 U	2.9	0.12	1.4	<0.13	<0.077	1.8	0.8	200	0.03	0.06	391	45	55	-311	7.30	12.8	1,151
	27-Aug-02	4.4	1.6 U	1.4 U	13	<0.01	2.0	<0.13	<0.077	2.1	1.5	150	0.04	0.08	374	65	55	-136	6.81	12.5	1,106
	10-Dec-02	210	0.020	0.081	24	R	1.5	<0.057	<0.018	2.1	0.8	220	0.14	0.09	425	35	50	-60	7.35	10.6	727
	8-Apr-03	1,700	0.005 U	0.007	2.0 J	4.91	1.9	<0.058	<0.018	2.7	0.8	190	0.04	0.09	408	35	55	-100	7.29	10.8	1,178
	20-Aug-03	1.3	0.012	0.026	2.6 J	1.2	3.4	<0.058	<0.018	2.0	1.9	200	0.12	0.04	357	50	55	-93	7.07	17.8	1,134
	14-Apr-05	88	0.038	0.065	1.6	R	NM	NM	NM	2.4	1.4	180	0.02	NM	NM	40	NM	-86	7.09	11.4	1,106

TABLE 4.6 (Continued)
SUMMARY OF GROUNDWATER GEOCHEMICAL DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Methane (µg/L)[a/]	Ethane (µg/L)	Ethene (µg/L)	TOC [b/] (mg/L) [c/]	Dissolved Oxygen (mg/L)	Dissolved Hydrogen (nM)[d/]	Nitrate (mg/L)	Nitrite (mg/L)	Ferrous Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Ammonia (mg/L)	Total Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Chloride (mg/L)	Redox Potential (mV)[e/]	pH (SU)[f/]	Temperature (°C) [g/]	Specific Conductivity (µs/cm) [h/]
PES-MW-4	14-Nov-01	2.0 U	1.6 U	1.4 U	Na	1.3	Na	<0.2	<0.2	<0.01	0.9	230	<0.01	0.02	374	55	70	-48	7.12	12.1	1,115
	12-Feb-02	2.0 U	1.6 U	1.4 U	1.3	3.0	Na	<0.13	<0.077	0.11	0.7	120	<0.01	0.03	408	35	65	-133	7.38	9.0	1,045
	21-May-02	2.0 U	1.6 U	1.4 U	2.0	1.2	2.9	0.18	<0.077	0.13	<0.6	180	<0.01	0.03	357	40	65	-129	7.10	13.1	1,123
	27-Aug-02	2.0 U	1.3 U	1.4 U	10	0.12	3.8	<0.13	<0.077	0.04	<0.6	200	0.08	0.05	340	60	70	6	6.62	12.2	1,083
	10-Dec-02	2.0 U	0.018	0.068	15	R	1.6	0.56	<0.018	0.31	<0.6	180	<0.01	0.07	408	35	65	20	7.30	10.7	740
	8-Apr-03	0.42	0.008	0.025	1.7 J	3.16	1.6	<0.058	<0.018	0.39	0.6	190	<0.01	0.05	340	30	60	4	7.28	10.6	1,133
	19-Aug-03	2.6	0.019	0.082	1.2 J	0.87	1.4	<0.058	<0.018	0.26	1.9	90	0.01	0.11	340	35	60	-47	7.07	20.5	1,087
	12-Apr-05	5.8	0.056	0.085	51	R	NM	NM	NM	0.46	1.4	180	0.20	NM	NM	50	NM	15	7.20	10.2	941
	14-Nov-05	NM	NM	NM	4.1J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	47	7.10	10.3	1,028
PES-MW-5	14-Nov-01	2.0 U	1.6 U	1.4 U	1.6	1.4	Na	0.58	<0.2	0.02	<0.6	120	<0.01	<0.01	422	85	105	104	6.80	11.7	1,279
	12-Feb-02	2.0 U	1.6 U	1.4 U	1.7	3.8	Na	<0.13	<0.077	0.04	<0.6	90	0.02	0.01	561	70	120	-64	7.04	10.1	1,241
	21-May-02	2.0 U	1.6 U	1.4 U	1.8	0.7	2.3	0.28	<0.077	0.01	<0.6	130	<0.01	<0.01	459	70	100	-65	6.90	13.1	1,266
	27-Aug-02	2.0 U	1.6 U	1.4 U	12	5.5	2.1	0.26	<0.077	<0.01	<0.6	120	<0.01	<0.01	202	50	80	197	6.17	11.9	1,011
	10-Dec-02	2.0 U	0.008	0.009	23	2.5	1.4	<0.057	<0.018	0.02	<0.6	111	<0.01	0.02	442	60	95	240	7.08	10.5	828
	8-Apr-03	0.04	0.005 U	0.009	< 1.0	3.3	1.9	0.87	< 0.018	0.06	<0.6	150	<0.01	<0.01	408	60	105	131	7.08	10.6	1,367
	19-Aug-03	0.1	0.015	0.026	<1.0	1.4	2.2	<0.058	<0.018	0.02	0.7	180	<0.01	0.01	306	40	85	218	7.10	21.9	1,081
	12-Apr-05	4.5	0.050	0.062	6.9	R	NM	NM	NM	0.02	<0.6	170	0.01	NM	NM	35	NM	13	6.99	9.4	1,403
PES-MW-6	15-Nov-01	2.0 U	1.6 U	1.4 U	1.4	0.22	Na	<0.2	<0.2	0.01	<0.6	160	0.20	0.04	306	40	55	-158	7.79	11.5	1,030
	15-Feb-02	2.0 U	1.6 U	1.4 U	12	0.35	Na	<0.13	<0.077	0.47	1.1	290	1.2	0.04	408	50	55	-408	7.29	11.0	1,107
	23-May-02	2.0 U	1.6 U	1.4 U	<0.83	0.03	1.9	<0.13	<0.077	0.28	<0.6	190	1.8	0.07	391	30	45	-160	7.30	11.1	1,256
	28-Aug-02	3.8	1.6 U	1.4 U	7	<0.01	2.6	<0.13	<0.077	0.52	1.0	170	0.80	0.07	357	70	55	-296	7.09	12.7	1,109
	12-Dec-02	70	0.019	0.082	16	0.90	3.5	<0.057	<0.018	0.55	<0.6	220	0.59	0.08	391	35	50	R	7.31	10.5	R
	10-Apr-03	12	0.012	0.051	<1.0	0.88	2.9	<0.058	<0.018	0.51	1.1	180	0.61	0.09	340	25	50	-292	7.30	11.0	1,163
	21-Aug-03	8.0	0.010	0.066	1.7 J	3.6	1.9	<0.058	<0.018	0.56	2.2	200	0.31	0.06	306	40	60	-98	7.19	14.3	1,075
	15-Apr-05	210	0.051	0.110	2.6	R	NM	NM	NM	0.38	1.5	200	0.02	NM	NM	30	NM	-89	7.37	12.3	1,104
PES-MW-7	16-Nov-01	2.0 U	1.6 U	1.4 U	1.4	2.3	Na	<0.2	<0.2	<0.01	<0.6	110	<0.01	0.03	238	50	60	-26	8.96	11.6	854
	14-Feb-02	2.0 U	1.6 U	1.4 U	26,000	0.50	Na	<0.13	<0.077	1.9	3.0	160	0.51	0.04	765	85	55	-314	6.93	10.9	1,552
	22-May-02	3.4	1.6 U	1.4 U	150	0.01	5.8	<0.65	2.2	7.8	18	80	0.35	0.23	663	200	60	-188	6.70	12.3	1,531
	28-Aug-02	7,400	1.6 U	1.4 U	150	0.06	3.2	<0.13	1.0	3.9	9.8	60	1.5	2.5	561	180	60	-395	6.58	12.5	1,351
	12-Dec-02	18,000	0.005 U	0.95	200	0.78	4.3	<0.057	0.69	6.3	29	100	0.36	0.70	629	190	60	R	6.74	10.6	R
	10-Apr-03	9,800	0.170	0.076	210	R	3.1	<0.058	<0.018	3.2	28	<7.0	0.25	0.50	629	200	60	-173	6.60	11.9	1,523
	21-Aug-03	8,500	0.006 U	0.001 U	53	0.29	2.5	<0.058	<0.018	4.7	33	<7.0	2.50	1.15	544	165	60	-161	6.71	13.0	1,285
	15-Apr-05	16,000	0.100	0.092	29	R	NM	NM	NM	5.2	33	140	0.07	NM	NM	70	NM	-110	6.80	11.4	1,123
	17-Nov-05	NM	NM	NM	110	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-43	6.88	9.9	1,827
PES-MW-8	15-Nov-01	2.0 U	1.6 U	1.4 U	2.4	0.43	Na	<0.2	<0.2	0.70	0.9	110	<0.01	0.04	408	55	65	-54	7.02	11.6	1,120
	14-Feb-02	2.0 U	1.6 U	1.4 U	6.8	0.55	Na	<0.13	<0.077	1.3	0.8	310	<0.01	0.05	442	40	50	-200	7.29	9.8	1,129
	22-May-02	2.0 U	1.6 U	1.4 U	1.9	0.07	1.2	<0.13	<0.077	1.1	0.7	220	<0.01	<0.01	408	40	60	-85	7.20	12.1	1,318
	28-Aug-02	2.6 J	1.6 U	1.4 U	14	<0.01	2.1	<0.13	<0.077	1.2	1.3	220	0.01	0.04	374	75	60	-69	6.83	12.7	1,160
	12-Dec-02	35	0.016	0.062	4.6	0.12	1.2	<0.057	<0.018	1.2	1.0	180	0.05	0.06	357	35	50	-80	7.15	10.2	R
	9-Apr-03	3.7	0.002 J	0.011	<1.0	2.55	1.7	<0.058	<0.018	1.2	1.4	160	<0.01	0.04	374	30	55	-128	7.25	11.2	1,201
	21-Aug-03	12	0.015	0.066	3.7	0.29	1.6	<0.058	<0.018	1.1	2.3	150	0.01	0.04	306	50	70	-82	7.08	13.3	1,087
	14-Apr-05	11	0.035	0.049	1.7	R	NM	NM	NM	1.0	1.5	180	0.03	NM	NM	50	NM	-87	7.22	11.9	1,097
PES-MW-9	15-Nov-01	2.0 U	1.6 U	1.4 U	1.4	1.1	Na	<0.2	<0.2	0.40	1.1	140	0.01	0.03	391	45	60	-123	7.09	10.9	1,051
	13-Feb-02	2.0 U	1.6 U	1.4 U	1.8	0.79	Na	<0.13	<0.077	0.55	0.9	220	0.01	0.05	340	25	50	-183	7.30	10.7	1,018
	22-May-02	2.0 U	1.6 U	1.4 U	58	0.15	1.5	<0.65	<0.39	4.7	2.1	30	0.04	<0.01	510	80	50	-460	7.10	11.2	1,346
	27-Aug-02	28	5.4 J	13	180	<0.01	8.2	<0.13	0.66	3.3	8.5	7.0	0.22	0.60	646	250	80	-180	6.58	12.5	1,445
	11-Dec-02	3,200	0.012	0.210	240	0.15	3.3	<0.057	0.37	NA	13	<7.0	0.06	1.1	646	600	60	R	7.03	10.4	1,650
	9-Apr-03	5,500	0.001 U	0.035	2.6	1.88	1.8	<0.058	<0.018	4.1	10	110	0.12	0.68	347	65	45	-192	7.52	11.1	1,182
	21-Aug-03	5,000	0.006 U	0.001 U	1.5 J	0.42	1.9	<0.058	<0.018	4.7	2.7	135	0.10	0.25	340	55	60	-180	7.30	15.9	1,141
	16-Apr-05	300	0.012	0.030	3.6	R	NM	NM	NM	2.5	1.6	190	0.02	NM	NM	35	NM	-93	7.41	10.7	991
	16-Nov-05	NM	NM	NM	2.8J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-207	6.27	10.5	1,023
PES-CW-1	13-Nov-01	2.0 U	1.6 U	1.4 U	1.0	0.25	Na	<0.2	<0.2	0.04	0.6	80	<0.01	<0.01	333	60	60	-25	7.08	11.9	1,064
	11-Feb-02	2.0 U	1.6 U	1.4 U	1.3	0.92	Na	0.49	<0.077	0.05	<0.6	130	<0.01	0.03	387	116	65	-195	7.23	11.3	1,079
	20-May-02	2.0 U	1.6 U	1.4 U	<1.3	2.3	2.3	0.20	<0.077	0.01	<0.6	160	<0.01	0.01	347	60	65	-28	7.04	11.2	1,079
	26-Aug-02	2.0 U	1.6 U	1.4 U	11	1.8	3.3	0.19	<0.077	0.04	<0.6	110	<0.01	0.04	408	70	110	45	6.47	13.1	1,258
	9-Dec-02	2.6 J	0.017	0.014	1.6	0.25	2.5	<0.057	<0.018	0.03	<0.6	120	<0.01	0.04	391	35	60	120	7.27	10.4	770
	7-Apr-03	0.23	0.005 U	0.013	< 1.0	0.65	3.1	0.73	<0.018	<0.01	<0.6	140	<0.01	0.02	408	50	125	72	6.89	10.4	1,354
	18-Aug-03	0.16	0.004 J	0.013	1.6 J	0.71	1.5	0.65	<0.018	0.03	2.0	160	<0.01	0.02	357	70	130	103	7.00	15.7	215

TABLE 4.6 (Continued)
SUMMARY OF GROUNDWATER GEOCHEMICAL DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Methane (µg/L)[a/]	Ethane (µg/L)	Ethene (µg/L)	TOC [b/] (mg/L) [c/]	Dissolved Oxygen (mg/L)	Dissolved Hydrogen (nM)[d/]	Nitrate (mg/L)	Nitrite (mg/L)	Ferrous Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Ammonia (mg/L)	Total Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Chloride (mg/L)	Redox Potential (mV)[e/]	pH (SU)[f/]	Temperature (°C) [g/]	Specific Conductivity (µs/cm) [h/]
PES-CW-2	13-Nov-01	2.0 U	1.6 U	1.4 U	0.97	0.28	Na	<0.2	<0.2	0.30	1.1	50	<0.01	0.05	323	74	65	-32	7.05	12.0	1,064
	11-Feb-02	2.0 U	1.6 U	1.4 U	0.97	2.3	Na	<0.13	<0.077	<0.01	<0.6	190	<0.01	0.01	340	45	55	-78	7.21	10.6	1,011
	20-May-02	2.0 U	1.6 U	1.4 U	<1.0	1.1	2.9	<0.13	<0.077	0.06	<0.6	140	<0.01	0.06	357	45	60	-44	7.10	11.9	1,020
	26-Aug-02	2.0 U	1.6 U	1.4 U	12	1.1	3.3	0.15	<0.077	0.02	<0.6	130	0.01	<0.01	357	55	80	82	6.59	13.2	1,134
	9-Dec-02	4.0	0.017	0.006	5.4	0.33	1.8	<0.057	<0.018	0.01	<0.6	170	<0.01	0.09	357	30	55	210	7.35	10.6	819
	7-Apr-03	0.12	0.005 U	0.011	< 1.0	0.85	3.8	0.84	<0.018	<0.01	0.6	140	<0.01	0.02	425	45	100	128	6.94	10.6	1,292
	19-Aug-03	0.3	0.007	0.023	1.7 J	1.79	1.8	1.10	<0.018	0.02	0.4	120	<0.01	0.01	391	50	125	87	6.50	15.8	140
	11-Apr-05	NM	NM	NM	3.6	R	NM	NM	NM	0.03	0.3	160	<0.01	NM	NM	60	NM	-3	7.14	11.9	1,164
	14-Nov-05	NM	NM	NM	30	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-9	7.22	11.2	1,273
PES-CW-3	13-Nov-01	2.0 U	1.6 U	1.4 U	0.75	0.60	Na	<0.2	<0.2	0.02	1.0	110	<0.01	0.04	357	70	63	32	7.07	12.8	1,014
	12-Feb-02	2.0 U	1.6 U	1.4 U	2.1	1.0	Na	<0.13	<0.077	<0.01	<0.6	150	<0.01	0.03	323	25	50	71	7.03	10.4	988
	20-May-02	2.0 U	1.6 U	1.4 U	<1.6	1.5	2.6	<0.13	<0.077	0.04	<0.6	130	<0.01	0.03	340	40	60	-60	7.10	14.0	920
	26-Aug-02	2.8	1.6 U	1.4 U	11	1.3	6.7	<0.13	<0.077	0.04	<0.6	150	0.01	0.08	238	35	50	81	6.74	13.4	962
	10-Dec-02	2.0 U	0.016	0.013	14	0.20	2.6	<0.057	<0.018	0.02	<0.6	140	<0.01	0.05	306	30	55	200	7.02	10.2	458
	7-Apr-03	1.2	0.007	0.011	< 1.0	0.80	3.0	<0.058	<0.018	0.03	<0.6	180	<0.01	0.01	289	30	55	103	7.29	7.4	1,056
	19-Aug-03	1.3	0.012	0.026	<1.0	0.98	3.4	0.360	<0.018	0.01	1.0	140	<0.01	<0.01	340	50	80	215	6.92	20.0	1,142
	11-Apr-05	NM	NM	NM	3.7	R	NM	NM	NM	0.03	0.4	170	<0.01	NM	NM	45	NM	29	7.50	11.5	1,153
	14-Nov-05	NM	NM	NM	3.5J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	38	7.11	10.7	1,029
PES-MW-10A	15-Apr-05	21,000	0.360	0.110	190	R	NM	NM	NM	5.1	17	87	0.10	NM	NM	120	NM	-111	6.61	11.4	1,365
	16-Nov-05	NM	NM	NM	51	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-202	5.54	10.0	1,037
PES-MW-10B	14-Apr-05	4.5	0.034	0.045	3.3	R	NM	NM	NM	0.04	0.8	180	0.04	NM	NM	40	NM	-52	7.15	13.0	1,064
	15-Nov-05	NM	NM	NM	<5.0	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	19	7.32	10.5	901
PES-MW-11A	13-Apr-05	3,900	0.090	0.066	8.9	R	NM	NM	NM	3.1	2.4	150	0.01	NM	NM	35	NM	-21	6.91	10.8	1,047
	15-Nov-05	NM	NM	NM	3.6J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	4	7.40	10.6	807
PES-MW-12A	12-Apr-05	2.1	0.042	0.080	6.0	R	NM	NM	NM	0.08	<0.6	150	0.03	NM	NM	35	NM	60	7.31	11.7	1,291
	15-Nov-05	NM	NM	NM	2.9J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	32	7.26	10.5	1,270
PES-MW-12B	20-Apr-05	7.8	0.140	0.180	5.5	R	NM	NM	NM	0.03	1.6	150	0.01	NM	NM	25	NM	18	7.08	10.6	1,348
	15-Nov-05	NM	NM	NM	3.5J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-6	7.39	10.7	827
PES-MW-13A	22-Apr-05	4.8	0.032	0.042	5.1	R	NM	NM	NM	0.19	1.3	190	0.01	NM	NM	25	NM	-34	7.57	13.5	1,102
	16-Nov-05	NM	NM	NM	3.0J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	210	6.00	10.3	942
PES-MW-14A	12-Apr-05	6,900	0.150	0.180	50	R	NM	NM	NM	3.19	2.3	130	0.12	NM	NM	65	NM	-44	6.88	12.0	901
	15-Nov-05	NM	NM	NM	7.1	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-12	7.05	10.3	1,044
PES-MW-14B	20-Apr-05	7.7	0.120	0.140	4.2J	R	NM	NM	NM	0.01	0.7	220	0.01	NM	NM	20	NM	57	7.28	12.1	1,082
	16-Nov-05	NM	NM	NM	2.8J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	195	6.03	10.7	984
INJECTION WELLS																					
PES-INJ-1	19-Nov-01	2.0 U	1.6 U	1.4 U	1.1	0.14	Na	<0.2	<0.2	0.01	0.6	140	<0.01	0.03	323	25	55	-1	7.62	10.7	1,015
	18-Feb-02	200 U	160 U	140 U	11,000	0.15	Na	19	<13	NA	NA	NA	36	6.3	8,500	8,500	85	-325	5.67	10.9	4,660
	23-May-02	140 U	280 U	250 U	2,500	0.10	4.4	0.9	9.7	280	3.3	<7.0	1.0	0.6	21,250	5,500	2,500	-89	5.50	11.3	1,702
	29-Aug-02	190	70	41	2,900	<0.01	16	<2.6	21	17	6.6	<7.0	0.11	0.1	2,975	2,500	125	-98	5.23	12.0	4,520
	13-Dec-02	630	35	24	2,600	R	5.2	<2.5	7.9	13	6.9	<7.0	0.14	1.3	4,675	2,800	125	-40	5.25	8.2	R
	10-Apr-03	73	3.1	7.6	2,300	1.58	4.4	<0.58	13	3.9	16	<7.0	0.04	0.7	4,250	2,500	250	-91	5.24	12.6	3,310
	22-Aug-03	660	21	25	2,100	0.65	32	<0.58	9.8 J	4.8	9.3	<7.0	0.03	0.5	2,040	2,000	100	-33	5.21	12.1	2,950
	19-Apr-05	14,000	6.3	4.6	2,500	R	NM	NM	NM	3.6	14	<7.0	6.9	NM	NM	2,500	NM	0 R	5.60	11.6	3,081
PES-INJ-2	19-Nov-01	2.0 U	1.6 U	1.4 U	0.8	<0.01	Na	<0.2	<0.2	0.01	<0.6	130	<0.01	0.04	289	25	55	74	7.77	10.5	971
	15-Feb-02	50 U	40 U	35 U	9,500	0.01	Na	34	110	NA	NA	NA	9	7.0	8,500	3,000	2,500	-323	5.44	10.6	4,200
	23-May-02	28 U	56 U	50 U	4,100	0.05	93	2.7	19	2.6	14	<7.0	1.9	3.1	29,750	7,500	2,500	-93	5.10	12.3	1,872
	29-Aug-02	13	5	2.8	4,130	<0.01	4.9	<2.6	28	NA	17	23	2.9	0.72	2,550	2,250	100	-55	5.10	12.4	4,870
	13-Dec-02	11	0.34	1.4	4,400	R	12	20	13	NA	5.4	61	0.8	0.68	4,250	2,900	100	-30	5.10	10.5	R
	11-Apr-03	99	0.35	1.4	2,300	0.63	39	<0.58	11 J	NA	78	<7.0	0.8	0.40	5,100	2,750	100	-33	5.09	11.1	3,160
	22-Aug-03	1,500	1.1	4.5	2,000	1.05	300	<0.58	6.7 J	2.4	69	<7.0	0.3	0.56	1,700	1,300	150	1	5.11	12.8	2,650
	19-Apr-05	5,800	1.1	3.8	2,400	R	NM	NM	NM	1.6	50	5	12	NM	NM	3,500	NM	5 R	5.35	11.0	2,434

TABLE 4.6 (Continued)
SUMMARY OF GROUNDWATER GEOCHEMICAL DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Methane (µg/L)[a/]	Ethane (µg/L)	Ethene (µg/L)	TOC [b/] (mg/L) [c/]	Dissolved Oxygen (mg/L)	Dissolved Hydrogen (nM)[d/]	Nitrate (mg/L)	Nitrite (mg/L)	Ferrous Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Ammonia (mg/L)	Total Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Chloride (mg/L)	Redox Potential (mV)[e/]	pH (SU)[f/]	Temperature (°C) [g/]	Specific Conductivity (µs/cm) [h/]
PES-INJ-3	16-Nov-01	2.0 U	1.6 U	1.4 U	1.0	0.92	Na	<0.2	<0.2	0.01	0.6	110	<0.01	0.06	255	10	60	-79	8.47	12.1	881
	18-Feb-02	200 U	160 U	140 U	6,900	0.67	Na	15	<7.7	NA	NA	NA	23	3.3	11,900	4,500	60	-317	5.65	10.8	6,310
	23-May-02	140 U	280 U	250 U	4,100	0.12	30	1.9	23	NA	NA	66	1.8	2.2	25,500	7,500	2,500	-76	5.30	12.9	1,843
	29-Aug-02	7.5	5.6 J	1.4 U	3,650	<0.01	15	<2.6	32	5.6	31	<7.0	1.6	1.5	2,975	2,875	100	-98	5.23	12.0	4,520
	13-Dec-02	3.3	0.630	1.2	4,900	0.47	57	<2.5	13	NA	30	<7.0	2.8	2.0	5,525	3,875	100	-35	5.26	10.3	R
	11-Apr-03	58	0.35	1.4	4,600	0.04	39	<0.58	17 J	NA	20	<7.0	4.6	2.7	5,950	5,000	100	-88	5.14	11.3	4,010
	22-Aug-03	290	1.4	3.7	2,600	2.34	150	<0.58	15 J	5.7	22	<7.0	0.2	0.7	2,380	2,100	100	-54	5.19	15.0	3,710
	19-Apr-05	2,800	3.6	3.4	4,700	R	NM	NM	NM	4.5	74	<7.0	14	NM	NM	2,000	NM	9 R	5.33	11.6	3,328
	17-Nov-05	NM	NM	NM	13,000	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	3	5.86	10.5	5,081

[a/] µg/L = micrograms per liter.

[b/] TOC = total organic carbon.

[c/] mg/L = milligrams per liter.

d/ nM = nano-Mol

[e/] mV = millivolts.

[f/] SU = pH standard units.

[g/] °C = degrees Centigrade.

[h/] µs/cm = microsiemens per centimeter.

[i/] J indicates that the analyte was detected at a concentration above the method detection limit but below the reporting limit resulting in an estimated value.

[j/] NM = Not measured.

[k/] <20 indicates that the analyte was not detected above the referenced method detection limit.

[l/] R = This data point is of suspect quality or was collected in the incorrect units (as percent saturation instead of mg/L). Therefore it is rejected and was not considered during data interpretation.

Baseline concentrations of TOC ranged from a minimum of 0.8 milligrams per liter (mg/L) at PES-INJ-2 to a maximum of 3.7 mg/L at GWMS-27S. Following injection, elevated concentrations of TOC (i.e., greater than 10 mg/L) were observed at the injection wells and at monitoring wells PES-MW-1, PES-MW-6, and PES-MW-7 (Table 4.6). These data indicate that TOC was distributed as far as the first downgradient line of monitoring wells (approximately 15 feet) within approximately 2 months of injection. Elevated TOC concentrations (greater than 10 mg/L) were observed in later events (particularly the August 2002 event) in all of the remaining monitoring wells including the contingency (i.e., "CW") wells and GWMS-27S and GWMS-47S. High concentrations (greater than 100 mg/L) of TOC were detected in PES-MW-7 during the February 2002 sampling event, indicating that this well was heavily impacted by the injection. High concentrations of TOC were also detected in PES-MW-9 during the August 2002 and December 2002 sampling events, indicating that large quantities of TOC mass are migrating to this well. These values are relatively low (with the exception of PES-MW-7 in February 2002) compared to TOC measured in groundwater samples collected from the injection wells, which ranged from 2,000 mg/L to 2,600 mg/L during the August 2003 sampling event (Table 4.6).

TOC data indicate that the zone of influence of the vegetable oil injection within the first few months following injection was limited primarily to the area of wells PES-MW-1, PES-MW-6, PES-MW-7, and PES-MW-9; these wells are located only 10 feet from the injection wells. However, during subsequent sampling events TOC concentrations in all of the other monitoring wells had increased approximately one order of magnitude, indicating that the zone of influence expanded as dissolved TOC migrated downgradient. However, between December 2002 and April 2003 TOC concentrations decreased significantly at nearly all of the monitoring well locations. This decrease mirrors CAH concentration trend changes during the same time period and is likely related to temporal changes in groundwater flow conditions.

4.5.2 Dissolved Hydrogen as an Indicator of Substrate Addition and Area of Influence

As organic material is broken down though fermentation, H_2 is produced. This H_2 is then used by the microbial population during the reductive dechlorination of chlorinated solvent mass. The spatial distribution of dissolved H_2 is a good indicator of the spatial distribution of organic material that is being fermented and of areas where reductive dechlorination is likely to occur.

Dissolved H_2 data were not collected during the baseline and February 2002 process monitoring events. Thus, background dissolved H_2 data are not available for the wells installed within the pilot test area. However, dissolved H_2 data from wells that were not impacted by the injected vegetable oil (e.g., the contingency wells and existing wells GWMS-27S and GWMS-47S) can be evaluated to determine how much dissolved H_2 is in the aquifer system naturally. The data from the contingency wells and existing wells GWMS-27S and GWMS-47S indicate that dissolved H_2 concentrations as high as 4 nanomolar (nM) may be naturally occurring within the pilot test area. During process monitoring sampling, concentrations of dissolved H_2 exceeding 4 nM were observed only in the injection wells and in monitoring wells PES-MW-7 and PES-MW-9. This lack of elevated dissolved H_2 implies that dissolved H_2 related to the injected vegetable oil was

not effectively distributed to the monitoring well network. However, H_2 is very reactive and tends to be consumed readily through biotic and abiotic processes. Therefore, the lack of elevated concentrations of dissolved H_2 does not necessarily indicate that vegetable oil breakdown products were not distributed beyond the injection area or that reductive dechlorination will not occur outside of the injection area.

Dissolved H_2 concentrations also can be used to determine the dominant terminal electron accepting process (TEAP) in an aquifer. This method has been shown to provide a direct, independent measurement that identifies which redox reactions are taking place in anaerobic groundwater (Lovley and Goodwin, 1988; Lovley *et al.*, 1994; Vroblesky and Chapelle, 1994). When dissolved H_2 concentrations are measured, the concentrations directly indicate which TEAP is dominant in a given location at a given time. Dissolved H_2 concentrations ranging from 0.2 nM to 0.8 nM are indicative of iron reduction, concentrations ranging from 1 to 4 nM are indicative of sulfate reduction, and concentrations greater than 5 nM are indicative of methanogenesis (USEPA, 1998). Dissolved H_2 concentrations throughout the pilot test area typically ranged between 1 and 4 nM except at the injection wells and monitoring wells PES-MW-7 and PES-MW-9 where dissolved H_2 concentrations were elevated due to the injected vegetable oil. These data suggests that sulfate reduction should be the dominant TEAP at the majority of the well locations within the pilot test area.

4.5.3 Microbial Population and Volatile Fatty Acid Data

Groundwater sample aliquots were collected for VFA and PLFA analysis from each of the pilot test monitoring wells, existing well GWMS-46S, and the three injection wells during all of the process monitoring sampling events, with the exception of the February 2002 event. These analyses were performed by Microbial Insights, Inc.. Additional sample aliquots were collected from GSMW-46S, PES-MW-1, PES-MW-3, PES-MW-4 PES-MW-5, and PES-INJ-2 during the December 2002 sampling event and submitted to Microbial Insights Inc. for PLFA analysis. The results of these analyses are summarized in Table 4.7.

4.5.3.1 Biomass and Microbial Starvation Indicators

Biomass is represented by the total amount of PLFA present and provides a quantitative measure of the viable microbial biomass present. Elevated concentrations of biomass are an indicator of enhanced microbial activity. Biomass estimates were elevated in injection well PES-INJ-2, and slightly elevated in monitoring wells GWMS-46S and PES-MW-1. The biomass present at the remaining wells was one to two orders of magnitude lower than that measured in GWMS-46S and PES-MW-1. These data indicate that the microbial biomass was stimulated in the vicinity of the injection wells.

During times of decreasing food supply, or when the microbial community expands beyond the available food supply, some microbial strains will convert *cis*-fatty acid to cyclopropyl. The degree of starvation occurring at a particular location can be determined by measuring the concentration of cyclopropyl in groundwater and dividing it by the concentration of its biosynthetic precursor *cis*-fatty acid. Thus, an increase in the starvation ratio indicates that there has been a decrease in the food supply (organic

TABLE 4.7
BIOMASS AND VOLATILE FATTY ACIDS IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Distance Downgradient From Injection Wells (feet)	Sample Date	Total Organic Carbon (mg/L)[a/]	Bacterial Biomass (pmol/mL)[b/]	Starvation Ratio (unitless)	Total Volatile Fatty Acids (mg/L)	Metabolic Acids					
							Pyruvic (mg/L)	Lactic (mg/L)	Formic (mg/L)	Acetic (mg/L)	Proprionic (mg/L)	Butyric (mg/L)
MONITORING WELLS												
18S		4/18/2005	3.8	NM	0.00	< 4	< 4	< 1	< 1	< 1	< 1	< 1
26-S		4/15/2005	2.2	NM	0.09	NM	NM	NM	NM	NM	NM	NM
GWMS-27S	220	21-May-02	<1.7 [c/]	NM [d/]	NM	< 4 [b/]	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	9.9	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		9-Dec-02	16	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		7-Apr-03	2.8	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		18-Aug-03	1.2 J	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
GWMS-46S [e/]	-22	22-May-02	2.3	NM	NM	5.6	< 40	< 1	4.0	1.6	< 1	< 1
		28-Aug-02	10	NM	NM	6.2	< 4	0.8 J [f/]	1.9	2.6	0.9 J	< 1
		11-Dec-02	18	13.4	0.56	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	1.0 J	3	0.12	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		20-Aug-03	1.0 UJ	11	0.32	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		18-Apr-05	4	NM	1.22	< 4	< 4	< 1	< 1	< 1	< 1	< 1
GWMS-47S	224	21-May-02	<1.1	NM	NM	< 4	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	11	NM	NM	3.8	< 4	< 1	1.8	2.0	< 1	< 1
		10-Dec-02	38	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	1.1	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		19-Aug-03	1.0 J	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-1	16	22-May-02	3.0	NM	NM	6.5	< 40	< 1	3.7	1.8	0.97	< 1
		28-Aug-02	14	NM	NM	10.4	< 4	< 1	1.7	6.8	1.9	< 1
		12-Dec-02	12	31.3	1.13	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		10-Apr-03	<1.0	54	0.07	3.0	< 4	1.0	< 1	1.0	1.0	< 1
		21-Aug-03	1.4 J	14	0.25	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		15-Apr-05	3	NM	0.26	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-2	28	22-May-02	2.5	NM	NM	8.0	< 40	< 1	3.9	1.9	2.2	< 1
		28-Aug-02	12	NM	NM	3.6	< 4	< 1	1.7	1.9	< 1	< 1
		9-Dec-02	6.5	0.2	1.54	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		9-Apr-03	<1.0	7	0.11	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		20-Aug-03	1 J	19	0.07	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		14-Apr-05	1.9	NM	0.16	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-3	48	21-May-02	2.9	NM	NM	8.1	< 40	< 1	4.0	2.4	1.7	< 1
		27-Aug-02	13	NM	NM	6.7	< 4	< 1	1.7	3.8	1.2	< 1
		10-Dec-02	24	0.0	0.00	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	2.0 J	194	0.92	3.6	< 4	< 1	< 1	1.9	1.7	< 1
		20-Aug-03	2.6 J	44	0.27	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		14-Apr-05	2	NM	0.76	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-4	76	21-May-02	2.0	NM	NM	1.5	< 80	< 1	1.5	< 1	< 1	< 1
		27-Aug-02	10	NM	NM	3.7	< 4	< 1	1.8	1.9	< 1	< 1
		10-Dec-02	15	1.0	0.09	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	1.7 J	6.0	0.36	2.0	< 4	< 1	< 1	1.0	1.0	< 1
		19-Aug-03	1.2 J	119	0.62	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		12-Apr-05	51	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1

TABLE 4.7 (Continued)
BIOMASS AND VOLATILE FATTY ACIDS IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Distance Downgradient From Injection Wells (feet)	Sample Date	Total Organic Carbon (mg/L)[a/]	Bacterial Biomass (pmol/mL)[b/]	Starvation Ratio (unitless)	Total Volatile Fatty Acids (mg/L)	Metabolic Acids					
							Pyruvic (mg/L)	Lactic (mg/L)	Formic (mg/L)	Acetic (mg/L)	Proprionic (mg/L)	Butyric (mg/L)
PES-MW-5	142	21-May-02	1.8	NM	NM	1.4	< 80	< 0	1.4	< 1	< 1	< 1
		27-Aug-02	12	NM	NM	4.3	< 4	< 0.9	1.8	2.5	< 1	< 1
		10-Dec-02	23	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	<1.0	NM	NM	2.0	< 4	< 1	< 1	1.0	1.0	< 1
		19-Aug-03	<1.0	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-6	16	23-May-02	<0.83	NM	NM	19.1	< 40	< 1	4.1	12.3	2.7	< 1
		28-Aug-02	7	NM	NM	6.3	< 4	< 1	2.1	4.2	< 1	< 1
		12-Dec-02	16	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		10-Apr-03	<1.0	57	0.07	8.0	4.0	1.0	< 1	1.0	1.0	1.0
		21-Aug-03	1.7 J	18	0.02	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		15-Apr-05	3	NM	0.07	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-7	16	22-May-02	150	NM	NM	347	< 20	< 1	3.9	133	182	28
		28-Aug-02	150	NM	NM	212	< 4	< 1	1.9	57.8	122	30
		12-Dec-02	200	NM	NM	149	< 4	< 1	< 1	28.3	98	23
		10-Apr-03	210	87	0.50	202.2	< 4	< 1	< 1	43.4	153.5	5.3
		21-Aug-03	53	558	0.21	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		15-Apr-05	29	NM	0.10	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-8	40	22-May-02	1.9	NM	NM	5.6	< 40	< 1	4.0	1.6	< 1	< 1
		28-Aug-02	14	NM	NM	3.9	< 4	< 1	1.9	2.0	< 1	< 1
		12-Dec-02	4.6	NM	NM	< 1	< 4	< 1	< 1	< 1	< 1	< 1
		9-Apr-03	<1.0	62	2.35	8.0	4.0	1.0	< 1	1.0	1.0	1.0
		21-Aug-03	3.7	29	1.45	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		14-Apr-05	1.7	NM	0.67	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-9	36	22-May-02	58 J	NM	NM	140	< 40	< 1	4.2	53.8	82.4	< 1
		27-Aug-02	180	NM	NM	308	< 4	< 0.5	1.9	199	99.1	7.6
		11-Dec-02	240	NM	NM	295	< 4	< 1	0.6 J	229	47.5	18.1
		9-Apr-03	2.6	45	0.42	4.0	< 4	1.0	< 1	1.0	1.0	1.0
		20-Aug-03	1.5 J	121	0.19	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		16-Apr-05	4	NM	0.58	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-10A	16	15-Apr-05	190	NM	0.20	50.5	< 4	< 1	< 1	26.8	11.6	12.1
PES-MW-10B	13	14-Apr-05	3	NM	0.07	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-11A	38	13-Apr-05	9	NM	0.17	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-12A	155	12-Apr-05	6	NM	0.08	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-12B	155	20-Apr-05	6	NM	0.00	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-13A	NA	20-Apr-05	5	NM	0.08	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-14A	75	12-Apr-05	50	NM	0.37	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-14B	75	20-Apr-05	4.2J	NM	0.05	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-CW-1	220	20-May-02	<1.3	NM	NM	<1	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	11	NM	NM	3.4	< 4	< 1	1.6	1.8	< 1	< 1
		9-Dec-02	1.5	NM	NM	< 1	< 4	< 1	< 1	< 1	< 1	< 1
		7-Apr-03	<1.0	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		18-Aug-03	1.6 J	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1

TABLE 4.7 (Continued)
BIOMASS AND VOLATILE FATTY ACIDS IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Distance Downgradient From Injection Wells (feet)	Sample Date	Total Organic Carbon (mg/L)[a/]	Bacterial Biomass (pmol/mL)[b/]	Starvation Ratio (unitless)	Total Volatile Fatty Acids (mg/L)	Metabolic Acids					
							Pyruvic (mg/L)	Lactic (mg/L)	Formic (mg/L)	Acetic (mg/L)	Proprionic (mg/L)	Butyric (mg/L)
PES-CW-2	212	20-May-02	<1.0	NM	NM	<1	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	12	NM	NM	3.4	< 4	< 1	1.7	1.7	< 1	< 1
		9-Dec-02	5.4	NM	NM	< 1	< 4	< 1	< 1	< 1	< 1	< 1
		7-Apr-03	<1.0	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		19-Aug-03	1.7 J	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-CW-3	220	20-May-02	<1.6	NM	NM	<1	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	11	NM	NM	4.0	< 4	0.4 J	1.8	1.8	< 1	< 1
		10-Dec-02	14	NM	NM	< 1	< 4	< 1	< 1	< 1	< 1	< 1
		8-Jul-03	<1.0	NM	NM	3.0	< 4	< 1	< 1	1.0	1.0	1.0 J
		19-Aug-03	<1.0	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
INJECTION WELLS												
PES-INJ-1	NA [d/]	23-May-02	2,500	NM	NM	3,279	< 80	1.2	4.9	1,500	843	930
		29-Aug-02	2,900	NM	NM	2,910	< 4	1.2	3.0	1,468	458	980
		13-Dec-02	2,600	NM	NM	2,509	< 4	< 1	3.8	1,294	255	956
		10-Apr-03	2,300	3.0	2.47	2,321	< 4	< 1	1.5	1,276	179	865
		22-Aug-03	2,100	4.0	1.73	1,973	< 4	< 1	< 1	963	311	699
		19-Apr-05	2,500	NM	NM	1,954	< 4	< 1	< 1	1,222	167	565
PES-INJ-2	NA	23-May-02	4,100	NM	NM	5,777	< 80	< 20	32.7	1,471	2,835	1,438
		29-Aug-02	4,130	NM	NM	4,371	333	< 20	< 20	1,059	1,753	1,226
		13-Dec-02	4,400	7,698	0.05	3,176	177	< 10	< 10	917	1,047	1,035
		11-Apr-03	2,300	98	0.18	2,139	40	10	10	905	466	708
		22-Aug-03	2,000	350	0.00	1,879	< 4	< 1	< 1	893	379	607
		19-Apr-05	2,400	NM	0.25	1,334	< 4	< 1	< 1	794	174	366
PES-INJ-3	NA	23-May-02	4,100	NM	NM	5,410	< 80	< 20	33.4	1,303	2,355	1,719
		29-Aug-02	3,650	NM	NM	2,965	< 80	< 20	< 20	889	806	1,270
		13-Dec-02	4,900	NM	NM	3,202	< 4	< 10	< 10	1,265	652	1,285
		11-Apr-03	4,600	27	0.00	2,668	< 4	< 1	2.2	1,039	255	1,372
		22-Aug-03	3,600	59	0.79	2,787	243	< 1	20	963	231	1,330
		19-Apr-05	4,700	NM	NM	1,822	< 4	2.3	84	646	127	963
OTHER WELLS												
MS-53PC	NA	11-Apr-05	110	NM	NM	792	< 4	1.0	106	469	210	6

[a/] mg/L = milligrams per liter.
[b/] pmol/mL = picomoles per milliliter.
[c/] "<" indicates that anayte was below the limit of quantitation.
[d/] NM = not measured.
[e/] This well is located upgradient of the injection area.
f/ J indicates that the analyte was detectedat a concentration greater than the method detection limit and less than the reporting limit. Thus, the concentration is estimated.

carbon) or that microbial population growth (increasing bacterial biomass) has outstripped the available food supply.

The PLFA data summarized in Table 4.7 indicate that microbial starvation is highly variable both spatially and temporally. During the December 2002 sampling event high starvation ratios were measured at locations PES-MW-1 and PES-MW-2, indicating that the food supply (i.e., organic carbon) available to the microbial population was declining and the microbial populations at these locations were starving as a result. A low starvation ratio was measured at PES-INJ-2, indicating that the microbial population at this location had a plentiful food supply available. The starvation data are supported by observed decreases in TOC concentrations at PES-MW-1 and PES-MW-2 and high concentrations of TOC detected at PES-INJ-2.

Review of the starvation ratio data, bacterial biomass data, and TOC concentration data (Table 4.7) from the April and August 2003 sampling rounds indicates that bioavailable organic carbon mass increased at monitoring well locations PES-MW-7 and PES-MW-9. This increase in bioavailable organic carbon is evidenced by large increases in bacterial biomass and coincident decreases in starvation ratio. During the same period, TOC concentrations decreased or remained stable at these locations, likely due to increased bacterial biomass and a resultant increase in consumption of TOC. At location PES-MW-2 there was a small increase in bacterial biomass coincident with a decrease in starvation ratio and a small decrease in TOC concentration, indicating that bioavailable organic carbon mass may have increased at this location. The biomass and starvation ratio data from locations PES-MW-6 and PES-MW-8 indicate that bioavailable organic carbon mass at these locations was relatively low in December 2002 and remained low through August 2003. At location PES-MW-4 the bacterial biomass increased substantially between April and August 2003. This increase in bacterial biomass was accompanied by stable TOC concentrations and a slight increase in starvation ratio. These data indicate that bioavailable organic carbon mass at this location may have increased during 2003, but that the additional carbon mass was consumed by microbial processes.

The bacterial biomass, starvation ratio, and TOC concentration data indicate that a significant mass of bioavailable organic carbon is present at PES-MW-7 and PES-MW-9, and that a lower mass is present at PES-MW-2. The data also indicate that a significant quantity of bioavailable organic carbon is not present at wells PES-MW-6 and PES-MW-8, and that bioavailable organic carbon mass at PES-MW-4 either remained stable or increased slightly.

4.5.3.2 Denatured Gradient Gel Electrophoresis

DGGE is a powerful tool for detection and identification of organisms from environmental samples. In this method, sample microbial DNA is first isolated and purified. The DNA sequence for the Bacterial 16S ribosomal DNA (rDNA) is then amplified (many copies are made) using a polymerase chain reaction. The 16S rDNA gene is used for bacterial identification since it is common to all bacteria, and there are large databases of sequences available for comparison. The amplified sequences are separated into bands using a denaturing gradient gel. Numerically dominant members of the microbial community (greater than 1 to 2 percent of the community) can be detected,

so the bacterial identifications reported are examples of abundant members of the microbial community. For each sequenced DNA band, the closest described relative of each is reported. Phylogenetic affiliations are determined by comparing the rDNA sequences from samples to known bacterial sequences in the National Center for Biotechnology Information Database (GenBank).

High throughput DNA screening by DGGE analysis was conducted during the April and August 2003 sampling events at the injection wells, existing well GWMS-46S, and the nine pilot test monitoring wells to determine the composition of the microbial population at each location. During April and August 2003, the microbial populations at the injection wells were dominated by bacterial strains *Clostridium*, *Trichococcus*, and *Rahnella*. These bacterial strains are known organic material fermenters and nitrate reducers. The microbial populations at well locations PES-MW-1, PES-MW-6, PES-MW-7, and PES-MW-9 were similar in that the population at each location was dominated by microbial strains *Sulfurospirillum* and *Sulfuricurvum*. These microbial strains are known sulfate and nitrate reducers known to be capable of dechlorinating PCE. *Dechloromonas*, a known perchlorate reducer, was also detected at PES-MW-7 during the August 2003 event. *Sulfurospirillum* was also detected at PES-MW-8 during the April 2003 event but not during the August 2003 event. The microbial communities at the remaining well are dominated by various bacterial strains including *Pseudomonas*, a nitrate reducer; *Methylobacter*, a methane utilizer; and Hydrogenophaga, an organic carbon fermenter and oxygen reducer.

The similarities in microbial population between PES-MW-1, PES-MW-6, PES-MW-7, and PES-MW-9 indicate that these well locations have similar geochemical environments which are dissimilar from the remaining well locations. The geochemical environment and resulting microbial populations at well locations PES-MW-1, PES-MW-6, PES-MW-7, and PES-MW-9 have probably been modified by the presence of vegetable oil-related organic carbon.

4.5.3.3 Targeted Gene Detection

Groundwater samples were collected from the injection wells, existing well GWMS-46S, and the pilot test monitoring wells and analyzed via targeted gene detection to determine the presence or absence and relative population of *Dehalococcoides Ethenogenes*. *Dehalococciodes Ethenogenes* is the only microbial strain that has been documented to be capable of sequential reductive dechlorination of PCE and TCE to *cis*-1,2-DCE, VC, and ethene. *Dehalococcoides Ethenogenes* was not detected at any of the sampled locations during the April and August 2003 sampling rounds. The absence of *Dehalococcoides Ethenogenes* does not mean that PCE and TCE will not be completely dechlorinated. Rather, either populations of *Dehalococcoides Ethenogenes* have not developed yet or reductive dechlorination is occurring via other microbial strains within the pilot test area.

4.5.3.4 Volatile Fatty Acids

VFAs (or metabolic acids) are microbial degradation byproducts of organic material and are also a quantitative indicator of microbial activity. These primary degradation products are further utilized as fermentation products, which can produce hydrogen for

reductive dechlorination. VFA analyses indicate that the primary metabolic byproducts of the degradation of soybean oil in injection wells PES-INJ-1, PES-INJ-2, and PES-INJ-3 are acetic, propionic, and butyric acids. Elevated concentrations of these acids were measured in monitoring wells PES-MW-7 and PES-MW-9. Low concentrations of VFAs (3 to 4 mg/L total VFAs) were also detected in all of the monitoring wells during the August sampling event. However these VFA detections were all near the MDL and were not repeated during the December 2002 sampling event, indicating that the low concentrations of VFAs detected during the August sampling event may have been laboratory artifacts. The VFA data also indicate that different metabolic acids are predominant in different locations (e.g. acetic acid is dominant at PES-INJ-1 while propionic acid is dominant at PES-INJ-2). This heterogeneity in VFA content indicates that the microbial population is relatively heterogeneous within the pilot test area, which is to be expected considering the relatively heterogeneous distribution of vegetable oil (Section 4.5.1).

Based on biomass and VFA data, the most significant impact from injected vegetable oil appears to have occurred in the immediate vicinities of the injection wells and monitoring wells PES-MW-7, and PES-MW-9. However, the biomass data indicate that there may be smaller impacts to monitoring wells PES-MW-1 and PES-MW-6 as well.

4.5.4 Cross-Borehole Radar Data

During substrate injection, Ferrofluid™ was added to the vegetable oil emulsion injected into PES-INJ-3 and colloidal iron was added to the emulsion injected into PES-INJ-1. The iron materials were added to serve as tracers to allow the USGS to determine the three dimensional distribution of vegetable oil in the subsurface. The USGS performed downhole tomography and cross borehole radar geophysical surveys during several of the process monitoring events in order to map the distribution of the substrate over time. The results of these surveys are presented in detail in a draft report prepared by the USGS (2003) entitled *Application of Cross-Borehole Radar to Monitor Field-Scale Vegetable Oil Injection Experiments for Biostimulation* and are briefly summarized in the following paragraph.

The geophysical data collected by the USGS indicate that immediately after injection, the vegetable oil was present as a single mass surrounding the three injection wells. The injected radius of influence was estimated to be approximately two to three meters away from the injection wells. During the following 11 months (through November 2002) geophysical data indicate that the vegetable oil did not migrate away from the injection wells as a separate phase liquid. The geophysical data also indicate that geochemical changes related to vegetable oil injection extend as far downgradient as PES-MW-2 (a distance of approximately 30 feet) (USGS, 2003).

There is an apparent contradiction between the radius of influence of the injection as indicated by the cross borehole data (4-5 meters) and the radius of influence as indicated by field observations collected during drilling operations and groundwater geochemical data (3 meters). However, this apparent contradiction is likely simply a result of differences in the two approximations. It is likely that the injected vegetable oil spread laterally during injection at least 3 meters and no more than 5 meters from each injection point.

4.6 GEOCHEMICAL RESULTS

Biodegradation causes measurable changes in groundwater geochemistry that can be used to evaluate the effectiveness of vegetable oil in stimulating microbial activity. For reductive dechlorination to be an efficient process, the groundwater typically must be sulfate-reducing or methanogenic. Thus, groundwater in which reductive dechlorination is occurring should have the following geochemical signature:

- Depleted concentrations of DO, nitrate, and sulfate;
- Elevated concentrations of ferrous iron (Fe[II]), a reduced species of manganese (Mn[II]), methane, ethene, ethane, hydrogen, chloride, and alkalinity; and
- Reduced ORP.

The geochemistry of groundwater in the vicinity of the field test (Table 4.6) has changed significantly following injection of the vegetable oil. The following sections describe these changes and how the site geochemical conditions provide insights regarding the potential for biodegradation of CAHs.

4.6.1 Alternate Electron Acceptors and Metabolic Byproducts

Biodegradation of organic compounds, whether natural or anthropogenic, brings about measurable changes in the chemistry of groundwater in the affected area. Concentrations of compounds used as electron acceptors (e.g., DO, nitrate, and sulfate) are depleted, and byproducts of electron acceptor reduction (e.g., Fe(II) and methane) are produced. By measuring these changes, it is possible to evaluate what biological processes have been induced or enhanced by substrate addition. Results of alternate electron acceptor and metabolic byproduct analyses for ACP are presented in Table 4.6. The following paragraphs discuss those parameters most useful in evaluating site biodegradation processes.

4.6.1.1 Dissolved Oxygen

DO concentrations through time are tabulated in Table 4.6 and are shown graphically on Figures 4.12A and 4.12B. DO was measured at each monitoring and injection well during baseline sampling in November 2001 and during each process monitoring event. During the baseline sampling event DO concentrations ranged from less than 0.01 mg/L at PES-INJ-2 to a maximum of 2.3 mg/L at PES-MW-7. DO concentrations measured during the baseline sampling event were generally around 1 mg/L at most of the monitoring well locations. The baseline DO data set indicates that the groundwater was weakly aerobic prior to the injection of the vegetable oil.

During the February 2002 process monitoring event, DO concentrations were slightly higher in most locations, with a relatively large increase observed in GWMS-47S (Table 4.6). During subsequent process monitoring events DO concentrations dropped to below 1 mg/L at all of the well locations upgradient of PES-MW-5, indicating that the groundwater geochemical environment became predominantly anaerobic after the February 2002 process monitoring event. However, between December 2002 and April

FIGURE 4.12A
CONCENTRATIONS OF DISSOLVED OXYGEN OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

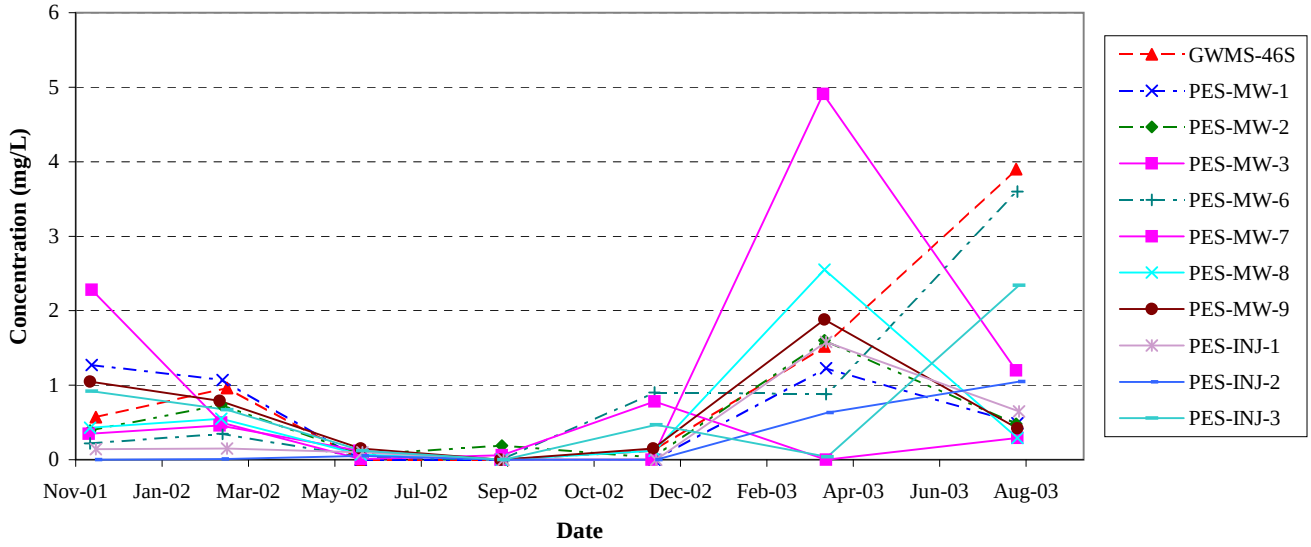
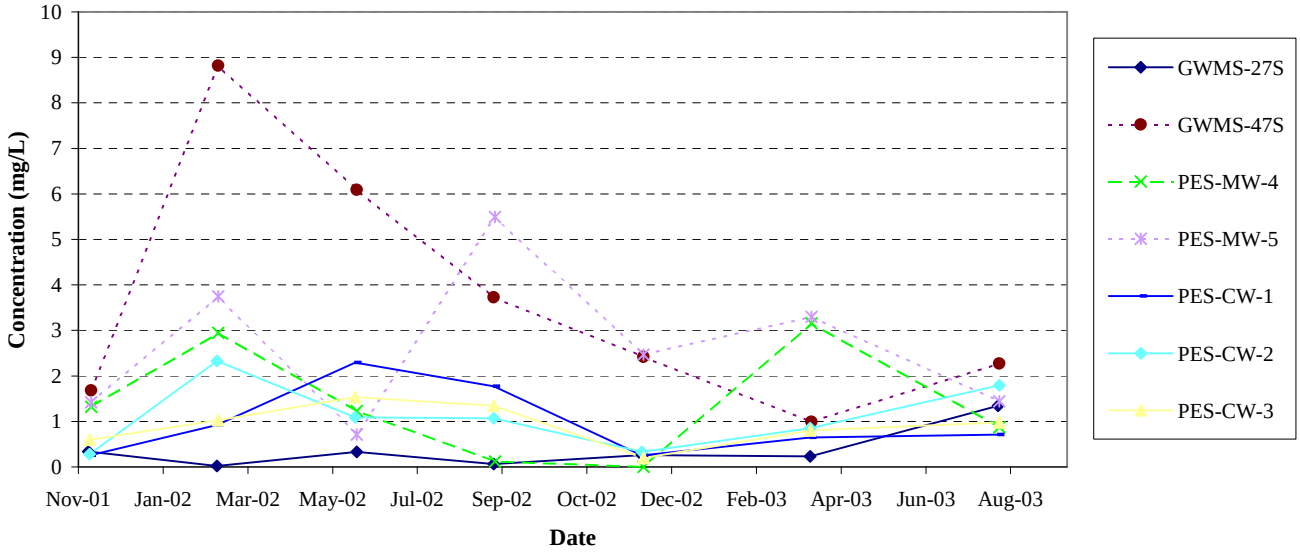


FIGURE 4.12B
CONCENTRATIONS OF DISSOLVED OXYGEN OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



2003 there was a reversal in the DO concentration trends at most well locations. During the April 2003 sampling event DO concentrations were significantly higher (greater than 1 mg/L) at most well locations. This reversal in the DO concentration trend mirrors trend changes in TOC and CAH concentrations discussed in earlier sections. DO concentrations decreased again between April and August 2003, indicating that the trend reversal was temporary. It should be noted that the elevated DO concentrations measured during the April 2003 sampling event contradict ORP and dissolved H_2 data collected during the same sampling event. These contradictions suggest that either the DO data or the ORP and H_2 data collected during the April 2003 sampling round are suspect.

An alternative explanation for the temporary increase in DO is related to spring surface water recharge. Surface water infiltration to groundwater is highest during the spring time as evidenced by higher water tables measured during sampling events conducted in the spring. This increased surface water infiltration may serve to DO concentrations in groundwater because the infiltrating surface water is highly oxygenated. This effect would be expected to be temporary and would diminish as surface water infiltration diminished.

There were a number of instances during the process monitoring events where DO concentration data contradicted ORP and dissolved H_2 data. These contradictions occurred most frequently at wells GWMS-47S, PES-MW-5, PES-MW-1, PES-CW-2, and PES-CW-3, all of which are installed in the area where upwelling of groundwater from the PC Aquifer is interpreted to occur (TtNUS, 2003 and USGS, 2003). Thus, these data contradictions may be related to the mixing of groundwater from the PC aquifer and the unconsolidated aquifer system.

DO concentrations throughout the pilot test area generally decreased over the course of the pilot test (with the notable exception of the April 2003 event), indicating that geochemical conditions within the pilot test area became less aerobic and therefore potentially more conducive to the occurrence of anaerobic degradation processes (including reductive dechlorination).

4.6.1.2 Nitrate and Nitrite

After DO has been depleted in the microbiological treatment zone, nitrate may be used as an electron acceptor for anaerobic biodegradation via denitrification. Nitrate concentrations below background in areas with high organic carbon concentrations and low DO are indicative of denitrification. The oxidation of organic carbon via the process of denitrification (using nitrate as an electron acceptor) yields a relatively large amount of free energy to microbial populations. Because nitrate may compete with CAHs as an alternate electron acceptor, nitrate concentrations less than 1 mg/L are desired for significant reductive dechlorination to occur (USEPA, 1998).

Groundwater samples were collected from all of the sampled monitoring and injection wells during all sampling events, and analyzed by Enchem, Inc. for nitrate and nitrite (as nitrogen [N]) using USEPA Method E300.1. Baseline concentrations measured using this method were less than 1.0 mg/L in all cases with the exception of GWMS-47S, and less than the MDL of 0.2 mg/L in most cases (Table 4.6).

During process monitoring, nitrate and nitrite concentrations remained below the MDL in all monitoring wells except GWMS-47S, PES-MW-4, and PES-MW-9. At PES-MW-4 and PES-MW-9 nitrate and nitrite concentrations increased slightly, but remained well below 1 mg/L. At GWMS-47S nitrate concentrations decreased initially, than increased to a maximum concentration of 2.5 mg/L. Nitrate concentrations also increased slightly at the contingency wells during the December 2002 and 2003 sampling events. It is likely that these well locations are strongly influenced by the nearby Mississippi River, thus the observed increases in nitrate concentrations are likely related to the river water quality.

During the process monitoring events, substantial increases in nitrate and nitrite concentrations were observed in the injection wells. Peak concentrations were observed during the February 2002 (PES-INJ-2) and August 2002 (PES-INJ-1 and PES-INJ-3) sampling events (Table 4.6). The increases in nitrate concentrations in the injection wells indicate that nitrate mass may have been mobilized from the soil matrix or injected with the vegetable oil emulsion. The nitrate data is somewhat anomalous. However, it does indicate that denitrification could be a competing TEAP to reductive dechlorination even though there is no nitrate mass naturally present within the dissolved phase.

However, within monitoring wells that show definitive signs of enhanced reductive dechlorination (PES-MW-7 and PES-MW-9), nitrate concentrations remained below the MDL and nitrite concentrations remained below 2.5 mg/L. These observations indicate that nitrate reduction is a relatively minor reduction-oxidation (redox) process outside of the area that is directly impacted by vegetable oil, and nitrate should not exert an excessive electron acceptor demand downgradient of the injection wells.

4.6.1.3 Ferrous Iron

The reduction of ferric iron [Fe(III)] has been shown to be a major metabolic pathway for some micro-organisms (Lovley and Phillips, 1988; Chapelle, 1993). Reduction of Fe(III) produces ferrous iron [Fe(II)], which is soluble in natural groundwater systems and can be readily measured in the field. Concentrations of Fe(II) measured in groundwater samples are summarized in Table 4.6 and are depicted on Figures 4.13A and 4.13B.

During the baseline sampling event, Fe(II) concentrations ranged from not detected (less than 0.01 mg/L) to a maximum of 2.2 mg/L (GWMS-46S). During the process monitoring events, Fe(II) concentrations increased substantially in the injection wells and in monitoring wells PES-MW-1, PES-MW-3, PES-MW-7, and PES-MW-9. There were also small increases in Fe(II) concentrations observed in GWMS-27S and PES-MW-6. Fe(II) concentration increases were most dramatic in the injection wells and in monitoring wells PES-MW-7 and PES-MW-9 (Table 4.6), indicating that the Fe(II) concentration changes are directly related to the stimulation of microbial processes following injection of vegetable oil. At the injection wells, very high concentrations of Fe(II) were detected after injection, with a maximum concentration of 280 mg/L detected at PES-INJ-1 during the May 2002 sampling event. However, the high Fe(II) concentrations detected in the injection wells also may be related to the addition of iron by the USGS for use as a tracer (i.e., they may have resulted from abiotic reduction of Fe(III)). This supposition is supported by the elevated Fe(II) concentrations detected in

FIGURE 4.13A
CONCENTRATIONS OF FE (II) OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

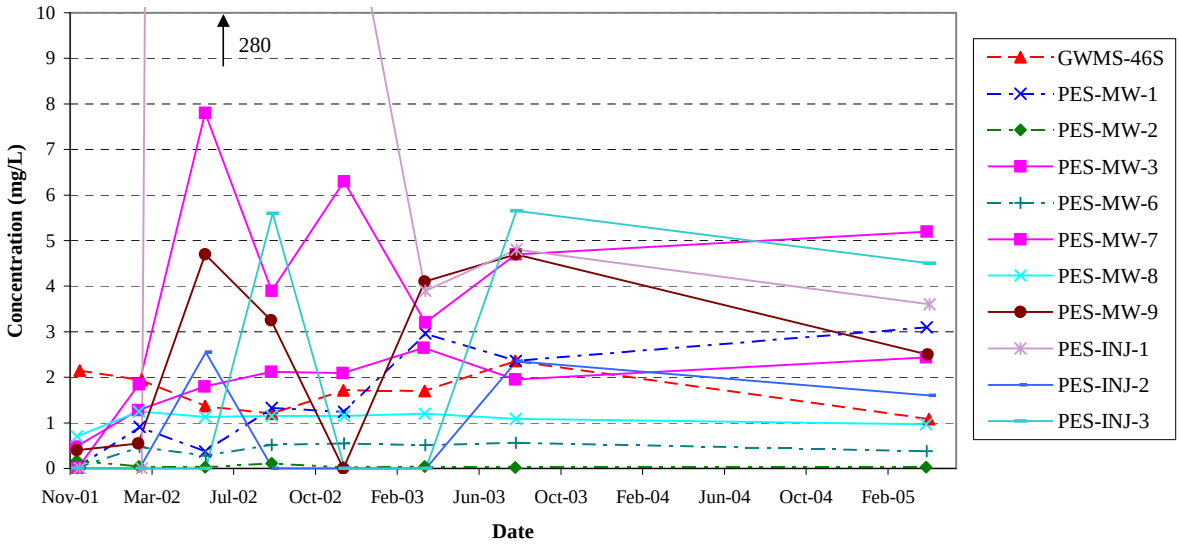
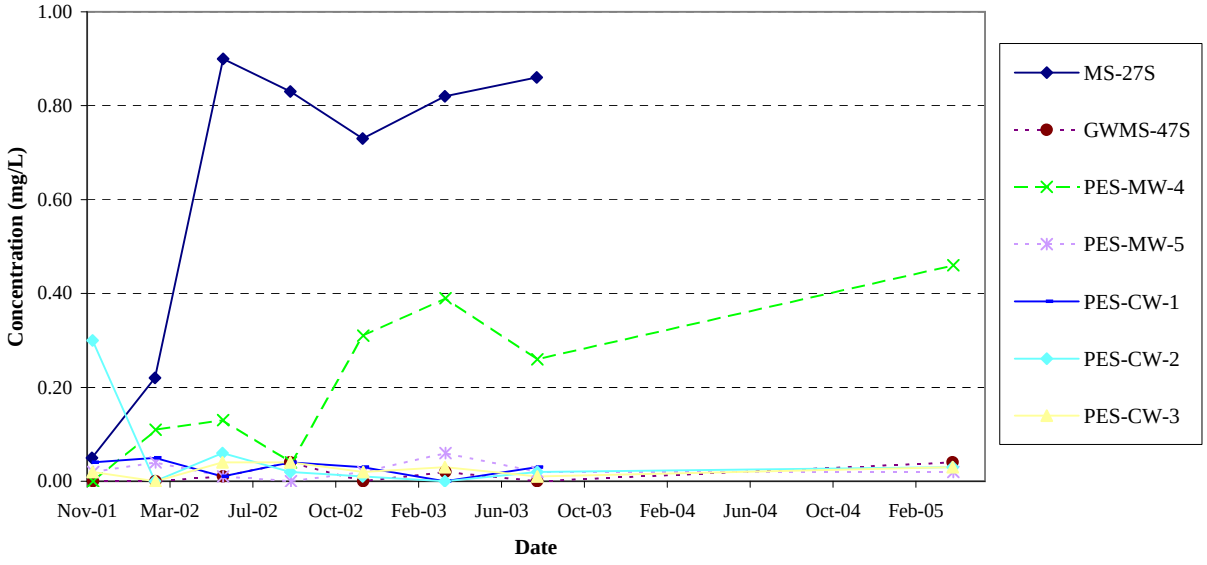


FIGURE 4.13B
CONCENTRATIONS OF FE (II) OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



PES-INJ-1 and PES-INJ-3, where iron was added, with respect to PES-INJ-02, where no iron was added. The decreasing concentrations of Fe(II) in the injection wells after May 2002 indicate that iron reduction rates are decreasing, potentially as a result of Fe(III) depletion.

Geochemical data collected during the process monitoring events indicates that the most elevated Fe(II) concentrations generally coincide with the most elevated ORP measurements. This indicates that Fe(III) reduction is a prevalent TEAP under the proper redox conditions (i.e., ORP greater than -200 millivolts [mV]). Exceptions to this observation occur at GWMS-27S and PES-MW-1. However, it would be expected that DO will be completely consumed and ORP would decrease below -200 mV at locations where sufficient TOC is present. Therefore, Fe(III) reduction should not be a significant competing TEAP to reductive dechlorination at locations where there is sufficient TOC present.

4.6.1.4 Sulfate and Sulfide

Sulfate also may be used as an electron acceptor (sulfate reduction) during microbial degradation of an organic substrate under anaerobic conditions (Grbic-Galic, 1990). Sulfate is reduced to sulfide during the sulfate reduction process. Therefore, sulfate and sulfide concentrations were measured in groundwater samples collected during baseline sampling and during each of the performance monitoring sampling events (Table 4.6). Sulfate concentrations measured during baseline sampling ranged from 19 mg/L at GWMS-27S to 230 mg/L at PES-MW-4. Sulfate concentrations measured during the baseline sampling event were generally greater than 100 mg/L with the exceptions of GWMS-27S, GWMS-47S, PES-CW-1, and PES-CW-2. Sulfide concentrations measured during the baseline sampling event were generally near or below the MDL of 0.01 mg/L. The maximum concentration of sulfide detected during the baseline sampling event was 0.20 mg/L at PES-MW-6.

During the process monitoring sampling events, sulfate concentrations decreased rapidly at the injection wells and at monitoring wells PES-MW-7 and PES-MW-9. Relatively small decreases in sulfate concentration were also observed at well PES-MW-4. Sulfate concentrations actually increased in 10 monitoring wells (Table 4.6) during the process monitoring events. The observed sulfate concentration increases may be related to geochemical changes induced by the observed increases TOC concentrations.

Sulfide concentrations measured during the process monitoring events generally remained near the MDL in most of the monitoring wells. The most substantial increases in sulfide concentrations occurred at monitoring wells PES-MW-1, PES-MW-6, PES-MW-7, and in the injection wells. Smaller sulfide concentration increases occurred at wells PES-MW-3 and PES-MW-9. The maximum sulfide concentration detected during process monitoring was 36 mg/L at PES-INJ-1.

Review of the geochemical data collected during the sampling events at ACP (Table 4.6) indicate that low sulfate and high sulfide concentrations generally correspond to ORP measurements of less than -300 mV. These data indicate that sulfate will be a competing TEAP to reductive dechlorination where the groundwater ORP is less than -300 mV.

It is important to note that at locations where there was sufficient organic carbon present (the injection wells, PES-MW-7, and PES-MW-9), sulfate mass was rapidly reduced to sulfide (within a few months in the case of the injection wells and PES-MW-9). Therefore, the sulfate mass present in the subsurface environment is expected to act as a competing TEAP to reductive dechlorination. However, sulfate reduction is expected to only delay the onset of reductive dechlorination for a few months at locations where there is sufficient TOC mass present because the sulfate mass present at a particular location will be rapidly depleted.

4.6.1.5 Methane, Ethane, and Ethene in Groundwater

Although anaerobic degradation of CAHs may occur under nitrate-, iron- and sulfate-reducing conditions (Vogel *et al*., 1987; Chapelle, 1993), the most rapid reductive dechlorination rates occur under methanogenic conditions (Bouwer, 1994). However, methanogenic organisms are known to compete with dechlorinating organisms for hydrogen (electron donor) produced by fermentation of organic substrate. Strongly elevated methane concentrations may be an indication that the majority of the organic substrate is being used to support methanogenesis, at the expense of dechlorination reactions.

Methane, ethane, and ethene concentrations were measured at all of the well locations during the baseline sampling event and subsequent process monitoring events. During the baseline sampling event methane, ethane, and ethene concentrations were all below their respective MDLs of 2 µg/L, 1.6 µg/L, and 1.4 µg/L with the exception of GWMS-27S (Table 4.6).

Methane concentration data are tabulated in Table 4.6 and are presented graphically on Figures 4.14A and 4.14B. During the process monitoring events substantial increases in methane concentrations were observed in the injection wells and in monitoring wells PES-MW-1, PES-MW-2, PES-MW-3, PES-MW-6, PES-MW-7, and PES-MW-9. The largest increases in methane concentration were generally observed during the December 2002 and April and August 2003 monitoring events. The highest methane concentration measured during the process monitoring events was 18,000 µg/L at PES-MW-7. The large increases in methane concentration at all of the monitoring wells upgradient of PES-MW-4, except PES-MW-8, indicate that methanogenesis is actively occurring in the upgradient portion of the pilot test area (Table 4.6). At PES-MW-1 and PES-MW-7, methane concentrations started to increase as early as the May 2002 sampling event. At locations PES-MW-3 and PES-MW-9, methane concentration increases were not observed until the August 2002 event. During the August 2003 sampling event methane concentrations increased slightly at PES-MW-4. These observations indicate that the area characterized by the occurrence of methanogenesis is slowly expanding into the downgradient portions of the pilot test area.

Ethene and ethane are end products of reductive dechlorination. An increase in ethene and/or ethane concentration is strong indication that complete degradation of chlorinated ethenes has occurred. During baseline sampling, ethane and ethene were not detected at any of the wells sampled. Ethene and ethane concentrations detected during the various sampling events are summarized in Table 4.6, and ethene concentration data are depicted on Figures 4.15A and 4.15B. Significant ethane and ethene concentration increases were

FIGURE 4.14A
CONCENTRATIONS OF METHANE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

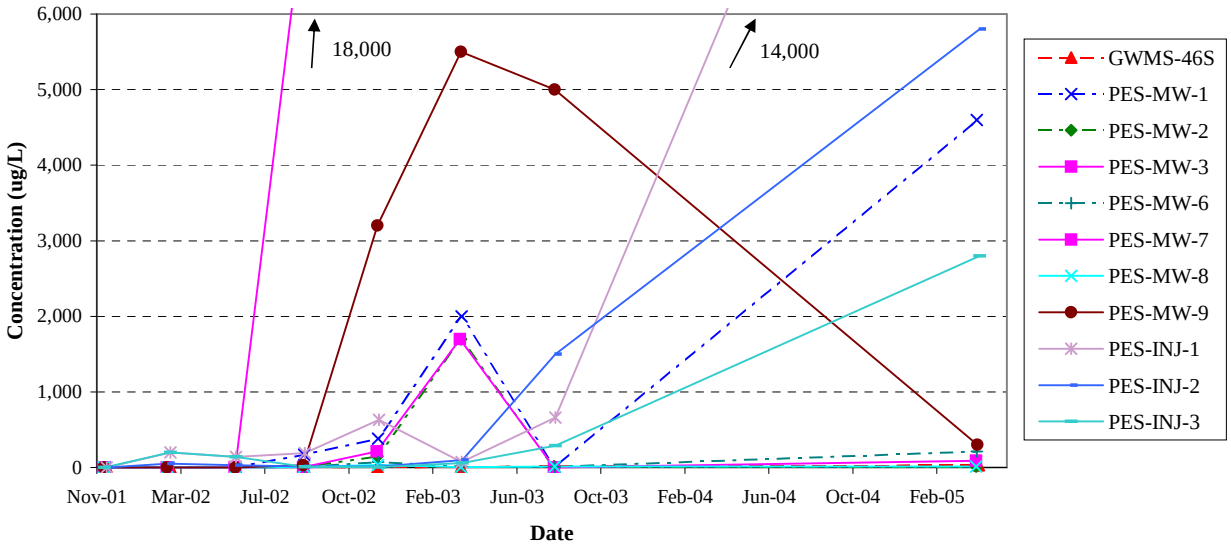


FIGURE 4.14B
CONCENTRATIONS OF METHANE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

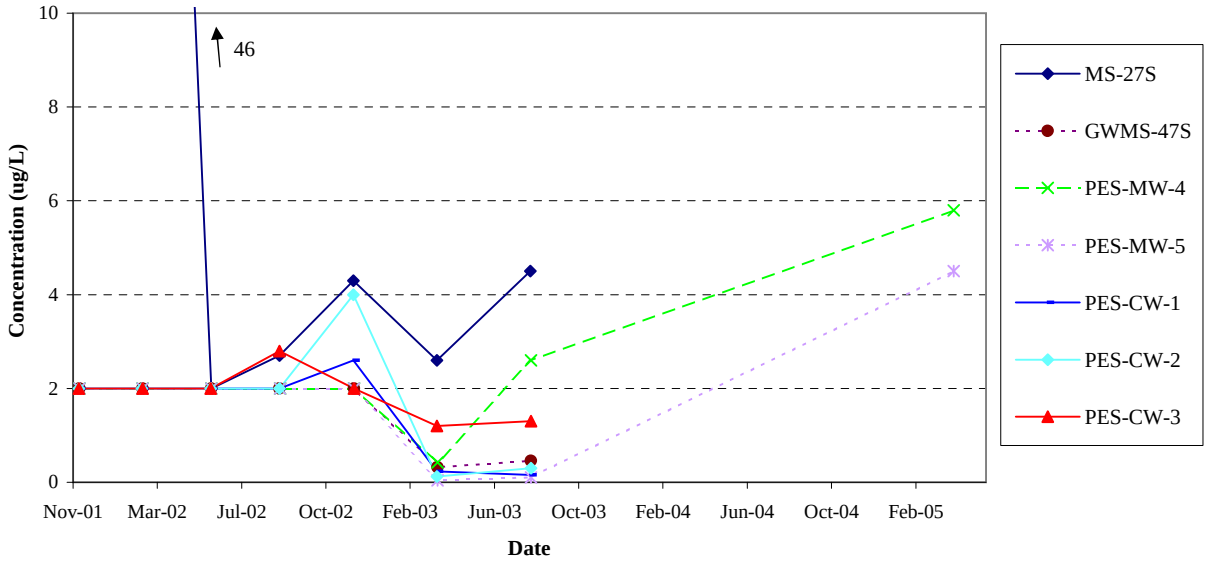


FIGURE 4.15A
CONCENTRATIONS OF ETHENE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

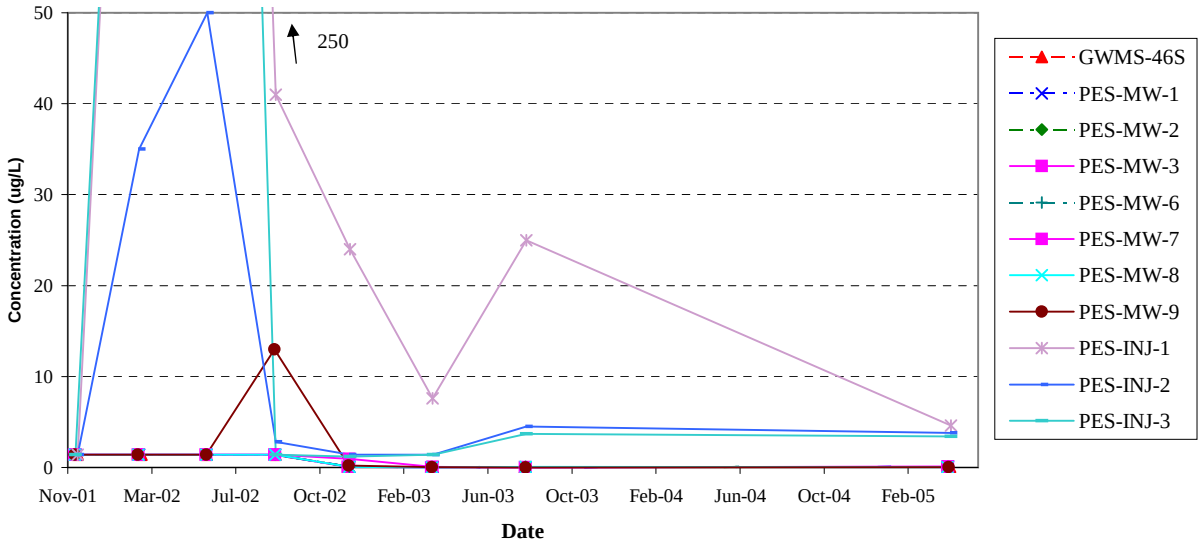
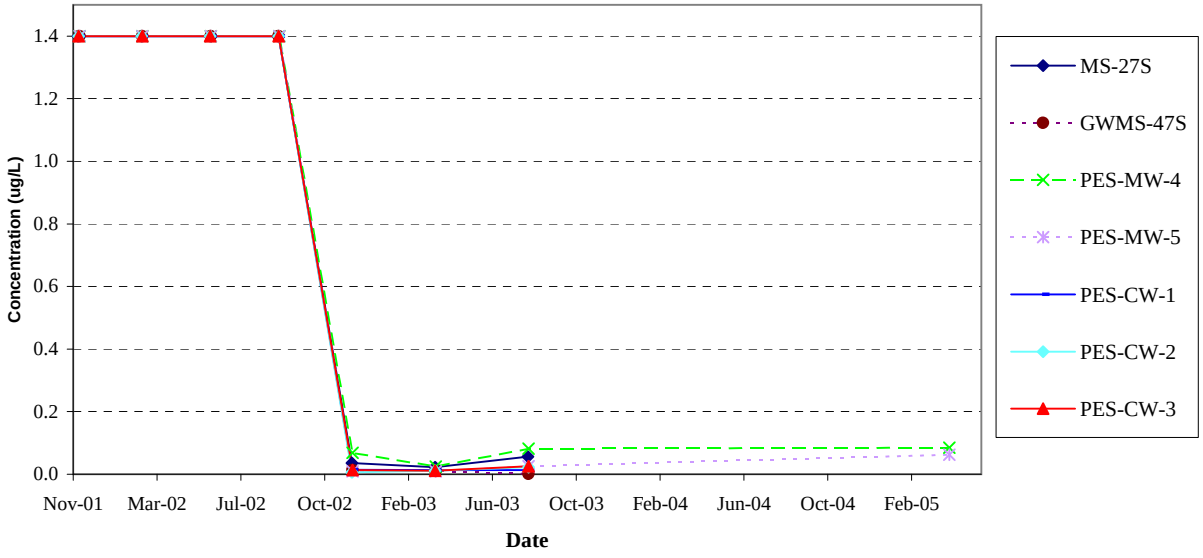


FIGURE 4.15B
CONCENTRATIONS OF ETHENE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



observed during process monitoring of the injection wells and monitoring well PES-MW-9 (August 2002 sampling event). These data indicate that reductive dechlorination is proceeding to completion at these locations. The observed increasing trends in methane concentration indicate that the injection of vegetable oil may have preferentially stimulated methanogenic biodegradation processes rather than reductive dechlorination processes at ACP. However, increasing trends in ethane and ethene concentrations coupled with decreasing TCE concentration trends indicate that reductive dechlorination has also been stimulated by the injection of the vegetable oil.

4.6.2 ORP as an Indicator of Redox Processes

ORP is a quantitative measure of the relative tendency of a solution to accept or transfer electrons. The ORP of a groundwater system depends on which electron acceptors are being reduced by microbes during oxidation of organic compounds. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994; Reinhard et al., 1984). Oxygen reduction would be expected in an aerobic environment with microorganisms capable of aerobic respiration, because oxygen reduction yields significant energy (Bouwer, 1992; Chapelle, 1993). However, once the available DO is depleted and anaerobic conditions dominate the interior regions of a contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate (denitrification), manganese (manganese reduction), ferric iron (iron reduction), sulfate (sulfate reduction), and finally carbon dioxide (methanogenesis). Each successive oxidation/reduction reaction provides less energy to the system, and each step down in redox energy yield is paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

ORP values measured during baseline and performance monitoring sampling are presented in Table 4.6 and are depicted on Figures 4.16A and 4.16B. The quality of the ORP data set collected during the December 2002 sampling round is suspect and was largely discounted during the interpretation of the ORP data set.

Baseline ORP values exhibited a wide range of redox conditions, ranging from a high of +115 mV to a low of -185 mV. In general, these values indicate that both aerobic and anaerobic processes were occurring in site groundwater (USEPA, 1998). ORP values also varied substantially within the treatment zone. For example, the ORPs at PES-INJ-2 and PES-INJ-3 were +74 mV and –79 mV, respectively, suggesting heterogeneity in the natural redox conditions present at the site prior to injection.

After injection, ORP decreased to approximately -200 to -400 mV at most of the wells installed upgradient of PEW-MW-5 (with the exceptions of PES-MW-2 and PES-MW-4), indicating that geochemical conditions upgradient of PES-MW05 generally became moderately to strongly reducing and more conducive to reductive dechlorination of CAHs following the vegetable oil injection. It is notable that the two locations with the lowest ORP values (PES-MW-7, PES-MW-9) exhibited some evidence of dechlorination of TCE to DCE (PES-MW-7) and TCE to DCE to ethene (PES-MW-9). At wells downgradient of PES-MW-5, redox conditions remained relatively oxidizing, with ORP ranging from approximately 0 to +300 mV. This observation indicates that monitoring

FIGURE 4.16A
OXIDATION/REDUCTION POTENTIAL OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

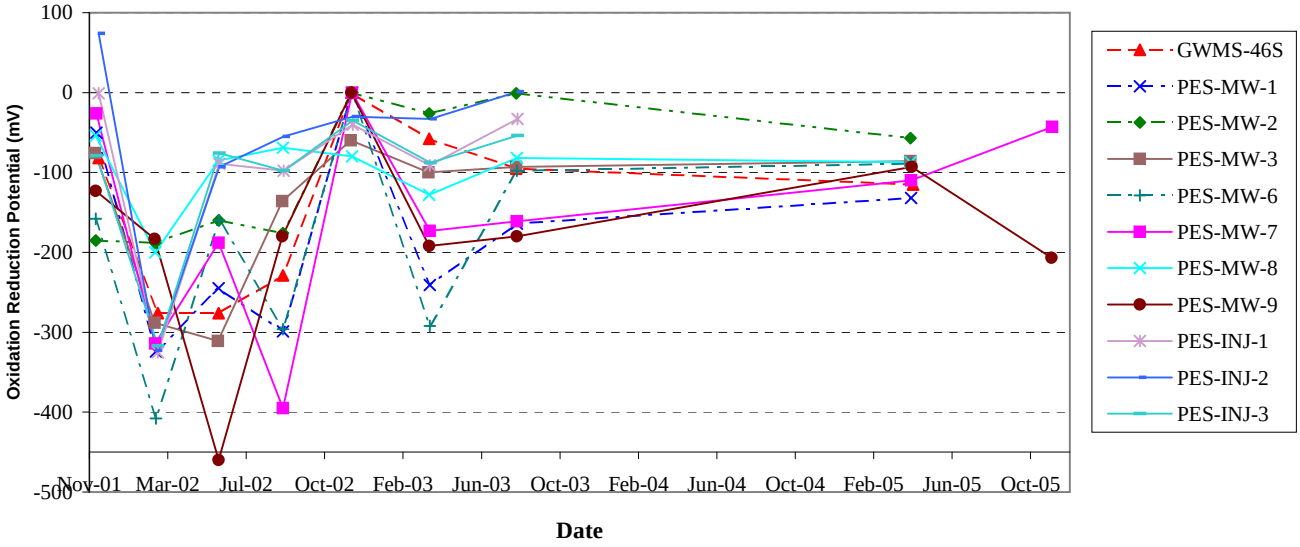


FIGURE 4.16B
OXIDATION/REDUCTION POTENTIAL OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

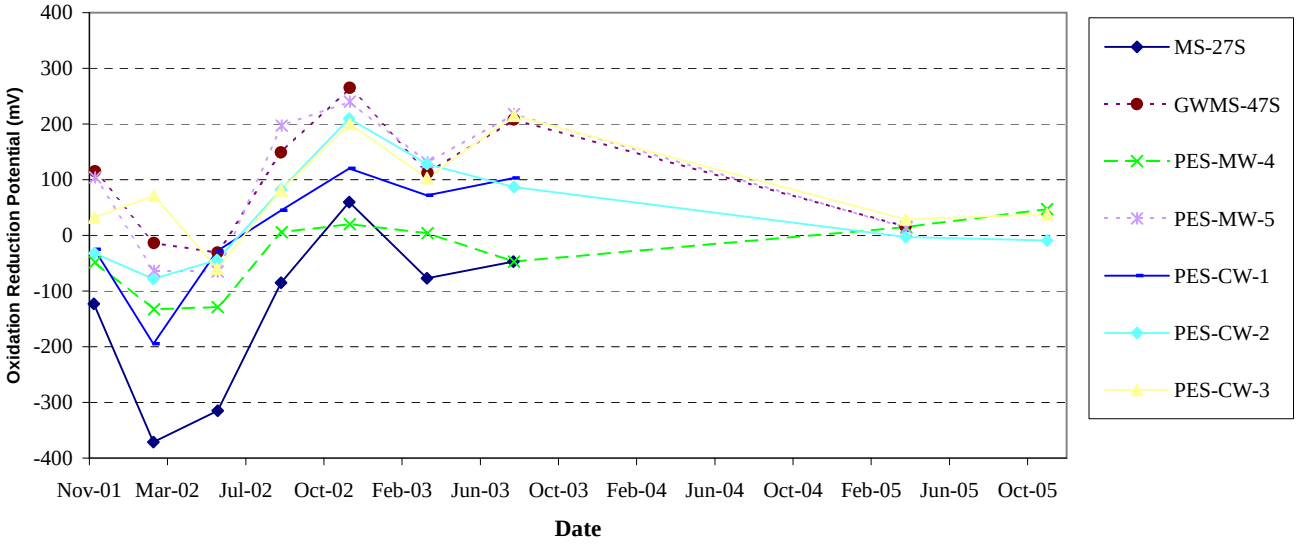


FIGURE 4.17A
CONCENTRATIONS OF CHLORIDE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

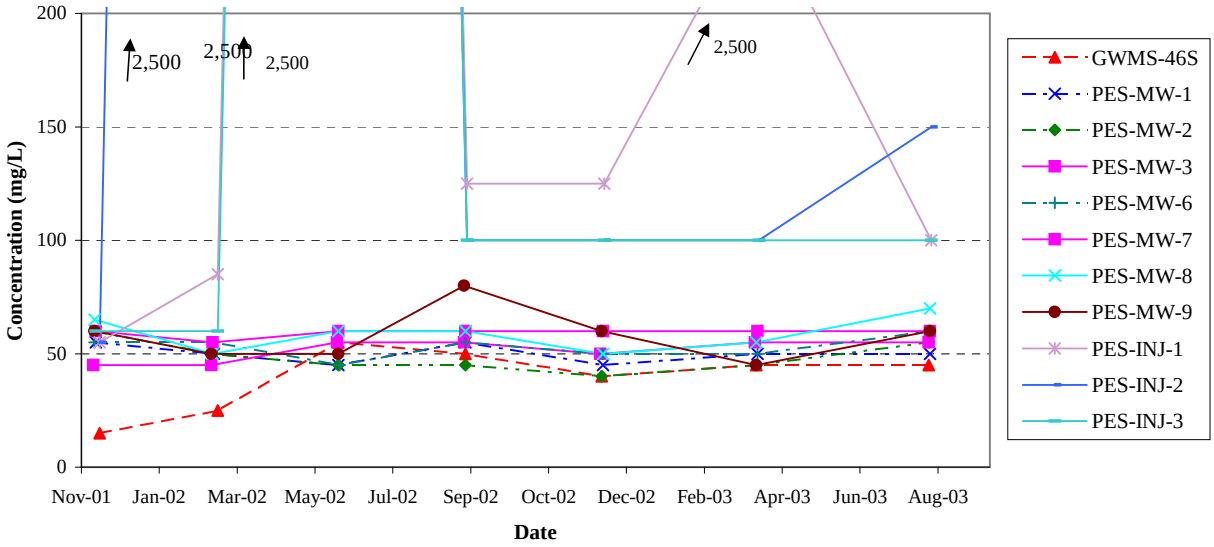
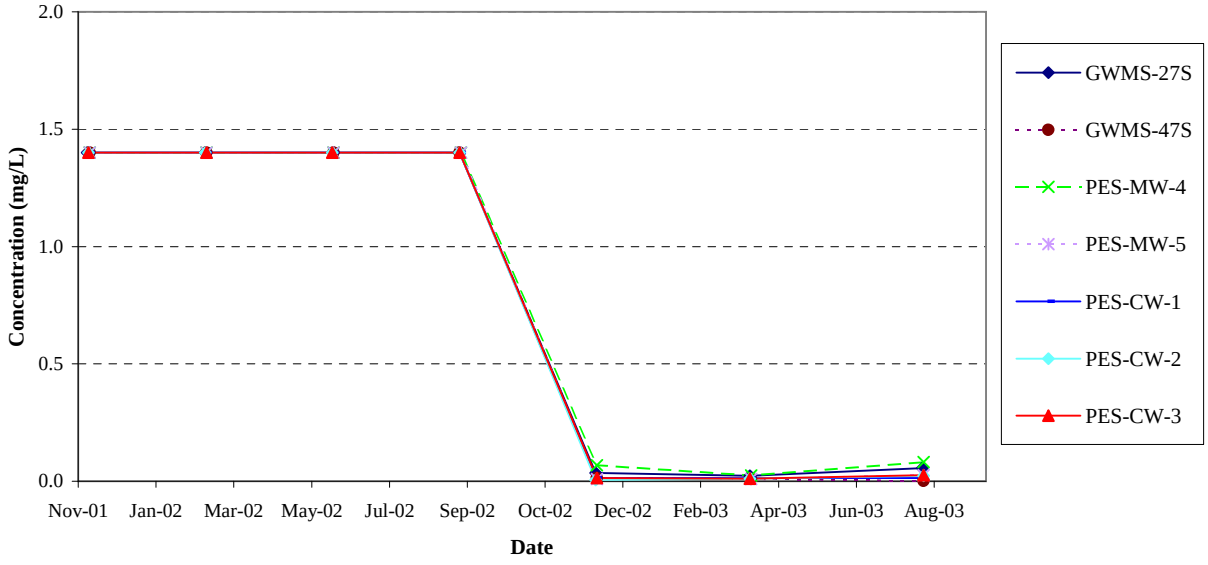


FIGURE 4.17B
CONCENTRATIONS OF CHLORIDE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



well locations downgradient of PES-MW-5 were not as significantly impacted by the injected vegetable oil.

4.6.3 Additional Geochemical Indicators

Other geochemical data collected for this evaluation can be used to further interpret and support the contaminant, electron donor, electron acceptor, and byproduct data previously discussed. These parameters provide additional qualitative indications of what microbial processes may be operating at the site.

4.6.3.1 Chloride as an Indicator of Reductive Dechlorination

Chloride ions are removed from chlorinated solvents and enter solution during biodegradation, whether via reductive dechlorination or aerobic oxidation. Therefore, chloride concentrations in groundwater should increase above baseline levels in areas where these processes are occurring.

Chloride concentrations detected during baseline sampling and process monitoring are presented in Table 4.6 and depicted on Figures 4.17A and 4.17B. Chloride concentrations detected during the baseline sampling event range from 15 mg/L (GWMS-46S) to 105 mg/L (PES-MW-5). During the process monitoring events, chloride concentrations were highly variable, with no consistent concentration trends apparent in the majority of the wells. This temporal variability in chloride content is likely due to changing groundwater flow conditions observed within the pilot test area (Section 4.1). Some of the variability in chloride content also is likely related to the significant changes in pH observed in the wells that are relatively close to the river (GWMS-27S and the three contingency wells). Large changes in pH (6.36 to 9.81 at GWMS-27S) would affect the solubility of various minerals in the soil matrix, which could in turn affect the concentration of chloride, as well as other cations and anions, in the groundwater. These changes in pH are likely related to the river stage since large variations in pH were not observed during process monitoring of the majority of the wells installed upgradient of the contingency wells.

During process monitoring, significant increases in chloride concentration were only observed in the injection wells, where chloride concentrations increased by approximately two orders of magnitude, from baseline concentrations of approximately 50 to 60 mg/L to a maximum of 2,500 mg/L.

The maximum chloride concentrations detected in the injection wells occurred during the May 2002 process monitoring event; since this event, concentrations have declined to approximately 100 mg/L. The high concentrations of chloride measured at the injection wells indicates that chloride is being added to the groundwater system within the injection area. This addition of chloride mass may be related to reductive dechlorination of chlorinated ethene mass.

4.6.3.2 Carbon Dioxide and Alkalinity

Carbon dioxide is produced during the biodegradation of organic carbon compounds. In aquifers that have carbonate minerals as part of the matrix, carbon dioxide forms

carbonic acid, which dissolves these minerals, increasing the alkalinity of the groundwater. An increase in carbon dioxide and alkalinity (measured as calcium carbonate [$CaCO_3$]) in the treatment zone can be used to infer that organic carbon (i.e., vegetable oil), and possibly less-chlorinated solvents, have been destroyed through aerobic and anaerobic microbial respiration. Alkalinity also is a measure of the ability of groundwater to buffer changes in pH. Because microbial degradation produces metabolic acids, the ability of the groundwater system to buffer these acids is beneficial to maintaining pH within the optimal range for halorespirating organisms.

Total alkalinity and carbon dioxide concentrations over time are summarized in Table 4.6 and shown on Figures 4.18 and 4.19, respectively. During the baseline sampling event, alkalinity concentrations ranged from 119 to 1,700 mg/L, but were generally between 300 mg/L to 400 mg/L. During the February 2002 process monitoring event, large alkalinity concentration increases were observed at PES-MW-1, PES-MW-5, PES-MW-7, and very large alkalinity concentration increases were observed in the injection wells (Table 4.6). Conversely, alkalinity concentrations decreased substantially in GWMS-46S and PES-MW-2 between the baseline event and the February 2002 event. During the remaining process monitoring events, alkalinity concentrations remained relatively stable in the majority of the monitoring wells with the exceptions of PES-MW-9 and the injection wells. At PES-MW-9, alkalinity concentrations increased through the December 2002 process monitoring event. At the injection wells alkalinity concentrations peaked during the May 2002 event, than declined. These observations, coupled with the other geochemical indicator data described above, indicate that the observed changes in alkalinity concentrations are a result of enhanced microbial destruction of organic carbon (i.e., vegetable oil).

Carbon dioxide concentrations measured during the various sampling events exhibit a similar pattern to the alkalinity concentration changes discussed above (Figure 4.19). During the baseline sampling event, carbon dioxide concentrations ranged from 1.25 mg/L to 134 mg/L, but generally were between 40 and 60 mg/L. During the process monitoring events, large increases in carbon dioxide concentrations were observed in the injection wells and in wells PES-MW-7 and PES-MW-9. The spatial distribution of the observed increases in carbon dioxide, coupled with the previously discussed geochemical data, indicates that the observed increases in carbon dioxide concentration are related to the vegetable oil injection. These data indicate that the vegetable oil injection was successful in encouraging biological activity in the injection wells and in monitoring wells PES-MW-7 and PES-MW-9.

4.7 ISOTOPIC FRACTIONATION DATA

The degradation of organic compounds by biological enzymatic processes can cause significant shifts in the ratio of the carbon isotopes carbon-13 (^{13}C) and carbon-12 (^{12}C) in both the reactants and the products (e.g., PCE and TCE or TCE and DCE) (Song *et al*., 2002). This shift in carbon isotope ratios occurs because of the stronger molecular bonds formed by ^{13}C in comparison to ^{12}C and the preferential selection of ^{12}C bonded atoms by the microorganisms involved (Song *et al*., 2002). As a result of this phenomenon, TCE that is undergoing biologically mediated reductive dechlorination tends to become enriched in ^{13}C and depleted in ^{12}C because the lighter isotopes are transformed more quickly. At the same time, the DCE that is being produced through the biologically

FIGURE 4.18A
ALKALINITY OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

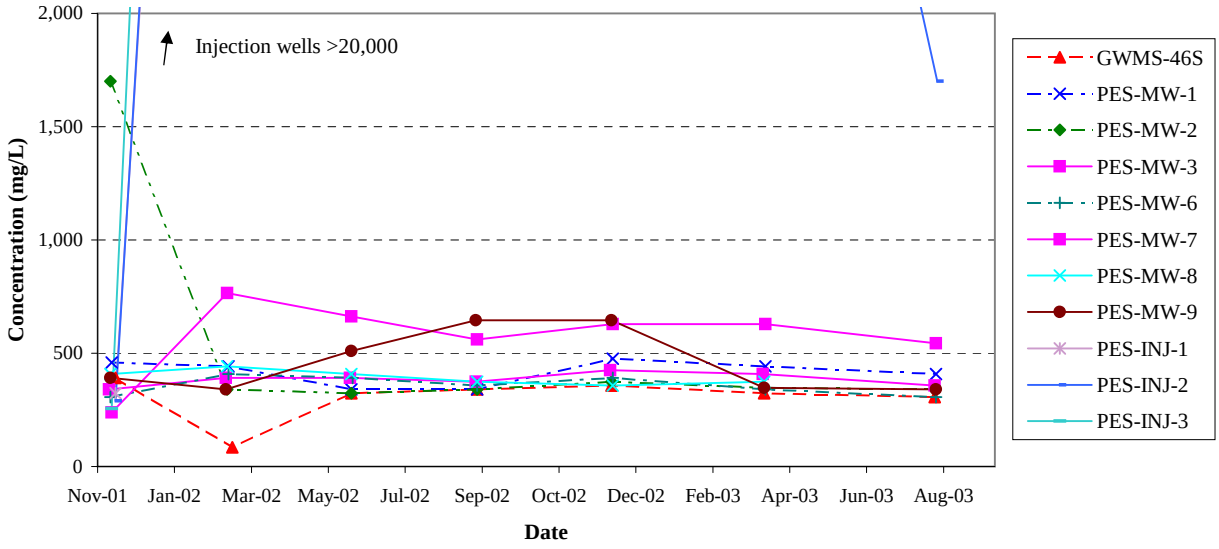


FIGURE 4.18B
ALKALINITY OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

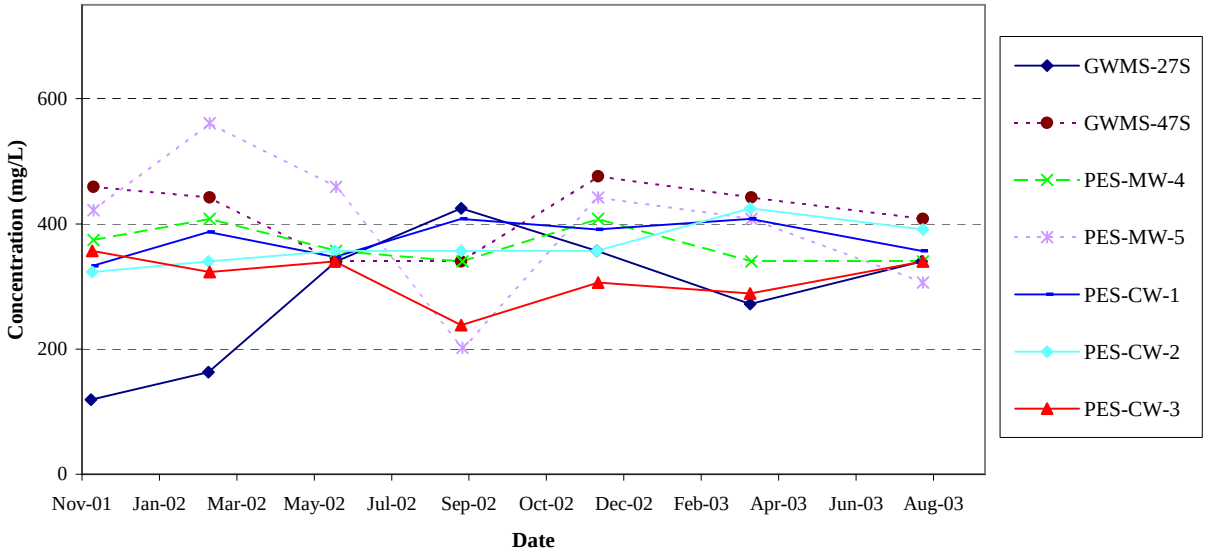


FIGURE 4.19A
CONCENTRATIONS OF CARBON DIOXIDE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

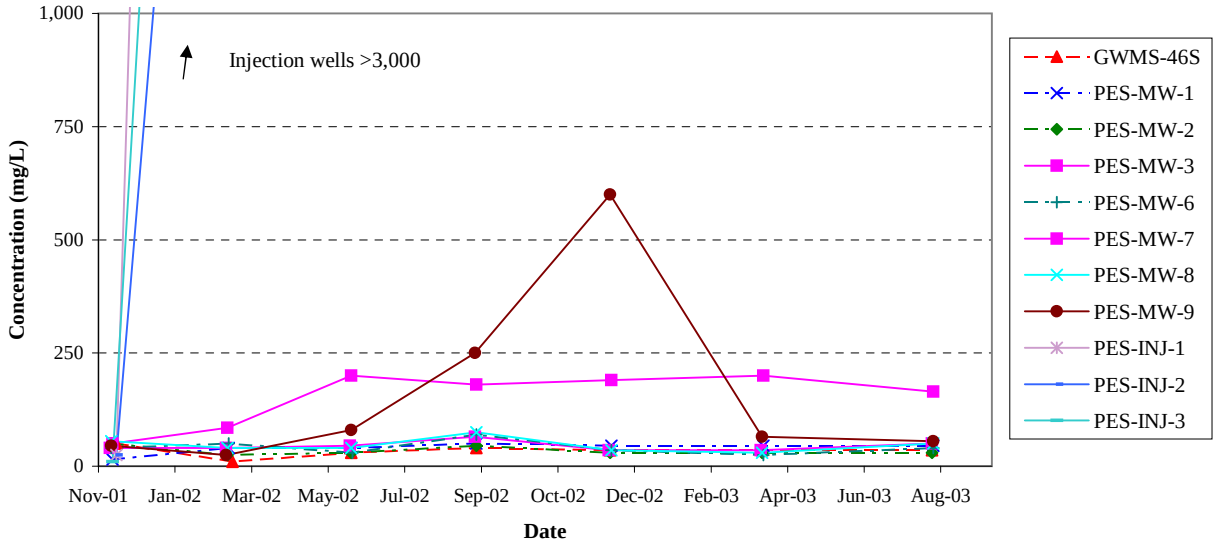
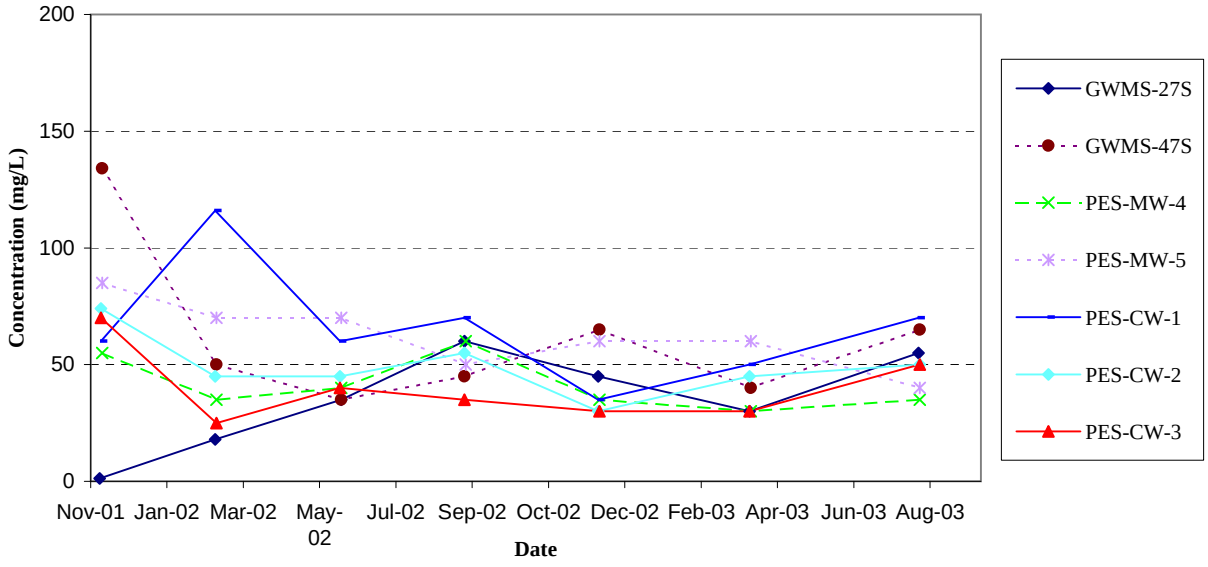


FIGURE 4.19B
CONCENTRATIONS OF CARBON DIOXIDE OVER TIME
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



mediated reductive dechlorination of TCE becomes enriched in ^{12}C with respect to ^{13}C (Song *et al*., 2002). Thus, a significant positive change in the ^{13}C fraction in TCE would be indicative of biologically mediated degradation, as would a significant negative change in ^{13}C fraction in DCE.

A complicating factor in evaluating DCE ^{13}C data is that DCE is an intermediate degradation product and may be undergoing continuing degradation to VC (thus depleting ^{12}C in DCE). Thus, ^{13}C data for TCE and DCE must be evaluated together. However, if a finite amount of reactant (e.g., TCE) is present and the reaction proceeds to completion, the isotopic ratio of the product (e.g., DCE) would equal that of the reactant. Thus, isotopic fractionation analysis is a useful tool to determine if chlorinated solvent mass is being degraded through biologically mediated processes in systems where the degradation process is incomplete (Song, *et al*., 2002).

Isotopic fractionation analyses were conducted on sample aliquots collected from the injection wells, existing well GWMS-46S, and the pilot test monitoring wells to determine if chlorinated solvents are being degraded through microbially mediated processes at these locations. The isotopic fractionation data collected during the 2003 sampling rounds is presented in Table 4.8. At well locations PES-INJ-2, PES-INJ-3, PES-MW-1, PES-MW-3, PES-MW-8, and PES-MW-9, there were significant (i.e., larger than the sum of the standard deviations [Table 4.8]) changes in the ^{13}C fraction in TCE, indicating that TCE was undergoing biologically mediated reductive dechlorination to DCE at these locations. At well locations PES-INJ-3, GWMS-46S, PES-MW-1, PES-MW-6, PES-MW-8, and PES-MW-9, there were significant negative changes in the ^{13}C fraction in *cis*-1,2-DCE, indicating that *cis*-1,2-DCE is being produced at these locations through biologically mediated reductive dechlorination. Locations where ^{13}C data from both TCE and DCE indicate that TCE is being degraded through biologically mediated processes include PES-INJ-3, PES-MW-1, PES-MW-8, and PES-MW-9. Thus, it can be stated with some certainty that at least partial biologically mediated reductive dechlorination of TCE to DCE is occurring at these four well locations, and also is likely occurring at wells PES-INJ-2, GWMS-46S, PES-MW-3, and PES-MW-6. The same analytical exercise can be used to determine if DCE is degrading to VC and on to ethene. However, significant concentrations of VC and ethene were not detected within the pilot test area during the baseline or process monitoring events. Therefore, these determinations cannot be made for VC or ethene.

4.8 SUMMARY OF ENHANCED BIODEGRADATION

There are several lines of evidence that can be used to determine if biologically mediated reductive dechlorination of chlorinated ethene mass is occurring and/or if geochemical conditions are conducive to the development of reductive dechlorination. The primary line of evidence used to assess the occurrence of reductive dechlorination is the composition of the chlorinated ethene mass present, and any changes in that mass. As chlorinated ethene mass is reductively dechlorinated within an aquifer system, decreasing trends in chlorinated ethene parent compound concentrations (PCE and TCE) and increasing trends in less chlorinated ethenes (*cis*-1,2-DCE, and VC) would be expected. As reductive dechlorination progresses, and the parent compounds are degraded, the 1,2-DCE and VC concentrations would be expected to decrease. These chlorinated ethene concentration trends would be paralleled by an increasing trend in ethene and ethane

TABLE 4.8
CARBON ISOTOPE FRACTIONATION DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Distance Downgradient From Injection Wells (feet)	Sample Date	PCE[a/] Average ^{13}C Fraction (Parts per thousand)	TCE[a/] Average ^{13}C Fraction (Parts per thousand)	Standard Deviation	Variance [b/]	*cis*-1,2-DCE[a/] Average ^{13}C Fraction (Parts per thousand)	Standard Deviation	Variance	*trans*-1,2-DCE Average ^{13}C Fraction (Parts per thousand)	Standard Deviation	Variance
MONITORING WELLS												
GWMS-46S [c/]	22	8-Apr-03	NA [d/]	-24.56	0.72		-41.83	NA		-32.06	NA	
		20-Aug-03	NA	-24.58	0.18	-0.02	-49.55	0.35	**-7.72**	-42.89	3.52	**-10.83**
PES-MW-1	16	10-Apr-03	NA	-23.84	0.26		-26.31	0.62		-35.54	2.57	
		21-Aug-03	NA	-21.36	0.08	**2.48**	-29.05	0.68	**-2.74**	-38.12	2.74	-2.58
PES-MW-2	28	9-Apr-03	-39.40	-25.67	0.28		-42.58	NA		-42.29	2.29	
		20-Aug-03	NA	-25.76	0.06	-0.09	-36.81	1.23	5.77	-43.10	2.59	-0.81
PES-MW-3	48	8-Apr-03	NA	-34.21	0.15		-41.20	NA		-38.51	NA	
		20-Aug-03	NA	-23.80	0.17	**10.41**	-37.05	0.81	4.15	-37.69	4.43	0.82
PES-MW-4	76	8-Apr-03	NA	-24.64	0.01		-38.67	0.21		-36.90	2.03	
		19-Aug-03	-25.25	-24.87	0.25	-0.23	-37.83	0.08	0.84	-37.80	2.88	-0.90
PES-MW-6	16	10-Apr-03	NA	-23.18	0.64		-30.00	NA		-40.38	NA	
		21-Aug-03	NA	-24.58	0.03	-1.40	-34.53	1.34	**-4.53**	-35.08	1.57	5.30
PES-MW-7	16	10-Apr-03	-32.14	-7.33	NA		-30.20	0.24		-35.78	NA	
		21-Aug-03	NA	-23.47	8.16	-16.14	-26.26	1.77	3.94	-37.11	2.10	-1.33
PES-MW-8	40	9-Apr-03	NA	-30.13	1.65		-34.06	1.46		NA	NA	
		21-Aug-03	NA	-25.03	0.32	**5.10**	-38.01	4.84	-3.95	4.84	4.37	
PES-MW-9	36	9-Apr-03	NA	-24.18	0.89		-31.98	2.00		-20.61	NA	
		20-Aug-03	NA	-22.10	0.06	**2.08**	-41.69	0.93	**-9.71**	-38.31	0.48	**-17.70**
INJECTION WELLS												
PES-INJ-1	--	10-Apr-03	-29.97	-26.08	1.32		-27.48	1.12		1.12	NA	
		22-Aug-03	-27.84	-25.49	1.32	0.59	NA	NA		NA	NA	
PES-INJ-2	--	11-Apr-03	-40.76	-35.38	1.79		-34.02	0.58		-30.63	NA	
		22-Aug-03	-28.10	-32.40	0.60	**2.98**	-33.93	0.74	0.09	NA	NA	
PES-INJ-3	--	11-Apr-03	-29.71	-39.18	2.17		-33.07	0.61		-24.41	NA	
		22-Aug-03	-28.62	-34.90	0.02	**4.28**	-42.43	2.42	**-9.36**	NA	NA	

[a/] PCE = tetrachloroethene; TCE = trichloroethene; DCE = dichloroethene

[b/] A positive variance indicates that the ^{13}C ratio has increased due to reductive dechlorination of the compound to the left of the variance column.
A negative variance indicates that the ^{13}C ratio has decreased, indicating that this compound is being produced through dechlorination or that this compound is being depleted.

[c/] This well is located upgradient of the injection area.

[d/] NA = not analyzed.

concentrations as the chlorinated ethene mass is completely reductively dechlorinated to the reaction end products, ethene and ethane.

TCE concentrations detected during the August 2003 process monitoring event were significantly lower than concentrations detected during the baseline sampling event in monitoring wells MS-46S, PES-MW-1, PES-MW-2, PES-MW-3, PES-MW-4, PES-MW-6, PES-MW-7, PES-MW-8, and PES-MW-9. TCE concentrations in the wells installed upgradient of PES-MW-5 (with the exception of PES-MW-9) increased initially, than decreased between the August 2002 and August 2003 sampling events. By the August 2003 sampling event, TCE concentrations had declined to near-baseline levels at PES-MW-1 and PES-MW-2. TCE concentration reductions were coupled with increases in the concentration of *cis*-1,2-DCE at wells PES-MW-1, PES-MW-3, PES-MW-4, PES-MW-6, PES-MW-7, and PES-MW-9. These data indicate that TCE is being reductively dechlorinated at least to *cis*-1,2-DCE at these locations. Increases in VC and ethene concentrations observed at monitoring well PES-MW-9 during 2002 indicated that a limited amount of TCE was being completely reductively dechlorinated to the reaction end product ethene at this location during this time period. However, TCE concentrations increased and *cis*-1,2-DCE, VC, and ethene concentrations decreased in December 2002 and April 2003. The cause(s) of this reversal in contaminant concentrations and molar fractions are not well understood, and may include subtle variations in groundwater flow directions that were not detected by the water-level measurement events, or temporal variation in the rate and efficiency with which native microbial populations were degrading the TCE. Between April and August 2003, TCE concentrations decreased slightly and *cis*-1,2-DCE and VC concentrations increased, reversing the trend observed between December 2002 and April 2003.

Significant TCE concentration decreases were observed in the injection wells immediately after vegetable oil injection. However, these decreases were not paralleled by significant increases in *cis*-1,2-DCE, VC, or ethene concentrations, indicating that they were due to partitioning of the TCE mass into the vegetable oil and/or dilution. During the course of process monitoring events, the TCE concentrations detected in each injection well continued to decline. This post-injection decrease in TCE concentrations at the injection wells was accompanied by stable concentrations of *cis*-1,2-DCE and VC in all three of the injection wells and increasing concentrations of ethene in PES-INJ-1 and PES-INJ-2. These dissolved phase concentration trends were also accompanied by decreasing concentrations of TCE in the vegetable oil (Table 4.5). These data indicate that TCE is being re-released into the groundwater from the vegetable oil and that re-released TCE mass is being rapidly reductively dechlorinated to ethene. The lack of significant VC concentrations in the injection wells indicates that the VC mass is being degraded to ethene as fast as it is being produced.

There are several indirect lines of evidence that can be used to augment chlorinated ethene concentration data to determine whether reductive dechlorination is occurring or has the potential to occur. These indirect lines of evidence include geochemical indicator parameters, microbial population data, and isotopic fractionation data. Changes in these conditions during the course of the pilot test are generally more important than the absolute values of the properties.

Changes observed during the process monitoring events, with respect to the baseline event and to previous process monitoring events, indicate that the groundwater at the ACP pilot test site has become more reducing and therefore more conducive to anaerobic biodegradation processes as a result of the vegetable oil injection. TOC concentrations have increased from baseline levels at all of the monitoring wells upgradient of the contingency wells by approximately one order of magnitude. DO concentrations and ORP have decreased since the baseline sampling event at wells upgradient of PES-MW-5, indicating that the area downgradient of the injection wells and upgradient of PES-MW-5 has become more reducing since vegetable oil injection.

The geochemical data indicates that there is substantial competing electron acceptor mass (sulfate and nitrate) in the groundwater system that may be preferentially used by microbial consortia prior to use of chlorinated ethene mass. However, at wells where sufficient TOC mass is present, the competing electron acceptor mass has been depleted and reductive dechlorination is proceeding. This indicates that the competing electron acceptor mass will delay the onset of significant reductive dechlorination, but not preclude it.

Methane concentrations increased in the injection wells and in all of the monitoring wells upgradient of PES-MW-4, relative to baseline conditions, indicating that methanogenesis is becoming more prevalent upgradient of PES-MW-4. Reductive dechlorination has been shown to proceed relatively rapidly under methanogenic conditions (Bower, 1994). Thus, the onset of methanogenic conditions upgradient of PES-MW-4 indicates that geochemical conditions in this area are becoming more conducive to reductive dechlorination.

Review of the analytical data collected during the various sampling rounds indicates that the wells where complete reductive dechlorination is occurring (the injection wells, PES-MW-7, and PES-MW-9 [prior to December 2002 and after April 2003]) have several properties in common. These properties are summarized below:

- DO concentration less than 1 mg/L;
- ORP less than -100 mV;
- Carbon dioxide concentration greater than 100 mg/L;
- Sulfate concentration less than 50 mg/L;
- TOC concentration equal to or greater than approximately 20 mg/L;
- Measurable concentrations of VFAs equal to or greater than 50 mg/L;
- Ferrous iron concentration greater than 2 mg/L;
- Methane concentration greater than 1 mg/L; and
- Total biomass greater than approximately 50 picomoles of PLFA per milliliter (pmoles PLFA/mL).

Figure 4.20 depicts the area where partial or complete reductive dechlorination is occurring based on the geochemical and contaminant data collected to date.

These data indicate that the lack of wide-spread reductive dechlorination at the ACP pilot test site is primarily a function of sub-optimal organic carbon distribution. This conclusion is supported by the microbial population data and cross-borehole radar data. The geochemical data collected during the first 20 months of monitoring indicate that dissolved phase organic carbon is not being transported to downgradient monitoring

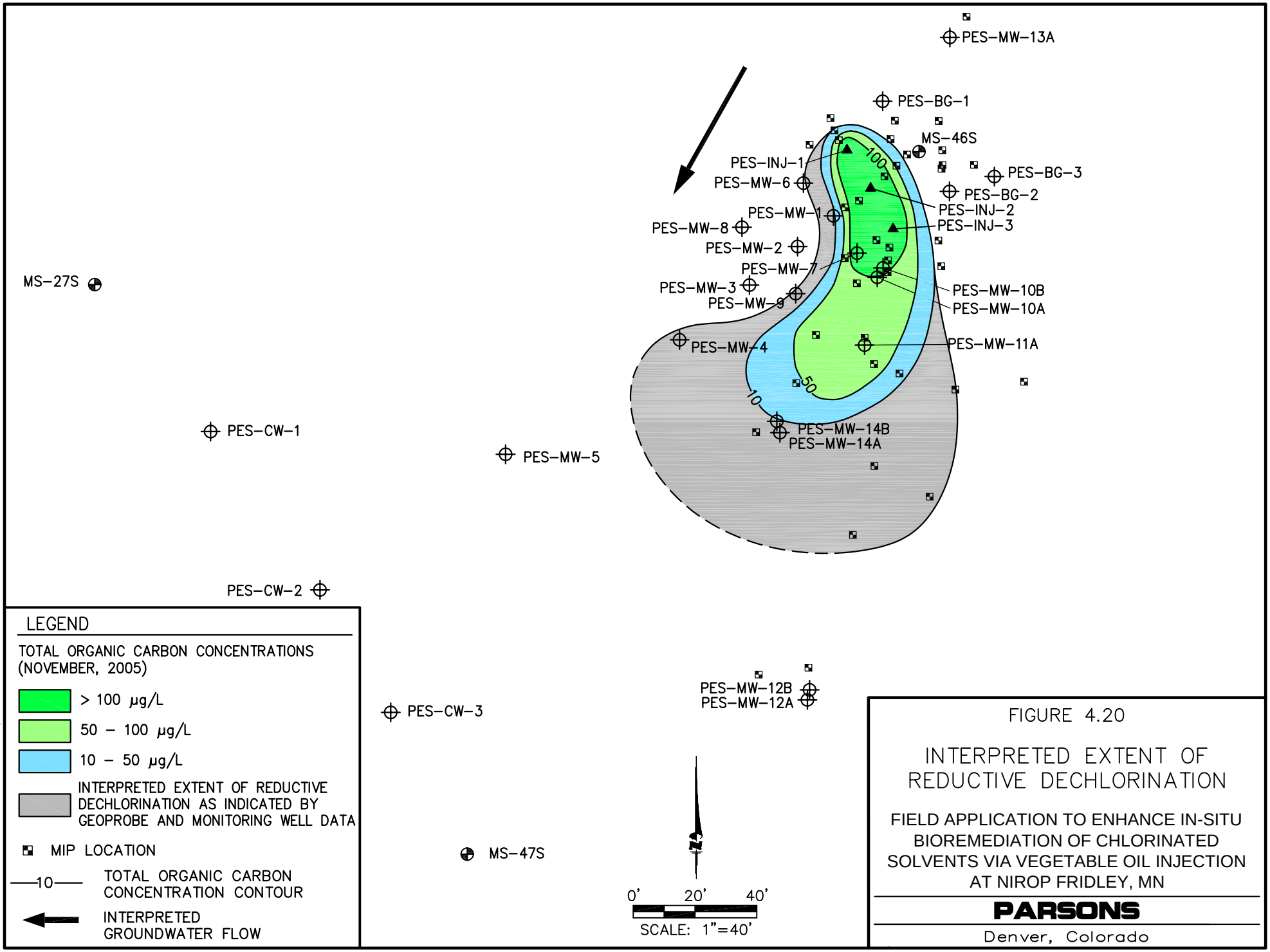


FIGURE 4.20

INTERPRETED EXTENT OF REDUCTIVE DECHLORINATION

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado

wells as rapidly as was expected. The slow migration rates are likely a result of the low hydraulic gradient in the injection area and the transient groundwater flow reversals observed occasionally during the process monitoring activities. Alternatively, organic carbon may be moving beyond the injection area but is being consumed by the microbial population prior to its arrival at downgradient monitoring wells. The result is that organic carbon is not being transported to downgradient monitoring wells at a rate that is sufficient to drive reductive dechlorination as rapidly as expected. However, it is apparent that reductive dechlorination has been stimulated and it is expected that reductive dechlorination will continue, albeit at slower rates and in a more limited area than was expected. The isotopic fractionation data indicate that the limited reductive dechlorination observed is at least partially biologically mediated.

4.9 IRON ADDITION AND THE ROLE OF ABIOTIC DEGRADATION

During vegetable oil injection, the USGS added approximately 110 pounds of colloidal iron to the vegetable oil emulsion injected into PES-INJ-01 and approximately 7.9 pounds of dissolved magnetite to the vegetable oil emulsion injected into PES-INJ-03 (USGS, 2003). These iron products were added to the injected emulsion in order to track the emulsion in the subsurface following injection using geophysical techniques.

Prior to injection, the colloidal iron was mixed with the extracted groundwater in a large tank using a recirculation pump. The groundwater, with the colloidal iron in suspension, was than emulsified with the vegetable oil and injected into PES-INJ-1. During mixing and injection, it was extremely difficult to maintain the colloidal iron product in suspension in the vegetable oil-in-water emulsion. The colloidal iron settled out of the groundwater very rapidly within the mixing tank. After injection activities were complete at PES-INJ-1 there was a significant mass of iron remaining in the bottom of the mixing tank. Thus, is it expected that only a portion of the 110 pounds of colloidal iron added to the tank was actually injected into PES-INJ-1. In addition, because the colloidal iron settled out so rapidly within the mixing tank it is expected that a significant amount of the iron mass ended up in the injection well sump and did not make its way into the aquifer matrix. A significant amount of colloidal iron was in fact observed in the injection well sump during post-injection sampling activities. Thus, it is impossible to determine how much of the colloidal iron actually made it into the aquifer matrix.

The colloidal iron was injected as micro-powder metallic iron which means that the valence state of the injected iron was zero. ZVI) is very reactive and is known to be capable of degrading CAH species through abiotic degradation processes. Thus, it is likely that the ZVI injected by the USGS was capable of degrading CAH contaminant mass within the injection area. However, the extremely small particle size of the injected powder would have made the reaction kinetics associated with the iron very rapid. The reaction rate increases with the available surface area of the iron particles, and the surface area to mass ratio increases with decreasing particle size. The occurrence of rapid reaction kinetics at the pilot test site is supported by the Fe(II) data collected during the process monitoring rounds. Fe(II) concentrations measured at PES-INJ-1 peaked at 180 mg/L during the May 2002 sampling event and decreased rapidly to less than 20 mg/L by the following sampling event. These data indicate that the ZVI injected in PES-MW-1 was depleted within approximately eight months of substrate injection. Thus, the ZVI may have been responsible for degrading some contaminant mass in close proximity to

PES-INJ-1. However, contaminant mass degradation attributable to the ZVI was likely limited primarily to the first eight months of process monitoring.

The small volume of magnetite injected into PES-INJ-3 was injected as a fluid consisting of approximately 2.8 to 3.5 percent magnetite suspended in water by proprietary dispersants. The magnetite product mixed very rapidly and completely with the extracted groundwater and did not appear to fall out of suspension prior to injection. Thus, the majority of the magnetite product injected into PES-INJ-3 probably entered the aquifer matrix with the vegetable oil emulsion. The valence state of the iron associated with the magnetite is unknown. Thus, it can not be determined if the iron injected into PES-INJ-3 had any effect on the chlorinated solvents in the vicinity of PES-INJ-3. However, the mass of iron injected into PES-INJ-3 was extremely small (7.9 pounds) compared to the mass of vegetable oil (9,360 pounds) injected into the same well. Thus, it is not expected that this iron had a significant impact on contaminant degradation at PES-INJ-3.

The mass of TCE that could have been dechlorinated by the injected magnetite can be estimated by combining the specific reductive capacity of the magnetite (0.37 uM/g of TCE) from Lee and Batchelor (2002) with the mass of magnetite injected (7.9 pounds) from USGS (2003b). The maximum specific reductive capacity of the 7.9 pounds of magnetite is approximately 1.3 millimoles of TCE (7.9 lb*453.6 grams/lb*0.37 uMol/gram* 1 mMol/1000 µMol). Thus, the maximum mass of TCE that could have been dechlorinated by the magnetite is equal to approximately 0.17 grams of TCE (1.3 millimoles multiplied by the molecular weight of TCE of 131.38 grams/mole). The total mass of TCE that was degraded at MW-7 can be approximated by combining the volume of water impacted by the injection at INJ-3 (immediately upgradient of MW-7) with the TCE concentration reduction observed at MW-7. The volume of water affected by the injection at INJ-03 can be estimated by combining the volume of water impacted by the initial injection with the volume of water moving through the system during the pilot test. The volume of water initially impacted by the injection would be approximately equal to the volume of vegetable oil emulsion injected at INJ-03 (3,600 gallons). The volume of water moving through the system can be approximated by multiplying the cross sectional area of the injection volume at INJ-3 of 160 square feet (diameter of the injection area of approximately 16 feet (USGS, 2003a) multiplied by the injection interval of 10 feet) by the effective porosity of the aquifer matrix of 0.25 (Fetter, 1994) and by the estimated groundwater flow rate at INJ-03 of 32 feet/year (Table 4.2) and by the length of the pilot test of 1.8 years (November 2001 to August 2003). The total estimated groundwater flux through the system is approximately 2,304 cubic feet or 65,200 liters of water. Thus, the total volume of water impacted by the injection over the course of the pilot test at INJ-03 is approximately 78,800 liters. The TCE mass present in this volume of water can be conservatively estimated by multiplying 78,800 liters by the TCE concentration reduction observed at MW-7 of 1298 µg/L (1,300 µg/L – 2 µg/L). Thus, a conservative estimate of the TCE mass impacted by the injection at INJ-03 and reduced (as evidenced by the concentration of 2 µg/L at MW-7) is approximately 102 grams. Thus, it can be estimated that the magnetite could have been responsible for the reduction of approximately 0.17 percent of the TCE mass reduction.

4.10 DATA QUALITY OBJECTIVES

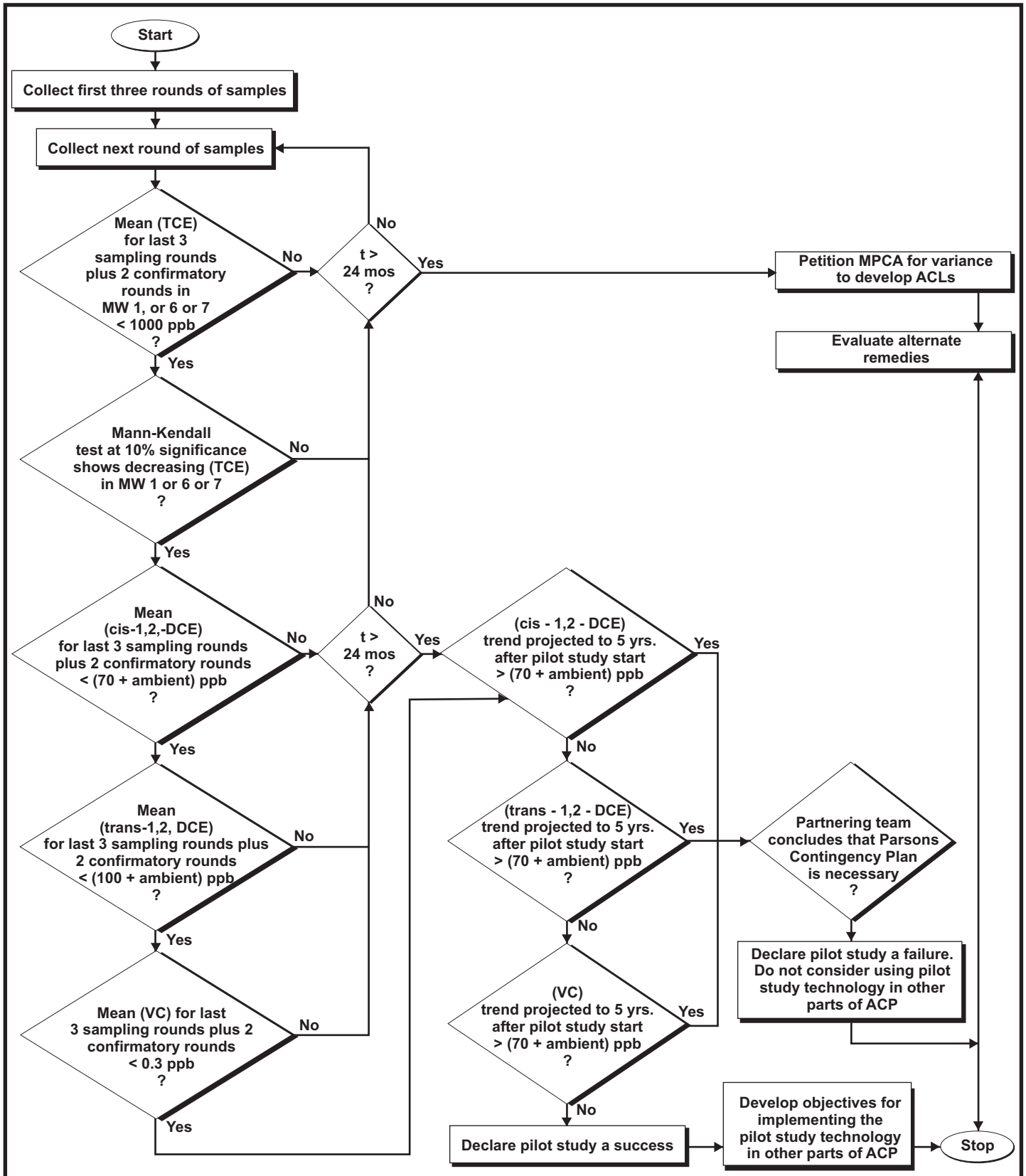
During the work plan preparation phase of this project a series of DQOs were developed to provide criteria to determine the success of this pilot test. The DQOs were agreed to collectively by the US Navy and the various regulatory agencies involved in this project. The DQOs were established in a relatively rigid decision matrix that addresses contaminant mass reduction and the potential for contaminant mass mobilization and migration. The DQO decision matrix is presented on Figure 4.21.

Step one of the DQO matrix was designed to demonstrate the degree of TCE concentration reduction in the immediate vicinity of the injected vegetable oil. Step one requires that the mean TCE concentration at monitoring wells PES-MW-1, PES-MW-6, or PES-MW-7 be below 1,000 µg/L for five consecutive sampling rounds. The mean TCE concentration at PES-MW-7 over the last five rounds of data was approximately 529 µg/L, meeting this objective. The TCE concentration reduction at PES-MW-7 (300 µg/L to 2.1 µg/L measured in August 2003) represents a decline of 99.3 percent. It should be noted that the TCE concentration at PES-MW-7 prior to vegetable oil injection was below 1,000 µg/L, invalidating the letter of this objective. However, Parsons believes that the spirit of this objective was met through the 99+ percent TCE concentration reduction observed at this location.

Step two of the DQO matrix was designed to demonstrate the statistical significance of the TCE concentration reductions in the pilot test area. Step two required that 1) a Mann-Kendall statistical evaluation be conducted on TCE concentrations at monitoring wells PES-MW-1, PES-MW-6, and PES-MW-7, and 2) this evaluation show that TCE concentrations are deceasing in one or more of the three wells evaluated at 10% significance. The results of the Mann-Kendall evaluation indicate that TCE concentrations at PES-MW-6 are decreasing with a 98% confidence (2% significance) and that TCE concentrations are decreasing at PES-MW-7 with an 82% confidence (18% significance). Thus, this pilot test objective has been met.

Steps three, four, and five of the DQO matrix were designed to determine if regulated daughter products migrated downgradient of the pilot test area. These steps require that mean concentrations of *cis*-1,2-DCE, *trans*-1,2-DCE and VC at the contingency wells, over the last five sampling events be below the USEPA Maximum Contaminant Level (MCL) plus the baseline concentration of each analyte. The mean concentrations of *cis*-1,2-DCE at PES-CW-1, PES-CW-2, and PES-CW-3 were 15 µg/L, 10.5 µg/L, and 6.4 µg/L, respectively, compared to baseline concentrations of 12 µg/L, 7.3 µg/L, and 5.7 µg/L, respectively. The mean concentrations of *trans*-1,2-DCE at PES-CW-1, PES-CW-2, and PES-CW-3 were 2.2 µg/L, 2.0 µg/L, and 1.3 µg/L, respectively, compared to baseline concentrations of 7.5 µg/L, <1.9 µg/L, and <0.76 µg/L, respectively. VC was not detected at a concentration above the MDL at any of the contingency wells during the course of the pilot test. The MCLs for *cis*- and *trans*-1,2-DCE are 70 µg/L and 100 µg/L, respectively. Thus, these pilot test objectives have been met.

Steps six, seven, and eight of the DQO matrix were designed to determine if concentrations of *cis*-1,2-DCE, *trans*-1,2-DCE and VC are increasing at the contingency wells and if the increasing concentrations would exceed USEPA MCLs plus the baseline concentrations of each analyte within five years after vegetable oil injection. These steps



TCE is to be measured in the well selected from CW 1, CW 2, CW 3, 27 S, 47S that shows the greatest (TCE) reduction;
(cis-1,2-DCE), (TRANS-1,2-DCE), and (VC) are to be measured in all downgradient wells (CW 1, CW 2, CW 3, 27 S and 47S).
cis-1, 2-DCE = cis-1, 2-dichloroethene
trans-1, 2-DCE = trans-1,2-dichlorodthene
VC = Vinyl chloride

FIGURE 4.21

PROJECT DATA QUALITY OBJECTIVES

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PARSONS

Denver, Colorado

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required that *cis*-1,2-DCE, *trans*-1,2-DCE, and VC concentration trends from each of the three contingency wells be plotted and extended to a point corresponding to five years after vegetable oil injection. The projected concentration of each analyte could not exceed the USEPA MCL plus the baseline concentration of each analyte. *cis*- and *trans*-1,2-DCE concentration trends were plotted and projected out to five years after injection for each contingency well; the plots are presented on Figures 4.22, 4.23, and 4.24.

The projected concentrations of *cis*- and *trans*-1,2-DCE at each contingency well five years after vegetable oil injection were all substantially below the USEPA MCLs for these compounds (listed above) plus the baseline concentration of each analyte at each location. The highest projected concentration was approximately 22 µg/L of *cis*-1,2-DCE at PES-CW-2. This concentration projection exercise was not conducted for VC because

VC was not detected at any of the contingency wells or at newly installed monitoring well cluster PES-MW-12 during the course of the pilot test. Thus, these pilot test objectives have been met.

All pilot test DQOs presented in the Project Work Plan (Parsons 2001b) have been met. Thus, this pilot test project can be considered a success from the DQO standpoint.

FIGURE 4.22
PROJECTED DCE CONCENTRATION TRENDS AT WELL PES-CW1
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

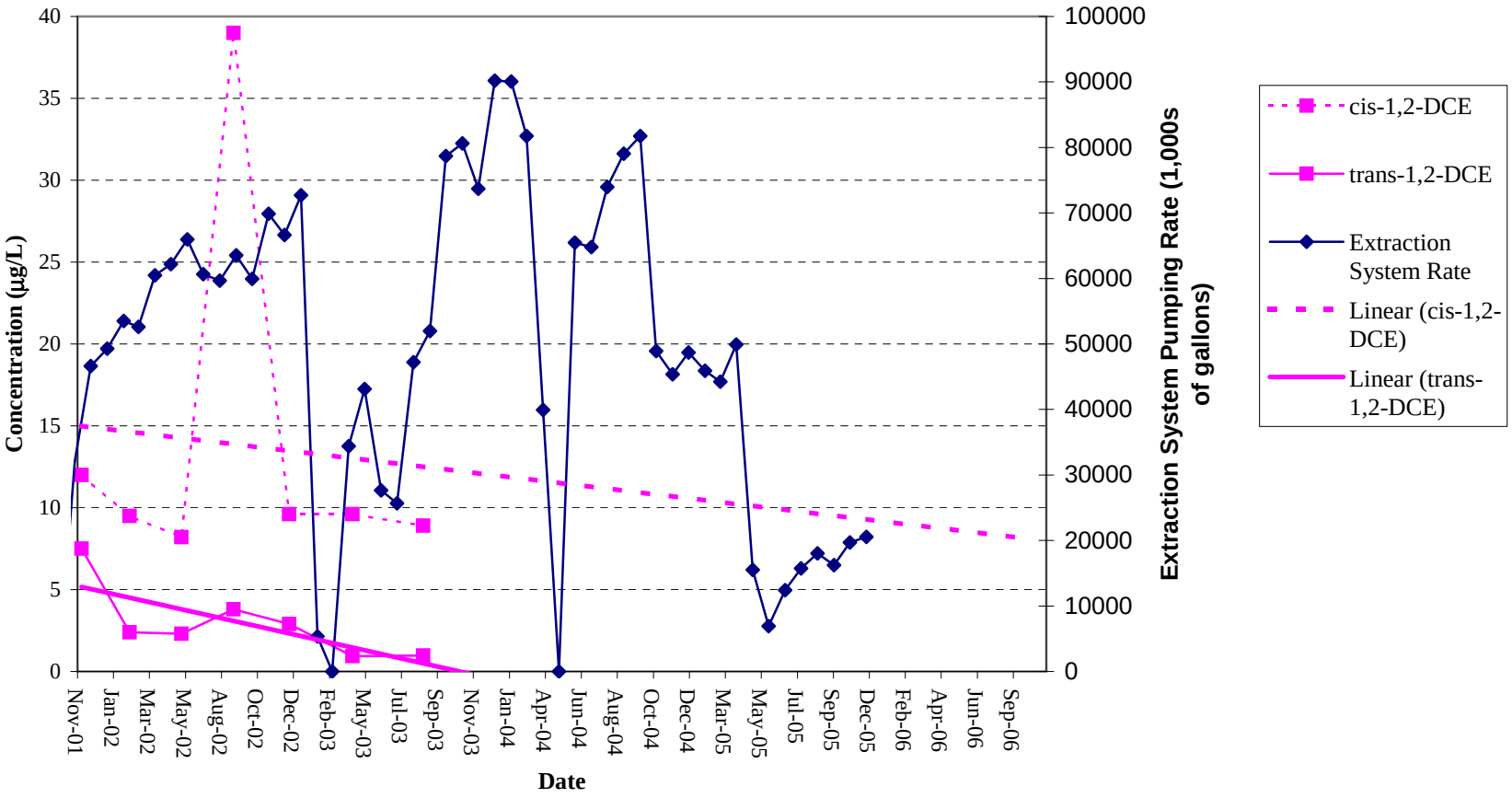
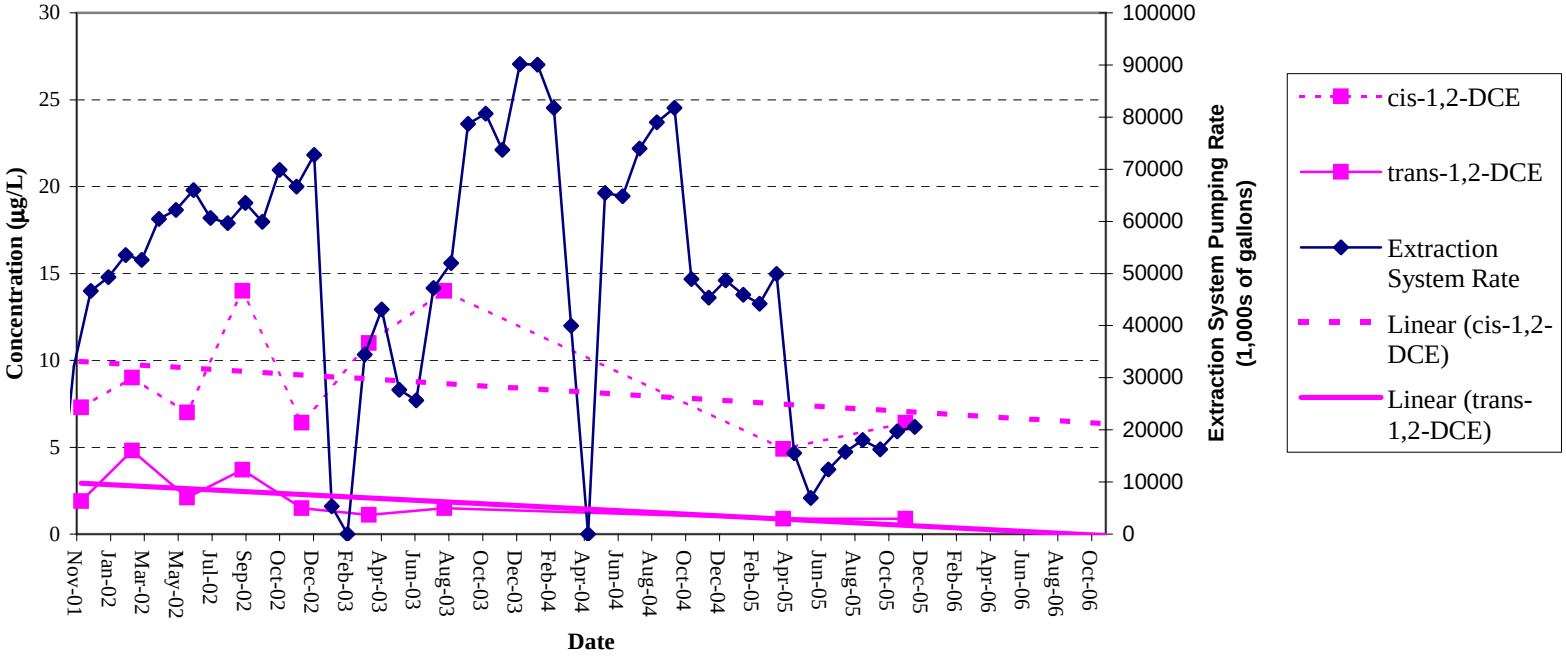
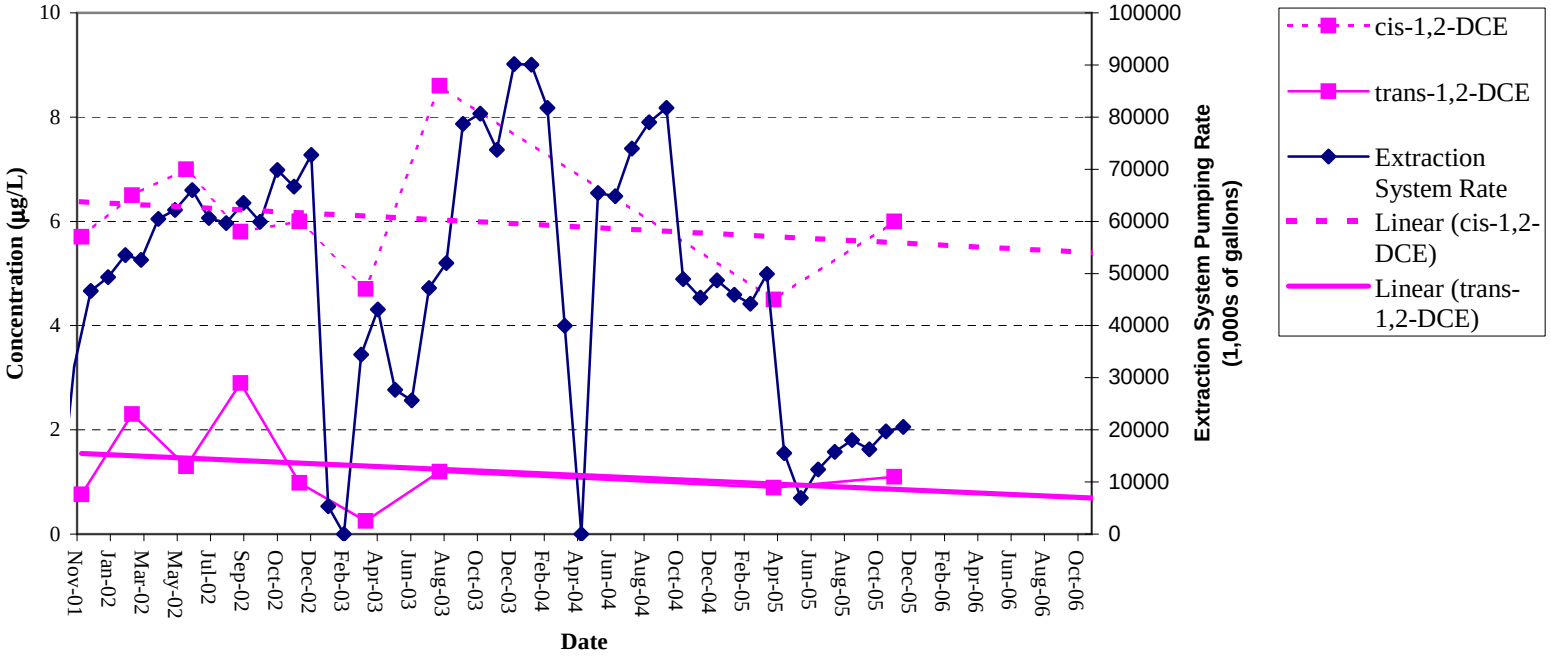


FIGURE 4.23
PROJECTED DCE CONCENTRATION TRENDS AT WELL PES-CW2
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



s:\es\remed\737490\05000\tables\DQO tables.xls

FIGURE 4.24
PROJECTED DCE CONCENTRATION TRENDS AT WELL PES-CW3
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions and recommendations for the field application to enhance *in-situ* bioremediation of chlorinated solvents via vegetable oil injection at NIROP Fridley, Minnesota.

5.1 CONCLUSIONS

5.1.1 Data Quality Objectives

During the work plan preparation phase of this project a series of DQOs were developed and agreed to collectively by the US Navy and the various regulatory agencies involved in this project. The DQOs provide specific criteria used to determine the success of this pilot test. All of the DQOs were successfully met and in most cases were exceeded. Thus, this pilot test can be considered a success with respect to the project DQOs.

5.1.2 Observed Changes in Site Geochemistry

Geochemical changes observed during process monitoring indicate that the addition of vegetable oil to the subsurface at ACP has induced environmental conditions conducive to reductive dechlorination upgradient of PES-MW-5. However, these geochemical changes are neither spatially uniform nor temporally consistent within the pilot test area.

Baseline geochemical conditions were generally weakly anaerobic to weakly aerobic, with DO concentrations ranging from 0.1 to 2 mg/L and ORP ranging from +123 to -185 mV. Following vegetable oil injection, geochemical conditions upgradient of PES-MW-5 became moderately to strongly anaerobic while conditions downgradient of PES-MW-5 remained weakly aerobic. These observations indicate that subsurface conditions upgradient of PES-MW-5 became more favorable for anaerobic degradation processes, while the area downgradient of PES-MW-5 was either not affected or only weakly affected by the injected vegetable oil. Increases in methane concentrations upgradient of PES-MW-5 indicate that methanogenesis has become more prevalent in this area. Reductive dechlorination is known to occur most rapidly under methanogenic conditions. Thus, geochemical conditions in this area have become more favorable for reductive dechlorination.

Sulfate data collected during the baseline sampling event indicated that there was significant sulfate mass present in the subsurface within the pilot test area. Thus, the baseline data set indicated that sulfate reduction would be a significant TEAP in the pilot

test area and would compete with reductive dechlorination for electron donor. Increasing concentrations of sulfide coupled with decreasing concentrations of sulfate at wells where there is significant TOC present support the assertion that sulfate reduction is occurring in the pilot test area and is likely consuming electron donor mass at the expense of reductive dechlorination.

Sulfate reduction and methanogenesis are the dominant TEAPs that have been stimulated at this site, and sulfate and carbon dioxide are competing with CAHs for use as electron acceptors in site groundwater. Sulfate mass is rapidly depleted in the presence of sufficient organic carbon. Thus, sulfate reduction is considered to be a temporary competing TEAP to reductive dechlorination at locations where sufficient TOC mass is present. Methanogenesis is expected to continue to be an active TEAP within the pilot test area and to continue to compete with reductive dechlorination for electron donor mass.

5.1.3 Microbial Population Characterization

Targeted gene detection analysis of soil samples collected during the 2005 sampling program indicates that DHC and DHB were positively identified in nearly all samples analyzed including both vegetable oil impacted and un-impacted samples. The population of DHC in the impacted samples was approximately one order of magnitude higher than the population measured in the non-impacted samples, while DHB populations in the impacted samples were approximately two to three orders of magnitude higher than background. Dechlorinating bacteria DSB, DSM, and GEO were also positively identified at lower concentrations. Thus, the microbial population within the pilot test area is capable of completely dechlorinating chlorinated VOC mass. In addition, moderate to high concentrations of sMMO (with respect to the un-impacted samples) were detected at locations PES-SB-1, PES-SB-7, and PES-MW-10B, indicating that it is possible that chlorinated solvent mass is being destroyed by methanotrophic bacteria through cometabolic oxidation at these locations. This data indicates that several microbial strains that are known to be capable of dechlorinating chlorinated VOC mass are present naturally in site soils, that the injected vegetable oil has been effective at increasing the populations of DHC, DHB, and to a lesser extent GEO. The injected vegetable oil may have also been successful in promoting contaminant mass destruction through cometabolic oxidation. Samples of groundwater were also collected for targeted gene detection analysis. Comparison of the targeted gene detection data collected in soil and in groundwater indicates that the analysis of groundwater from this site does not adequately represent the microbial population in the subsurface.

5.1.4 Aqueous and Mineral Intrinsic Bioremediation Assessment

A total of 11 samples were collected for AMIBA analysis during the 2005 drilling program. Comparison of the impacted and un-impacted sample sets indicates that bioavailable iron, bioavailable manganese, and chromium extractable sulfide have been depleted slightly in the impacted samples. This data indicates that the impacted soil matrix has been depleted of bioavailable metals and sulfide and therefore the capacity for abiotic degradation has been reduced slightly. However, the observed reduction in these species is relatively small in relation to the total mass present in the un-impacted

samples. Therefore, the impacted soils' capacity to support abiotic degradation remains relatively unchanged.

5.1.5 Actual/Significant Changes in Contaminant Concentrations

Groundwater VOC data is the primary line of evidence in determining the success of the vegetable oil pilot test. During the first extended monitoring program process monitoring round all of the original pilot test monitoring wells, the eight newly installed monitoring wells, and seven monitoring wells outside of the pilot test area were sampled for VOCs.

Review of the entire VOC data set indicates that TCE remains the most commonly detected contaminant across the site and that TCE is typically present at greater concentration than any other contaminant compound within each monitoring well. TCE concentrations have been decreasing at all of the wells (except for the newly installed wells) since 2002. *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE, and 1,1-DCA have also been detected routinely during the last 36 months at much lower concentrations than TCE. VC, acetone, and 2-butanone have also been detected sporadically both historically and during the most recent sampling event in November 2005.

Review of groundwater analytical data from the baseline sampling event in November 2001 indicates that four contaminants were detected at concentrations above associated method detection limits: PCE, TCE, *cis*-1,2-DCE, and *trans*-1,2-DCE. PCE was detected at only one location (GWMS-47S) at a low concentration of 0.92 micrograms per liter (µg/L). TCE was detected at elevated concentrations at all wells within the pilot test area, except GWMS-27S, with a maximum concentration of 20,000 µg/L detected at location MS-46S. TCE concentrations were generally highest (>1,000 µg/L in most cases) in the upgradient portions of the pilot test area, east of PES-MW-4. TCE concentrations detected in the downgradient portions of the pilot test area were significantly lower, generally below 300 µg/L, with the exception of PES-CW-1 (630 µg/L). *cis*-1,2-DCE, a breakdown product of TCE, was detected at most locations at concentrations significantly less than TCE. This data suggests that limited degradation of TCE to *cis*-1,2-DCE occurred naturally at the site prior to vegetable oil injection.

Review of groundwater analytical data collected after vegetable oil injection indicates that TCE concentrations detected in groundwater have been variable over time, but generally have declined at the three injection wells (PES-INJ-1, PES-INJ-2, and PES-INJ-3) and at all of the pilot test wells with the exception of GMW-27S. At the majority of these wells TCE concentrations increased initially, typically peaking during the May or August 2002 sampling rounds, then decreased through November 2005. Comparison of the pre-injection VOC data to the most recently collected VOC data indicates that TCE concentrations have decreased substantially since injection, with the largest decreases observed in and downgradient from the injection area.

2-butanone and acetone have been detected sporadically at elevated concentrations during all of the process monitoring events in several wells including PES-INJ-1, PES-INJ-2, PES-INJ-3, PES-MW-6, PES-MW-7, PES-MW-8, and PES-MW-9. Concentrations of both analytes were relatively low during the first round of process monitoring with a maximum concentration of 490 µg/L for 2-butanone and 240 µg/L for

acetone. During later process monitoring rounds concentrations of 2-butanone and acetone were highly variable and in some cases relatively high. However, 2-butanone and acetone have never been detected at concentrations approaching the MPCA Health Risk Limits of 4,000 µg/L for 2-butanone and 700 µg/L for acetone outside of the injection area and monitoring wells PES-MW-7 and PES-MW-9.

VC has not detected at concentrations above the method detection limit in any of the contingency wells (PES-CW1, PES-CW2, PES-CW3, GWMS-47S), or the new downgradient monitoring well cluster PES-MW-12A/B, during the course of the pilot test.

5.1.4 Daughter Product Formation and Persistence

The presence of the daughter products *cis*-1,2-DCE, VC, and ethene which were not used in facility operations, provides direct evidence that TCE is being reductively dechlorinated. Increasing concentrations of *cis*-1,2-DCE coupled with decreasing concentrations of TCE at wells installed close to the injection area (upgradient of PES-MW-5) indicate that partial degradation of TCE to *cis*-1,2-DCE is occurring in this area. The detection of low concentrations of VC and ethene in the same area indicate that limited complete reductive dechlorination is limited to close proximity to the injection area (wells PES-MW-7 and PES-MW-9). Complete dechlorination appears to correlate to areas where TOC is greater than 20 mg/L.

5.1.5 Degree of Electron Donor Utilization for Reductive Dechlorination

A significant percentage of the substrate mass is utilized for microbially mediated redox processes other than reductive dechlorination of chlorinated compounds. In particular, geochemical data indicate that sulfate reduction and methanogenesis may utilize a significant percentage of substrate (i.e., this mass is not being used to enhance reductive dechlorination of CAHs). However, reduction of TCE to *cis*-1,2-DCE (and in some cases to VC and ethene) observed at the injection wells and monitoring locations PES-MW-7 and PES-MW-9 are direct indications that reductive dechlorination is occurring in groundwater at the site. It may be that organic carbon concentrations greater than 20 mg/L are required to meet both the natural demand for electron donor and to provide sufficient electron donor for the dechlorination of CAH mass.

5.1.6 Substrate Distribution and Potential for Future Reductive Dechlorination

Wells where evidence of reductive dechlorination of TCE has occurred exhibit the following characteristics:

- DO concentration less than 1 mg/L;
- ORP less than -100 mV;
- Carbon dioxide concentration greater than 100 mg/L;
- Sulfate concentration less than 50 mg/L;
- TOC concentration equal to or greater than approximately 20 mg/L;
- Measurable concentrations of VFAs equal to or greater than 50 mg/L;
- Ferrous iron concentration greater than 2 mg/L;
- Methane concentration greater than 1 mg/L; and
- Total biomass concentration greater than approximately 50 pmoles PLFA/mL.

These conditions have not been uniformly induced across the treatment area. During the Spring 2005 sampling event TOC concentrations sufficient to support reductive dechlorination (>20 milligrams per liter (mg/L) (USEPA, 1998)) were detected at the injection wells and at monitoring wells PES-MW-4, PES-MW-7, PES-MW-10A, and PES-MW-14A. The TOC data indicates that there was a relatively large area of elevated TOC present to the south and southwest of the injection area present during the Spring 2005 sampling event. Within the relatively large area impacted by elevated (>10 mg/L) TOC concentrations was a smaller core of highly elevated TOC concentrations (>50 mg/L) which extended as far down gradient as PES-MW-4 and PES-MW-14A. Within this area TOC was present at concentrations sufficient to drive reductive dechlorination (USEPA, 1998). The TOC mass was most likely related to and derived from the vegetable oil injected as part of this pilot test.

Between the April 2005 and November 2005 sampling events TOC concentrations decreased at most locations sampled and the horizontal extent of TOC concentrations exceeding 10 mg/L decreased. The reductions in TOC concentrations observed downgradient of the injection area are not likely to be a result of, or indicative of, organic carbon depletion in the injection area because TOC concentrations in the injection area increased at PES-INJ-03 during the same time period. It is more likely that the observed reductions in TOC concentrations downgradient of the injection area are related to seasonal fluctuations in groundwater flow and TOC transport rates.

At monitoring locations where TOC concentrations were elevated (the injection wells, PES-MW-7, PES-MW-10A, and PES-MW-14A) geochemical conditions were moderately to strongly reducing as indicated by the presence of elevated concentrations ferrous iron, reduced manganese, sulfide, and methane. The presence of these reduced species indicated that iron reduction, manganese reduction, sulfate reduction and methanogenesis were occurring at, or in close proximity to, these locations. These reducing conditions are conducive to anaerobic biological processes including anaerobic reductive dechlorination.

During the Spring 2005 sampling event ethane and ethene concentrations present in wells known to be un-impacted by vegetable oil (MS-27S, MS-47S, PES-CW-1, PES-CW-2, PES-CW-3) ranged up to approximately 35 nanograms per liter (ng/L) and 50 ng/L, respectively. During this event ethane concentrations at least twice the concentration measured in non-impacted wells (70 ng/L) were detected in the injection wells and in monitoring wells MS-45S, MS-46S, PES-MW-1, PES-MW-7, PES-MW-10A, PES-MW-11A, PES-MW-12B, PES-MW-14A, and PES-MW-14B. During the same sampling event ethene concentrations at least twice the concentration measured in un-impacted wells (100 ng/L) were detected in the injection wells and in monitoring wells PES-MW-1, PES-MW-6, PES-MW-10A, PES-MW-12B, PES-MW-14A, and PES-MW-14B. This data indicates that complete reductive dechlorination may be occurring at these locations or immediately upgradient of these locations (in the case of PES-MW-1 and PES-MW-6). Methane, ethene, and ethane samples were not collected during the November 2005 sampling event.

5.2 RECOMMENDATIONS

The following recommendations are made for the consideration of the NIROP partnering team and are not necessarily required for future pilot-scale activities at ACP. Parsons suggests that the Navy continue to perform limited groundwater monitoring in the pilot test area in order to track the future progress of the pilot test and to define the life cycle of the injected substrate. Future sampling events could be combined with the base wide sampling events in order to decrease the monitoring costs and to produce site wide sampling rounds that are internally comparable. The sampling locations and analytical parameters could be scaled back to only those locations and parameters important for tracking the progress of the pilot test (Table 5.1). It is recommended that the following sampling be retained and repeated approximately annually in order to continue to track the effectiveness of the system and to track the depletion of the vegetable oil derived organic carbon:

TABLE 5.1
RECOMMENDATIONS FOR FUTURE ANNUAL SAMPLING
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well Identification	Well Stabilization Parameters [a/]	VOCs (8260B)	TOC (SW9060)
PES-INJ-03	X	X	X
PES-MW-4	X	X	X
PES-MW-5	X	X	X
PES-MW-7	X	X	X
PES-MW-9	X	X	X
PES-MW-10A	X	X	X
PES-MW-11A	X	X	X
PES-MW-12A	X	X	X
PES-MW-13A	X	X	
PES-MW-14A	X	X	X
PES-CW-2	X	X	
PES-CW-3	X	X	
MS-46S	X	X	
MS-47S	X	X	

[a/] Well stabilization parameters include dissolved oxygen, temperature, pH, oxidation reduction potential, and turbidity.

In addition it is recommended that a slightly expanded sampling program be implemented during the site wide sampling round immediately prior to a five year ROD

review in order to prepare a more complete representation of "current" site conditions. Parsons recommends that PES-MW-1 and PES-MW-6 be added to the pre-ROD review sampling protocol in order to assess groundwater conditions immediately downgradient from the injection area (Table 5.2). Parsons also recommends that the B interval wells be added at well clusters PES-MW-10, PES-MW-12, and PES-MW-14 in order to assess water quality downgradient from and slightly below the injection area.

TABLE 5.2
RECOMMENDATIONS FOR SAMPLING PRIOR TO A 5-YEAR ROD REVIEW
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well Identification	Well Stabilization Parameters [a/]	VOCs (8260B)	TOC (SW9060)
PES-MW-1	X	X	X
PES-MW-6	X	X	X
PES-MW-10B	X	X	X
PES-MW-12B	X	X	X
PES-MW-14B	X	X	X

Note: Sampling recommendations presented in this table are in addition to the sampling recommendations presented in Table 5.1.

[a/] Well stabilization parameters include dissolved oxygen, temperature, pH, oxidation reduction potential, and turbidity.

During the coming months the NIROP team will be required to make a series of decisions regarding the future of remedial activities at Anoka County Park. These decisions will be made based upon the results of the vegetable oil pilot test, research being conducted by the USGS with regard to the hydraulic system, and the impact of the extraction system currently operating on site. The vegetable oil pilot test has been successful in enhancing the destruction of chlorinated solvent mass in the subsurface and has thus been successful in reducing the overall toxicity of the groundwater plume. Vegetable oil has also been shown to be effective at stripping contaminant mass from the soil matrix through its surfactant properties and immobilizing contaminant mass through its preferential partitioning properties (Parsons, 2004). Therefore, Parsons recommends that organic substrate addition in general and vegetable oil injection specifically be considered as a future remedial option at this site.

In 1990 the record of decision (ROD) for groundwater at the NIROP facility was signed. The ROD specified that contaminated groundwater located offsite and downgradient of the NIROP facility in Anoka County Park would be allowed to dissipate naturally (TTNUS, 2005). During the 1998 5-year ROD review it was determined that VOC concentrations in Anoka County Park were not decreasing as rapidly as expected and it was recommended that the Navy determine what could be done to reduce residual

groundwater contamination in Anoka County Park (TTNUS, 2005). As a result of this recommendation the Navy embarked on this organic substrate addition pilot test program. In addition, the Navy started a groundwater extraction system expansion program in order to more fully capture the VOC plume emanating from the NIROP facility. Over the last several years of groundwater monitoring in Anoka County Park VOC concentrations at wells installed within and outside of the pilot testing area have been decreasing (TTNUS, 2006). The VOC concentration decreases observed outside of the pilot test area are likely a result of more complete capture afforded by the expanded extraction system and natural attenuation mechanisms active in the Park (TTNUS, 2006). Since VOC concentrations in Anoka County Park have been decreasing over the last several years, Parsons suggests that the Navy continue to monitor VOC concentrations at wells installed in the Park to determine if the VOC concentration reductions are sustainable. If VOC concentrations continue to decrease in the Park then the tenants of the ROD should be fulfilled and active remediation in the Park may be unnecessary to be protective of identified potential contaminant receptors. In the event that VOC concentrations in the Park increase significantly over a significant period of time the NIROP partnering team could re-consider the need for more active remediation measures.

In the event that a more active approach becomes warranted, Parsons suggests that future active remedial activities at Anoka County Park be designed to reduce the potential impact to receptors and therefore reduce the environmental risk and impact associated with the contaminant mass remaining in the subsurface instead of attempting to remove or destroy all of the remaining contaminant mass. To this end Parsons suggests that the NIROP team limit future remedial activities at the site to defined contaminant hot spots or source areas instead of attempting to treat large areas (for example attempting to treat an area within a particular interpreted VOC concentration contour). The control or elimination of contaminant mass present as hot spots will allow the environmental risk associated with the site to be reduced most significantly and most efficiently in terms of cost and in terms of impact to activities and access to the site.

SECTION 6

REFERENCES

Bouwer, E.J., 1992, Bioremediation of Subsurface Contaminants. In: Mitchell, R., ed.: Environmental Microbiology. Wiley-Liss, New York, New York.

Bouwer, E.J., 1994, Bioremediation of chlorinated solvents using alternate electron acceptors. In: Handbook of Bioremediation. CRC Press, Boca Raton, FL.

Butler, E.C., and Hayes, K.F. 1999. Kinetics of the Transformation of Trichloroethylene and Tetrachloroethylene by Iron Sulfide. *Environ. Sci. Technol., 33*(12), 2021-2027. Chapelle, F.H. 1993, *Ground-Water Microbiology and Geochemistry*: John Wiley & Sons, Inc., New York, 424 p.

CH2M Hill Constructors Incorporated (CCI), 2002. Project Completion Report (Revision 00), Pilot –Scale Study to Enhance In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at Anoka County Riverfront Park, Naval Industrial Reserve Ordnance Plant Fridley. January.

Chapelle, F.H., 1993. Ground-Water Microbiology and Geochemistry: John Wiley & Sons, Inc., New York, 424 p.

Grbic'-Galic', D., 1990. Anaerobic microbial transformation of non-oxygenated aromatic and alicyclic compounds in soil, subsurface, and freshwater sediments, in *Soil Biochemistry,* J.M. Bollag and G. Stotzky, eds. Marcel Dekker, Inc.: New York, NY.

Fennell, D. E., and J.M. Gossett. 1998. Modeling the Production of and Competition for Hydrogen in a Dechlorinating Culture. *Environ. Sci. Technol.*, v. 32, no. 16, pp. 2450-2460.

Godsey, E.M., 1994, Microbiological and Geochemical Degradation Processes. In: Symposium on Intrinsic Bioremediation in Ground Water. Denver, Colorado. August 30 - September 1. p.35-40.

Karickhoff, S.W., Brown, D.S., and Scott, T.A., 1979. Sorption of Hydrophobic Pollutants on Natural Sediments. *Water Resour. Res*., 13:241-248.

Karickhoff, S.W., 1981. Semi-empirical Estimation of Sorption of Hydrophobic Pollutants on Natural Sediments and Soils: *Chemosphere*, 10:833-846.

Lee, W and B. Batchelor, 2003. Reductive Capacity of Natural Reductants. *Environmental Science and Technology*. 37(3): 535-541.

Lindgren, R.J., 1990, Simulation of Ground-Water Flow in the Prairie du Chien-Jordan and Overlying Aquifers near the Mississippi River, Fridley, Minnesota. U.S. Geological Survey Water-Resources Investigations Report 90-4165, 152 p.

Lovley, D.R. and S. Goodwin, 1988. Hydrogen concentrations as an indicator of the predominant terminal electron-accepting reactions in aquatic sediments. *Geochim. Cosmochim. Acta.* 52:2993-3003.

Lovley, D.R., Chapelle, F.H., and J.C. Woodward, 1994. Use of dissolved H_2 concentrations to determine distribution of microbially catalyzed redox reactions in anoxic groundwater. *Environmental Science and Technology*. 28(7): 1205-1210.

Lovley, D.R. and E.J.P. Phillips, 1998. Novel mode of microbial energy metabolism: organic carbon oxidation coupled to dissimilatory reduction of iron or manganese. *Applied and Environmental Microbiology.* 54(6):1472-1480.

Lyman, W.J., Reidy, P.J., and Levy, B., 1992. Mobility and Degradation of Organic Contaminants in Subsurface Environments: C.K. Smoley, Chelsea, MI 395 p.

Maymo-Gatell, X., Gossett, J.M., and Zinder, S.H. 1997. *Dehalococcus Ethenogenes* Strain 195: Ethene Production from Halogenated Aliphatics (abstract). *In Situ and On-Site Bioremediation,* Vol. 3. p. 23. Alleman, B.C. and A. Leeson (Eds.). Battelle Press, Columbus, OH.

Parsons Engineering Science (Parsons). 2001a. Final Quality Assurance Project Plan for Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents Via Vegetable Oil Injection at The Naval Industrial Reserve Ordnance Plant (NIROP), Fridley, Minnesota. September.

Parsons. 2001b. Final Work Plan for Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at the Naval Industrial Reserve Plant (NIROP) Fridley, Minnesota. September

Parsons. 2002b. *Final Interim Report: Performance and Cost of Anaerobic Dechlorination, Phase I Site Survey.* Prepared for the Naval Facilities Engineering Service Center (NFESC), Port Hueneme, California and the Environmental Security Technology Certification Program, Arlington, Virginia. December 11, 2002.

Reinhard, M., Goodman, N.L., and Barker, J.F., 1984, Occurrence and distribution of organic chemicals in two landfill leachate plumes: *Environmental Science and Technology,* vol. 18, no. 12, p. 953-961.

Schoenberg, M.E., 1994, Characterization of Groundwater Discharge from Bedrock Aquitard to the Mississippi and Minnesota Rivers at Three Areas, Minneapolis-St. Paul, Minnesota, U.S. Geological Survey Water-Resources Investigations Report 94-4163 45 p.

Song, D.L., Conrad. M.E., Sorenson ,K.S., and Alverez-Cohen, L. 2002. Stable Carbon Isotope Fractionation During Enhanced In-Situ Bioremediation of Trichloroethene: *Environmental Science and Technology,* vol. 36, No. 10, p. 2262-2268.

Stumm, W. and J.J. Morgan, 1981. *Aquatic Chemistry*. John Wiley and Sons: New York, NY.

Tetra Tech NUS (TtNUS), 1999, Remedial Investigation for Operable Unit 3, Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, Draft, August.

TtNUS, 2000, Field Investigation Report at the NIROP and Anoka County Riverfront Park, Naval Industrial Reserve Ordnance Plant (NIROP), Fridley, Minnesota, April.

TtNUS, 2001. 2000 Annual Monitoring Report, Naval Industrial Reserve Ordnance Plant (NIROP), Fridley, Minnesota. March.

TtNUS, 2003, 2002 Annual Monitoring Report, Naval Industrial Reserve Ordnance Plant (NIROP), Fridley, Minnesota, August.

TtNUS, 2006. 2005 Annual Monitoring Report, Naval Industrial Reserve Ordnance Plant (NIROP), Fridley, Minnesota. April.

US Environmental Protection Agency (USEPA), 1998, Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater: EPA/600/R-98/128, September 1998; http://www.epa.gov/ada/reports.html.

United States Environmental Protection Agency (USEPA). Office of Solid Waste and Emergency Response. 2000a. *Engineered Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications.* Division of Solid Waste and Emergency Response. EPA 542-R-00-008. July. http://www.epa.gov/clu-in.org.

USEPA. 2000b. *Applicability of RCRA Section 3020 to In-Situ Treatment of Ground Water*. Memorandum from Elizabeth Cotsworth, Director Office of Solid Waste. December 27, 2000.

United States geological Survey [USGS], 2003a. Evaluation of the Capture Zones for Recovery Wells at the Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota.

USGS, 2003b. Application of Cross-Borehole Radar to Monitor Field-Scale Vegetable Oil Injection Experiments for Biostimulation. Draft. December.

Vogel, T.M., C.S. Criddle, and P.L. McCarty, 1987. Transformations of halogenated aliphatic compounds. *Environmental Science and Technology* 22:722-736.

Vroblesky, D.A., and F.H. Chapelle, 1994. Temporal and spatial changes of terminal electron-accepting processes in a petroleum hydrocarbon-contaminated aquifer and the significance for contaminant biodegradation. *Water Resource Res.*. 30(5):1561-1570.

APPENDIX A

PROCESS MONITORING ANALYTICAL DATA

This data is available upon request from CH2M Hill Constructors Inc.

APPENDIX B.1

SLUG TEST DATA

APRIL 2003

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-INJ-1**

Test Date: **April 5, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

Logger Data File:

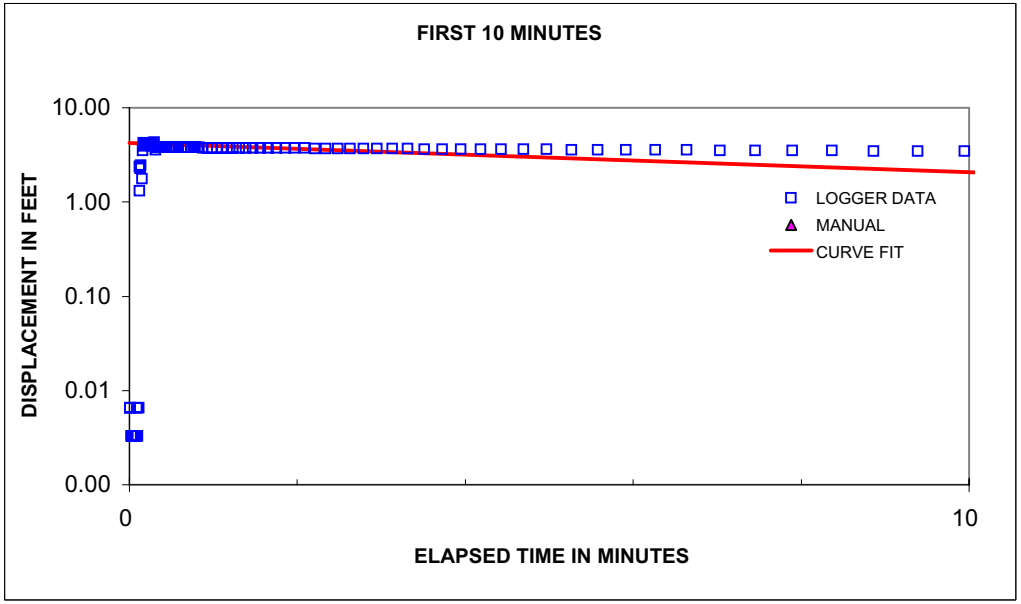
Hydraulic conductivity

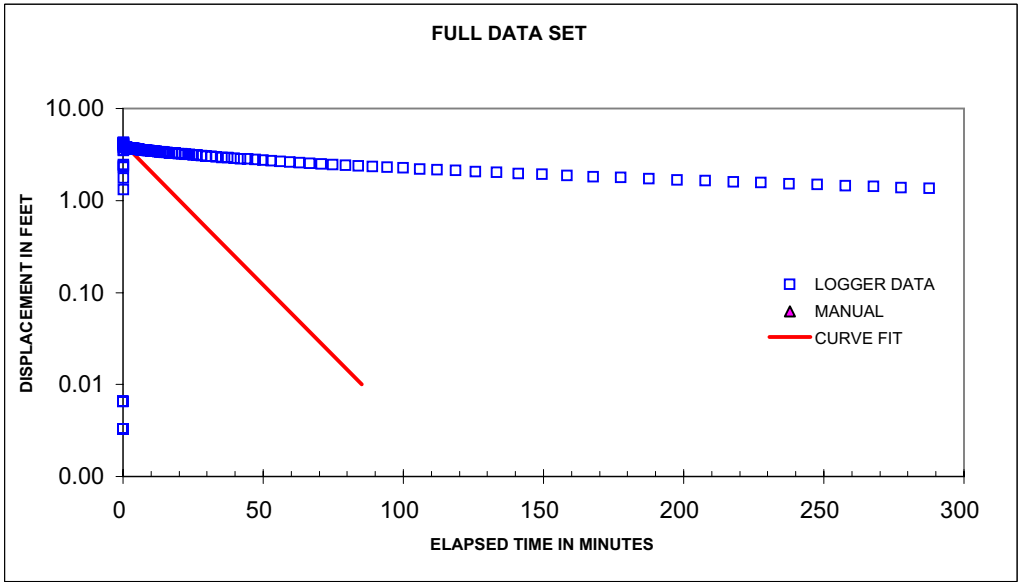
3.97E-04	cm/sec
7.81E-04	ft/min
1.12	ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.73	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	4.200	feet
ΔH at time t (Y_t)	0.500	feet
Time	30.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.23	769.01	*SW*		
19.77	602.59	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.77	602.59	*D*	#NUM!	*Ln[(D-H)/Rw]*
4.2	128.02	Y_0	#NUM!	equation (8)
0.5	15.24	Y_t	3.83	equation (9)
	1800.00	*t (seconds)*	3.83	*Ln(Re/Rw)*
	0.30	*n*	4.0E-04	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-INJ-1**

Test Date: **April 6, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

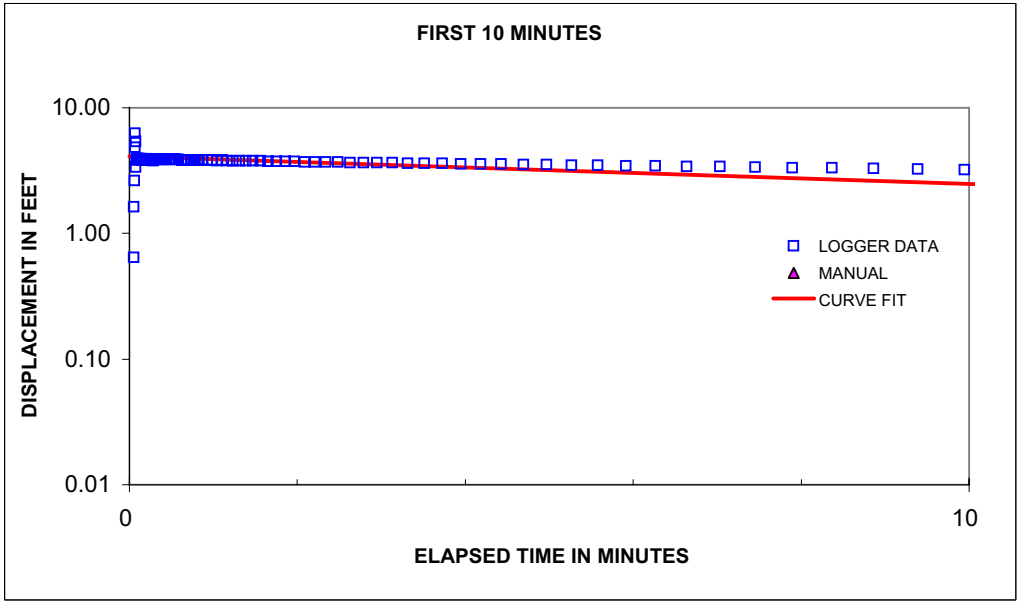
Logger Data File:

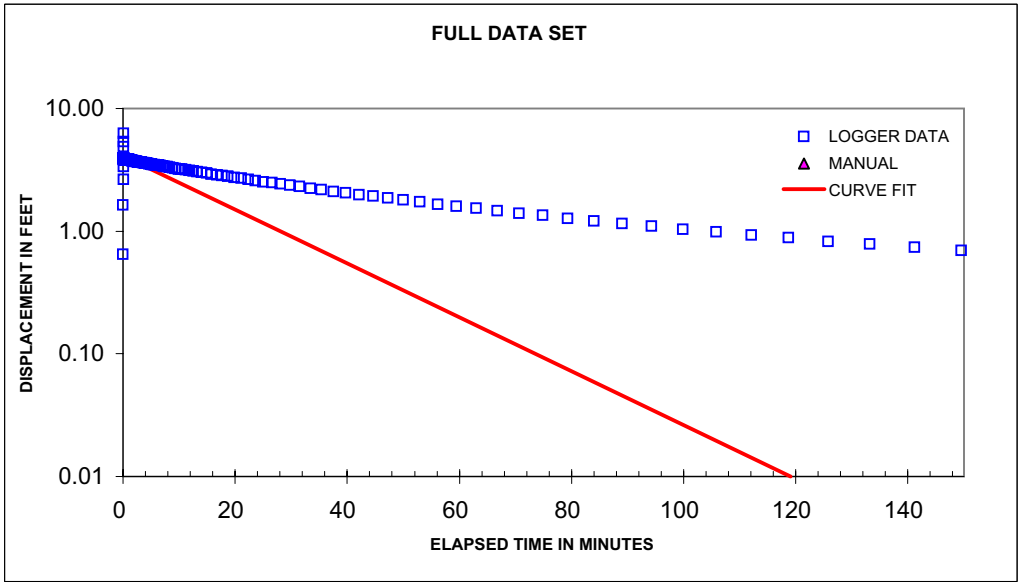
Hydraulic conductivity **2.83E-04 cm/sec**
5.56E-04 ft/min
0.80 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.73	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	4.100	feet
ΔH at time t (Y_t)	0.900	feet
Time	30.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.23	769.01	*SW*		
19.77	602.59	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.77	602.59	*D*	#NUM!	*Ln[(D-H)/Rw]*
4.1	124.97	Y_0	#NUM!	equation (8)
0.9	27.43	Y_t	3.83	equation (9)
	1800.00	*t (seconds)*	3.83	*Ln(Re/Rw)*
	0.30	*n*	2.8E-04	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-6**

Test Date: **April 4, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

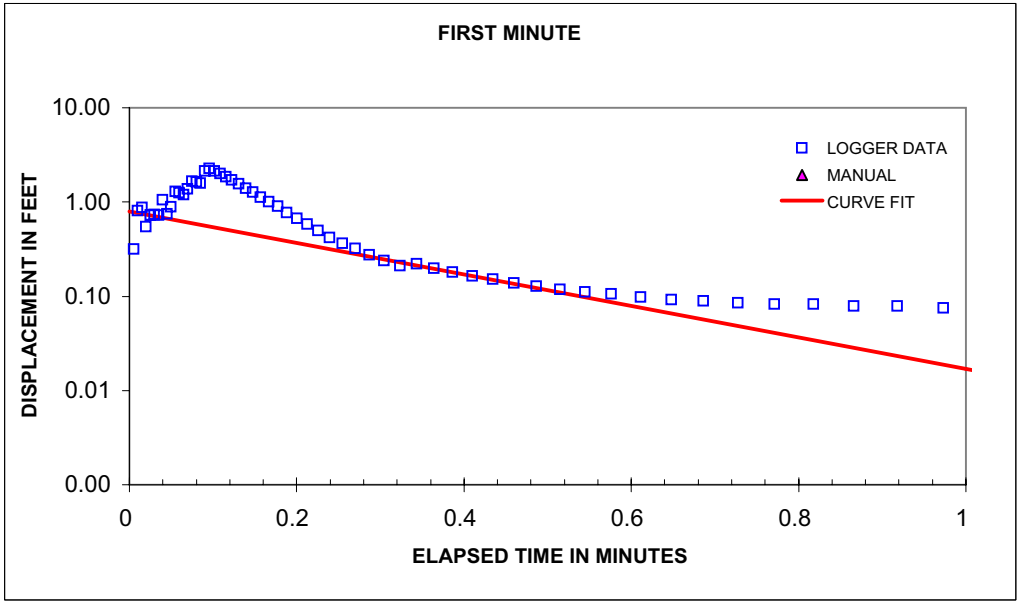
Logger Data File:

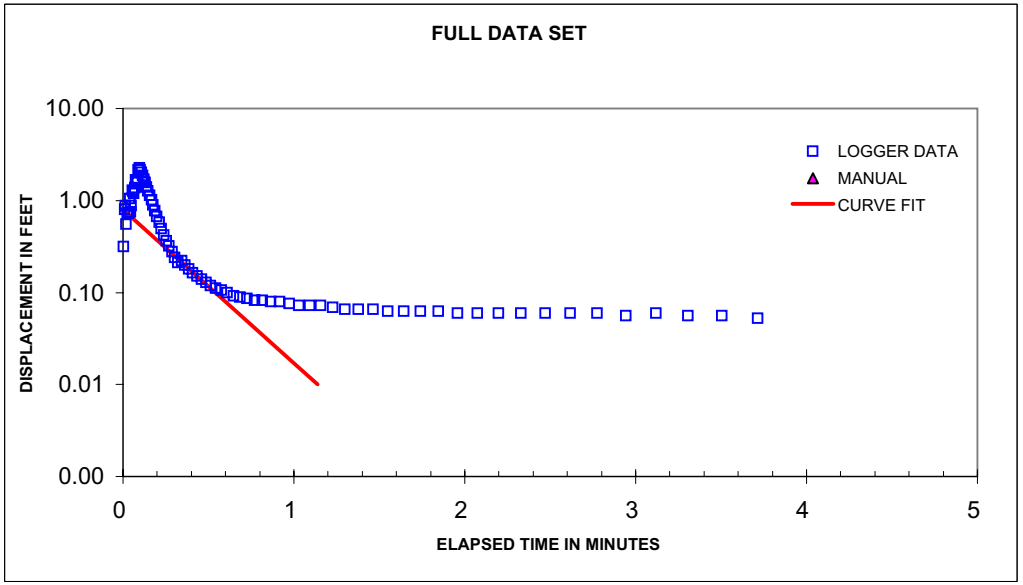
Hydraulic conductivity **2.15E-02 cm/sec**
4.24E-02 ft/min
61.04 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.71	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.800	feet
ΔH at time t (Y_t)	0.017	feet
Time	1.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.21	768.40	*SW*		
19.79	603.20	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.79	603.20	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.8	24.38	Y_0	#NUM!	equation (8)
0.017	0.52	Y_t	3.83	equation (9)
	60.00	*t (seconds)*	3.83	*Ln(Re/Rw)*
	0.30	*n*	2.2E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-6**

Test Date: **April 4, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

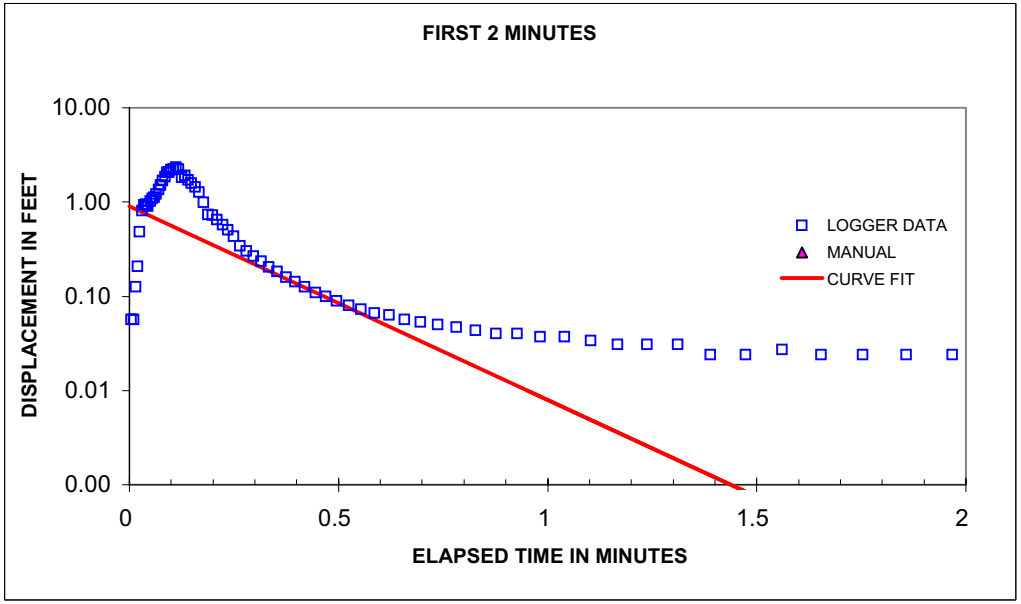
Logger Data File:

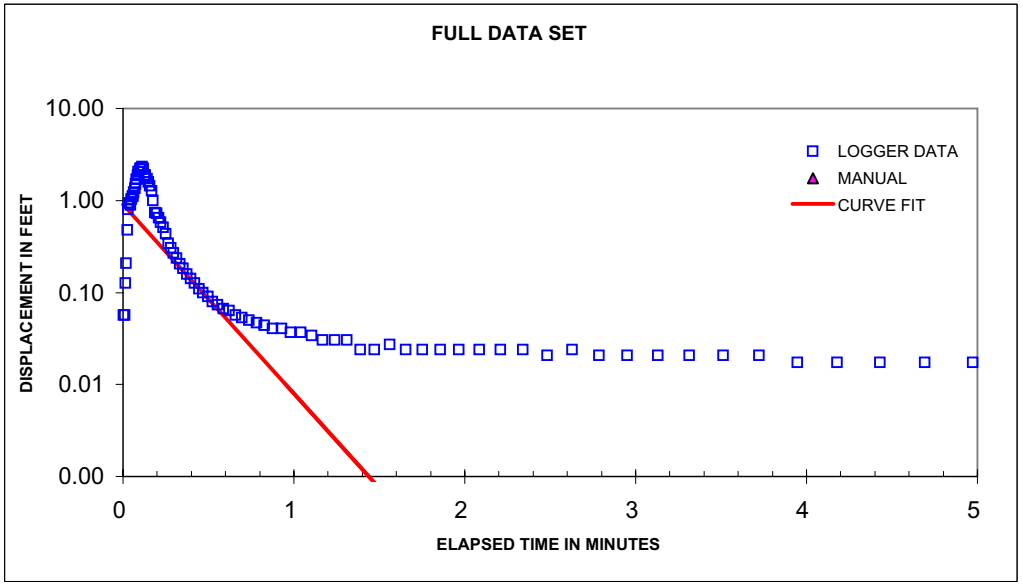
Hydraulic conductivity **2.64E-02 cm/sec**
5.21E-02 ft/min
74.98 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.71	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.900	feet
ΔH at time t (Y_t)	0.000	feet
Time	2.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.21	768.40	*SW*		
19.79	603.20	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.79	603.20	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.9	27.43	Y_0	#NUM!	equation (8)
0.00007	0.00	Y_t	3.83	equation (9)
	120.00	*t (seconds)*	3.83	*Ln(Re/Rw)*
	0.30	*n*	2.6E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-1**

Test Date: **April 4, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

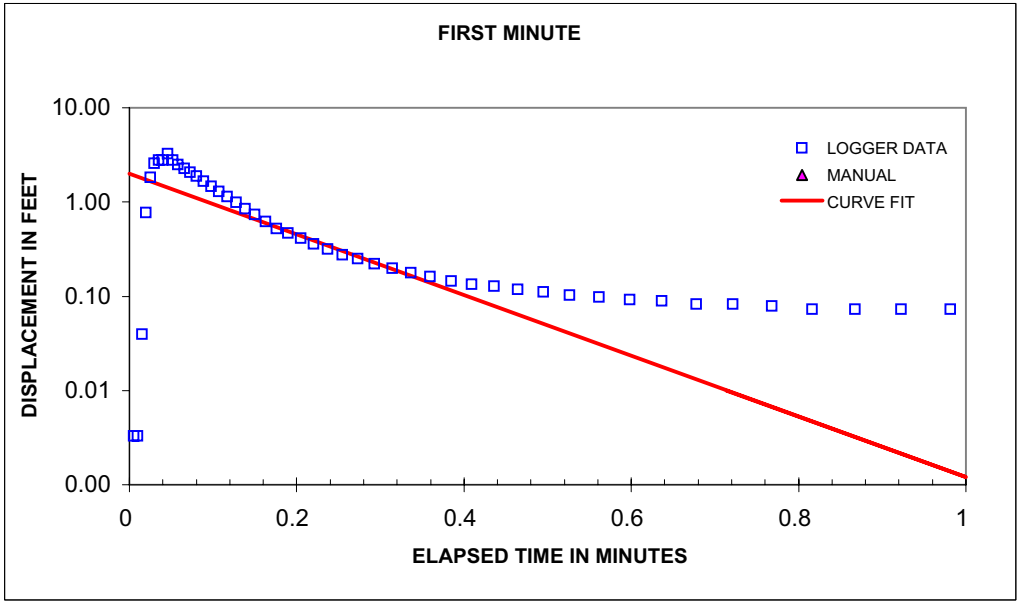
Logger Data File:

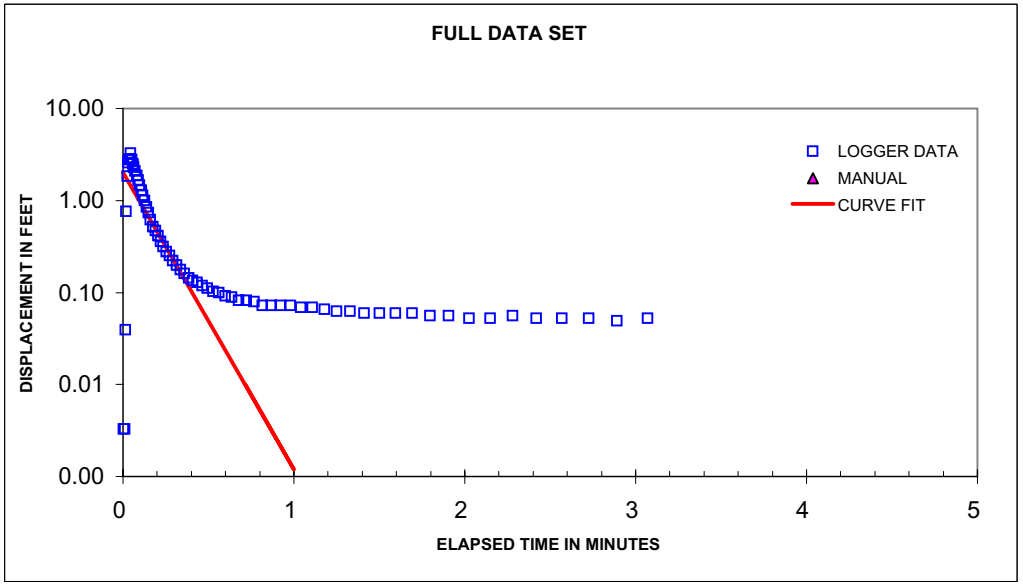
Hydraulic conductivity **4.15E-02 cm/sec**
8.16E-02 ft/min
117.51 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.77	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	2.000	feet
ΔH at time t (Y_t)	0.001	feet
Time	1.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.27	770.23	*SW*		
19.73	601.37	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.73	601.37	*D*	#NUM!	*Ln[(D-H)/Rw]*
2	60.96	Y_0	#NUM!	equation (8)
0.0012	0.04	Y_t	3.83	equation (9)
	60.00	*t (seconds)*	3.83	*Ln(Re/Rw)*
	0.30	*n*	4.1E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-1**

Test Date: **April 4, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

Logger Data File:

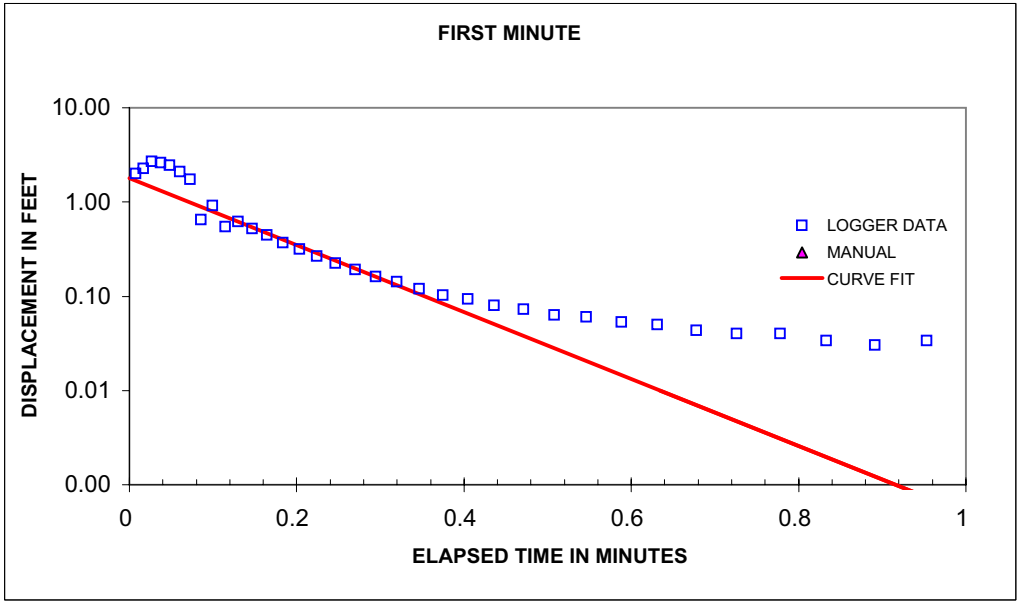
Hydraulic conductivity

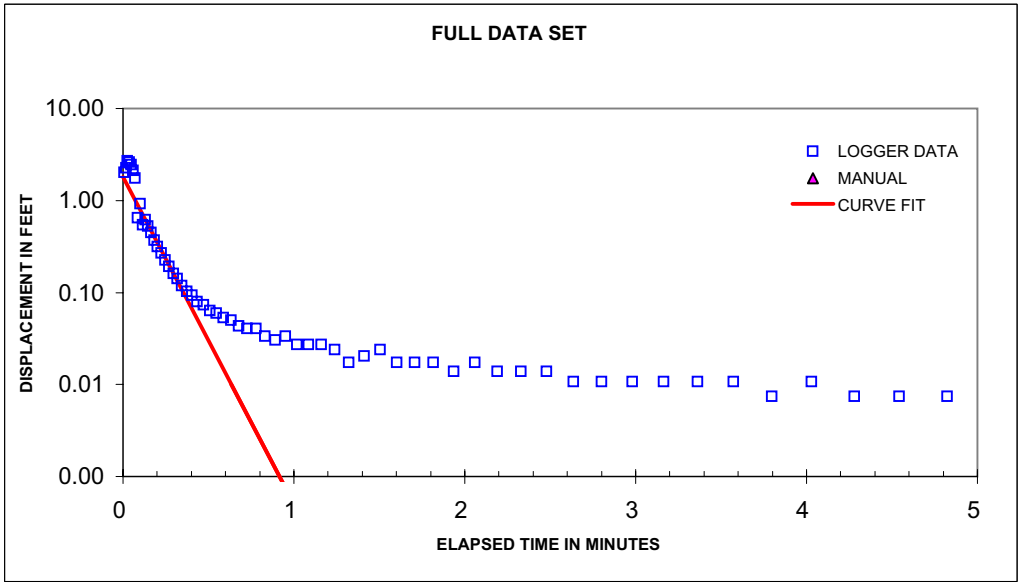
4.58E-02	cm/sec
9.01E-02	ft/min
129.71	ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.77	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	1.800	feet
ΔH at time t (Y_t)	0.001	feet
Time	1.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.27	770.23	*SW*		
19.73	601.37	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.73	601.37	*D*	#NUM!	*Ln[(D-H)/Rw]*
1.8	54.86	Y_0	#NUM!	equation (8)
0.0005	0.02	Y_t	3.83	equation (9)
	60.00	*t (seconds)*	3.83	*Ln(Re/Rw)*
	0.30	*n*	4.6E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-INJ-2**

Test Date: **April 4, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

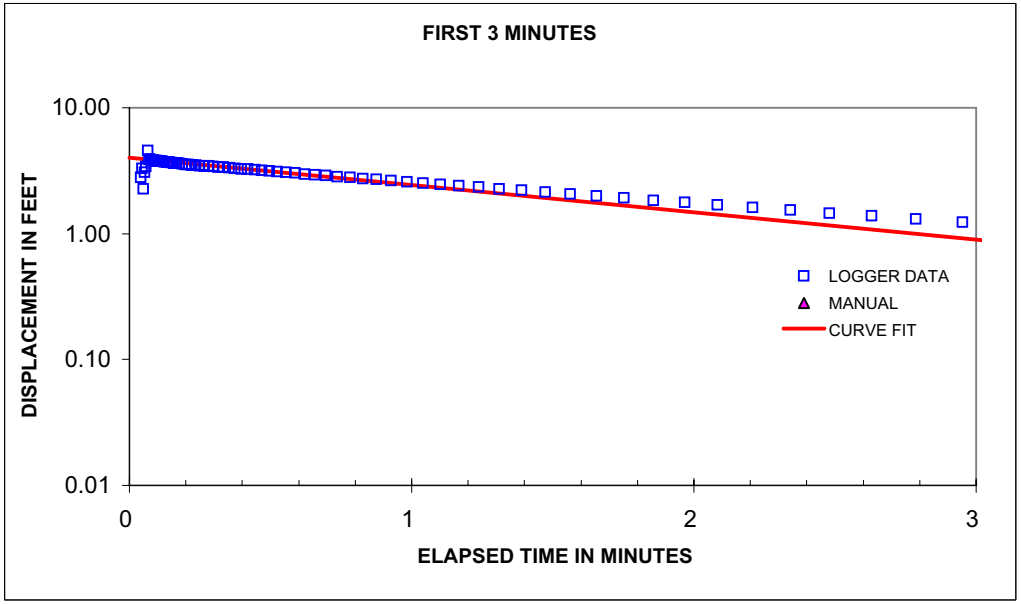
Logger Data File:

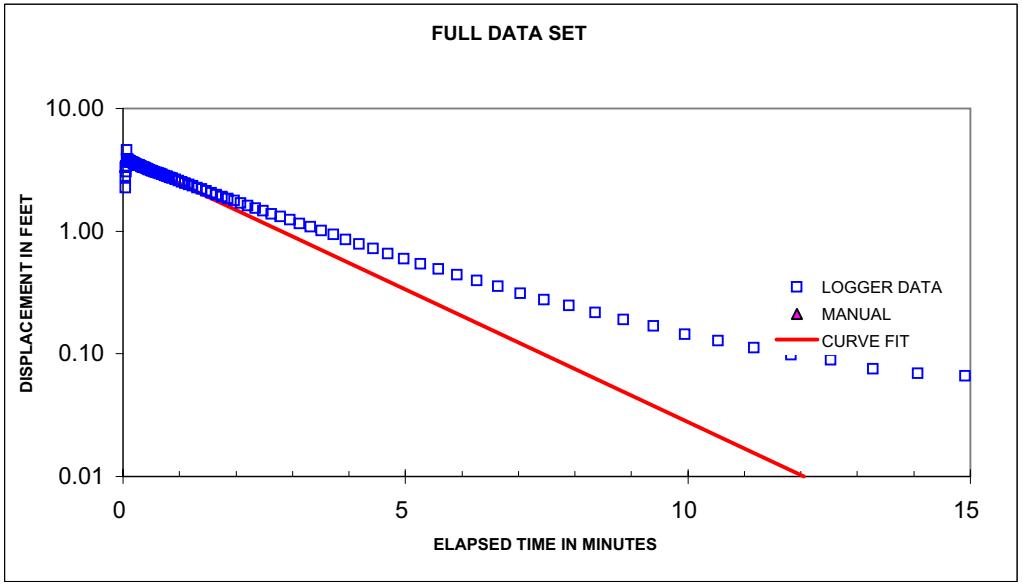
Hydraulic conductivity **2.87E-03 cm/sec**
5.65E-03 ft/min
8.14 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	28.23	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	4.000	feet
ΔH at time t (Y_t)	0.900	feet
Time	3.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.73	784.25	*SW*		
24.27	739.75	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.27	739.75	*D*	#NUM!	*Ln[(D-H)/Rw]*
4	121.92	Y_0	#NUM!	equation (8)
0.9	27.43	Y_t	3.96	equation (9)
	180.00	*t (seconds)*	3.96	*Ln(Re/Rw)*
	0.30	*n*	2.9E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-INJ-2**

Test Date: **April 4, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

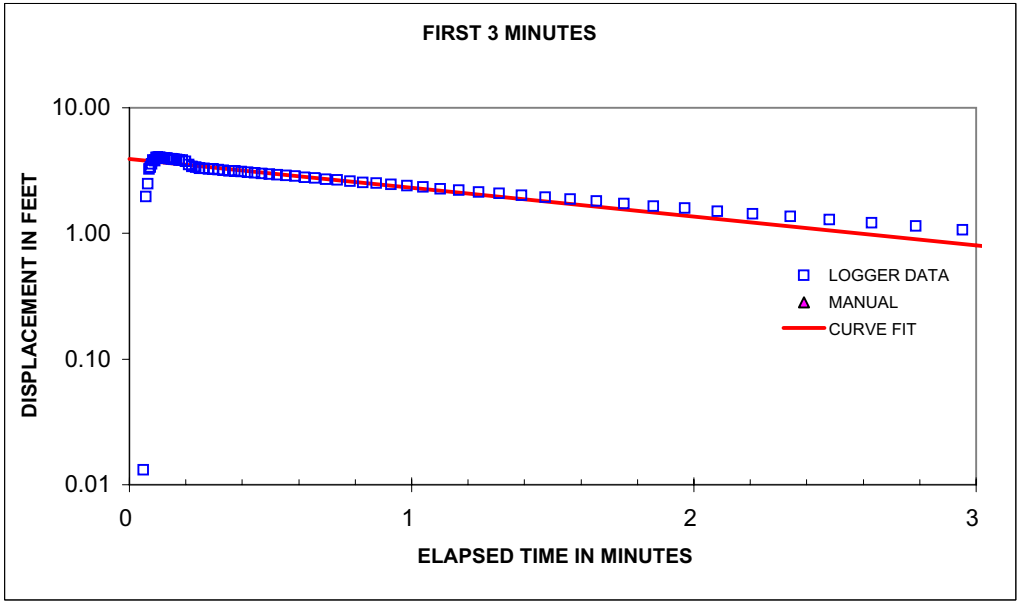
Logger Data File:

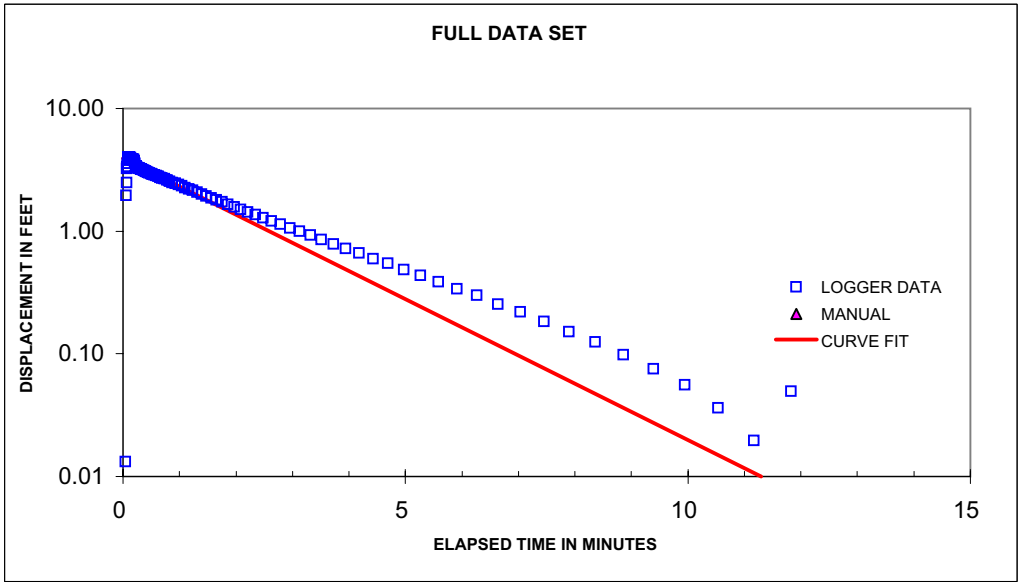
Hydraulic conductivity **3.05E-03 cm/sec**
6.01E-03 ft/min
8.65 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	28.23	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	3.900	feet
ΔH at time t (Y_t)	0.800	feet
Time	3.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.73	784.25	*SW*		
24.27	739.75	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.27	739.75	*D*	#NUM!	*Ln[(D-H)/Rw]*
3.9	118.87	Y_0	#NUM!	equation (8)
0.8	24.38	Y_t	3.96	equation (9)
	180.00	*t (seconds)*	3.96	*Ln(Re/Rw)*
	0.30	*n*	3.1E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-7**

Test Date: **April 4, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

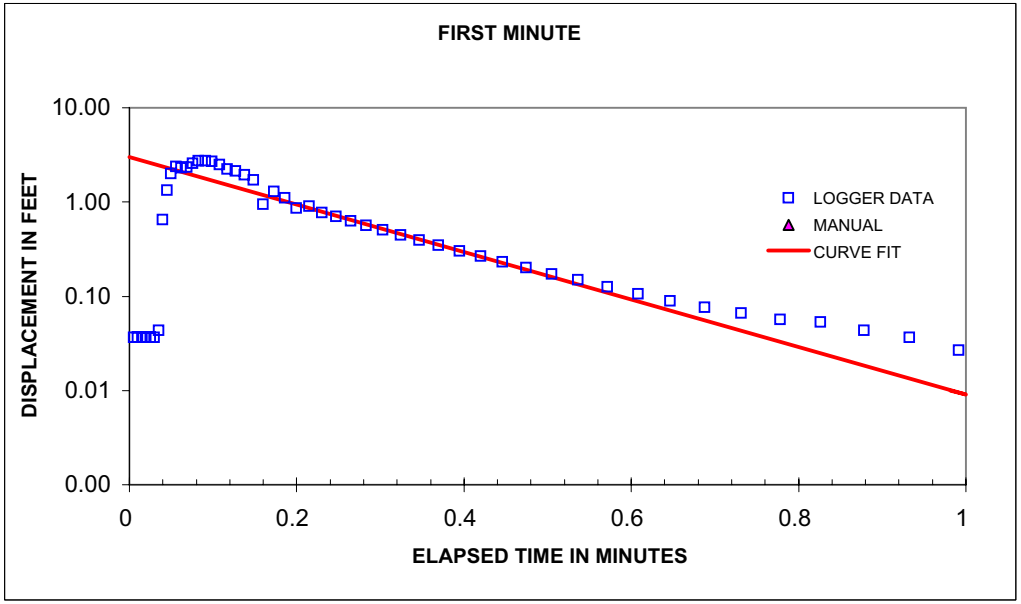
Logger Data File:

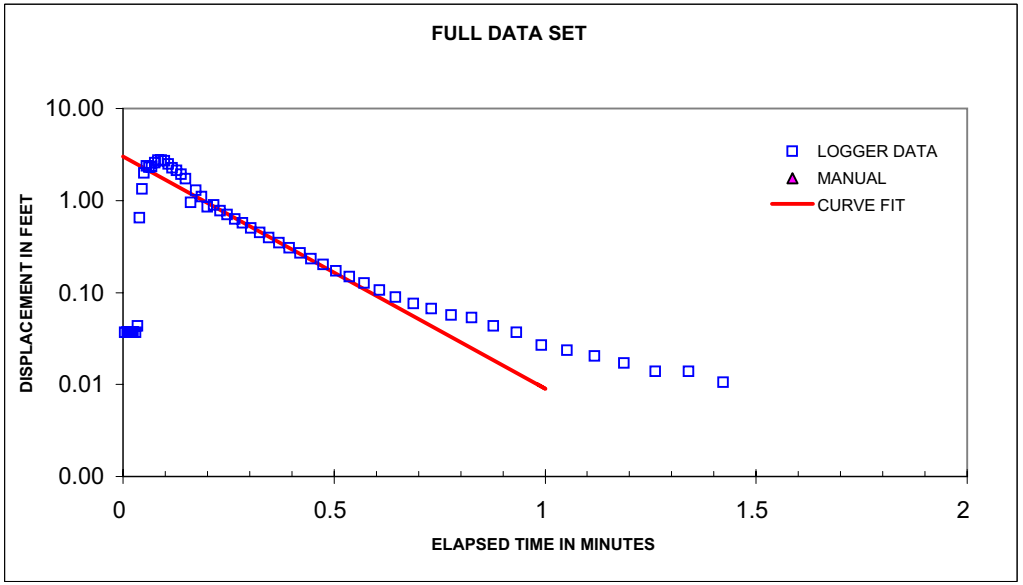
Hydraulic conductivity **3.36E-02 cm/sec**
6.62E-02 ft/min
95.34 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.89	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	3.000	feet
ΔH at time t (Y_t)	0.009	feet
Time	1.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.39	773.89	*SW*		
24.61	750.11	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.61	750.11	*D*	#NUM!	*Ln[(D-H)/Rw]*
3	91.44	Y_0	#NUM!	equation (8)
0.009	0.27	Y_t	3.97	equation (9)
	60.00	*t (seconds)*	3.97	*Ln(Re/Rw)*
	0.30	*n*	3.4E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-7**

Test Date: **April 4, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

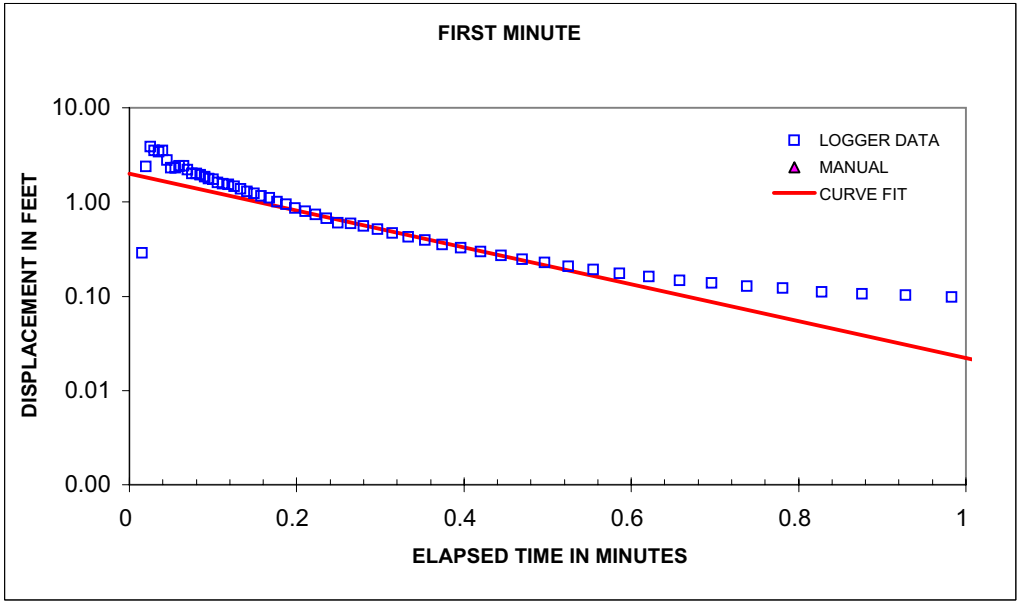
Logger Data File:

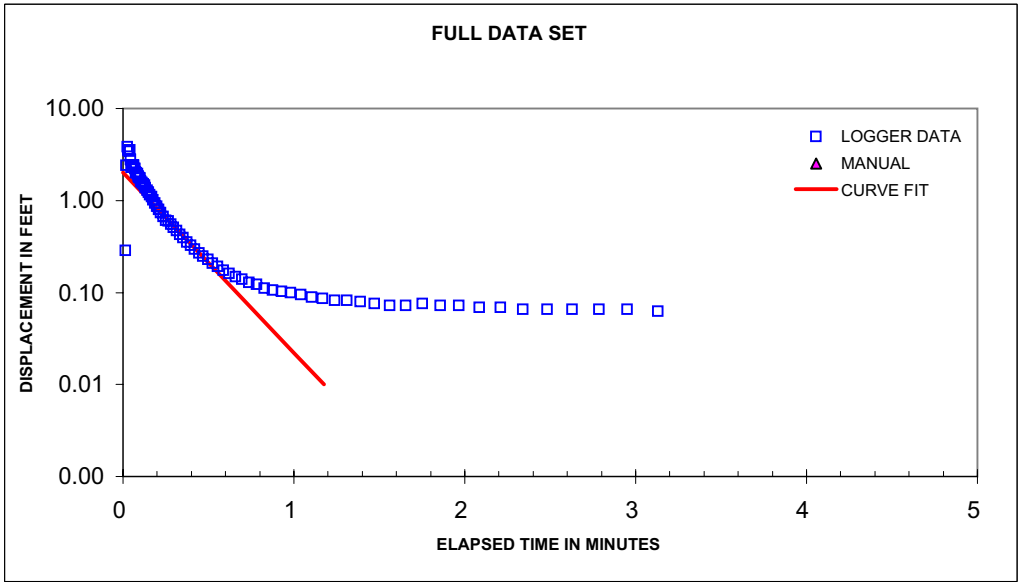
Hydraulic conductivity **2.61E-02 cm/sec**
5.14E-02 ft/min
74.02 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.89	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	2.000	feet
ΔH at time t (Y_t)	0.022	feet
Time	1.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.39	773.89	*SW*		
24.61	750.11	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.61	750.11	*D*	#NUM!	*Ln[(D-H)/Rw]*
2	60.96	Y_0	#NUM!	equation (8)
0.022	0.67	Y_t	3.97	equation (9)
	60.00	*t (seconds)*	3.97	*Ln(Re/Rw)*
	0.30	*n*	2.6E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

AUGUST 2003

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-INJ-1**

Test Date: **August 28, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

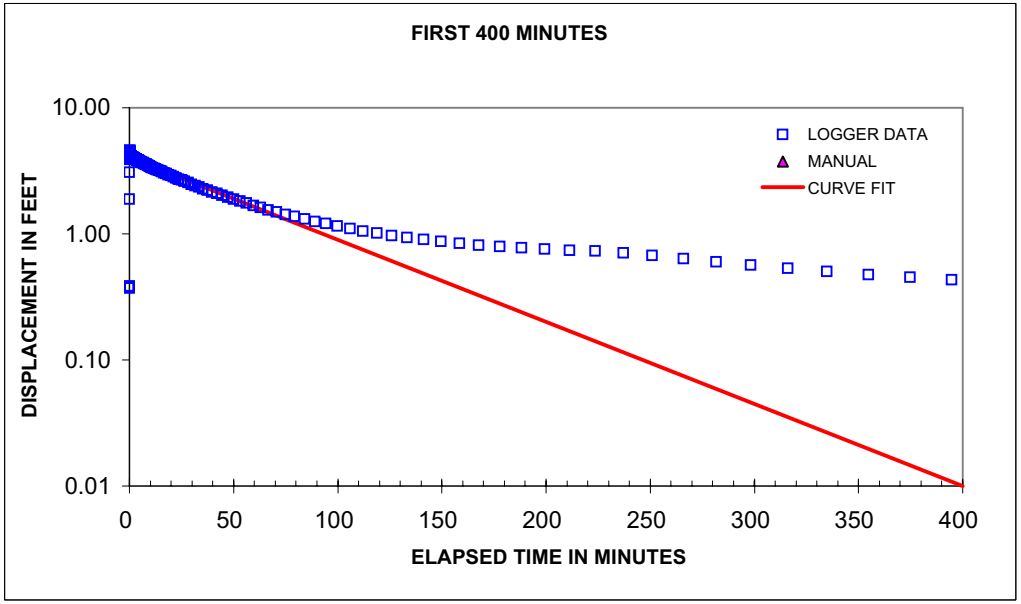
Logger Data File:

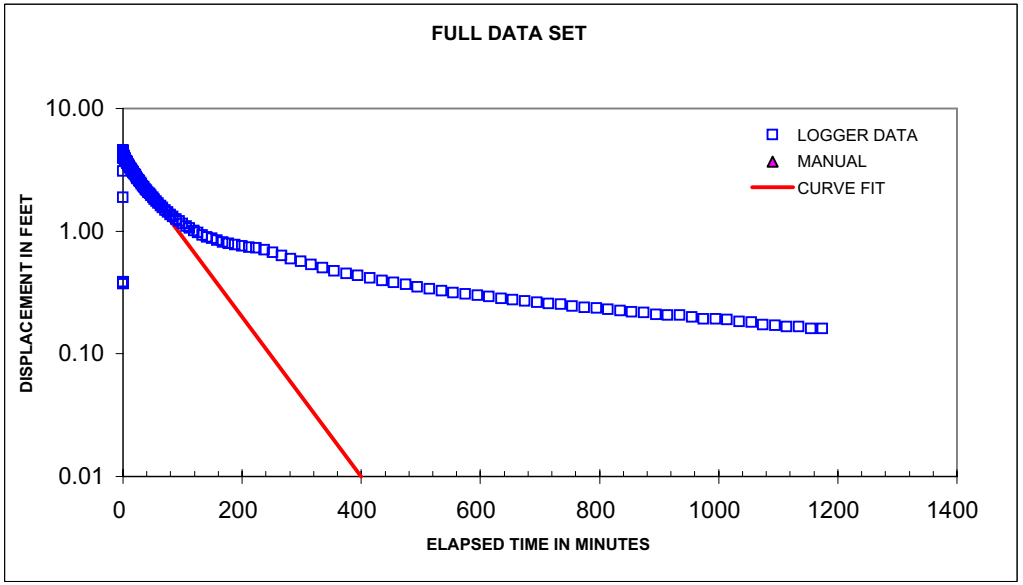
Hydraulic conductivity **8.39E-05 cm/sec**
1.65E-04 ft/min
0.24 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.48	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	4.000	feet
ΔH at time t (Y_t)	0.010	feet
Time	400.00	min

Bouwer-Rice Parameters

feet	cm		cm	
24.98	761.39	*SW*		
20.02	610.21	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
20.02	610.21	*D*	#NUM!	*Ln[(D-H)/Rw]*
4	121.92	Y_0	#NUM!	equation (8)
0.01	0.30	Y_t	3.84	equation (9)
	24000.00	*t (seconds)*	3.84	*Ln(Re/Rw)*
	0.30	*n*	8.4E-05	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-INJ-1**

Test Date: **August 28, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

Logger Data File:

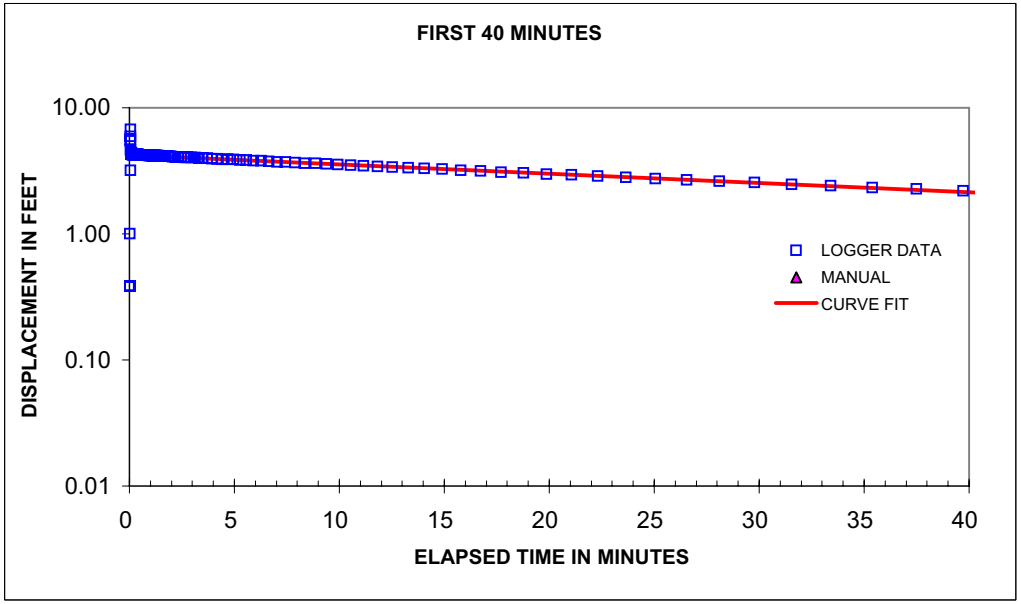
Hydraulic conductivity

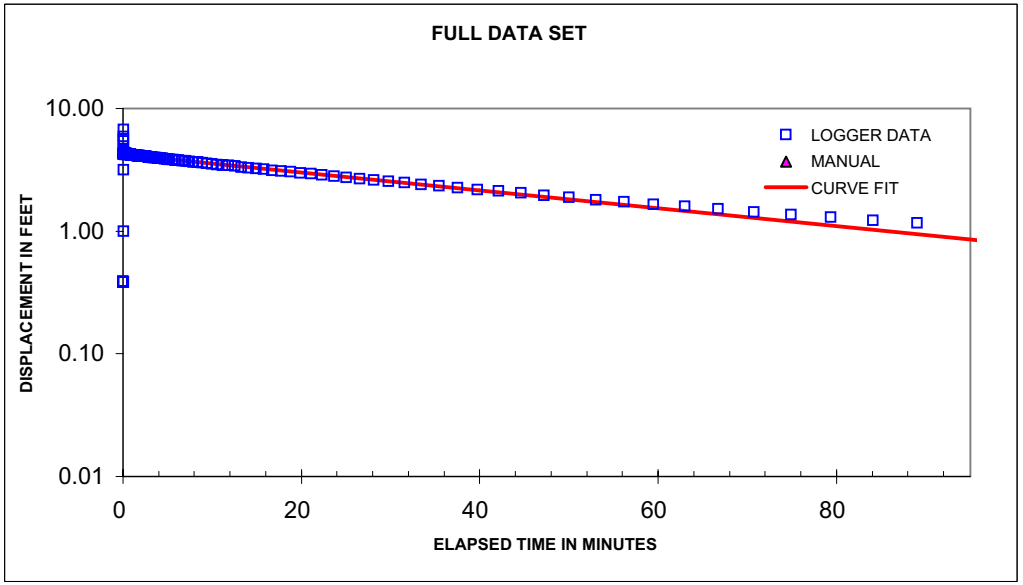
9.38E-05	cm/sec
1.85E-04	ft/min
0.27	ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.48	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	4.200	feet
ΔH at time t (Y_t)	2.150	feet
Time	40.00	min

Bouwer-Rice Parameters

feet	cm		cm	
24.98	761.39	*SW*		
20.02	610.21	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
20.02	610.21	*D*	#NUM!	*Ln[(D-H)/Rw]*
4.2	128.02	Y_0	#NUM!	equation (8)
2.15	65.53	Y_t	3.84	equation (9)
	2400.00	*t (seconds)*	3.84	*Ln(Re/Rw)*
	0.30	*n*	9.4E-05	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-6**

Test Date: **August 27, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

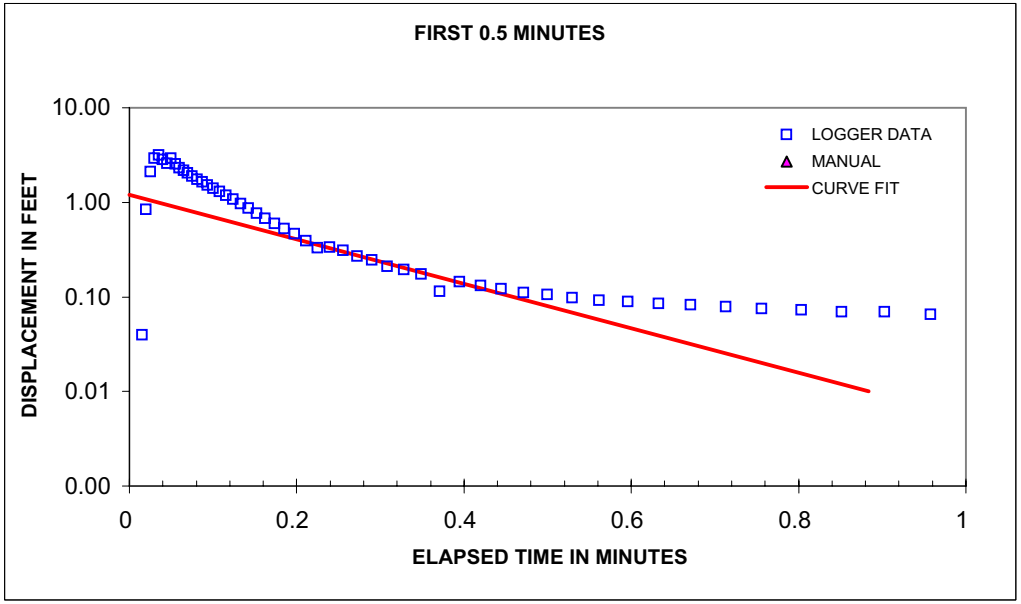
Logger Data File:

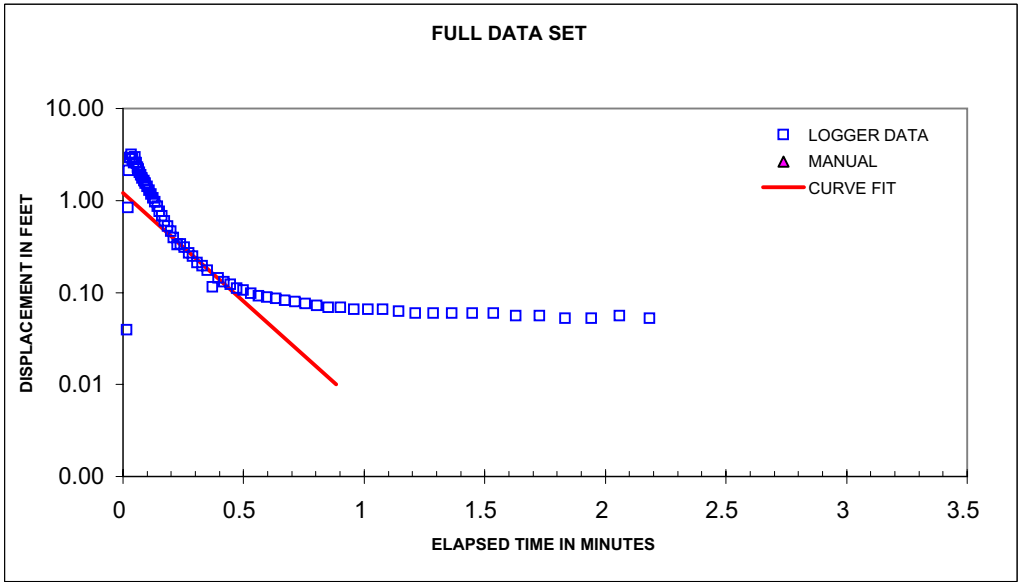
Hydraulic conductivity **3.03E-02 cm/sec**
5.97E-02 ft/min
85.97 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.54	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	1.200	feet
ΔH at time t (Y_t)	0.080	feet
Time	0.50	min

Bouwer-Rice Parameters

feet	cm		cm	
25.04	763.22	*SW*		
19.96	608.38	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.31	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.96	608.38	*D*	#NUM!	*Ln[(D-H)/Rw]*
1.2	36.58	Y_0	#NUM!	equation (8)
0.08	2.44	Y_t	3.84	equation (9)
	30.00	*t (seconds)*	3.84	*Ln(Re/Rw)*
	0.30	*n*	3.0E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-6**

Test Date: **August 27, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

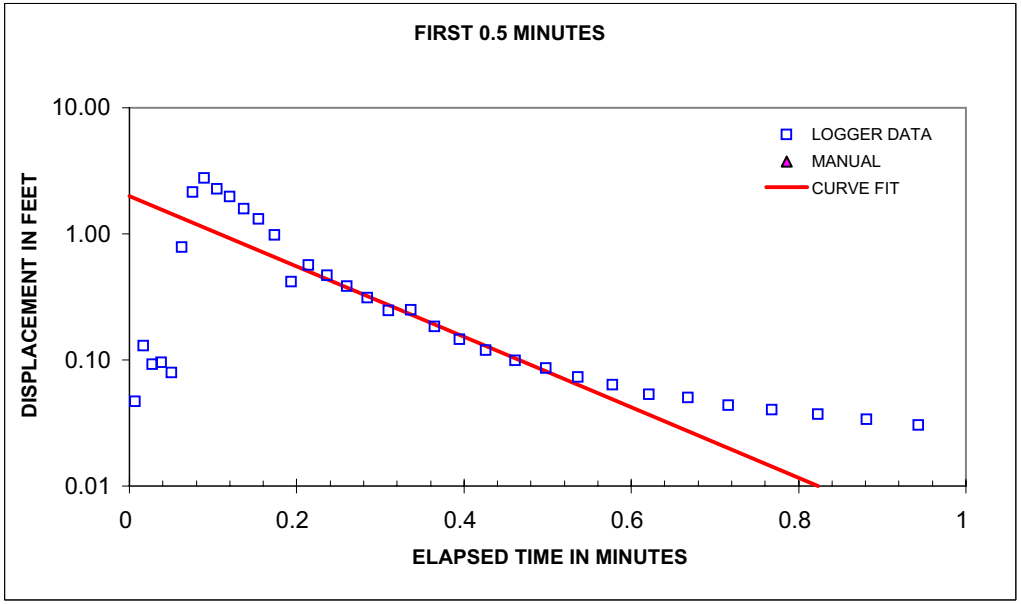
Logger Data File:

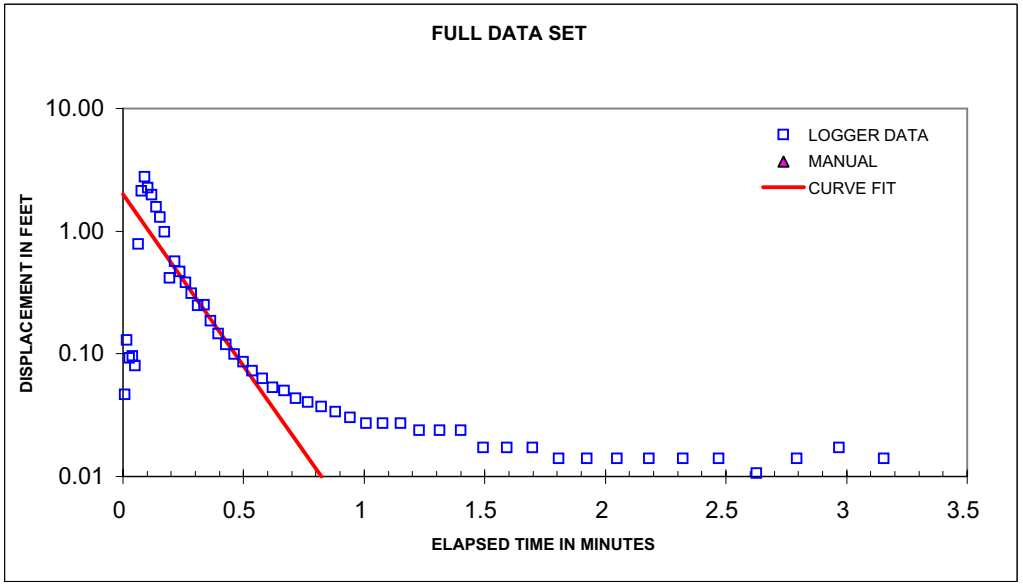
Hydraulic conductivity **3.61E-02 cm/sec**
7.10E-02 ft/min
102.19 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.54	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	2.000	feet
ΔH at time t (Y_t)	0.080	feet
Time	0.50	min

Bouwer-Rice Parameters

feet	cm		cm	
25.04	763.22	*SW*		
19.96	608.38	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.31	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.96	608.38	*D*	#NUM!	*Ln[(D-H)/Rw]*
2	60.96	Y_0	#NUM!	equation (8)
0.08	2.44	Y_t	3.84	equation (9)
	30.00	*t (seconds)*	3.84	*Ln(Re/Rw)*
	0.30	*n*	3.6E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-1**

Test Date: **August 27, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

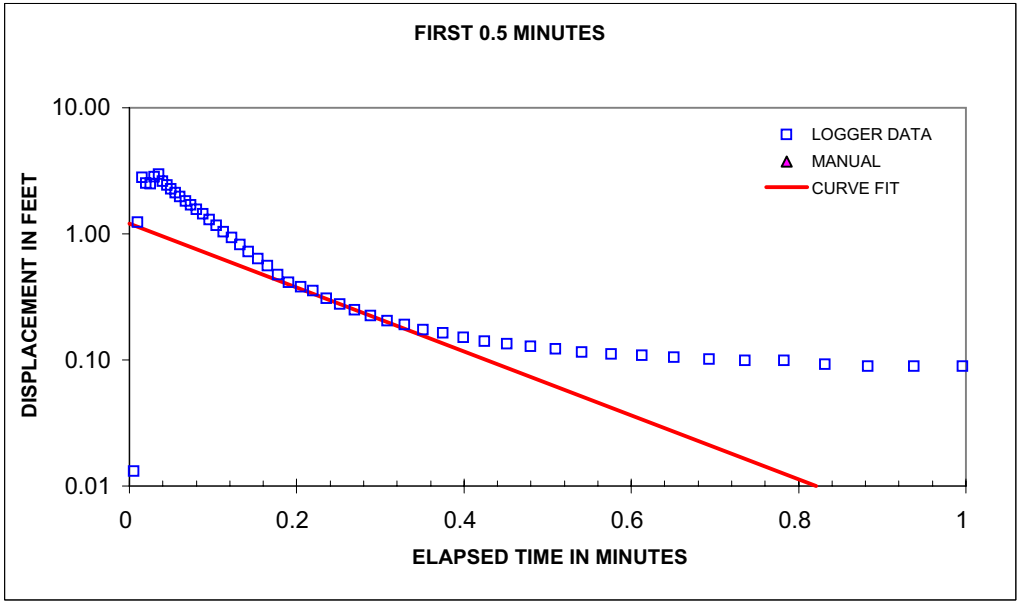
Logger Data File:

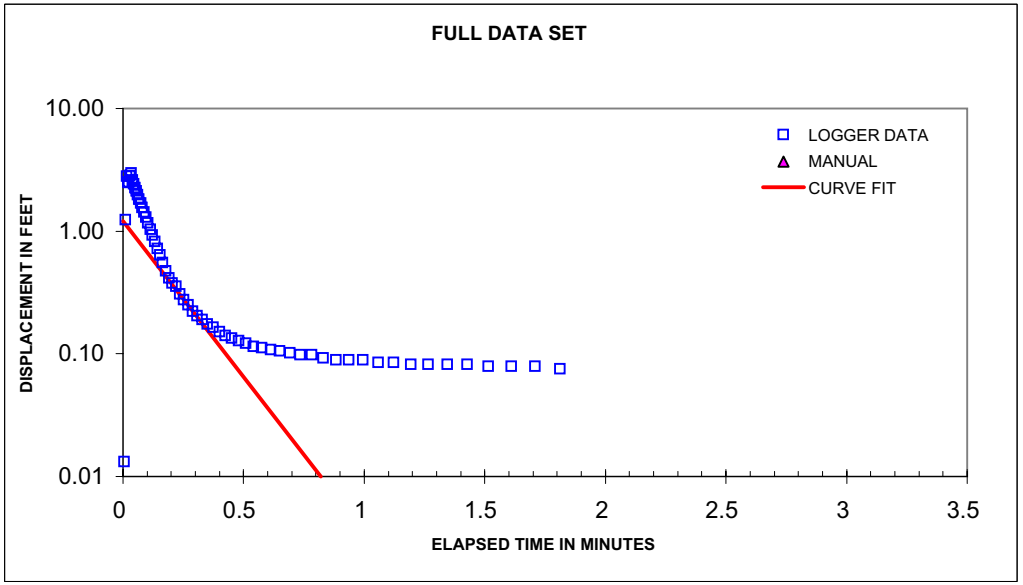
Hydraulic conductivity **3.27E-02 cm/sec**
6.43E-02 ft/min
92.60 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.50	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	1.200	feet
ΔH at time t (Y_t)	0.065	feet
Time	0.50	min

Bouwer-Rice Parameters

feet	cm		cm	
25	762.00	*SW*		
20	609.60	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.31	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
20	609.60	*D*	#NUM!	*Ln[(D-H)/Rw]*
1.2	36.58	Y_0	#NUM!	equation (8)
0.065	1.98	Y_t	3.84	equation (9)
	30.00	*t (seconds)*	3.84	*Ln(Re/Rw)*
	0.30	*n*	3.3E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-1**

Test Date: **August 27, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

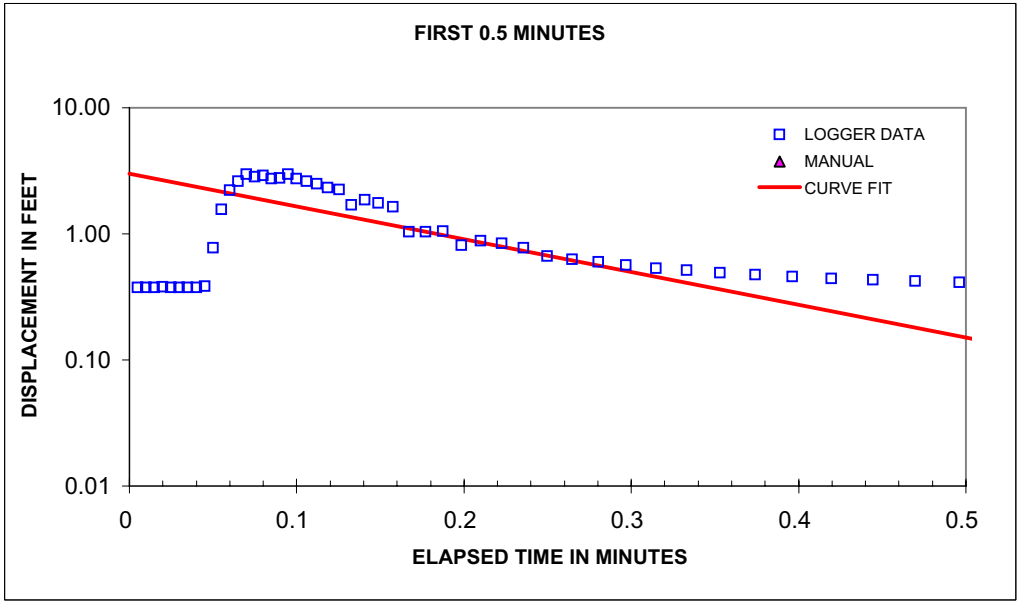
Logger Data File:

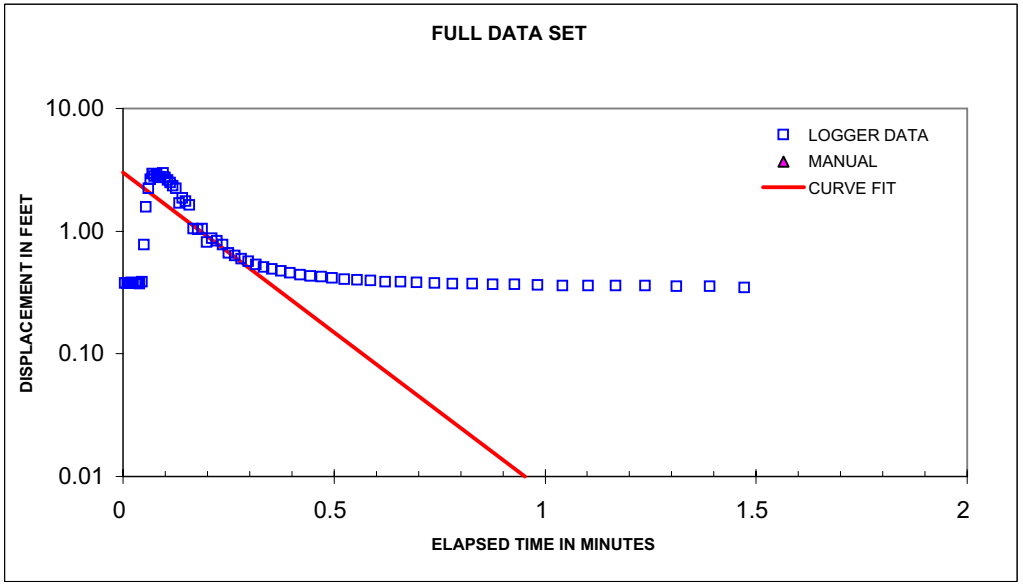
Hydraulic conductivity **3.36E-02 cm/sec**
6.61E-02 ft/min
95.14 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.50	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	3.000	feet
ΔH at time t (Y_t)	0.150	feet
Time	0.50	min

Bouwer-Rice Parameters

feet	cm		cm	
25	762.00	*SW*		
20	609.60	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.31	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
20	609.60	*D*	#NUM!	*Ln[(D-H)/Rw]*
3	91.44	Y_0	#NUM!	equation (8)
0.15	4.57	Y_t	3.84	equation (9)
	30.00	*t (seconds)*	3.84	*Ln(Re/Rw)*
	0.30	*n*	3.4E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-INJ-2**

Test Date: **August 27, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

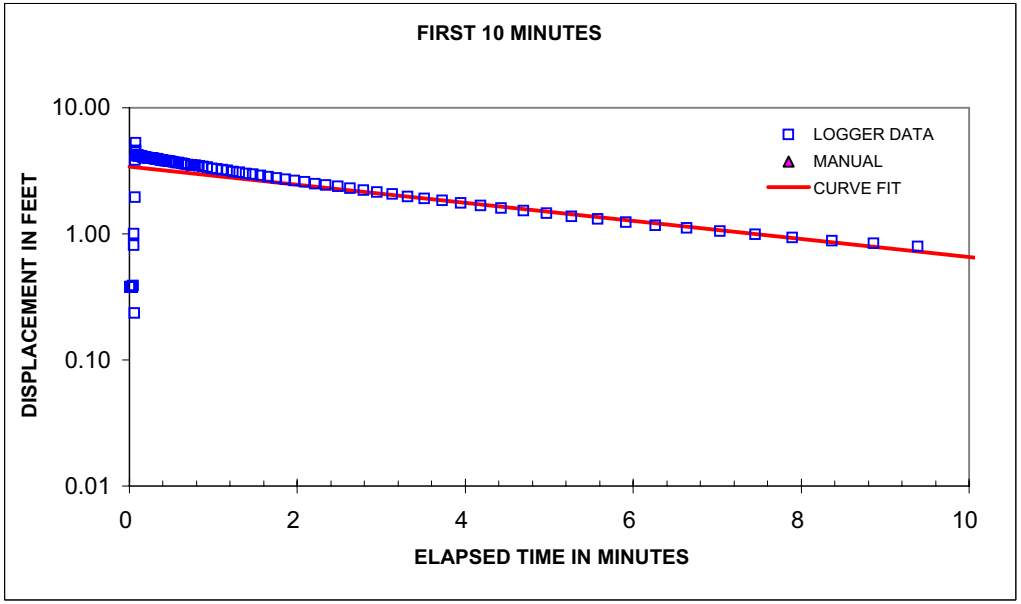
Logger Data File:

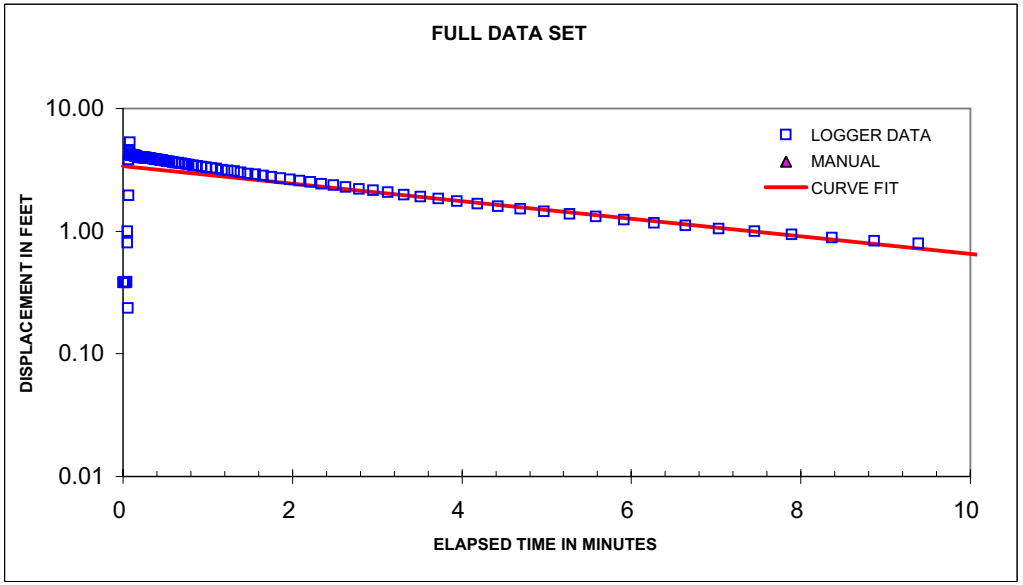
Hydraulic conductivity **9.20E-04 cm/sec**
1.81E-03 ft/min
2.61 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.96	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	3.400	feet
ΔH at time t (Y_t)	0.055	feet
Time	25.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.46	776.02	*SW*		
19.54	595.58	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.54	595.58	*D*	#NUM!	*Ln[(D-H)/Rw]*
3.4	103.63	Y_0	#NUM!	equation (8)
0.055	1.68	Y_t	3.82	equation (9)
	1500.00	*t (seconds)*	3.82	*Ln(Re/Rw)*
	0.30	*n*	9.2E-04	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-INJ-2**

Test Date: **August 27, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

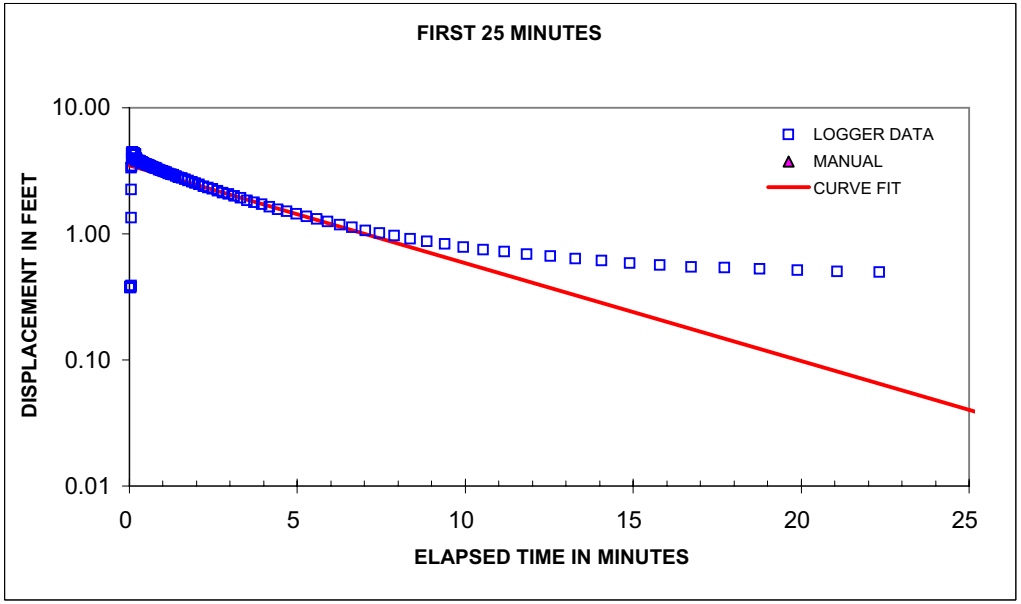
Logger Data File:

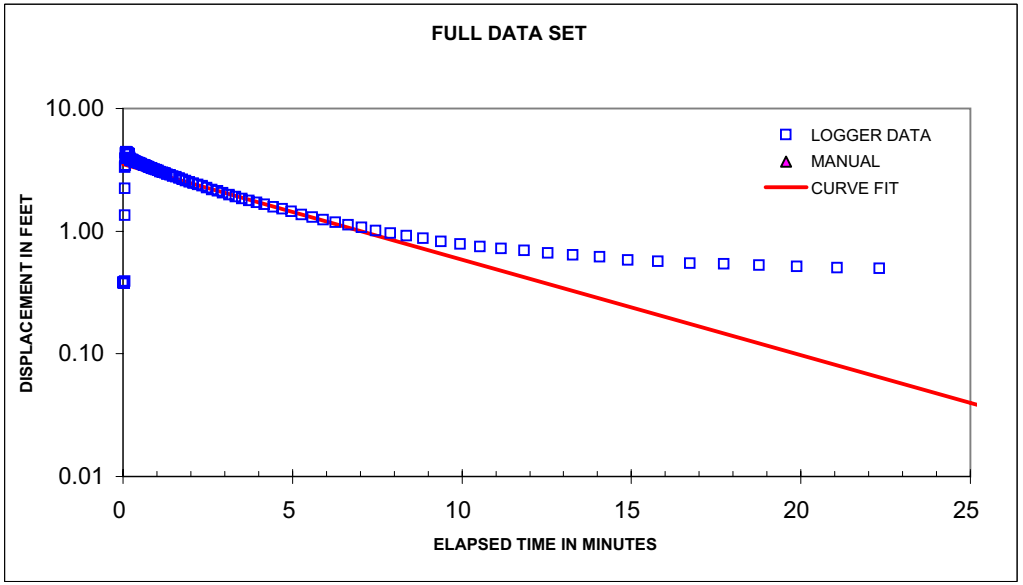
Hydraulic conductivity **9.98E-04 cm/sec**
1.96E-03 ft/min
2.83 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.96	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	3.500	feet
ΔH at time t (Y_t)	0.040	feet
Time	25.00	min

Bouwer-Rice Parameters

feet	cm		cm	
25.46	776.02	*SW*		
19.54	595.58	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.30	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.54	595.58	*D*	#NUM!	*Ln[(D-H)/Rw]*
3.5	106.68	Y_0	#NUM!	equation (8)
0.04	1.22	Y_t	3.82	equation (9)
	1500.00	*t (seconds)*	3.82	*Ln(Re/Rw)*
	0.30	*n*	1.0E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-7**

Test Date: **August 27, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

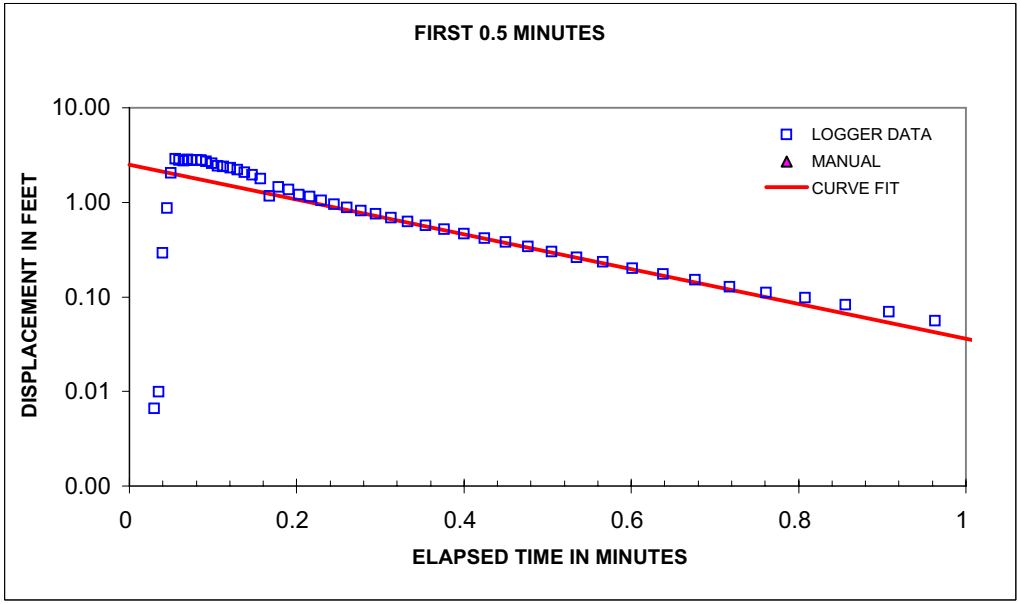
Logger Data File:

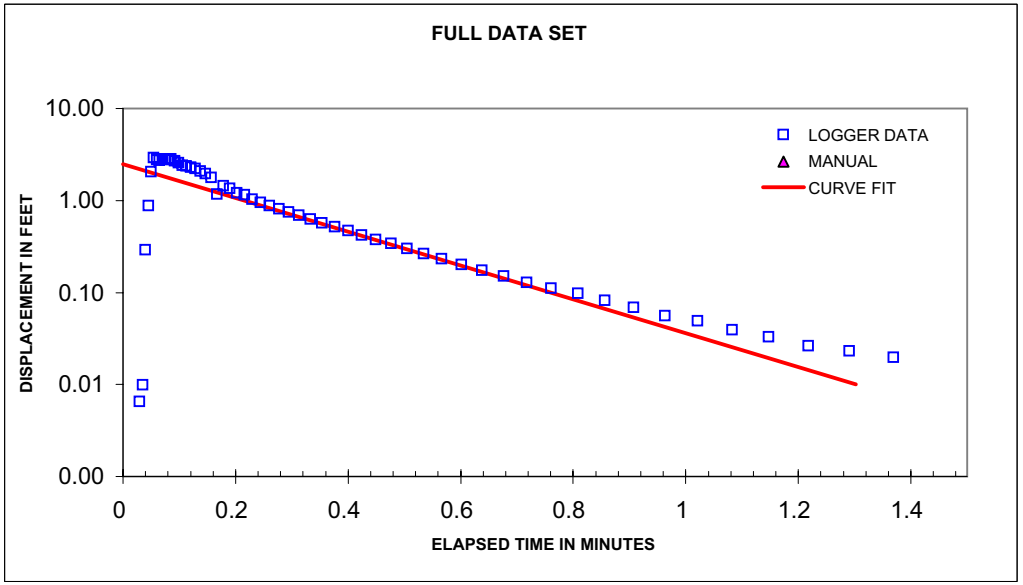
Hydraulic conductivity **2.46E-02 cm/sec**
4.84E-02 ft/min
69.71 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.66	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	2.500	feet
ΔH at time t (Y_t)	0.300	feet
Time	0.50	min

Bouwer-Rice Parameters

feet	cm		cm	
25.16	766.88	*SW*		
24.84	757.12	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.31	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.84	757.12	*D*	#NUM!	*Ln[(D-H)/Rw]*
2.5	76.20	Y_0	#NUM!	equation (8)
0.3	9.14	Y_t	3.97	equation (9)
	30.00	*t (seconds)*	3.97	*Ln(Re/Rw)*
	0.30	*n*	2.5E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **NIROP Fridley**

Project No.:

Well No.: **PES-MW-7**

Test Date: **August 27, 2003**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

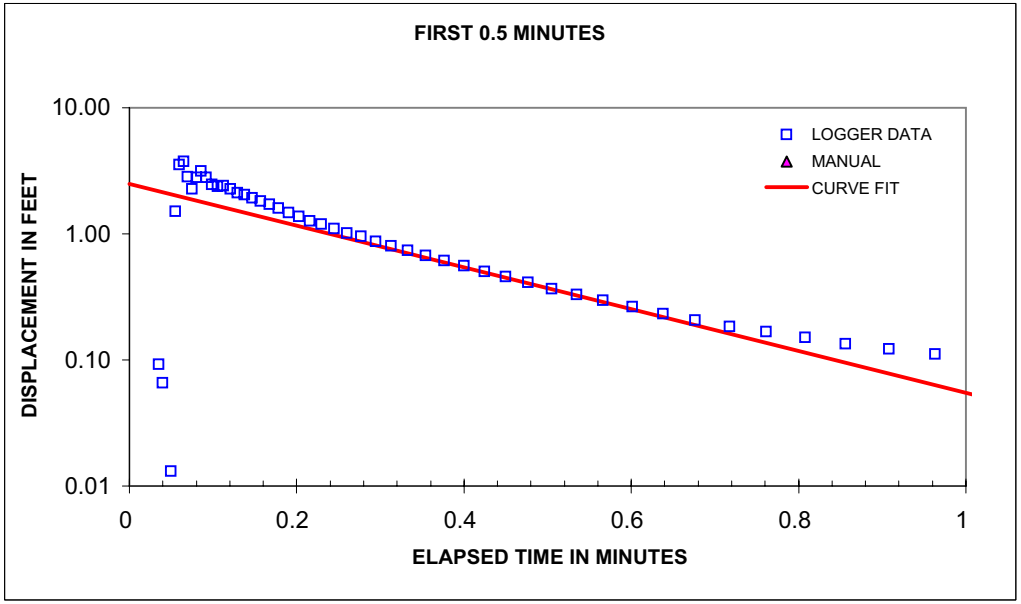
Logger Data File:

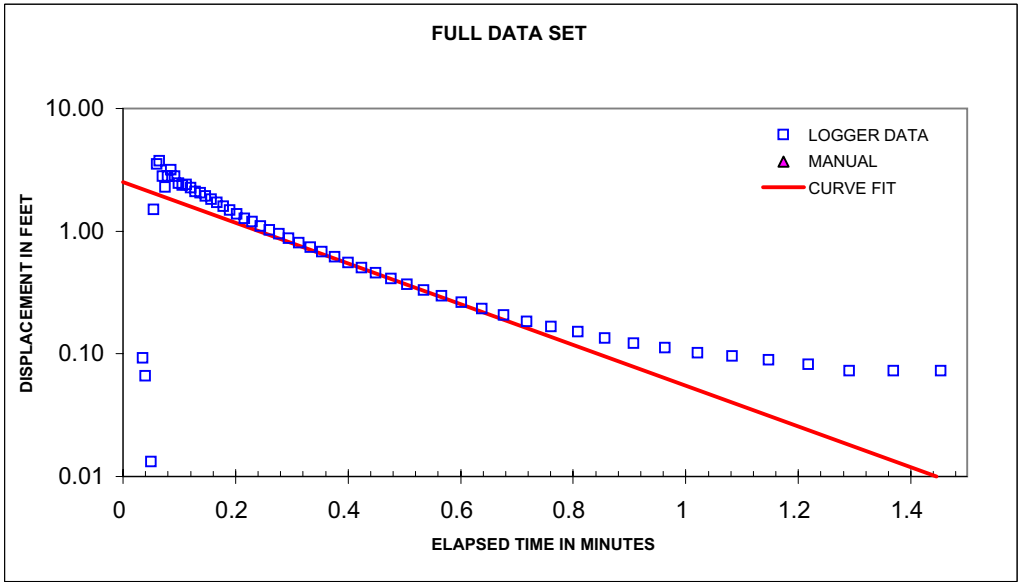
Hydraulic conductivity **2.22E-02 cm/sec**
4.36E-02 ft/min
62.82 ft/day

Casing stickup	2.50	feet
Static water level (from top of casing)	27.66	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	9.45	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	2.500	feet
ΔH at time t (Y_t)	0.370	feet
Time	0.50	min

Bouwer-Rice Parameters

feet	cm		cm	
25.16	766.88	*SW*		
24.84	757.12	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.240	7.31	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.84	757.12	*D*	#NUM!	*Ln[(D-H)/Rw]*
2.5	76.20	Y_0	#NUM!	equation (8)
0.37	11.28	Y_t	3.97	equation (9)
	30.00	*t (seconds)*	3.97	*Ln(Re/Rw)*
	0.30	*n*	2.2E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

DECEMBER 2001 PRE-INJECTION

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-CW2 Pre-Injection**

Test Date: **December 6, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

Logger Data File:

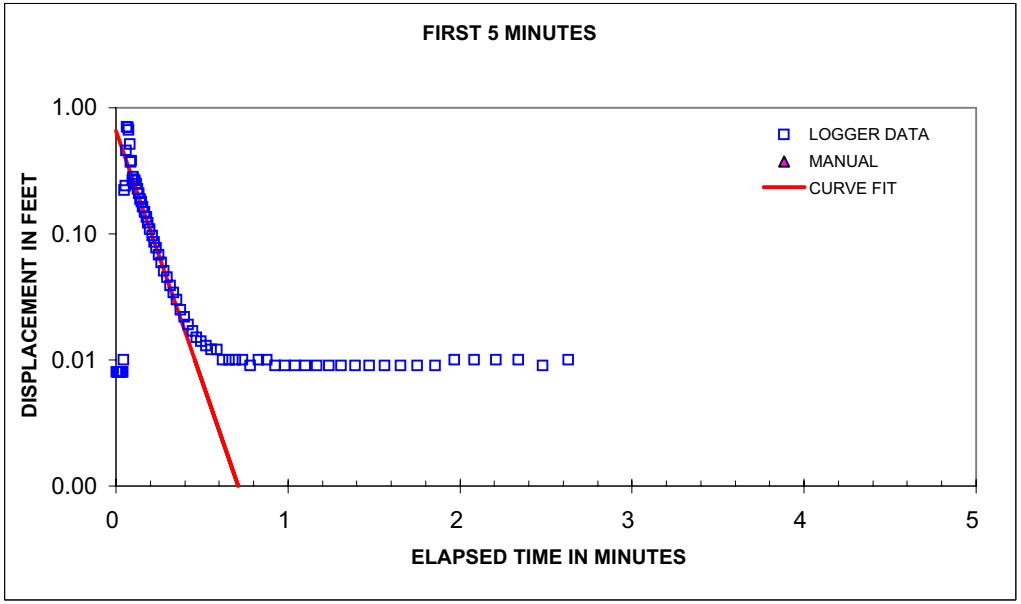
Hydraulic conductivity

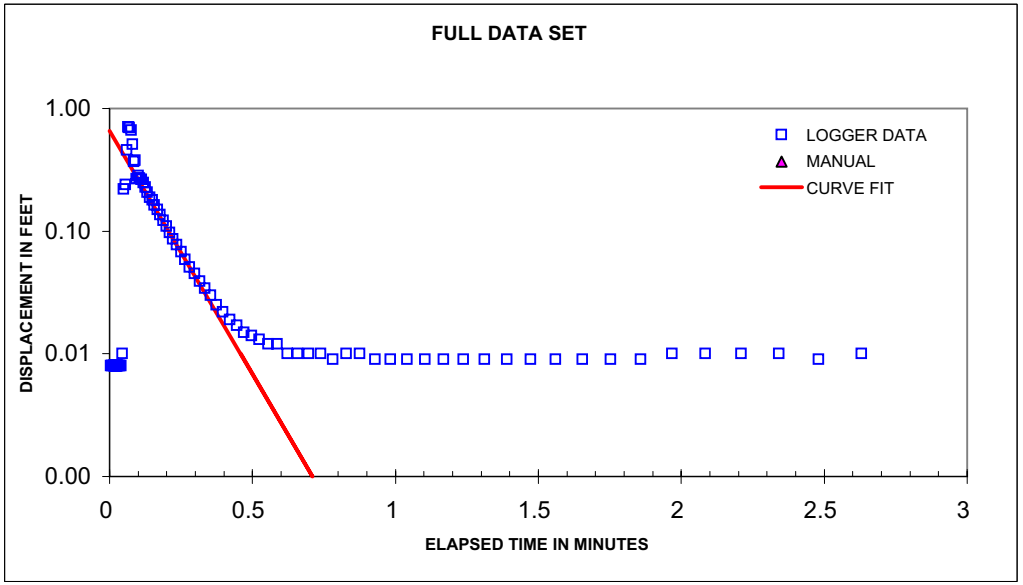
6.97E-02	cm/sec
1.37E-01	ft/min
197.51	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	31.38	feet
Depth to bottom of screen (from ground level)	40.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	40.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.660	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.71	min

Bouwer-Rice Parameters

feet	cm		cm	
28.38	865.02	*SW*		
11.62	354.18	*H*	80.00	*L/Rw*
30	914.40	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
11.62	354.18	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.66	20.12	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.49	equation (9)
	42.60	*t (seconds)*	3.49	*Ln(Re/Rw)*
	0.30	*n*	7.0E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-CW2 Pre-Injection**

Test Date: **December 6, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

Logger Data File:

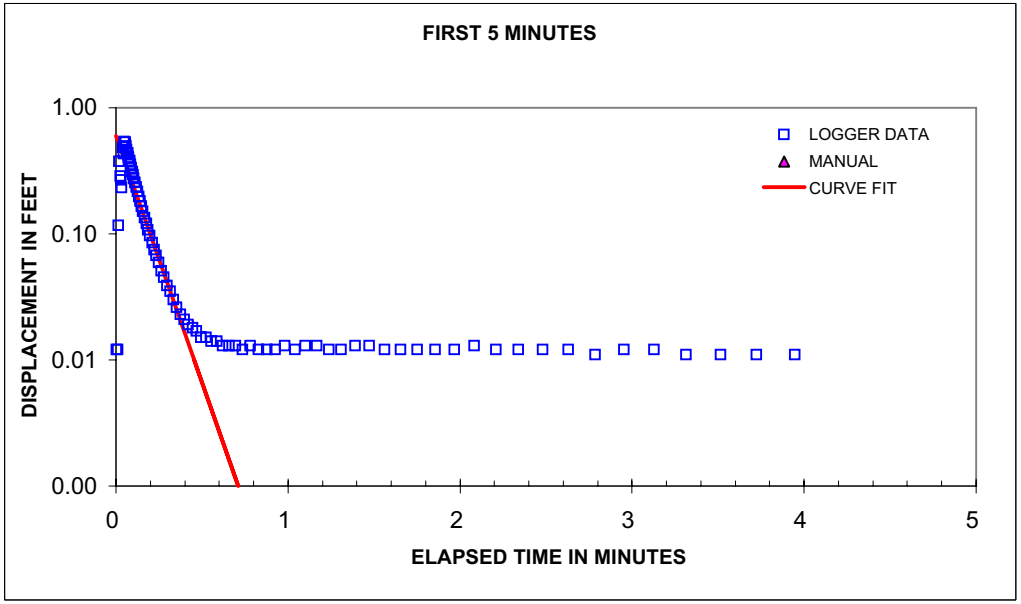
Hydraulic conductivity

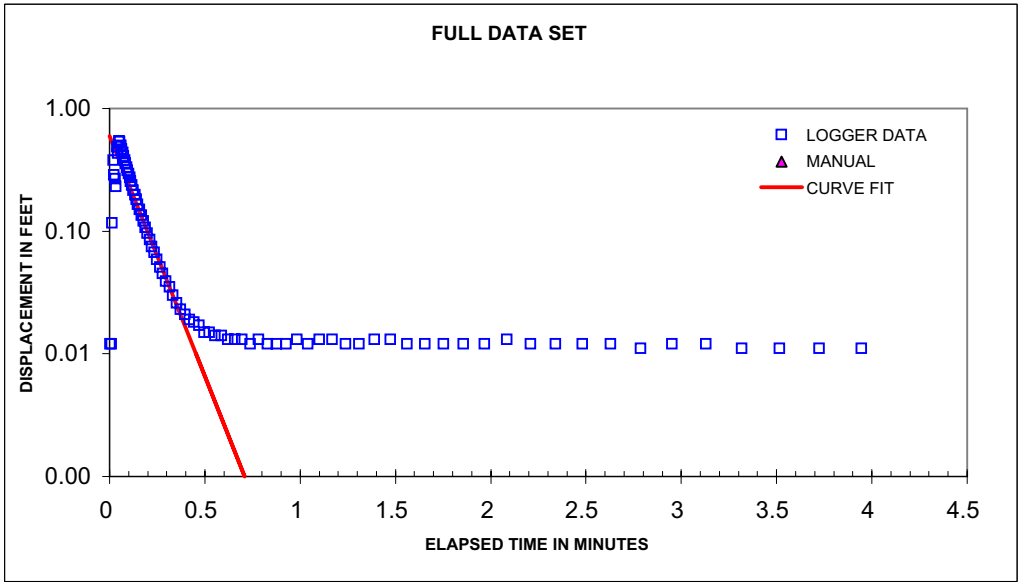
6.87E-02	cm/sec
1.35E-01	ft/min
194.61	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	31.38	feet
Depth to bottom of screen (from ground level)	40.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	40.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.600	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.71	min

Bouwer-Rice Parameters

feet	cm		cm	
28.38	865.02	*SW*		
11.62	354.18	*H*	80.00	*L/Rw*
30	914.40	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
11.62	354.18	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.6	18.29	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.49	equation (9)
	42.60	*t (seconds)*	3.49	*Ln(Re/Rw)*
	0.30	*n*	6.9E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ1 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

Logger Data File:

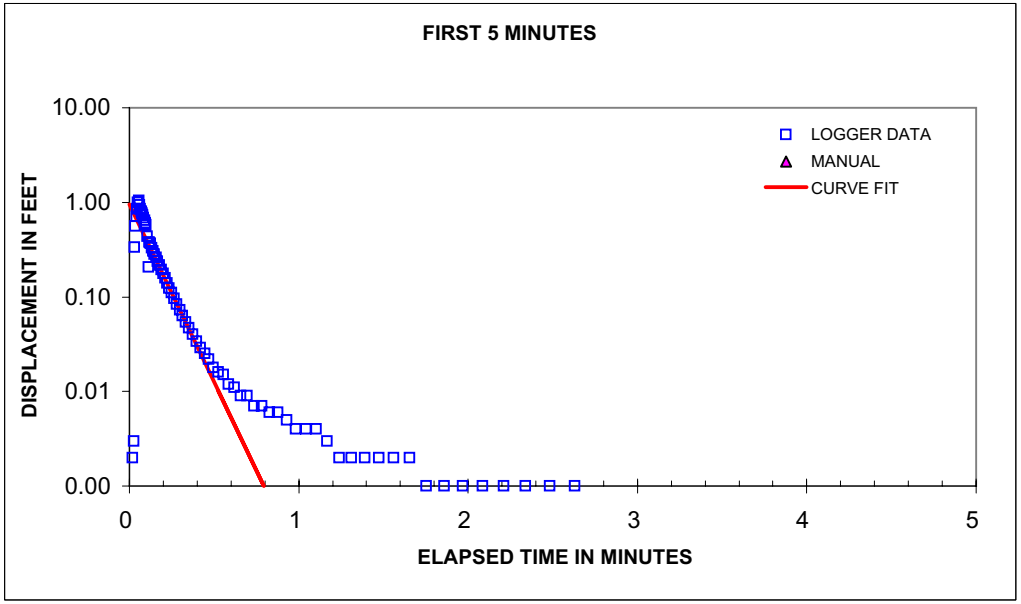
Hydraulic conductivity

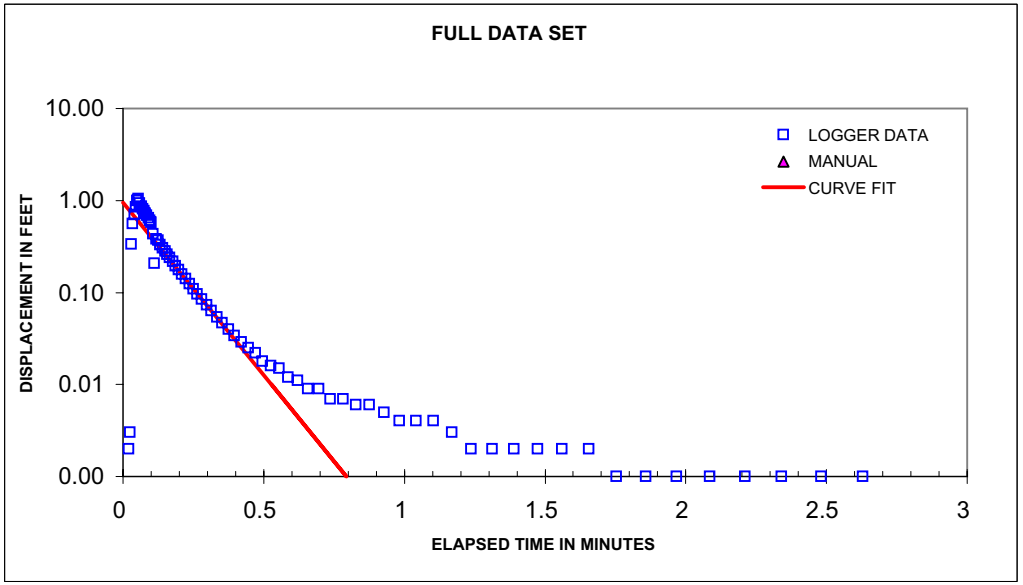
7.22E-02	cm/sec
1.42E-01	ft/min
204.70	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.37	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.951	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.79	min

Bouwer-Rice Parameters

feet	cm		cm	
25.37	773.28	*SW*		
19.63	598.32	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.63	598.32	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.9512	28.99	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.83	equation (9)
	47.60	*t (seconds)*	3.83	*Ln(Re/Rw)*
	0.30	*n*	7.2E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ1 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

Logger Data File:

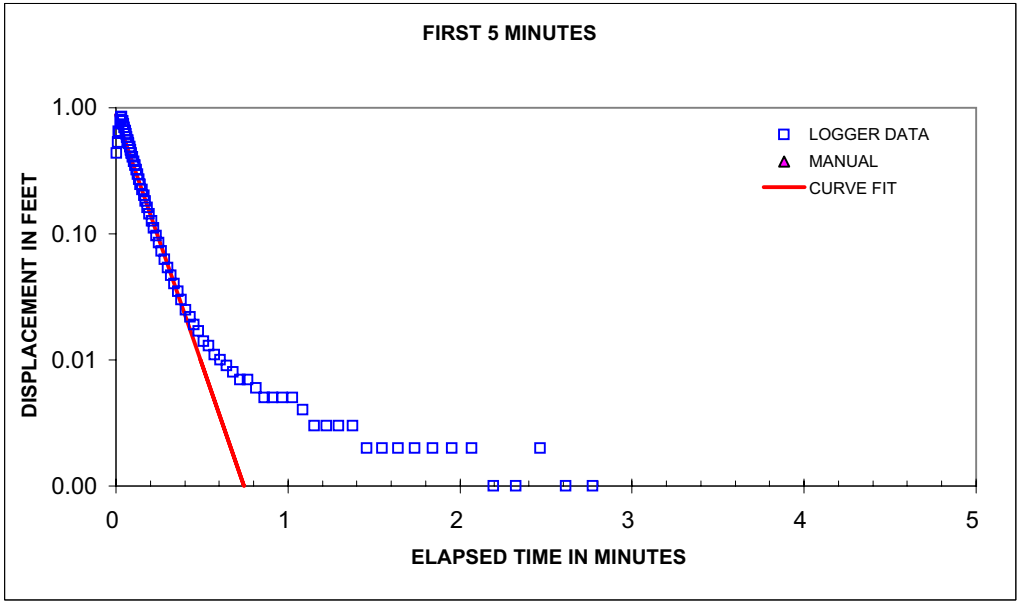
Hydraulic conductivity

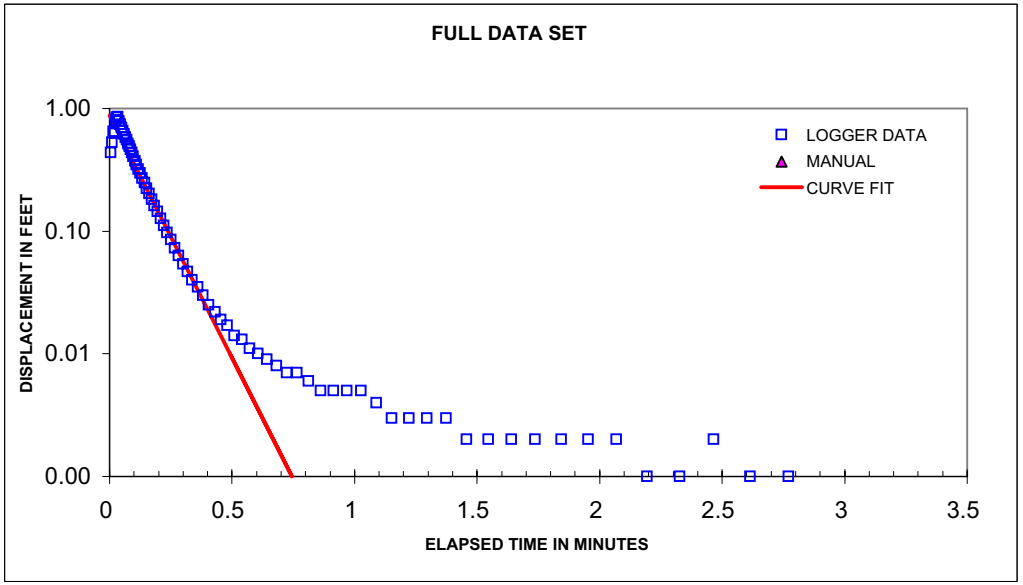
7.62E-02	cm/sec
1.50E-01	ft/min
216.03	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.37	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.881	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.74	min

Bouwer-Rice Parameters

feet	cm		cm	
25.37	773.28	*SW*		
19.63	598.32	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.63	598.32	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.8812	26.86	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.83	equation (9)
	44.60	*t (seconds)*	3.83	*Ln(Re/Rw)*
	0.30	*n*	7.6E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ2 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

Logger Data File:

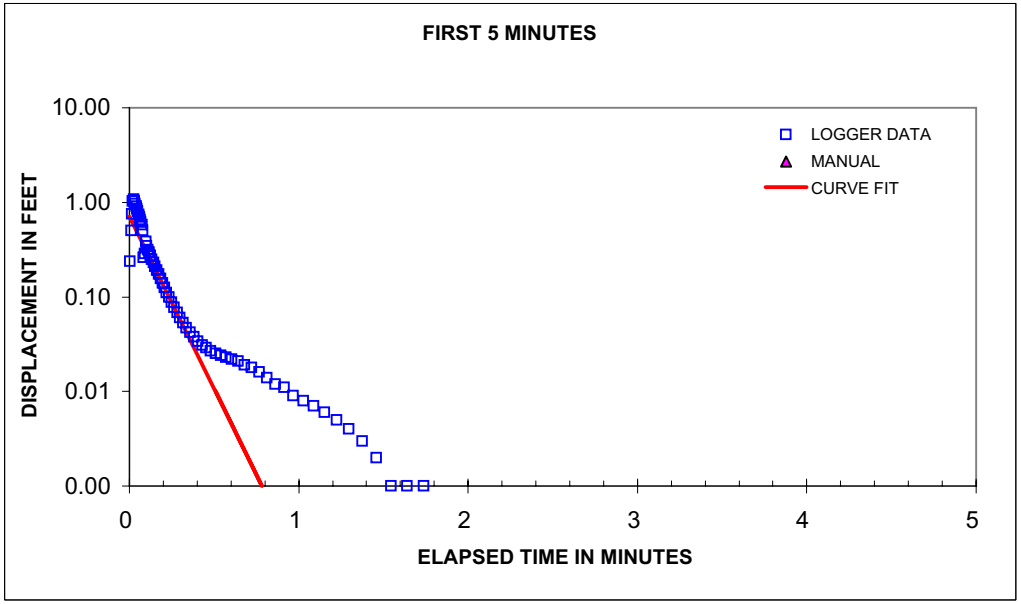
Hydraulic conductivity

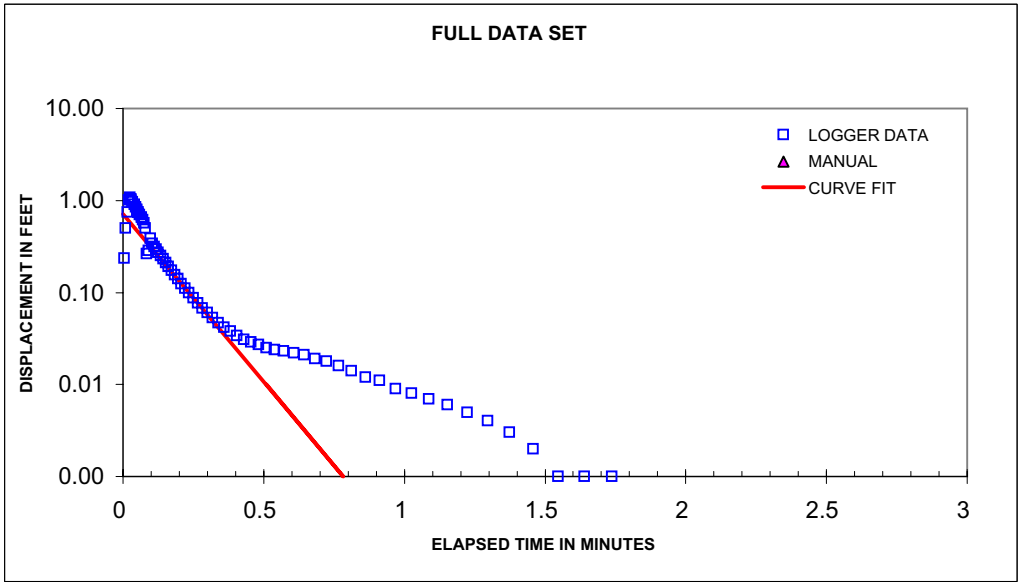
7.24E-02	cm/sec
1.43E-01	ft/min
205.26	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.84	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.711	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.78	min

Bouwer-Rice Parameters

feet	cm		cm	
25.84	787.60	*SW*		
24.16	736.40	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.16	736.40	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.7112	21.68	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.96	equation (9)
	47.00	*t (seconds)*	3.96	*Ln(Re/Rw)*
	0.30	*n*	7.2E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ2 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

Logger Data File:

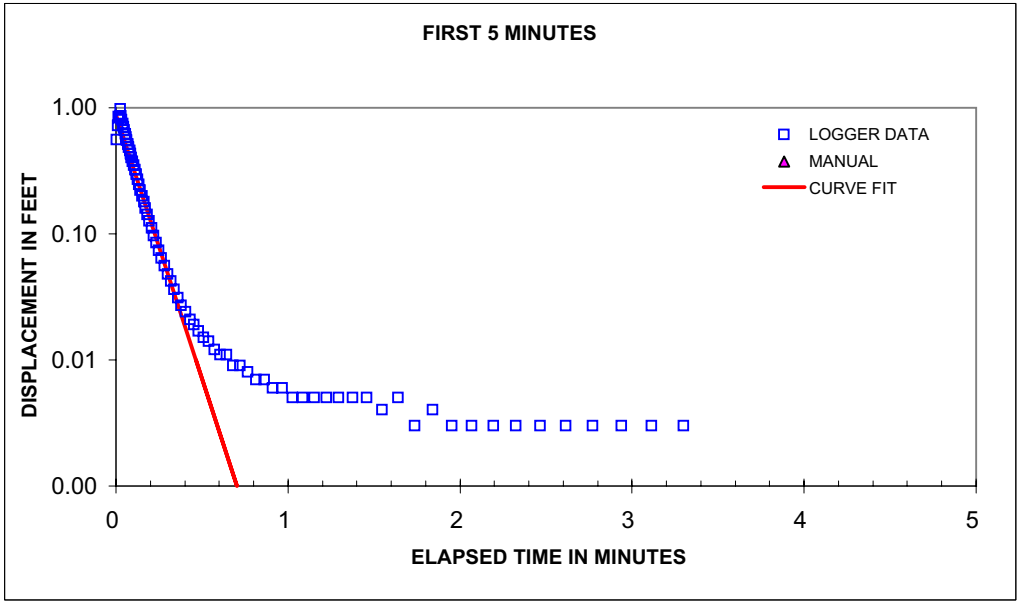
Hydraulic conductivity

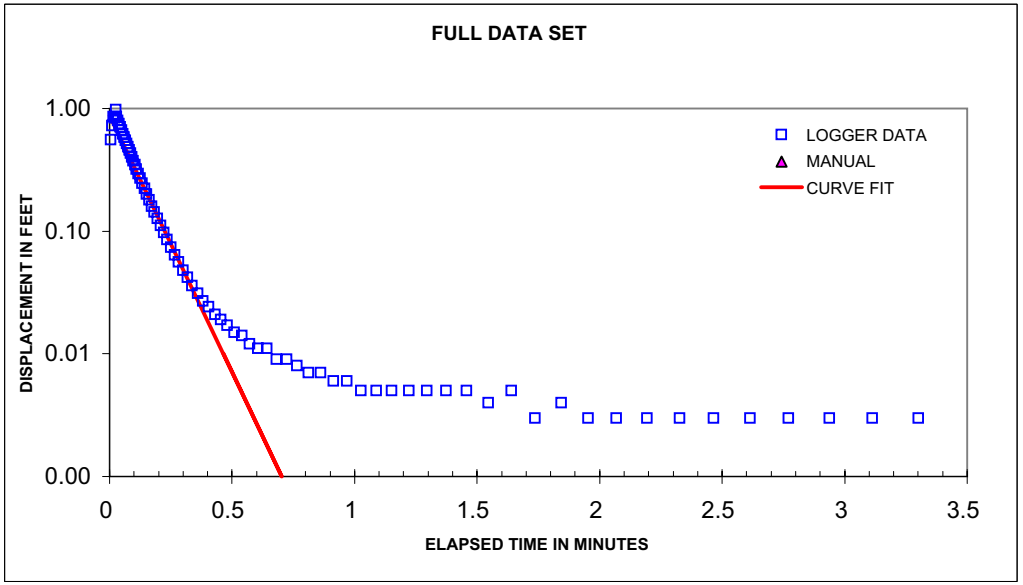
8.33E-02	cm/sec
1.64E-01	ft/min
236.07	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.84	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.881	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.70	min

Bouwer-Rice Parameters

feet	cm		cm	
25.84	787.60	*SW*		
24.16	736.40	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.16	736.40	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.8812	26.86	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.96	equation (9)
	42.20	*t (seconds)*	3.96	*Ln(Re/Rw)*
	0.30	*n*	8.3E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ3 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

Logger Data File:

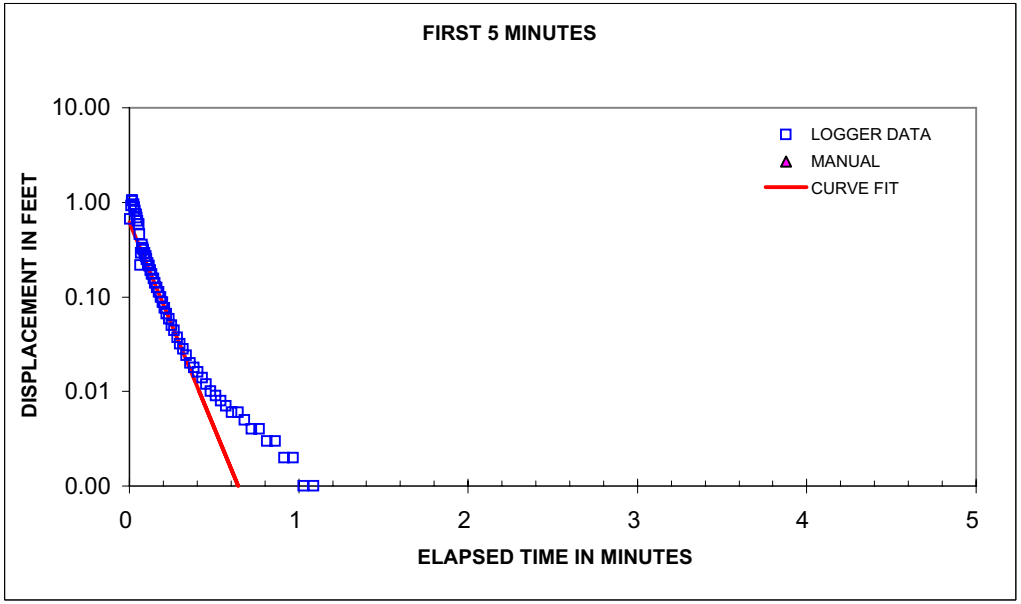
Hydraulic conductivity

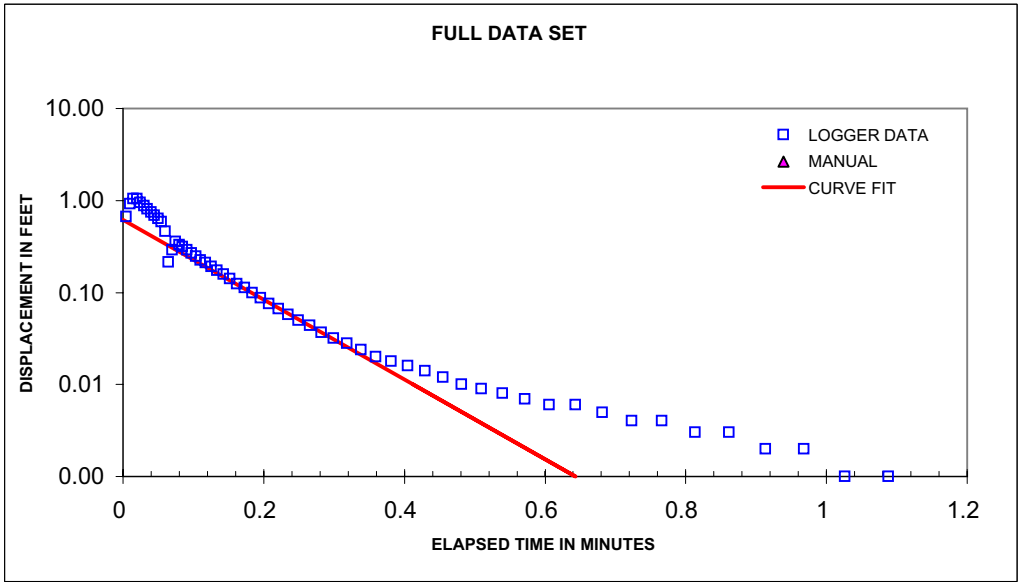
8.62E-02	cm/sec
1.70E-01	ft/min
244.34	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.73	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.611	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.64	min

Bouwer-Rice Parameters

feet	cm		cm	
25.73	784.25	*SW*		
24.27	739.75	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.27	739.75	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.6112	18.63	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.96	equation (9)
	38.60	*t (seconds)*	3.96	*Ln(Re/Rw)*
	0.30	*n*	8.6E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ3 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

Logger Data File:

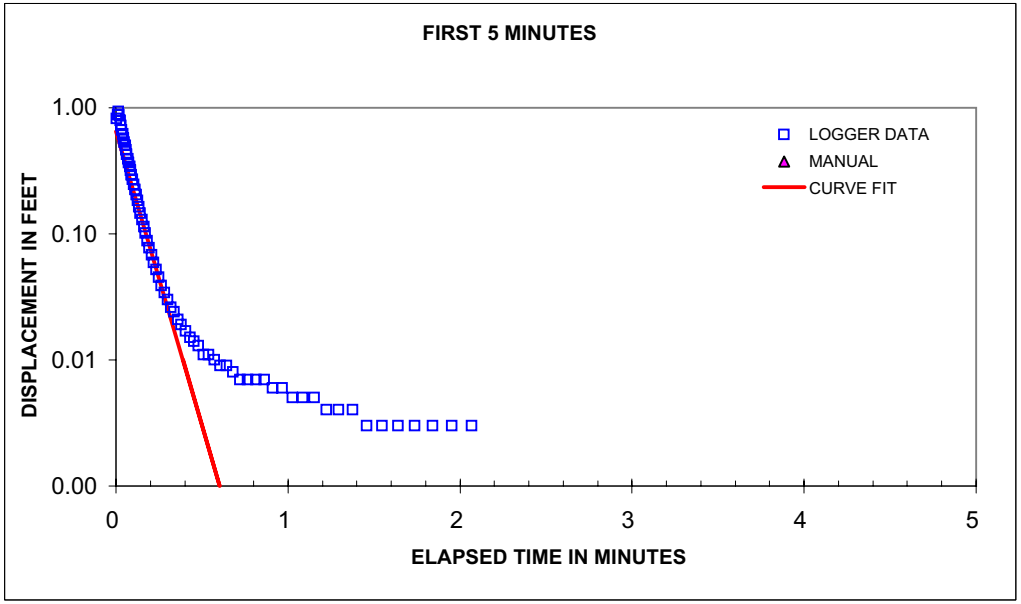
Hydraulic conductivity

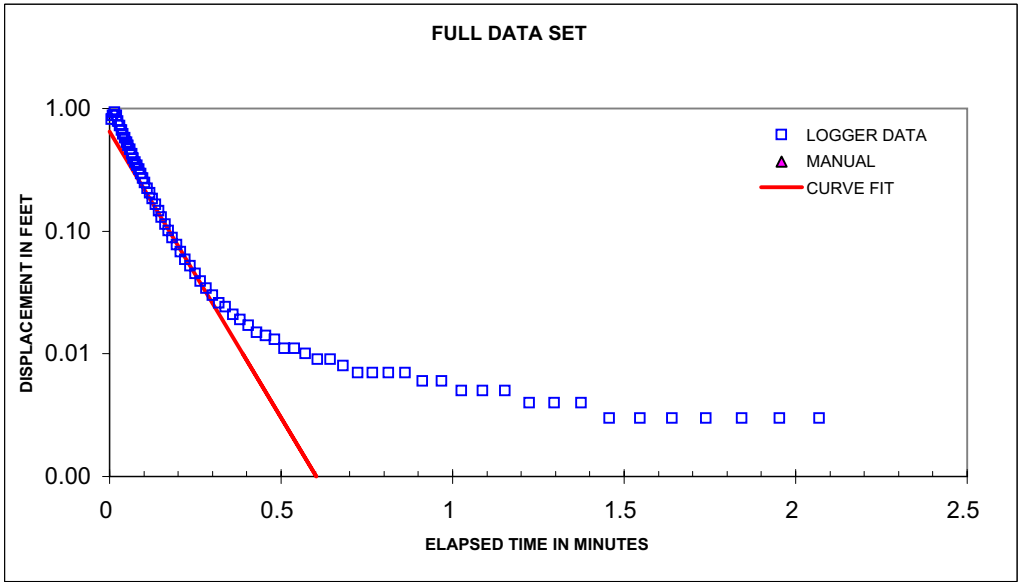
9.28E-02	cm/sec
1.83E-01	ft/min
263.11	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.73	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.651	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.60	min

Bouwer-Rice Parameters

feet	cm		cm	
25.73	784.25	*SW*		
24.27	739.75	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.27	739.75	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.6512	19.85	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.96	equation (9)
	36.20	*t (seconds)*	3.96	*Ln(Re/Rw)*
	0.30	*n*	9.3E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW1 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

Logger Data File:

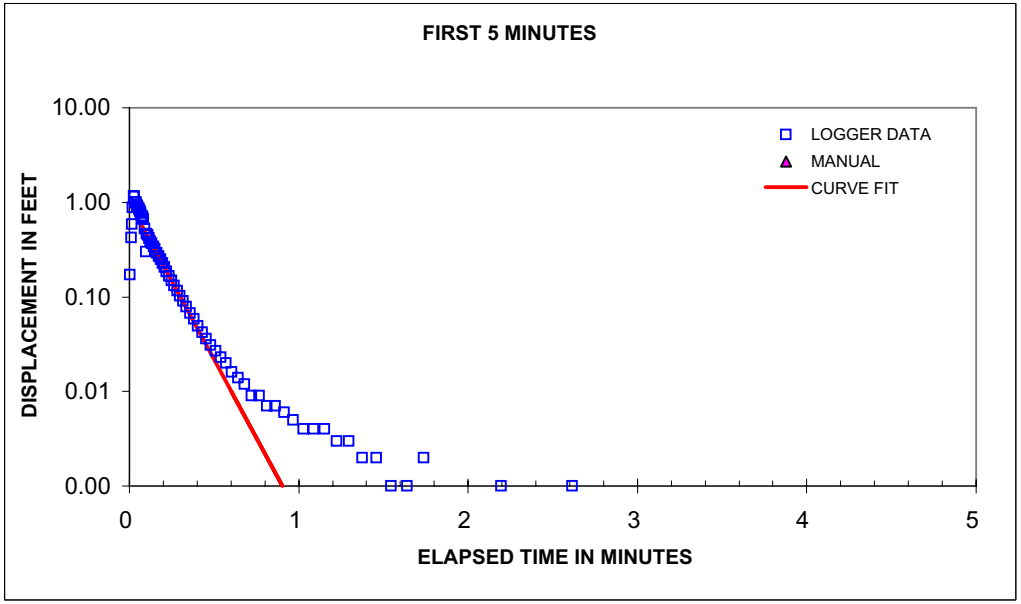
Hydraulic conductivity

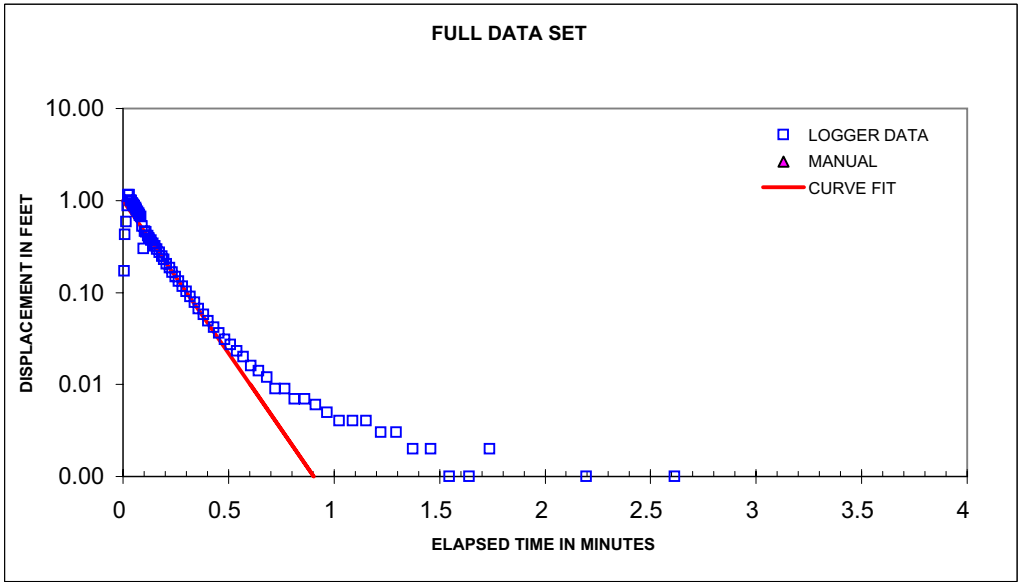
6.38E-02	cm/sec
1.26E-01	ft/min
180.81	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.55	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	1.000	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.90	min

Bouwer-Rice Parameters

feet	cm		cm	
25.55	778.76	*SW*		
19.45	592.84	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.45	592.84	*D*	#NUM!	*Ln[(D-H)/Rw]*
1	30.48	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.82	equation (9)
	54.20	*t (seconds)*	3.82	*Ln(Re/Rw)*
	0.30	*n*	6.4E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW1 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

Logger Data File:

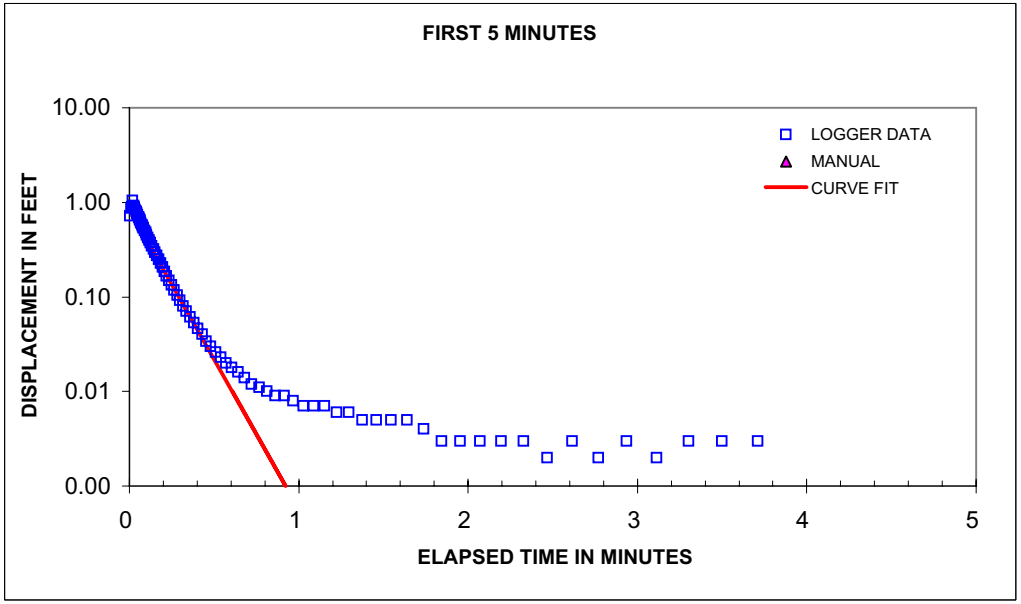
Hydraulic conductivity

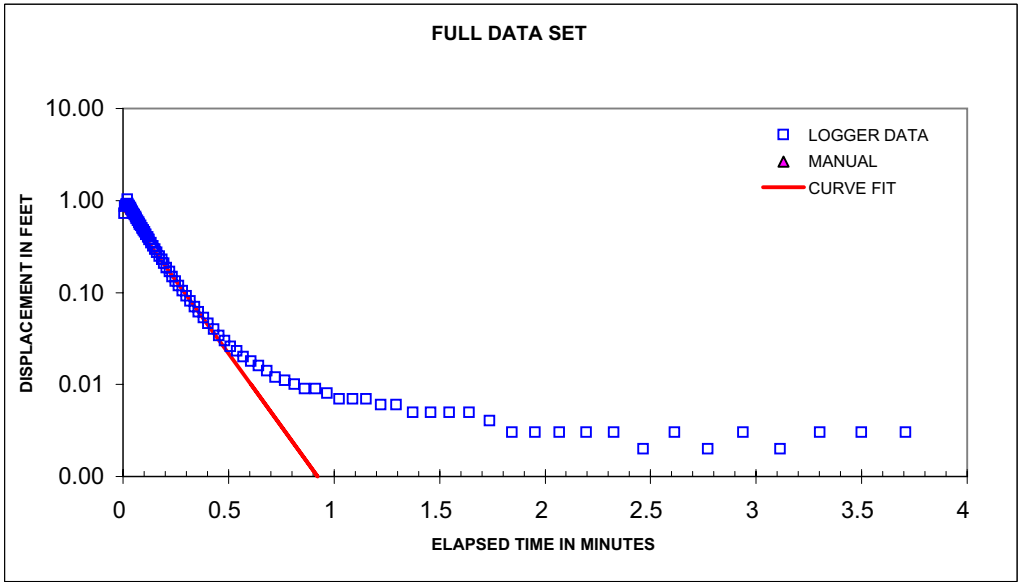
6.08E-02	cm/sec
1.20E-01	ft/min
172.43	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.55	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.840	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.92	min

Bouwer-Rice Parameters

feet	cm		cm	
25.55	778.76	*SW*		
19.45	592.84	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.45	592.84	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.84	25.60	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.82	equation (9)
	55.40	*t (seconds)*	3.82	*Ln(Re/Rw)*
	0.30	*n*	6.1E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW3 Pre-Injection**

Test Date: **December 6, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

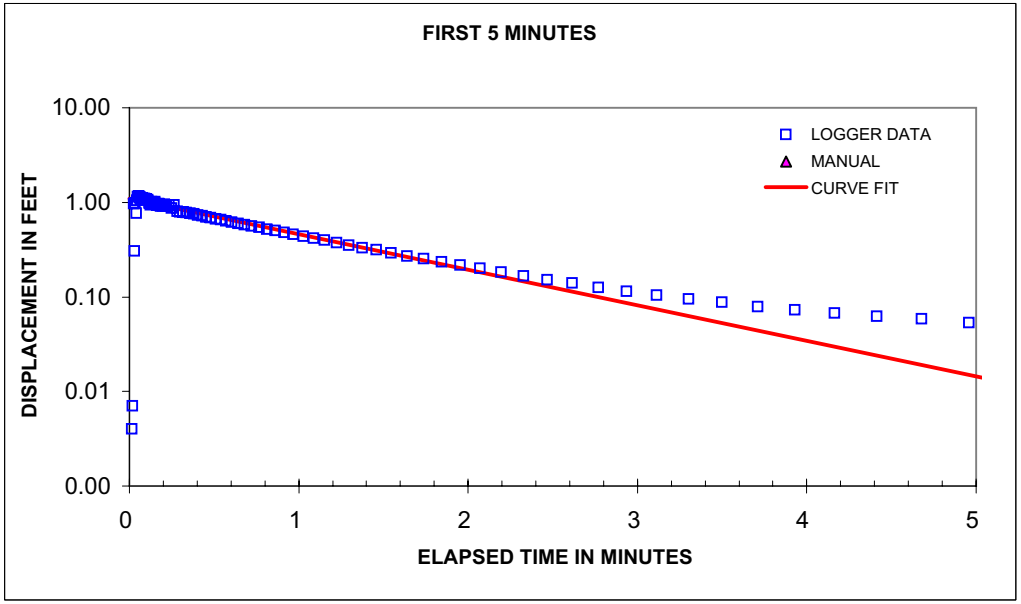
Logger Data File:

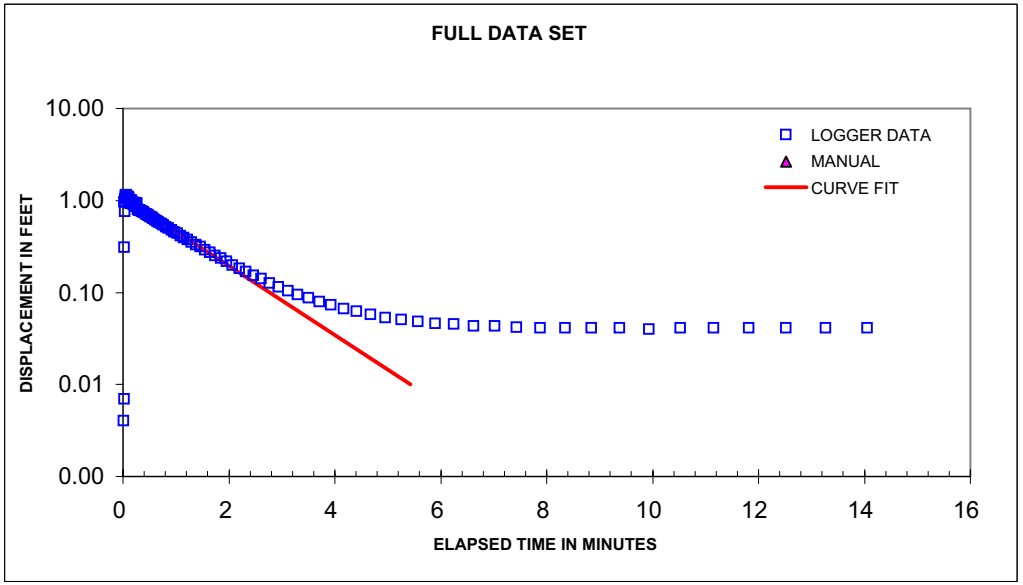
Hydraulic conductivity **6.78E-03 cm/sec**
1.33E-02 ft/min
19.21 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	29.66	feet
Depth to bottom of screen (from ground level)	40.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	40.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	1.100	feet
ΔH at time t (Y_t)	0.010	feet
Time	5.42	min

Bouwer-Rice Parameters

feet	cm		cm	
26.66	812.60	*SW*		
13.34	406.60	*H*	80.00	*L/Rw*
30	914.40	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
13.34	406.60	*D*	#NUM!	*Ln[(D-H)/Rw]*
1.1	33.53	Y_0	#NUM!	equation (8)
0.01	0.30	Y_t	3.58	equation (9)
	325.20	*t (seconds)*	3.58	*Ln(Re/Rw)*
	0.30	*n*	6.8E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW3 Pre-Injection**

Test Date: **December 6, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

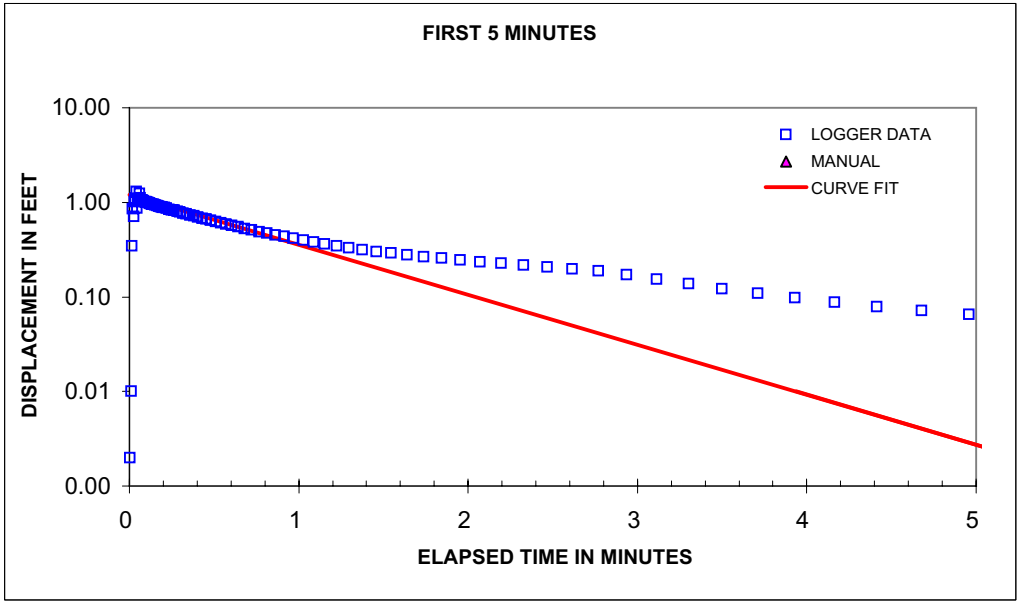
Logger Data File:

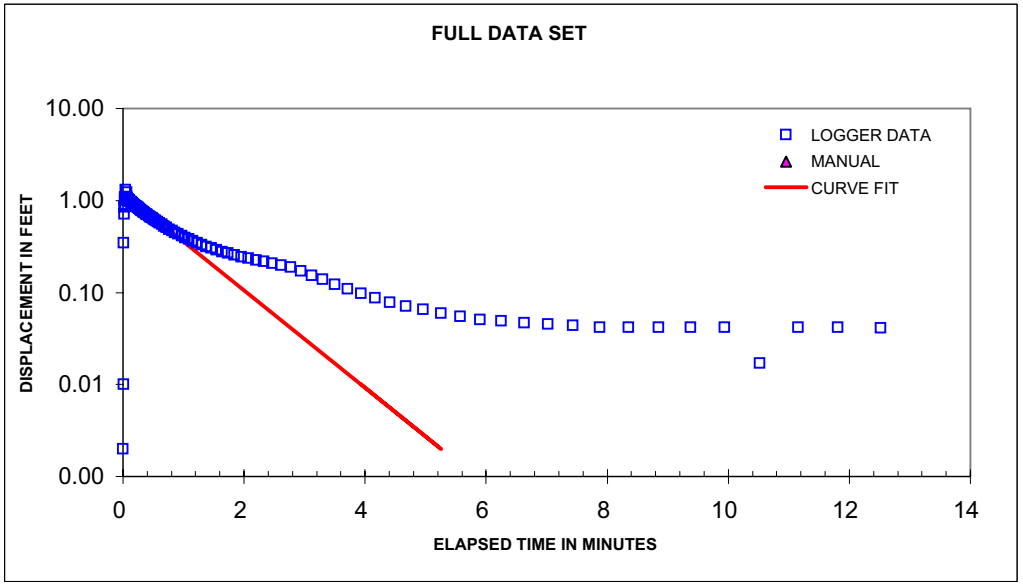
Hydraulic conductivity **9.51E-03 cm/sec**
1.87E-02 ft/min
26.94 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	29.66	feet
Depth to bottom of screen (from ground level)	40.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	40.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	1.200	feet
ΔH at time t (Y_t)	0.002	feet
Time	5.26	min

Bouwer-Rice Parameters

feet	cm		cm	
26.66	812.60	*SW*		
13.34	406.60	*H*	80.00	*L/Rw*
30	914.40	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
13.34	406.60	*D*	#NUM!	*Ln[(D-H)/Rw]*
1.2	36.58	Y_0	#NUM!	equation (8)
0.002	0.06	Y_t	3.58	equation (9)
	315.60	*t (seconds)*	3.58	*Ln(Re/Rw)*
	0.30	*n*	9.5E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW4 Pre-Injection**

Test Date: **December 6, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

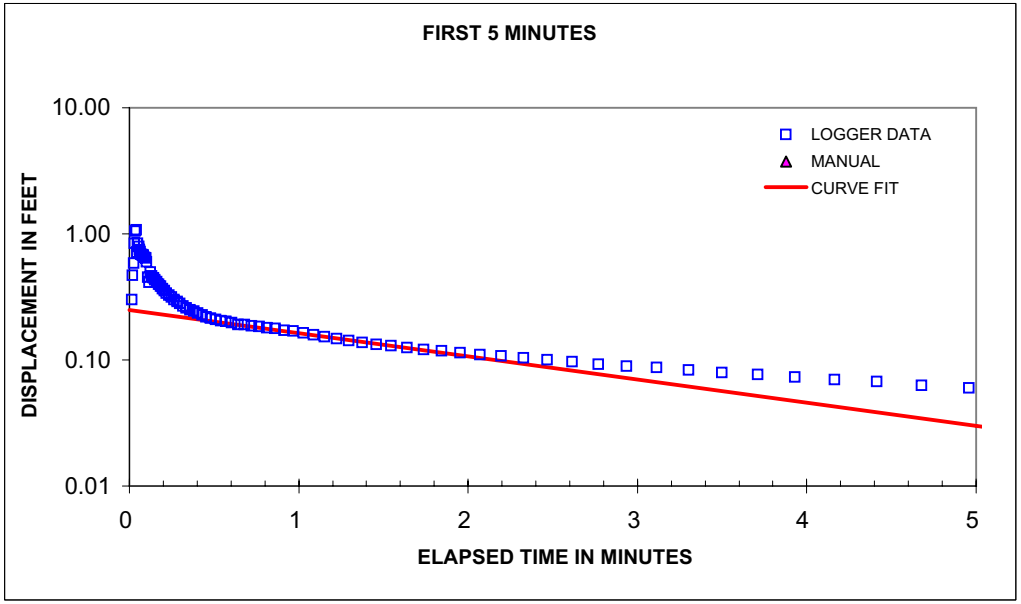
Logger Data File:

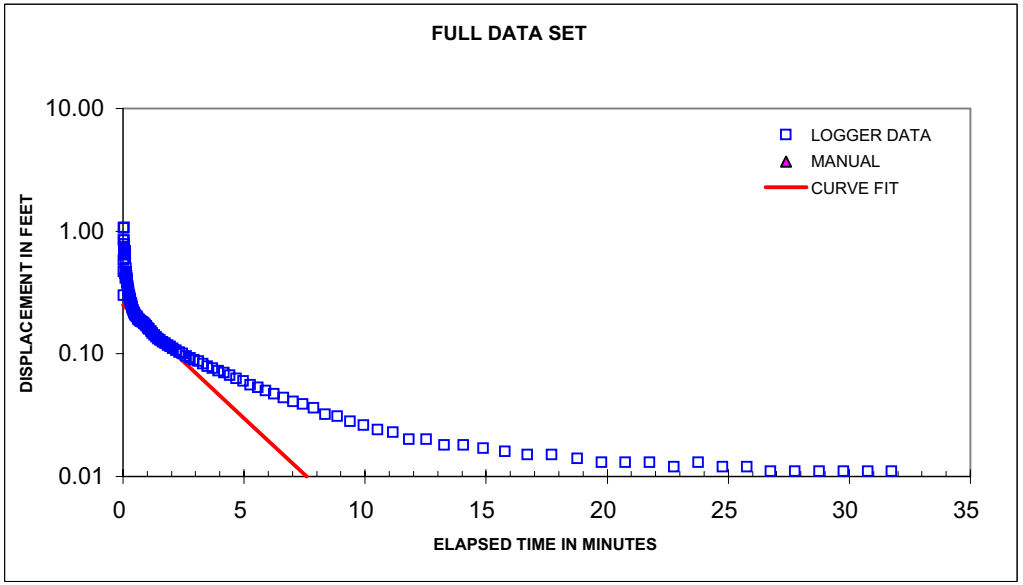
Hydraulic conductivity **3.24E-03 cm/sec**
6.38E-03 ft/min
9.19 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	31.20	feet
Depth to bottom of screen (from ground level)	40.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	40.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.250	feet
ΔH at time t (Y_t)	0.030	feet
Time	5.00	min

Bouwer-Rice Parameters

feet	cm		cm	
28.2	859.54	*SW*		
11.8	359.66	*H*	80.00	*L/Rw*
30	914.40	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
11.8	359.66	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.25	7.62	Y_0	#NUM!	equation (8)
0.03	0.91	Y_t	3.50	equation (9)
	300.00	*t (seconds)*	3.50	*Ln(Re/Rw)*
	0.30	*n*	3.2E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW4 Pre-Injection**

Test Date: **December 6, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

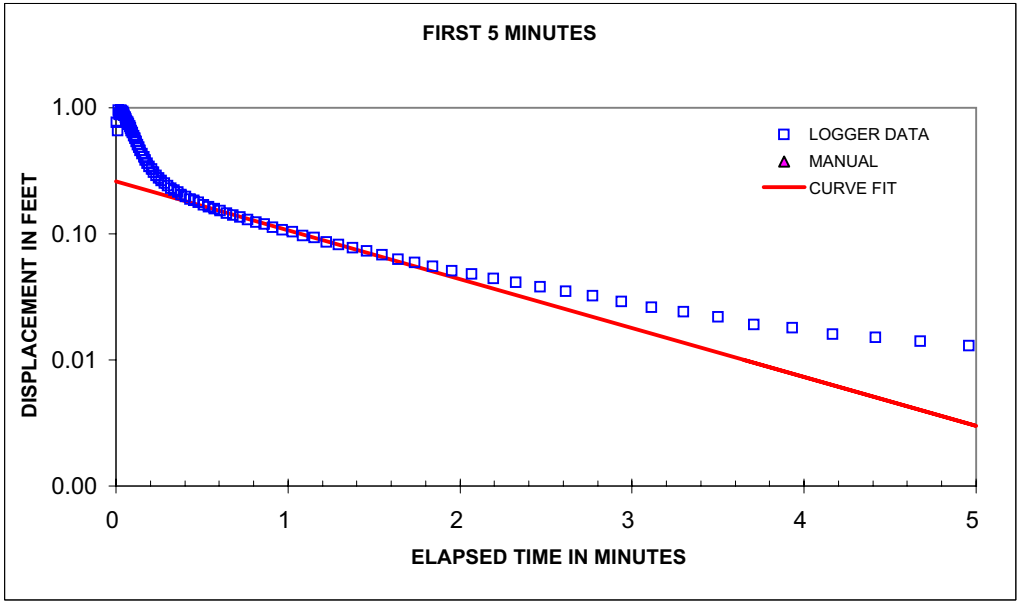
Logger Data File:

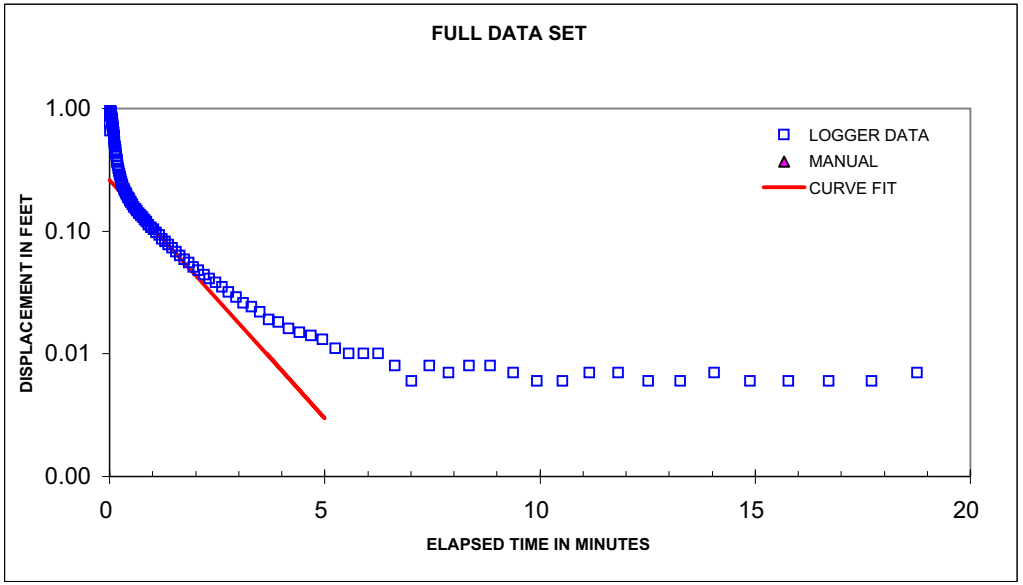
Hydraulic conductivity **6.82E-03 cm/sec**
1.34E-02 ft/min
19.33 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	31.20	feet
Depth to bottom of screen (from ground level)	40.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	40.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.260	feet
ΔH at time t (Y_t)	0.003	feet
Time	5.00	min

Bouwer-Rice Parameters

feet	cm		cm	
28.2	859.54	*SW*		
11.8	359.66	*H*	80.00	*L/Rw*
30	914.40	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
11.8	359.66	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.26	7.92	Y_0	#NUM!	equation (8)
0.003	0.09	Y_t	3.50	equation (9)
	300.00	*t (seconds)*	3.50	*Ln(Re/Rw)*
	0.30	*n*	6.8E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW8 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

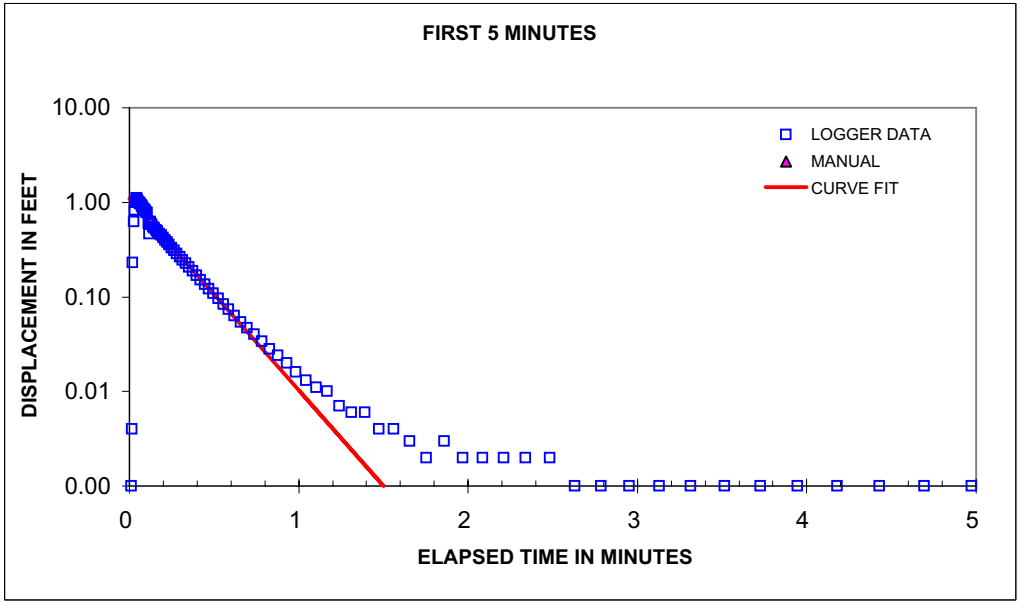
Logger Data File:

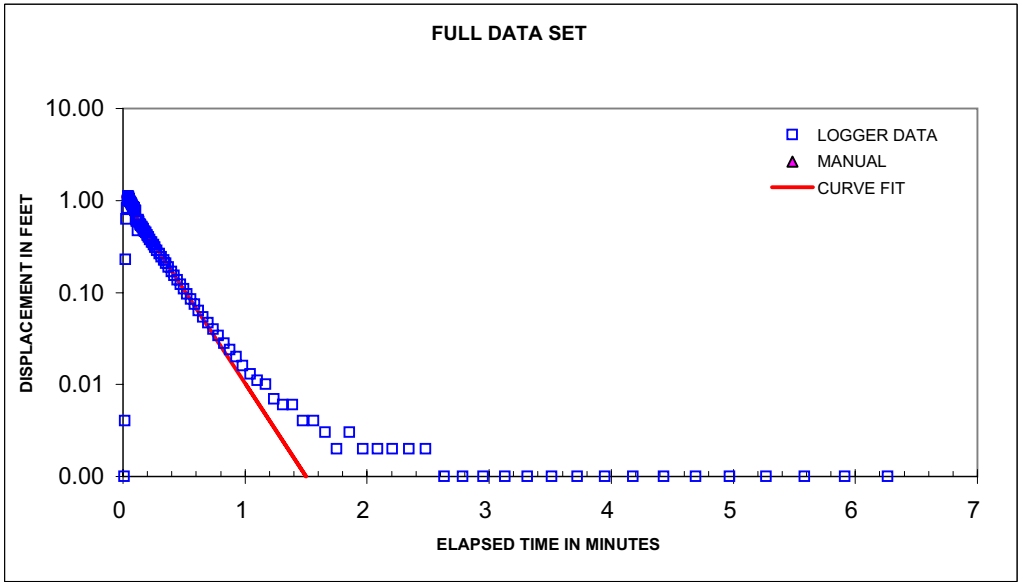
Hydraulic conductivity **3.69E-02 cm/sec**
7.27E-02 ft/min
104.73 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.70	feet
Depth to bottom of screen (from ground level)	40.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	40.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	1.100	feet
ΔH at time t (Y_t)	0.001	feet
Time	1.50	min

Bouwer-Rice Parameters

feet	cm		cm	
25.7	783.34	*SW*		
14.3	435.86	*H*	80.00	*L/Rw*
30	914.40	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
14.3	435.86	*D*	#NUM!	*Ln[(D-H)/Rw]*
1.1	33.53	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.63	equation (9)
	90.00	*t (seconds)*	3.63	*Ln(Re/Rw)*
	0.30	*n*	3.7E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW8 Pre-Injection**

Test Date: **December 7, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

Logger Data File:

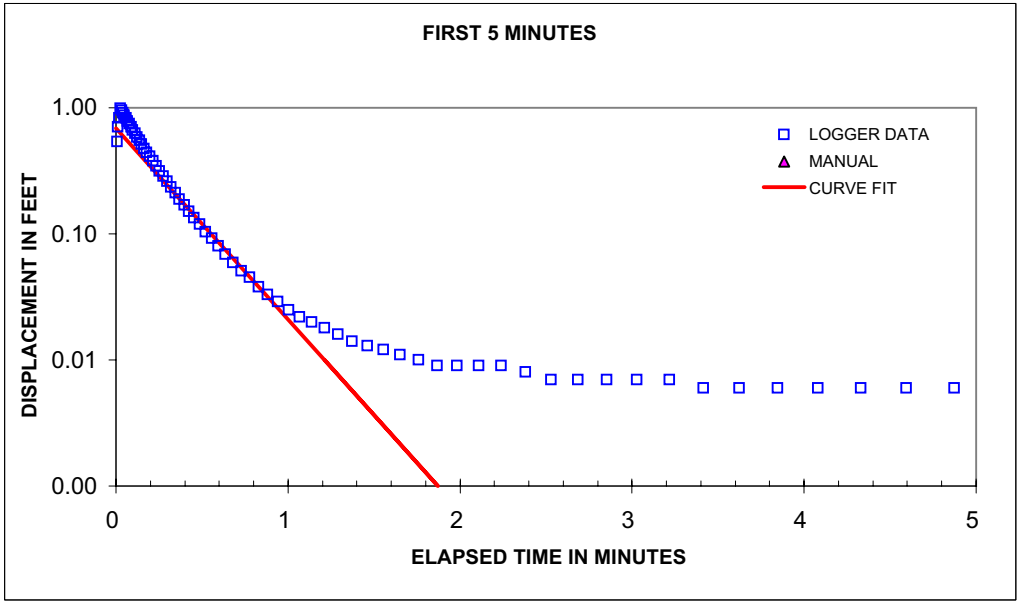
Hydraulic conductivity

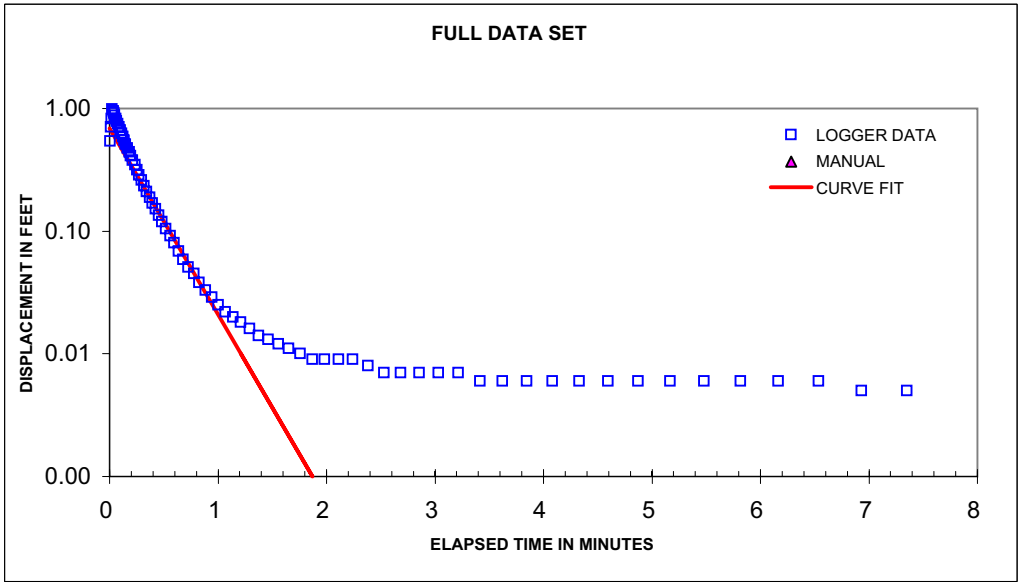
2.77E-02	cm/sec
5.45E-02	ft/min
78.41	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.70	feet
Depth to bottom of screen (from ground level)	40.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	40.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.690	feet
ΔH at time t (Y_t)	0.001	feet
Time	1.87	min

Bouwer-Rice Parameters

feet	cm		cm	
25.7	783.34	*SW*		
14.3	435.86	*H*	80.00	*L/Rw*
30	914.40	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
14.3	435.86	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.69	21.03	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.63	equation (9)
	112.20	*t (seconds)*	3.63	*Ln(Re/Rw)*
	0.30	*n*	2.8E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

DECEMBER 2001 POST INJECTION

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ1 Post-Injection**

Test Date: **December 14, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

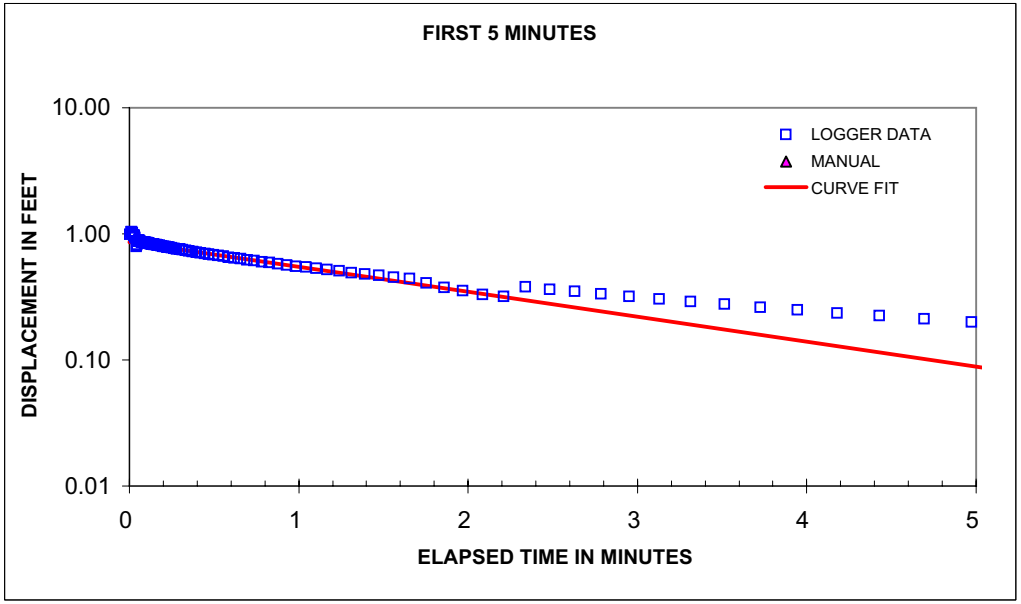
Logger Data File:

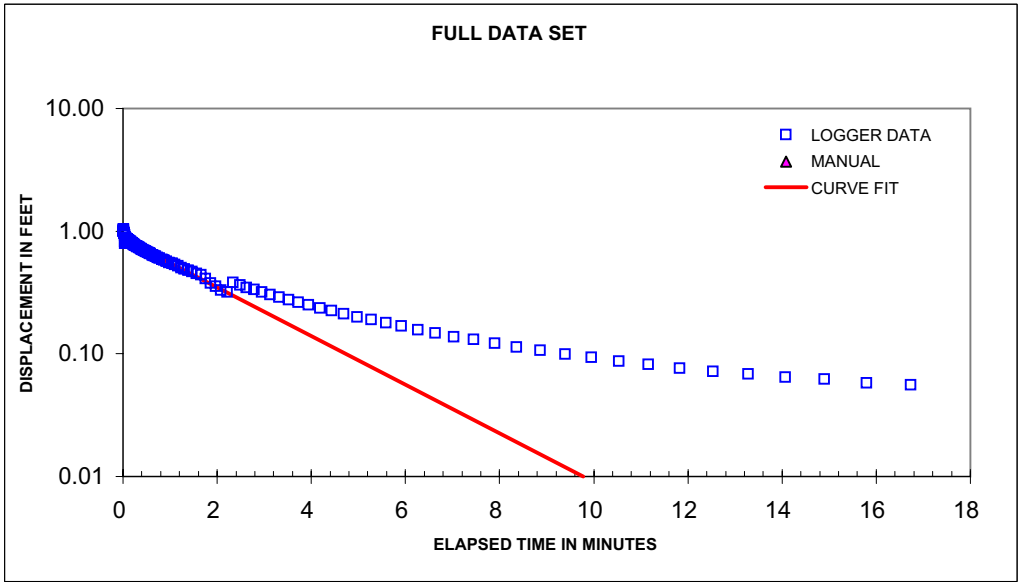
Hydraulic conductivity **3.81E-03 cm/sec**
7.50E-03 ft/min
10.79 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.32	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.861	feet
ΔH at time t (Y_t)	0.500	feet
Time	1.19	min

Bouwer-Rice Parameters

feet	cm		cm	
25.32	771.75	*SW*		
19.68	599.85	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.68	599.85	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.8612	26.25	Y_0	#NUM!	equation (8)
0.5	15.24	Y_t	3.83	equation (9)
	71.60	*t (seconds)*	3.83	*Ln(Re/Rw)*
	0.30	*n*	3.8E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ1 Post-Injection**

Test Date: **December 14, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

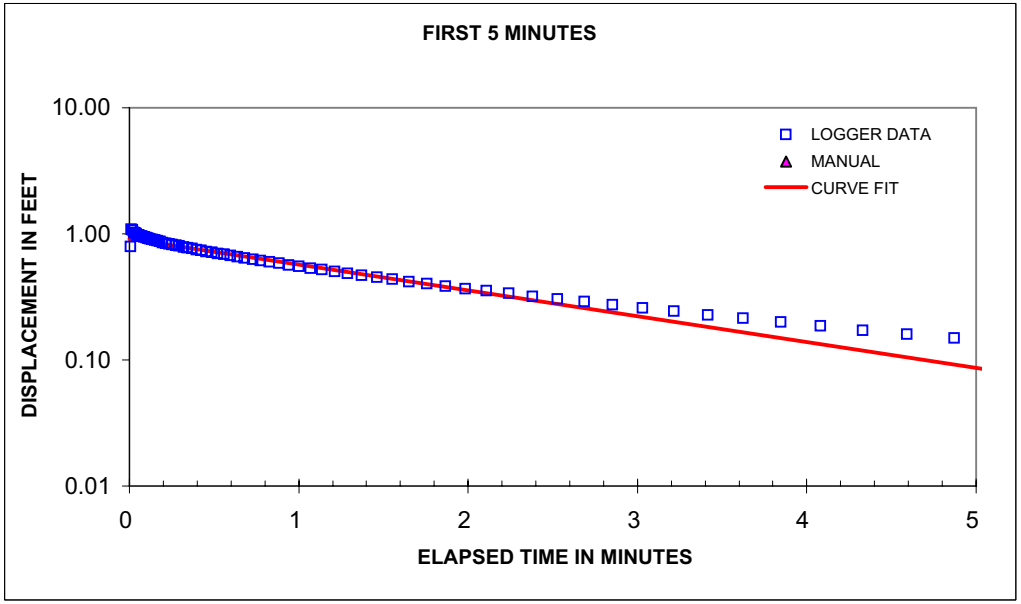
Logger Data File:

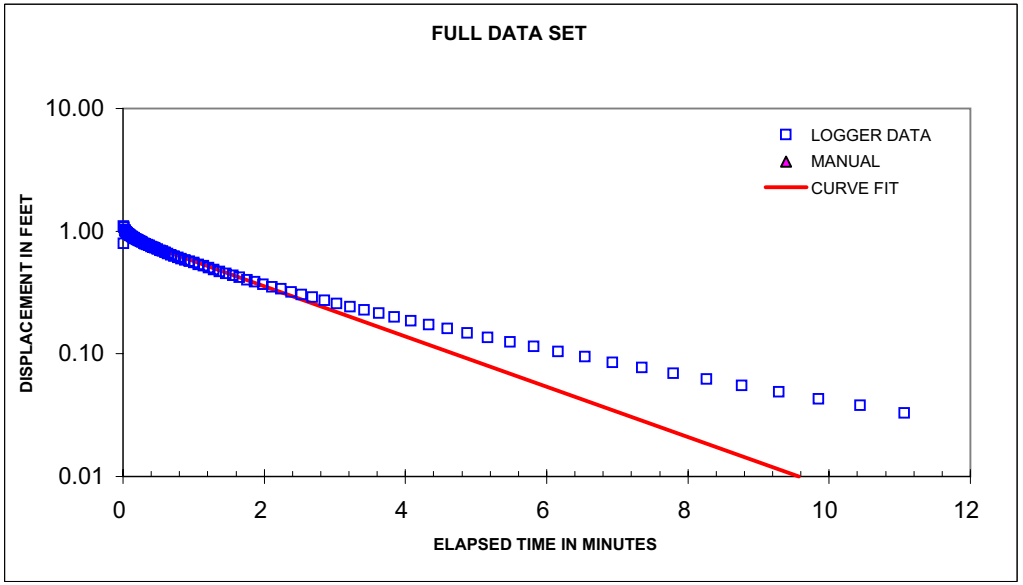
Hydraulic conductivity **3.93E-03 cm/sec**
7.73E-03 ft/min
11.13 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.73	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.911	feet
ΔH at time t (Y_t)	0.500	feet
Time	1.27	min

Bouwer-Rice Parameters

feet	cm		cm	
25.73	784.25	*SW*		
19.27	587.35	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
19.27	587.35	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.9112	27.77	Y_0	#NUM!	equation (8)
0.5	15.24	Y_t	3.82	equation (9)
	76.40	*t (seconds)*	3.82	*Ln(Re/Rw)*
	0.30	*n*	3.9E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ2 Post-Injection**

Test Date: **December 14, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

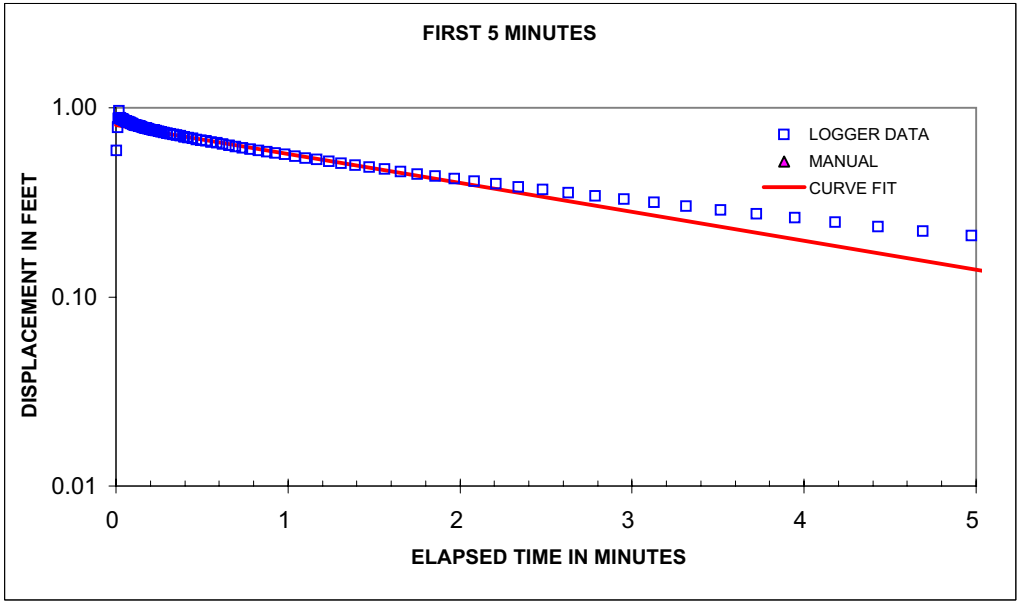
Logger Data File:

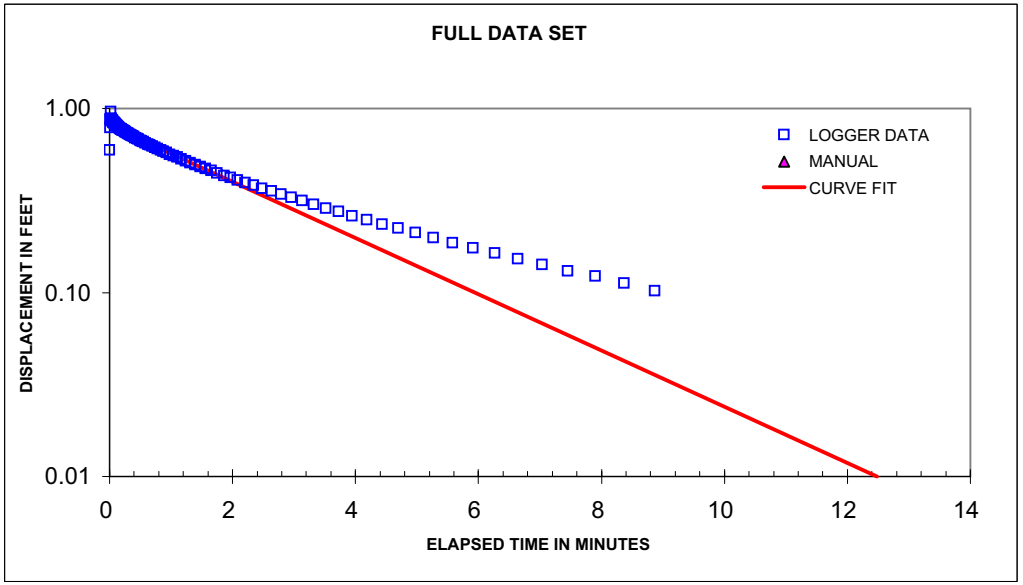
Hydraulic conductivity **2.78E-03 cm/sec**
5.48E-03 ft/min
7.89 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.82	feet
Depth to bottom of screen (from ground level)	40.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	40.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.811	feet
ΔH at time t (Y_t)	0.500	feet
Time	1.37	min

Bouwer-Rice Parameters

feet	cm		cm	
25.82	786.99	*SW*		
14.18	432.21	*H*	80.00	*L/Rw*
30	914.40	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
14.18	432.21	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.8112	24.73	Y_0	#NUM!	equation (8)
0.5	15.24	Y_t	3.62	equation (9)
	82.40	*t (seconds)*	3.62	*Ln(Re/Rw)*
	0.30	*n*	2.8E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ3 Post-Injection**

Test Date: **December 14, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

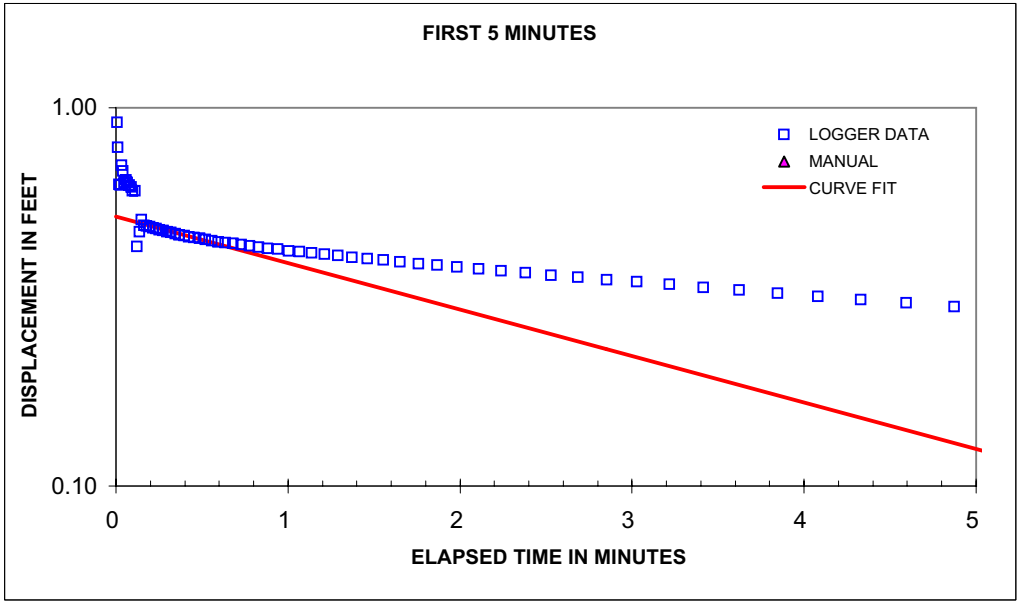
Logger Data File:

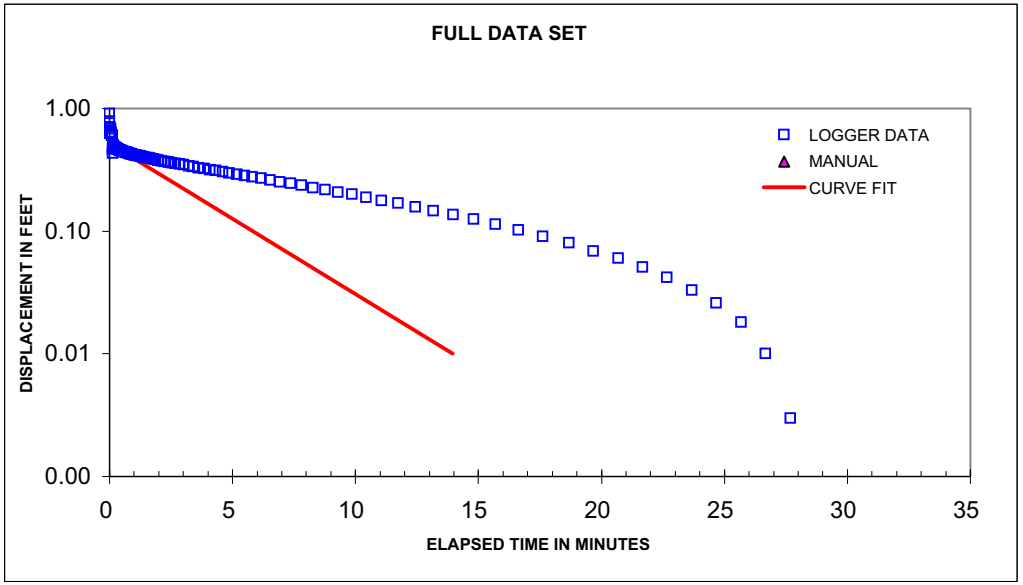
Hydraulic conductivity **2.44E-03 cm/sec**
4.81E-03 ft/min
6.93 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.73	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.515	feet
ΔH at time t (Y_t)	0.230	feet
Time	2.85	min

Bouwer-Rice Parameters

feet	cm		cm	
25.73	784.25	*SW*		
24.27	739.75	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.27	739.75	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.515	15.70	Y_0	#NUM!	equation (8)
0.23	7.01	Y_t	3.96	equation (9)
	171.00	*t (seconds)*	3.96	*Ln(Re/Rw)*
	0.30	*n*	2.4E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-INJ3 Post-Injection**

Test Date: **December 14, 2001**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

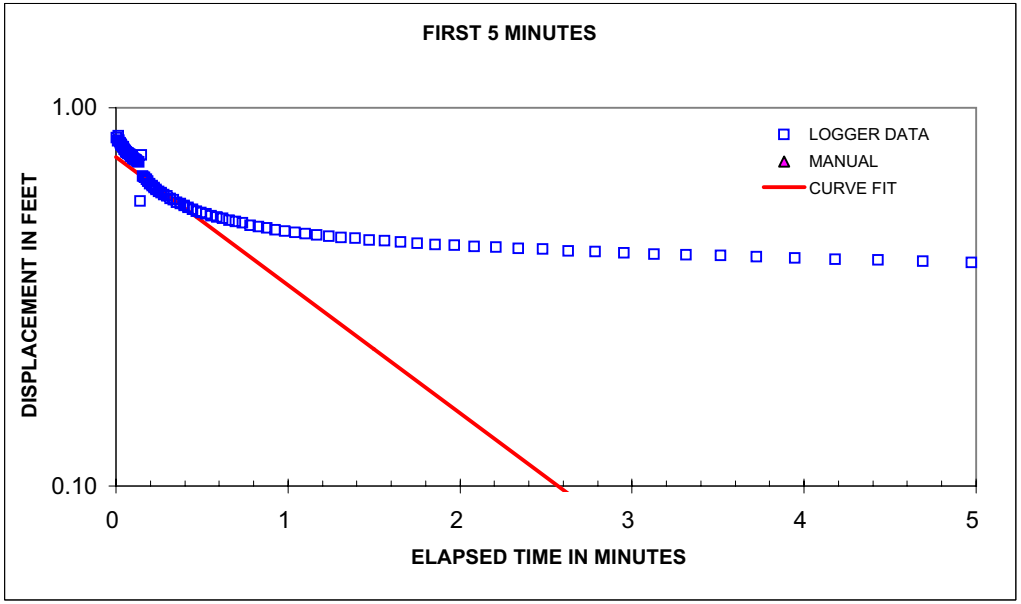
Logger Data File:

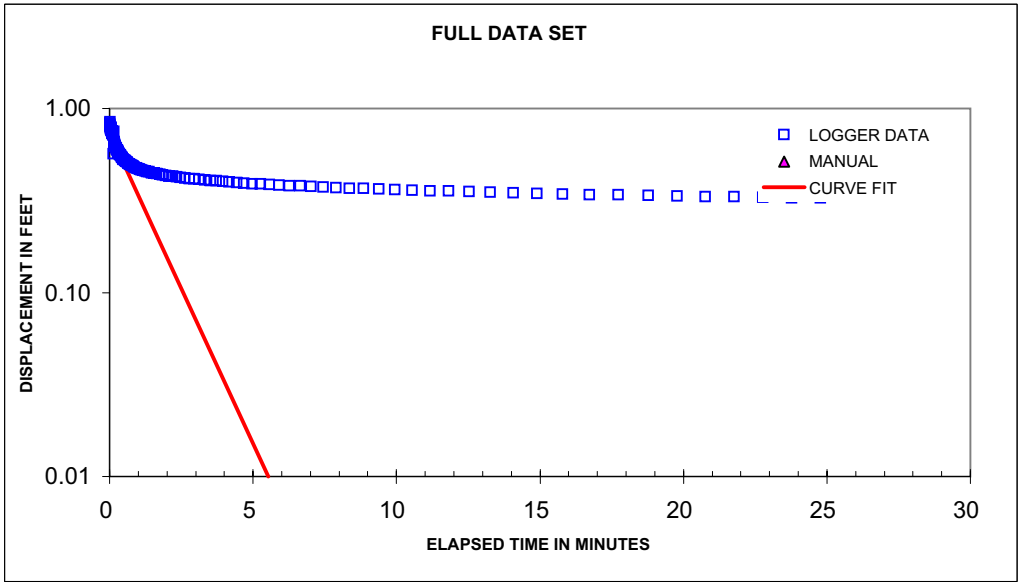
Hydraulic conductivity **6.73E-03 cm/sec**
1.33E-02 ft/min
19.09 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	28.73	feet
Depth to bottom of screen (from ground level)	50.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	50.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.740	feet
ΔH at time t (Y_t)	0.230	feet
Time	1.50	min

Bouwer-Rice Parameters

feet	cm		cm	
25.73	784.25	*SW*		
24.27	739.75	*H*	80.00	*L/Rw*
40	1219.20	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
24.27	739.75	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.74	22.56	Y_0	#NUM!	equation (8)
0.23	7.01	Y_t	3.96	equation (9)
	90.00	*t (seconds)*	3.96	*Ln(Re/Rw)*
	0.30	*n*	6.7E-03	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

DECEMBER 2002

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW1 Post-Injection**

Test Date: **December 16, 2002**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

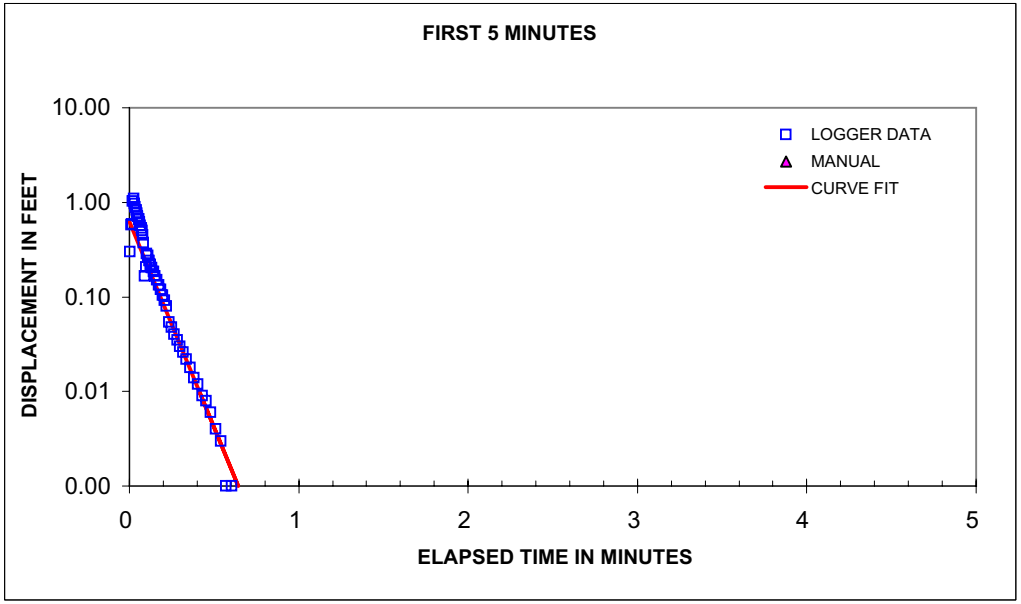
Logger Data File:

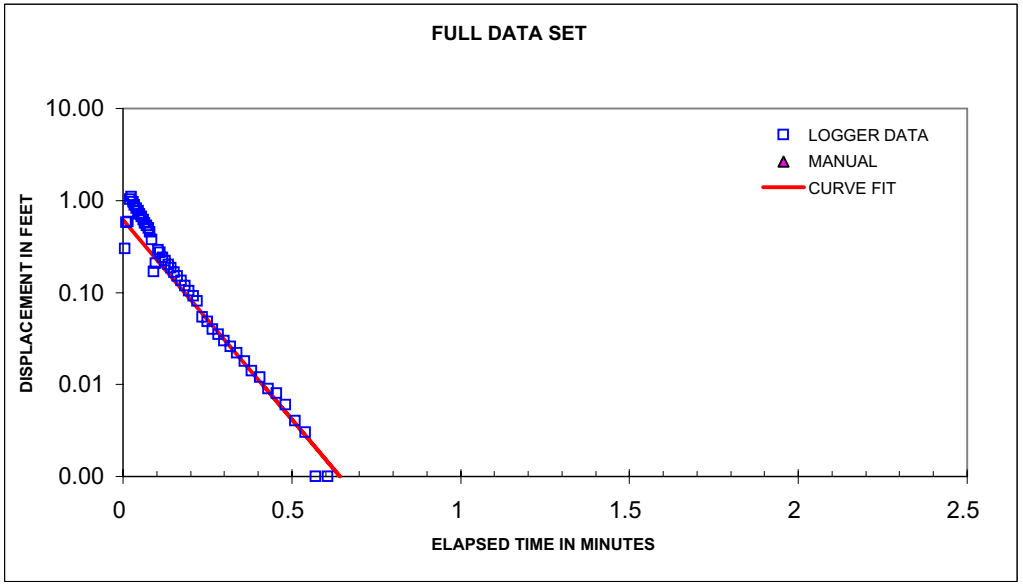
Hydraulic conductivity	8.46E-02	cm/sec
	1.67E-01	ft/min
	239.90	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	26.67	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.620	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.64	min

Bouwer-Rice Parameters

feet	cm		cm	
23.67	721.46	*SW*		
21.33	650.14	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
21.33	650.14	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.62	18.90	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.88	equation (9)
	38.60	*t (seconds)*	3.88	*Ln(Re/Rw)*
	0.30	*n*	8.5E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW1 Post-Injection**

Test Date: **December 16, 2002**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

Logger Data File:

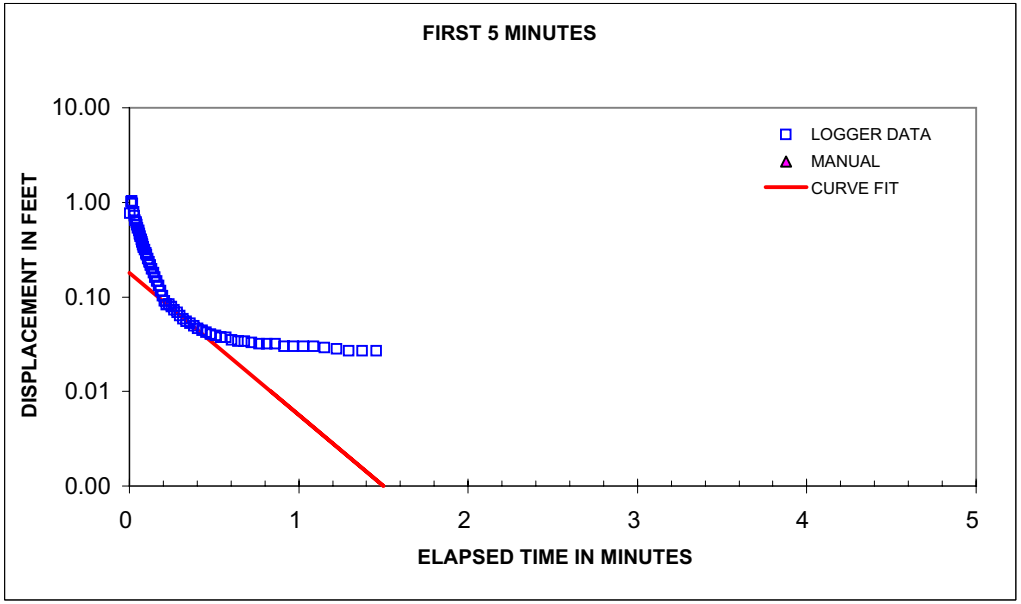
Hydraulic conductivity

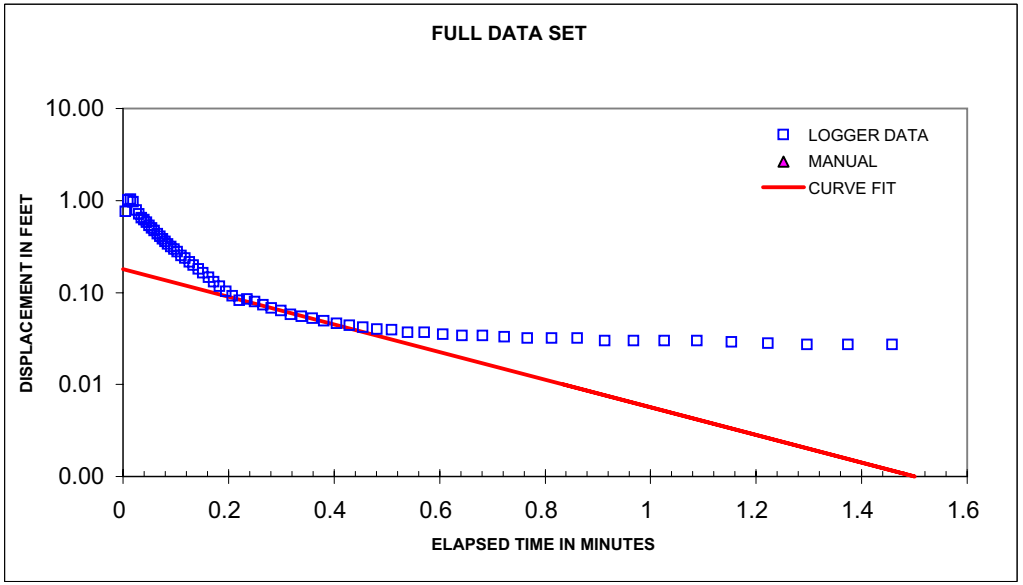
2.93E-02	cm/sec
5.77E-02	ft/min
83.10	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	26.67	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.180	feet
ΔH at time t (Y_t)	0.001	feet
Time	1.50	min

Bouwer-Rice Parameters

feet	cm		cm	
23.67	721.46	*SW*		
21.33	650.14	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
21.33	650.14	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.18	5.49	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.88	equation (9)
	90.00	*t (seconds)*	3.88	*Ln(Re/Rw)*
	0.30	*n*	2.9E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW6 Post-Injection**

Test Date: **December 16, 2002**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

Logger Data File:

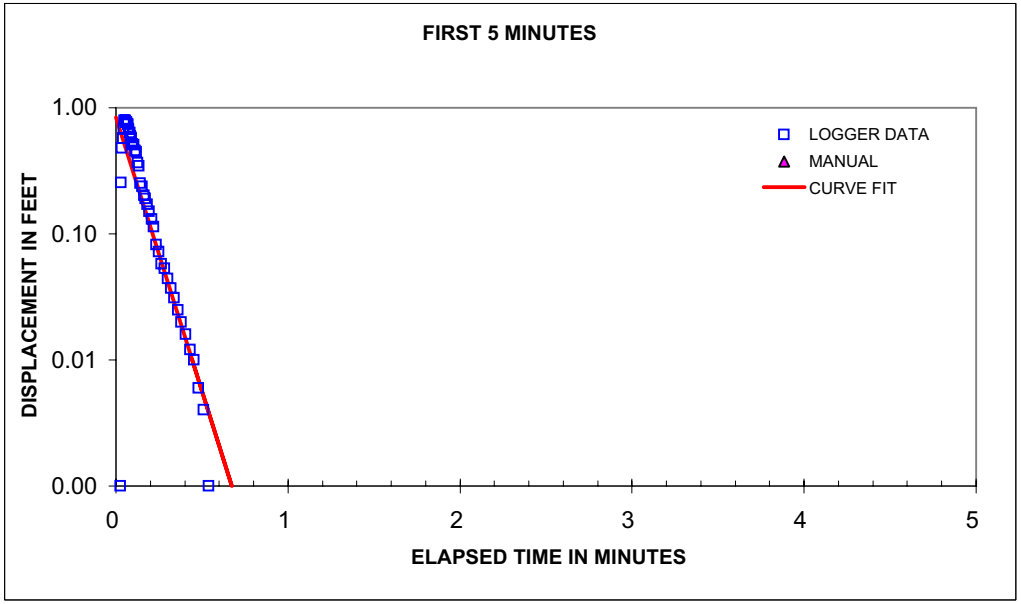
Hydraulic conductivity

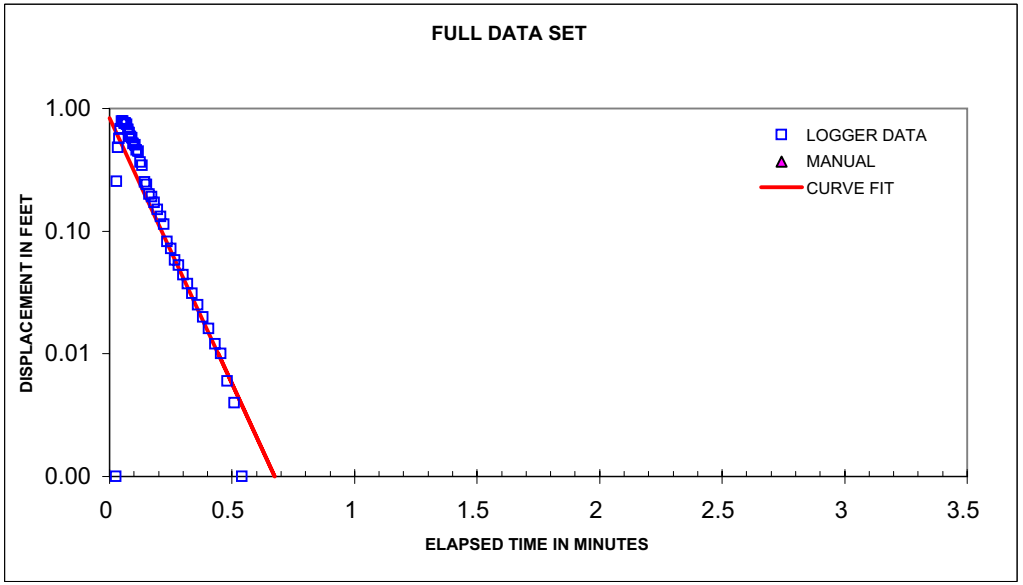
8.47E-02	cm/sec
1.67E-01	ft/min
240.16	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	26.60	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.840	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.67	min

Bouwer-Rice Parameters

feet	cm		cm	
23.6	719.33	*SW*		
21.4	652.27	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
21.4	652.27	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.84	25.60	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.88	equation (9)
	40.40	*t (seconds)*	3.88	*Ln(Re/Rw)*
	0.30	*n*	8.5E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW6 Post-Injection**

Test Date: **December 16, 2002**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

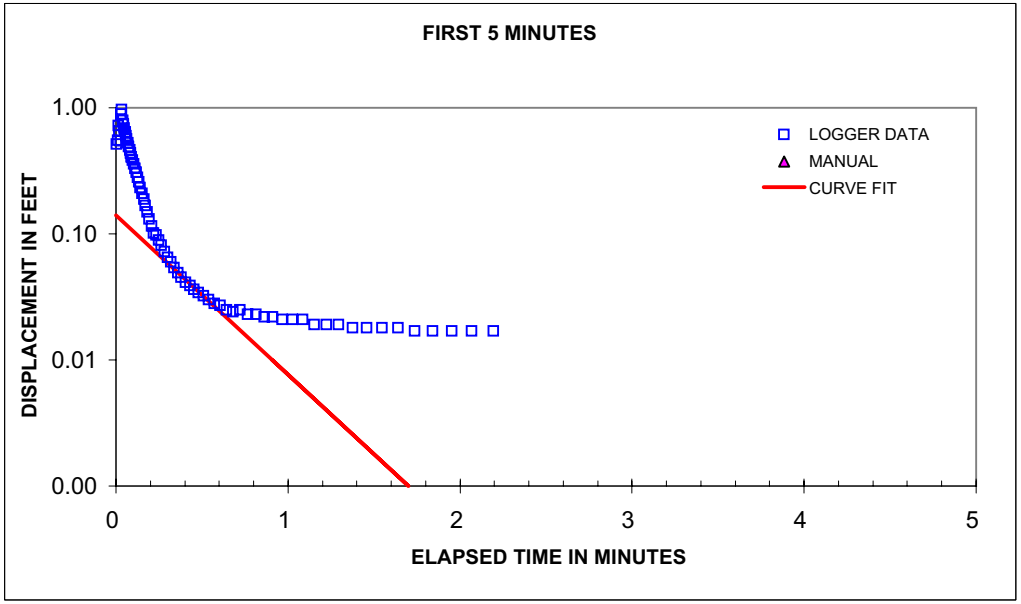
Logger Data File:

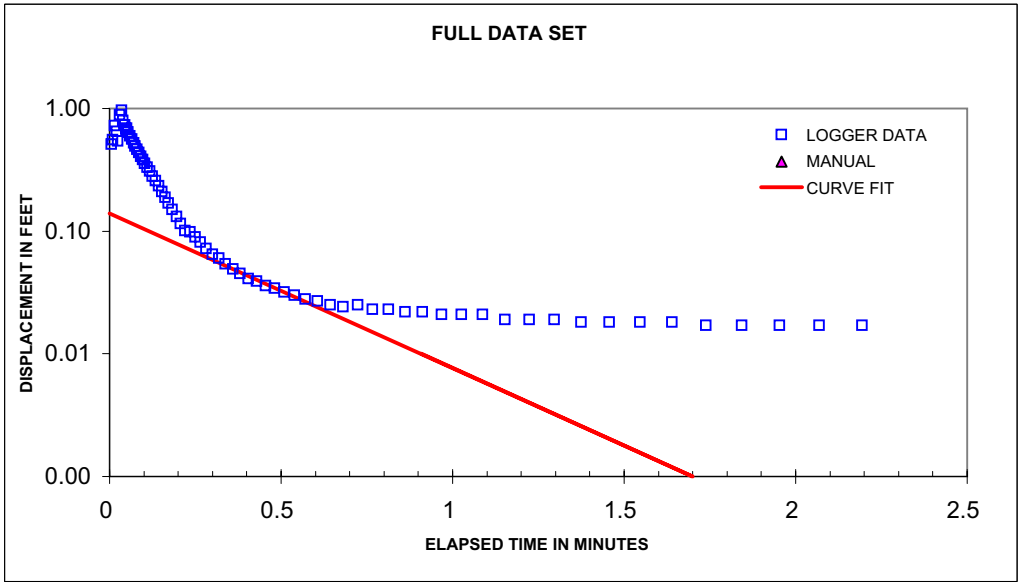
Hydraulic conductivity **2.46E-02 cm/sec**
4.85E-02 ft/min
69.81 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	26.60	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.140	feet
ΔH at time t (Y_t)	0.001	feet
Time	1.70	min

Bouwer-Rice Parameters

feet	cm		cm	
23.6	719.33	*SW*		
21.4	652.27	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
21.4	652.27	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.14	4.27	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.88	equation (9)
	102.00	*t (seconds)*	3.88	*Ln(Re/Rw)*
	0.30	*n*	2.5E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW7 Post-Injection**

Test Date: **December 16, 2002**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Falling**

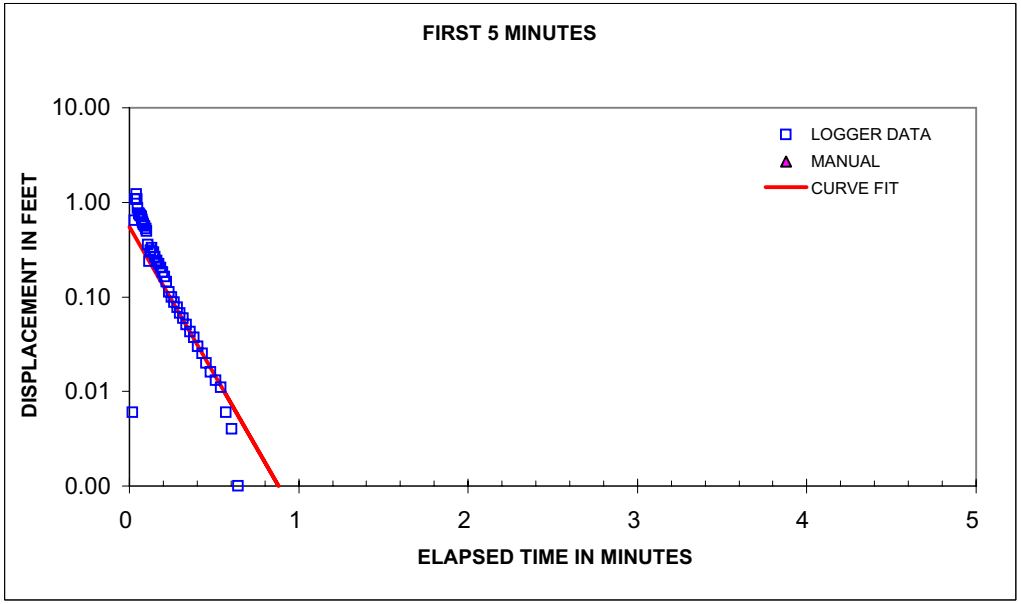
Logger Data File:

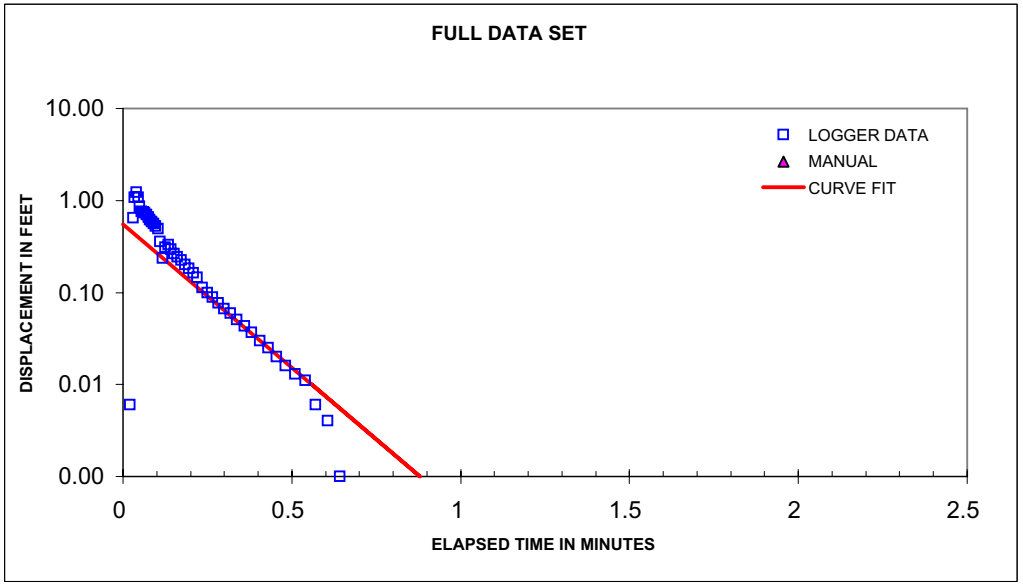
Hydraulic conductivity	6.07E-02	cm/sec
	1.20E-01	ft/min
	172.20	ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	26.60	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.550	feet
ΔH at time t (Y_t)	0.001	feet
Time	0.88	min

Bouwer-Rice Parameters

feet	cm		cm	
23.6	719.33	*SW*		
21.4	652.27	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
21.4	652.27	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.55	16.76	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.88	equation (9)
	52.80	*t (seconds)*	3.88	*Ln(Re/Rw)*
	0.30	*n*	6.1E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.

Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

Client: **CH2M Hill Constructors Inc.**

Project: **Verification against Bouwer & Rice (1976) Data**

Project No.:

Well No.: **PES-MW7 Post-Injection**

Test Date: **December 16, 2002**

Formation Tested: **Glacial/Fluvial Material**

Rising (R) or Falling (F) Head Test: **Rising**

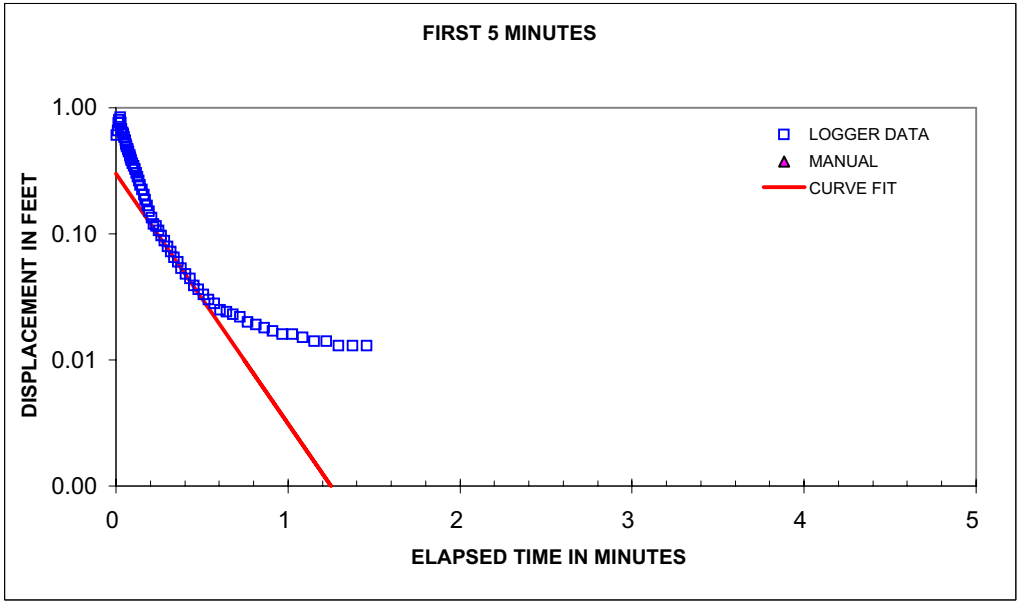
Logger Data File:

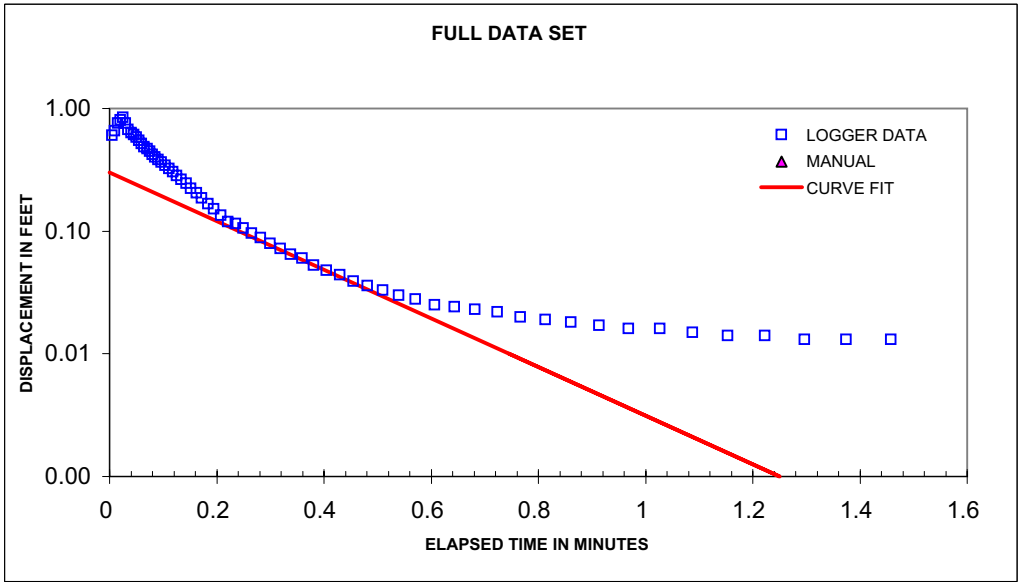
Hydraulic conductivity **3.87E-02 cm/sec**
7.61E-02 ft/min
109.59 ft/day

Casing stickup	3.00	feet
Static water level (from top of casing)	26.60	feet
Depth to bottom of screen (from ground level)	45.00	feet
Boring diameter	12.00	inches
Casing diameter	3.00	inches
Screen diameter	3.00	inches
Screen length	10.00	feet
Depth to "impermeable boundary"	45.00	feet
Porosity of filter pack	0.30	
Slug diameter (optional)		inches
Slug length (optional)		feet
Theoretical ΔH at time zero (Y_0)	0.00	feet
Actual ΔH at time zero (Y_0)	0.300	feet
ΔH at time t (Y_t)	0.001	feet
Time	1.25	min

Bouwer-Rice Parameters

feet	cm		cm	
23.6	719.33	*SW*		
21.4	652.27	*H*	80.00	*L/Rw*
35	1066.80	*Ts*	1.00	*H/D*
0.125	3.81	*Rw*	3.80	*A*
0.293	8.94	*Rc*	0.65	*B*
0.250	7.62	*DS*	3.50	*C*
10.00	304.80	*L*	#NUM!	*Ln[(D-H)/Rw]'*
21.4	652.27	*D*	#NUM!	*Ln[(D-H)/Rw]*
0.3	9.14	Y_0	#NUM!	equation (8)
0.001	0.03	Y_t	3.88	equation (9)
	75.00	*t (seconds)*	3.88	*Ln(Re/Rw)*
	0.30	*n*	3.9E-02	equation (5)





Bouwer, Herman. 1989. "The Bouwer and Rice Slug Test - An Update". Ground Water vol. 27, no. 3, May-June 1989.
Bouwer, H. and R.C. Rice. 1976. A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells". Water Resources Research. vol 12, no. 3, June 1976.

APPENDIX B.2

GROUNDWATER SAMPLING FORMS

This data is available upon request from CH2M Hill Constructors Inc.

APPENDIX C

CONCENTRATION AND MOLAR FRACTION PLOTS

TABLE C.1
MOLAR FRACTION OF CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

		PCE[a/]				TCE[a/]				cis+trans-1,2-DCE[a/]				VC[a/]				Ethene				Total CAH[a/]	
Well ID	Date	Concentration (µg/L[b/])	Molar Weight (g/mol)[c/]	Molar Concentration (mol/L[d/])	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Molar Concentration (mol/L)	Percent
GWMS-27S	12-Nov-01	0.39	165.834	2.35E-09	10.2%	0.44	131.38894	3.35E-09	14.6%	1.4	96.94388	1.41E-08	61.6%	0.17	62.49882	2.72E-09	11.9%	0.011	28.05376	3.92E-10	1.71%	2.29E-08	100.00%
	11-Feb-02	0.39	165.834	2.35E-09	5.9%	0.76	131.38894	5.78E-09	14.5%	2.8	96.94388	2.87E-08	71.8%	0.17	62.49882	2.72E-09	6.8%	0.011	28.05376	3.92E-10	0.98%	3.99E-08	100.00%
	21-May-02	0.39	165.834	2.35E-09	0.3%	89	131.38894	6.77E-07	82.9%	13	96.94388	1.34E-07	16.4%	0.17	62.49882	2.72E-09	0.3%	0.011	28.05376	3.92E-10	0.05%	8.17E-07	100.00%
	26-Aug-02	0.39	165.834	2.35E-09	0.1%	170	131.38894	1.29E-06	69.3%	55	96.94388	5.68E-07	30.4%	0.17	62.49882	2.72E-09	0.1%	0.011	28.05376	3.92E-10	0.02%	1.87E-06	100.00%
	9-Dec-02	0.25	165.834	1.51E-09	0.2%	54	131.38894	4.11E-07	53.4%	34	96.94388	3.51E-07	45.6%	0.30	62.49882	4.80E-09	0.6%	0.036	28.05376	1.28E-09	0.17%	7.69E-07	100.00%
	7-Apr-03	0.24	165.834	1.45E-09	0.1%	140	131.38894	1.07E-06	89.6%	12	96.94388	1.19E-07	10.0%	0.17	62.49882	2.72E-09	0.2%	0.023	28.05376	8.20E-10	0.07%	1.19E-06	100.00%
	18-Aug-03	0.30	165.834	1.81E-09	0.1%	290	131.38894	2.21E-06	80.4%	51	96.94388	5.30E-07	19.3%	0.17	62.49882	2.72E-09	0.1%	0.056	28.05376	2.00E-09	0.07%	2.74E-06	100.00%
GWMS-46S	19-Nov-01	78	165.834	4.70E-07	0.3%	20,000	131.38894	1.52E-04	96.7%	400	96.94388	4.13E-06	2.6%	34	62.49882	5.44E-07	0.3%	0.011	28.05376	3.92E-10	0.00%	1.57E-04	100.00%
	18-Feb-02	39	165.834	2.35E-07	0.2%	14,000	131.38894	1.07E-04	97.1%	260	96.94388	2.68E-06	2.4%	17	62.49882	2.72E-07	0.2%	0.011	28.05376	3.92E-10	0.0%	1.10E-04	100.00%
	22-May-02	1.9	165.834	1.15E-08	0.0%	5,600	131.38894	4.26E-05	97.2%	116	96.94388	1.20E-06	2.7%	0.85	62.49882	1.36E-08	0.0%	0.011	28.05376	3.92E-10	0.00%	4.38E-05	100.00%
	28-Aug-02	0.8	165.834	4.70E-09	0.0%	4,900	131.38894	3.73E-05	98.4%	58	96.94388	5.98E-07	1.6%	0.92	62.49882	1.47E-08	0.0%	0.011	28.05376	3.92E-10	0.00%	3.79E-05	100.00%
	11-Dec-02	1.2	165.834	7.24E-09	0.0%	7,200	131.38894	5.48E-05	97.4%	138	96.94388	1.42E-06	2.5%	1.5	62.49882	2.40E-08	0.0%	0.069	28.05376	2.46E-09	0.00%	5.63E-05	100.00%
	9-Apr-03	0.2	165.834	1.45E-09	0.0%	2,600	131.38894	1.98E-05	97.1%	56	96.94388	5.78E-07	2.8%	0.6	62.49882	9.28E-09	0.0%	0.030	28.05376	1.07E-09	0.01%	2.04E-05	100.00%
	20-Aug-03	0.2	165.834	1.45E-09	0.0%	4,500	131.38894	3.42E-05	95.8%	142	96.94388	1.46E-06	4.1%	1.3	62.49882	2.08E-08	0.1%	0.046	28.05376	1.64E-09	0.00%	3.57E-05	100.00%
	18-Apr-05	0.5	165.834	2.71E-09	0.0%	1,700	131.38894	1.29E-05	92.1%	106	96.94388	1.09E-06	7.8%	0.5	62.49882	7.20E-09	0.1%	0.080	28.05376	2.85E-09	0.02%	1.40E-05	100.00%
	17-Nov-05	0.5	165.834	2.71E-09	0.0%	1,300	131.38894	9.89E-06	93.0%	71	96.94388	7.32E-07	6.9%	0.4	62.49882	6.88E-09	0.1%	0.080	28.05376	2.85E-09	0.03%	1.06E-05	100.00%
GWMS-47S	14-Nov-01	0.92	165.834	5.55E-09	1.0%	44	131.38894	3.35E-07	57.6%	23	96.94388	2.38E-07	41.0%	0.17	62.49882	2.72E-09	0.5%	0.011	28.05376	3.92E-10	0.07%	5.82E-07	100.00%
	12-Feb-02	1.1	165.834	6.63E-09	0.4%	180	131.38894	1.37E-06	91.0%	12	96.94388	1.24E-07	8.2%	0.34	62.49882	5.44E-09	0.4%	0.011	28.05376	3.92E-10	0.03%	1.51E-06	100.00%
	21-May-02	0.60	165.834	3.62E-09	0.2%	220	131.38894	1.67E-06	92.5%	13	96.94388	1.30E-07	7.2%	0.17	62.49882	2.72E-09	0.2%	0.011	28.05376	3.92E-10	0.02%	1.81E-06	100.00%
	26-Aug-02	0.39	165.834	2.35E-09	0.2%	120	131.38894	9.13E-07	89.5%	10	96.94388	1.02E-07	10.0%	0.17	62.49882	2.72E-09	0.3%	0.011	28.05376	3.92E-10	0.04%	1.02E-06	100.00%
	10-Dec-02	0.64	165.834	3.86E-09	0.5%	62	131.38894	4.72E-07	62.6%	26	96.94388	2.72E-07	36.1%	0.30	62.49882	4.80E-09	0.6%	0.013	28.05376	4.63E-10	0.06%	7.53E-07	100.00%
	8-Apr-03	1.50	165.834	9.05E-09	1.2%	66	131.38894	5.02E-07	68.3%	21	96.94388	2.21E-07	30.0%	0.17	62.49882	2.72E-09	0.4%	0.010	28.05376	3.56E-10	0.05%	7.35E-07	100.00%
	19-Aug-03	1.10	165.834	6.63E-09	1.1%	57	131.38894	4.34E-07	72.3%	15	96.94388	1.57E-07	26.1%	0.17	62.49882	2.72E-09	0.5%	0.001	28.05376	4.99E-11	0.01%	6.00E-07	100.00%
	11-Apr-05	0.87	165.834	5.25E-09	1.4%	42	131.38894	3.20E-07	84.3%	5	96.94388	5.15E-08	13.6%	0.18	62.49882	2.88E-09	0.8%	0.001	28.05376	4.99E-11	0.01%	3.79E-07	100.00%
PES-MW-1	16-Nov-01	3.9	165.834	2.35E-08	0.3%	1,100	131.38894	8.37E-06	96.0%	29	96.94388	2.99E-07	3.4%	1.7	62.49882	2.72E-08	0.3%	0.011	28.05376	3.92E-10	0.00%	8.72E-06	100.00%
	15-Feb-02	7.8	165.834	4.70E-08	0.5%	1,100	131.38894	8.37E-06	94.2%	40	96.94388	4.13E-07	4.6%	3.4	62.49882	5.44E-08	0.6%	0.011	28.05376	3.92E-10	0.00%	8.89E-06	100.00%
	22-May-02	0.78	165.834	4.70E-09	0.0%	3,200	131.38894	2.44E-05	81.8%	525	96.94388	5.42E-06	18.2%	0.34	62.49882	5.44E-09	0.0%	0.011	28.05376	3.92E-10	0.00%	2.98E-05	100.00%
	28-Aug-02	0.39	165.834	2.35E-09	0.0%	2,600	131.38894	1.98E-05	74.1%	669	96.94388	6.90E-06	25.8%	1.3	62.49882	2.08E-08	0.1%	0.011	28.05376	3.92E-10	0.00%	2.67E-05	100.00%
	12-Dec-02	0.50	165.834	3.02E-09	0.0%	1,700	131.38894	1.29E-05	83.0%	256	96.94388	2.64E-06	16.9%	0.60	62.49882	9.60E-09	0.1%	0.079	28.05376	2.82E-09	0.02%	1.56E-05	100.00%
	10-Apr-03	0.24	165.834	1.45E-09	0.0%	1,300	131.38894	9.89E-06	70.5%	400	96.94388	4.13E-06	29.4%	0.17	62.49882	2.72E-09	0.0%	0.050	28.05376	1.78E-09	0.01%	1.40E-05	100.00%
	21-Aug-03	0.24	165.834	1.45E-09	0.0%	1,200	131.38894	9.13E-06	42.8%	1179	96.94388	1.22E-05	57.0%	1.40	62.49882	2.24E-08	0.1%	0.013	28.05376	4.63E-10	0.00%	2.13E-05	100.00%
	15-Apr-05	0.45	165.834	2.71E-09	0.1%	380	131.38894	2.89E-06	55.3%	226	96.94388	2.33E-06	44.5%	0.18	62.49882	2.88E-09	0.1%	0.120	28.05376	4.28E-09	0.08%	5.23E-06	100.00%
PES-MW-2	15-Nov-01	7.8	165.834	4.70E-08	0.3%	2,100	131.38894	1.60E-05	96.3%	49	96.94388	5.05E-07	3.0%	3.4	62.49882	5.44E-08	0.3%	0.011	28.05376	3.92E-10	0.00%	1.66E-05	100.00%
	14-Feb-02	20	165.834	1.21E-07	0.4%	3,600	131.38894	2.74E-05	94.9%	118	96.94388	1.22E-06	4.2%	8.5	62.49882	1.36E-07	0.5%	0.011	28.05376	3.92E-10	0.00%	2.89E-05	100.00%
	22-May-02	0.78	165.834	4.70E-09	0.0%	2,200	131.38894	1.67E-05	94.1%	101	96.94388	1.04E-06	5.9%	0.59	62.49882	9.44E-09	0.1%	0.011	28.05376	3.92E-10	0.00%	1.78E-05	100.00%
	28-Aug-02	0.78	165.834	4.70E-09	0.0%	3,200	131.38894	2.44E-05	98.0%	47	96.94388	4.85E-07	2.0%	0.34	62.49882	5.44E-09	0.0%	0.011	28.05376	3.92E-10	0.00%	2.49E-05	100.00%
	11-Dec-02	0.50	165.834	3.02E-09	0.0%	2,600	131.38894	1.98E-05	97.1%	56	96.94388	5.78E-07	2.8%	0.6	62.49882	9.60E-09	0.0%	0.054	28.05376	1.92E-09	0.01%	2.04E-05	100.00%
	9-Apr-03	0.24	165.834	1.45E-09	0.0%	2,900	131.38894	2.21E-05	95.4%	101	96.94388	1.04E-06	4.5%	0.53	62.49882	8.48E-09	0.0%	0.025	28.05376	8.91E-10	0.00%	2.31E-05	100.00%
	20-Aug-03	0.24	165.834	1.45E-09	0.0%	2,000	131.38894	1.52E-05	94.6%	84	96.94388	8.66E-07	5.4%	0.39	62.49882	6.24E-09	0.0%	0.023	28.05376	8.20E-10	0.01%	1.61E-05	100.00%
	14-Apr-05	0.45	165.834	2.71E-09	0.0%	930	131.38894	7.08E-06	91.5%	63	96.94388	6.50E-07	8.4%	0.18	62.49882	2.88E-09	0.0%	0.070	28.05376	2.50E-09	0.03%	7.74E-06	100.00%
PES-MW-3	14-Nov-01	20	165.834	1.21E-07	0.3%	5,000	131.38894	3.81E-05	94.7%	183	96.94388	1.89E-06	4.7%	8.5	62.49882	1.36E-07	0.3%	0.011	28.05376	3.92E-10	0.00%	4.02E-05	100.00%
	13-Feb-02	20	165.834	1.21E-07	0.2%	6,100	131.38894	4.64E-05	93.5%	290	96.94388	2.99E-06	6.0%	8.5	62.49882	1.36E-07	0.3%	0.011	28.05376	3.92E-10	0.00%	4.97E-05	100.00%
	21-May-02	1.9	165.834	1.15E-08	0.0%	6,200	131.38894	4.72E-05	92.3%	380	96.94388	3.92E-06	7.7%	0.85	62.49882	1.36E-08	0.0%	0.011	28.05376	3.92E-10	0.00%	5.11E-05	100.00%
	27-Aug-02	1.9	165.834	1.15E-08	0.0%	5,900	131.38894	4.49E-05	89.9%	485	96.94388	5.00E-06	10.0%	2.2	62.49882	3.52E-08	0.1%	0.011	28.05376	3.92E-10	0.00%	5.00E-05	100.00%
	10-Dec-02	1.2	165.834	7.24E-09	0.0%	5,000	131.38894	3.81E-05	90.6%	380	96.94388	3.92E-06	9.3%	1.5	62.49882	2.40E-08	0.1%	0.081	28.05376	2.89E-09	0.01%	4.20E-05	100.00%
	8-Apr-03	0.2	165.834	1.45E-09	0.0%	3,800	131.38894	2.89E-05	86.7%	430	96.94388	4.44E-06	13.3%	1.1	62.49882	1.76E-08	0.1%	0.007	28.05376	2.50E-10	0.00%	3.34E-05	100.00%
	20-Aug-03	0.2	165.834	1.45E-09	0.0%	2,400	131.38894	1.83E-05	80.4%	430	96.94388	4.44E-06	19.5%	0.9	62.49882	1.44E-08	0.1%	0.026	28.05376	9.27E-10	0.00%	2.27E-05	100.00%
	14-Apr-05	0.45	165.834	2.71E-09	0.0%	830	131.38894	6.32E-06	73.4%	221	96.94388	2.28E-06	26.5%	0.34	62.49882	5.44E-09	0.1%	0.065	28.05376	2.32E-09	0.03%	8.61E-06	100.00%

TABLE C.1
MOLAR FRACTION OF CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

		PCE[a/]				TCE[a/]				cis+trans-1,2-DCE[a/]				VC[a/]				Ethene				Total CAH[a/]	
Well ID	Date	Concentration (µg/L[b/])	Molar Weight (g/mol)[c/]	Molar Concentration (mol/L[d/])	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Molar Concentration (mol/L)	Percent
PES-MW-4	14-Nov-01	7.8	165.834	4.70E-08	0.2%	3,300	131.38894	2.51E-05	92.0%	203	96.94388	2.09E-06	7.7%	3.4	62.49882	5.44E-08	0.2%	0.011	28.05376	3.92E-10	0.00%	2.73E-05	100.00%
	12-Feb-02	7.8	165.834	4.70E-08	0.2%	3,300	131.38894	2.51E-05	92.1%	198	96.94388	2.04E-06	7.5%	3.4	62.49882	5.44E-08	0.2%	0.011	28.05376	3.92E-10	0.00%	2.73E-05	100.00%
	21-May-02	0.78	165.834	4.70E-09	0.0%	4,200	131.38894	3.20E-05	90.3%	330	96.94388	3.40E-06	9.6%	0.34	62.49882	5.44E-09	0.0%	0.011	28.05376	3.92E-10	0.00%	3.54E-05	100.00%
	27-Aug-02	0.78	165.834	4.70E-09	0.0%	3,100	131.38894	2.36E-05	94.9%	123	96.94388	1.27E-06	5.1%	0.34	62.49882	5.44E-09	0.0%	0.011	28.05376	3.92E-10	0.00%	2.49E-05	100.00%
	10-Dec-02	0.50	165.834	3.02E-09	0.0%	2,100	131.38894	1.60E-05	90.9%	154	96.94388	1.59E-06	9.0%	0.60	62.49882	9.60E-09	0.1%	0.068	28.05376	2.42E-09	0.01%	1.76E-05	100.00%
	8-Apr-03	0.24	165.834	1.45E-09	0.0%	2,300	131.38894	1.75E-05	90.4%	180	96.94388	1.86E-06	9.6%	0.17	62.49882	2.72E-09	0.0%	0.025	28.05376	8.91E-10	0.00%	1.94E-05	100.00%
	19-Aug-03	0.73	165.834	4.40E-09	0.0%	2,600	131.38894	1.98E-05	86.8%	290	96.94388	2.99E-06	13.1%	0.86	62.49882	1.38E-08	0.1%	0.082	28.05376	2.92E-09	0.01%	2.28E-05	100.00%
	12-Apr-05	0.45	165.834	2.71E-09	0.0%	820	131.38894	6.24E-06	67.8%	286	96.94388	2.95E-06	32.1%	0.33	62.49882	5.28E-09	0.1%	0.085	28.05376	3.03E-09	0.03%	9.20E-06	100.00%
	14-Nov-05	0.45	165.834	2.71E-09	0.0%	1000	131.38894	7.61E-06	77.3%	216	96.94388	2.23E-06	22.6%	0.18	62.49882	2.88E-09	0.0%	0.085	28.05376	3.03E-09	0.03%	9.85E-06	100.00%
PES-MW-5	14-Nov-01	0.39	165.834	2.35E-09	0.3%	75	131.38894	5.71E-07	63.5%	31	96.94388	3.18E-07	35.3%	0.47	62.49882	7.52E-09	0.8%	0.011	28.05376	3.92E-10	0.04%	8.99E-07	100.00%
	12-Feb-02	0.39	165.834	2.35E-09	0.2%	77	131.38894	5.86E-07	61.8%	34	96.94388	3.52E-07	37.1%	0.47	62.49882	7.52E-09	0.8%	0.011	28.05376	3.92E-10	0.04%	9.48E-07	100.00%
	21-May-02	0.39	165.834	2.35E-09	0.2%	82	131.38894	6.24E-07	62.2%	36	96.94388	3.69E-07	36.8%	0.47	62.49882	7.52E-09	0.7%	0.011	28.05376	3.92E-10	0.04%	1.00E-06	100.00%
	27-Aug-02	0.39	165.834	2.35E-09	0.0%	1000	131.38894	7.61E-06	94.4%	42	96.94388	4.33E-07	5.4%	1.00	62.49882	1.60E-08	0.2%	0.011	28.05376	3.92E-10	0.00%	8.06E-06	100.00%
	10-Dec-02	0.25	165.834	1.51E-09	0.1%	120	131.38894	9.13E-07	47.2%	98	96.94388	1.02E-06	52.5%	0.26	62.49882	4.16E-09	0.2%	0.009	28.05376	3.21E-10	0.02%	1.93E-06	100.00%
	8-Apr-03	0.24	165.834	1.45E-09	0.0%	780	131.38894	5.94E-06	89.1%	70	96.94388	7.22E-07	10.8%	0.22	62.49882	3.52E-09	0.1%	0.009	28.05376	3.21E-10	0.00%	6.66E-06	100.00%
	19-Aug-03	0.28	165.834	1.69E-09	0.0%	880	131.38894	6.70E-06	91.4%	58	96.94388	5.98E-07	8.2%	1.70	62.49882	2.72E-08	0.4%	0.026	28.05376	9.27E-10	0.01%	7.33E-06	100.00%
	12-Apr-05	0.45	165.834	2.71E-09	0.7%	38	131.38894	2.89E-07	73.0%	10	96.94388	9.92E-08	25.0%	0.18	62.49882	2.88E-09	0.7%	0.062	28.05376	2.21E-09	0.56%	3.96E-07	100.00%
PES-MW-6	15-Nov-01	20	165.834	1.21E-07	0.2%	6,200	131.38894	4.72E-05	94.8%	228	96.94388	2.35E-06	4.7%	8.5	62.49882	1.36E-07	0.3%	0.011	28.05376	3.92E-10	0.00%	4.98E-05	100.00%
	15-Feb-02	20	165.834	1.21E-07	0.3%	5,800	131.38894	4.41E-05	94.0%	250	96.94388	2.58E-06	5.5%	8.5	62.49882	1.36E-07	0.3%	0.011	28.05376	3.92E-10	0.00%	4.70E-05	100.00%
	23-May-02	1.9	165.834	1.15E-08	0.0%	5,100	131.38894	3.88E-05	94.5%	214	96.94388	2.21E-06	5.4%	1.7	62.49882	2.72E-08	0.1%	0.011	28.05376	3.92E-10	0.00%	4.11E-05	100.00%
	28-Aug-02	1.9	165.834	1.15E-08	0.0%	6,600	131.38894	5.02E-05	96.6%	170	96.94388	1.75E-06	3.4%	1.4	62.49882	2.24E-08	0.0%	0.011	28.05376	3.92E-10	0.00%	5.20E-05	100.00%
	12-Dec-02	0.50	165.834	3.02E-09	0.0%	3,800	131.38894	2.89E-05	90.0%	311	96.94388	3.21E-06	10.0%	0.6	62.49882	9.60E-09	0.0%	0.082	28.05376	2.92E-09	0.01%	3.21E-05	100.00%
	10-Apr-03	0.24	165.834	1.45E-09	0.0%	3,000	131.38894	2.28E-05	88.7%	280	96.94388	2.89E-06	11.2%	0.77	62.49882	1.23E-08	0.0%	0.051	28.05376	1.82E-09	0.01%	2.57E-05	100.00%
	21-Aug-03	0.24	165.834	1.45E-09	0.0%	2,000	131.38894	1.52E-05	90.3%	158	96.94388	1.63E-06	9.7%	0.59	62.49882	9.44E-09	0.1%	0.066	28.05376	2.35E-09	0.01%	1.69E-05	100.00%
	15-Apr-05	0.45	165.834	2.71E-09	0.0%	700	131.38894	5.33E-06	72.3%	197	96.94388	2.03E-06	27.6%	0.27	62.49882	4.32E-09	0.1%	0.110	28.05376	3.92E-09	0.05%	7.37E-06	100.00%
PES-MW-7	16-Nov-01	0.78	165.834	4.70E-09	0.2%	300	131.38894	2.28E-06	96.9%	6.0	96.94388	6.17E-08	2.6%	0.34	62.49882	5.44E-09	0.2%	0.011	28.05376	3.92E-10	0.02%	2.36E-06	100.00%
	14-Feb-02	1.90	165.834	1.15E-08	0.3%	540	131.38894	4.11E-06	95.7%	15	96.94388	1.58E-07	3.7%	0.85	62.49882	1.36E-08	0.3%	0.011	28.05376	3.92E-10	0.01%	4.29E-06	100.00%
	22-May-02	0.39	165.834	2.35E-09	0.0%	980	131.38894	7.46E-06	95.7%	32	96.94388	3.30E-07	4.2%	0.36	62.49882	5.76E-09	0.1%	0.011	28.05376	3.92E-10	0.01%	7.80E-06	100.00%
	28-Aug-02	0.48	165.834	2.89E-09	0.0%	1300	131.38894	9.89E-06	92.6%	76	96.94388	7.84E-07	7.3%	0.42	62.49882	6.72E-09	0.1%	0.011	28.05376	3.92E-10	0.00%	1.07E-05	100.00%
	12-Dec-02	0.25	165.834	1.51E-09	0.0%	350	131.38894	2.66E-06	57.3%	188	96.94388	1.94E-06	41.8%	0.53	62.49882	8.48E-09	0.2%	0.950	28.05376	3.39E-08	0.73%	4.65E-06	100.00%
	10-Apr-03	0.24	165.834	1.45E-09	0.0%	12	131.38894	9.13E-08	3.1%	276	96.94388	2.84E-06	96.4%	0.69	62.49882	1.10E-08	0.4%	0.076	28.05376	2.71E-09	0.09%	2.95E-06	100.00%
	21-Aug-03	0.24	165.834	1.45E-09	0.0%	2	131.38894	1.60E-08	0.4%	417	96.94388	4.30E-06	99.3%	0.90	62.49882	1.44E-08	0.3%	0.001	28.05376	4.99E-11	0.00%	4.34E-06	100.00%
	15-Apr-05	0.45	165.834	2.71E-09	0.2%	4	131.38894	3.12E-08	2.2%	135	96.94388	1.39E-06	97.1%	0.29	62.49882	4.64E-09	0.3%	0.092	28.05376	3.28E-09	0.23%	1.43E-06	100.00%
	17-Nov-05	0.45	165.834	2.71E-09	0.2%	1	131.38894	7.61E-09	0.5%	153	96.94388	1.58E-06	98.4%	0.80	62.49882	1.28E-08	0.8%	0.092	28.05376	3.28E-09	0.20%	1.60E-06	100.00%
PES-MW-8	15-Nov-01	20	165.834	1.21E-07	0.2%	6,700	131.38894	5.10E-05	92.4%	380	96.94388	3.92E-06	7.1%	8.5	62.49882	1.36E-07	0.2%	0.011	28.05376	3.92E-10	0.00%	5.52E-05	100.00%
	14-Feb-02	20	165.834	1.21E-07	0.3%	4,700	131.38894	3.58E-05	90.2%	350	96.94388	3.61E-06	9.1%	8.5	62.49882	1.36E-07	0.3%	0.011	28.05376	3.92E-10	0.00%	3.96E-05	100.00%
	22-May-02	1.9	165.834	1.15E-08	0.0%	5,400	131.38894	4.11E-05	91.0%	390	96.94388	4.02E-06	8.9%	2.2	62.49882	3.52E-08	0.1%	0.011	28.05376	3.92E-10	0.00%	4.52E-05	100.00%
	27-Aug-02	1.9	165.834	1.15E-08	0.0%	5,700	131.38894	4.34E-05	94.1%	260	96.94388	2.68E-06	5.8%	1.8	62.49882	2.88E-08	0.1%	0.011	28.05376	3.92E-10	0.00%	4.61E-05	100.00%
	12-Dec-02	1.2	165.834	7.24E-09	0.0%	5,500	131.38894	4.19E-05	96.5%	143	96.94388	1.48E-06	3.4%	1.5	62.49882	2.40E-08	0.1%	0.062	28.05376	2.21E-09	0.01%	4.34E-05	100.00%
	9-Apr-03	0.2	165.834	1.45E-09	0.0%	3,000	131.38894	2.28E-05	89.8%	250	96.94388	2.58E-06	10.1%	0.81	62.49882	1.30E-08	0.1%	0.011	28.05376	3.92E-10	0.00%	2.54E-05	100.00%
	21-Aug-03	0.3	165.834	1.93E-09	0.0%	2,200	131.38894	1.67E-05	90.4%	172	96.94388	1.77E-06	9.6%	0.17	62.49882	2.72E-09	0.0%	0.066	28.05376	2.35E-09	0.01%	1.85E-05	100.00%
	14-Apr-05	0.45	165.834	2.71E-09	0.0%	1100	131.38894	8.37E-06	84.6%	147	96.94388	1.52E-06	15.3%	0.34	62.49882	5.44E-09	0.1%	0.049	28.05376	1.75E-09	0.02%	9.90E-06	100.00%
PES-MW-9	15-Nov-01	3.9	165.834	2.35E-08	0.2%	1,400	131.38894	1.07E-05	96.3%	35	96.94388	3.61E-07	3.3%	1.7	62.49882	2.72E-08	0.2%	0.011	28.05376	3.92E-10	0.00%	1.11E-05	100.00%
	13-Feb-02	3.9	165.834	2.35E-08	0.2%	1,300	131.38894	9.89E-06	95.8%	37	96.94388	3.82E-07	3.7%	1.7	62.49882	2.72E-08	0.3%	0.011	28.05376	3.92E-10	0.00%	1.03E-05	100.00%
	22-May-02	0.78	165.834	4.70E-09	0.0%	410	131.38894	3.12E-06	14.0%	1863	96.94388	1.92E-05	85.9%	1.2	62.49882	1.92E-08	0.1%	0.011	28.05376	3.92E-10	0.00%	2.24E-05	100.00%
	27-Aug-02	1.9	165.834	1.15E-08	0.0%	120	131.38894	9.13E-07	2.7%	3067	96.94388	3.16E-05	95.2%	12	62.49882	1.92E-07	0.6%	13	28.05376	4.63E-07	1.40%	3.32E-05	100.00%
	11-Dec-02	0.50	165.834	3.02E-09	0.0%	20	131.38894	1.52E-07	0.9%	1533	96.94388	1.58E-05	98.4%	5.7	62.49882	9.12E-08	0.6%	0.210	28.05376	7.49E-09	0.05%	1.61E-05	100.00%
	9-Apr-03	0.24	165.834	1.45E-09	0.0%	2,300	131.38894	1.75E-05	88.4%	222	96.94388	2.29E-06	11.6%	0.17	62.49882	2.72E-09	0.0%	0.035	28.05376	1.25E-09	0.01%	1.98E-05	100.00%
	20-Aug-03	0.24	165.834	1.45E-09	0.0%	2,200	131.38894	1.67E-05	77.1%	480	96.94388	4.95E-06	22.8%	0.71	62.49882	1.14E-08	0.1%	0.001	28.05376	4.99E-11	0.00%	2.17E-05	100.00%
	13-Apr-05	2.20	165.834	1.33E-08	0.2%	490	131.38894	3.73E-06	54.4%	300	96.94388	3.09E-06	45.2%	0.77	62.49882	1.23E-08	0.2%	0.030	28.05376	1.07E-09	0.02%	6.85E-06	100.00%
	16-Nov-05	0.45	165.834	2.71E-09	0.0%	28	131.38894	2.13E-07	3.8%	518	96.94388	5.34E-06	95.8%	1.00	62.49882	1.60E-08	0.3%	0.030	28.05376	1.07E-09	0.02%	5.58E-06	100.00%

TABLE C.1
MOLAR FRACTION OF CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

		PCE[a/]				TCE[a/]				cis+trans-1,2-DCE[a/]				VC[a/]				Ethene				Total CAH[a/]	
Well ID	Date	Concentration (µg/L[b/])	Molar Weight (g/mol)[c/]	Molar Concentration (mol/L[d/])	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Molar Concentration (mol/L)	Percent
PES-CW-1	13-Nov-01	1.9	165.834	1.15E-08	0.2%	630	131.38894	4.79E-06	95.5%	20	96.94388	2.01E-07	4.0%	0.85	62.49882	1.36E-08	0.3%	0.011	28.05376	3.92E-10	0.01%	5.02E-06	100.00%
	11-Feb-02	0.78	165.834	4.70E-09	0.3%	170	131.38894	1.29E-06	90.7%	12	96.94388	1.23E-07	8.6%	0.34	62.49882	5.44E-09	0.4%	0.011	28.05376	3.92E-10	0.03%	1.43E-06	100.00%
	20-May-02	0.39	165.834	2.35E-09	0.2%	170	131.38894	1.29E-06	91.9%	11	96.94388	1.08E-07	7.7%	0.17	62.49882	2.72E-09	0.2%	0.011	28.05376	3.92E-10	0.03%	1.41E-06	100.00%
	26-Aug-02	0.89	165.834	5.37E-09	0.6%	61	131.38894	4.64E-07	50.8%	43	96.94388	4.41E-07	48.3%	0.17	62.49882	2.72E-09	0.3%	0.011	28.05376	3.92E-10	0.04%	9.14E-07	100.00%
	9-Dec-02	0.53	165.834	3.20E-09	0.2%	250	131.38894	1.90E-06	93.3%	13	96.94388	1.29E-07	6.3%	0.30	62.49882	4.80E-09	0.2%	0.014	28.05376	4.99E-10	0.02%	2.04E-06	100.00%
	7-Apr-03	1.5	165.834	9.05E-09	1.7%	54	131.38894	4.11E-07	77.3%	11	96.94388	1.09E-07	20.4%	0.17	62.49882	2.72E-09	0.5%	0.013	28.05376	4.63E-10	0.09%	5.32E-07	100.00%
	18-Aug-03	2	165.834	1.21E-08	1.9%	67	131.38894	5.10E-07	81.3%	10	96.94388	1.02E-07	16.2%	0.17	62.49882	2.72E-09	0.4%	0.013	28.05376	4.63E-10	0.07%	6.27E-07	100.00%
PES-CW-2	13-Nov-01	1.9	165.834	1.15E-08	0.5%	290	131.38894	2.21E-06	94.8%	9.2	96.94388	9.49E-08	4.1%	0.85	62.49882	1.36E-08	0.6%	0.011	28.05376	3.92E-10	0.02%	2.33E-06	100.00%
	11-Feb-02	0.78	165.834	4.70E-09	0.2%	350	131.38894	2.66E-06	94.6%	13.8	96.94388	1.42E-07	5.1%	0.34	62.49882	5.44E-09	0.2%	0.011	28.05376	3.92E-10	0.01%	2.82E-06	100.00%
	20-May-02	0.39	165.834	2.35E-09	0.1%	210	131.38894	1.60E-06	94.1%	9.1	96.94388	9.39E-08	5.5%	0.17	62.49882	2.72E-09	0.2%	0.011	28.05376	3.92E-10	0.02%	1.70E-06	100.00%
	26-Aug-02	0.39	165.834	2.35E-09	0.1%	200	131.38894	1.52E-06	89.0%	17.7	96.94388	1.83E-07	10.7%	0.17	62.49882	2.72E-09	0.2%	0.011	28.05376	3.92E-10	0.02%	1.71E-06	100.00%
	9-Dec-02	0.25	165.834	1.51E-09	0.1%	230	131.38894	1.75E-06	95.2%	7.9	96.94388	8.15E-08	4.4%	0.30	62.49882	4.80E-09	0.3%	0.006	28.05376	2.14E-10	0.01%	1.84E-06	100.00%
	7-Apr-03	0.75	165.834	4.52E-09	0.5%	100	131.38894	7.61E-07	85.2%	12.1	96.94388	1.25E-07	14.0%	0.17	62.49882	2.72E-09	0.3%	0.011	28.05376	3.92E-10	0.04%	8.94E-07	100.00%
	19-Aug-03	1.30	165.834	7.84E-09	0.9%	87	131.38894	6.62E-07	79.5%	15.5	96.94388	1.60E-07	19.2%	0.17	62.49882	2.72E-09	0.3%	0.023	28.05376	8.20E-10	0.10%	8.33E-07	100.00%
	11-Apr-05	0.45	165.834	2.71E-09	0.3%	110	131.38894	8.37E-07	83.4%	16	96.94388	1.60E-07	15.9%	0.18	62.49882	2.88E-09	0.3%	0.023	28.05376	8.20E-10	0.08%	1.00E-06	100.00%
	14-Nov-05	0.66	165.834	3.98E-09	0.7%	63	131.38894	4.79E-07	87.7%	6	96.94388	5.97E-08	10.9%	0.18	62.49882	2.88E-09	0.5%	0.023	28.05376	8.20E-10	0.15%	5.47E-07	100.00%
PES-CW-3	13-Nov-01	0.78	165.834	4.70E-09	0.2%	240	131.38894	1.83E-06	95.9%	6.5	96.94388	6.66E-08	3.5%	0.34	62.49882	5.44E-09	0.3%	0.011	28.05376	3.92E-10	0.02%	1.90E-06	100.00%
	12-Feb-02	0.78	165.834	4.70E-09	0.2%	330	131.38894	2.51E-06	96.1%	8.8	96.94388	9.08E-08	3.5%	0.34	62.49882	5.44E-09	0.2%	0.011	28.05376	3.92E-10	0.02%	2.61E-06	100.00%
	20-May-02	0.39	165.834	2.35E-09	0.1%	200	131.38894	1.52E-06	94.4%	8.3	96.94388	8.56E-08	5.3%	0.17	62.49882	2.72E-09	0.2%	0.011	28.05376	3.92E-10	0.02%	1.61E-06	100.00%
	26-Aug-02	0.39	165.834	2.35E-09	0.1%	230	131.38894	1.75E-06	94.8%	8.7	96.94388	8.97E-08	4.9%	0.17	62.49882	2.72E-09	0.1%	0.011	28.05376	3.92E-10	0.02%	1.85E-06	100.00%
	10-Dec-02	0.25	165.834	1.51E-09	0.1%	220	131.38894	1.67E-06	95.5%	7.0	96.94388	7.20E-08	4.1%	0.30	62.49882	4.80E-09	0.3%	0.013	28.05376	4.63E-10	0.03%	1.75E-06	100.00%
	8-Apr-03	0.24	165.834	1.45E-09	0.1%	190	131.38894	1.45E-06	96.3%	5.0	96.94388	5.11E-08	3.4%	0.17	62.49882	2.72E-09	0.2%	0.011	28.05376	3.92E-10	0.03%	1.50E-06	100.00%
	19-Aug-03	0.24	165.834	1.45E-09	0.1%	160	131.38894	1.22E-06	92.0%	9.8	96.94388	1.01E-07	7.6%	0.17	62.49882	2.72E-09	0.2%	0.026	28.05376	9.27E-10	0.07%	1.32E-06	100.00%
	11-Apr-05	0.45	165.834	2.71E-09	0.3%	120	131.38894	9.13E-07	93.6%	5	96.94388	5.56E-08	5.7%	0.18	62.49882	2.88E-09	0.3%	0.026	28.05376	9.27E-10	0.10%	9.75E-07	100.00%
	14-Nov-05	0.45	165.834	2.71E-09	0.2%	140	131.38894	1.07E-06	93.0%	7	96.94388	7.32E-08	6.4%	0.18	62.49882	2.88E-09	0.3%	0.026	28.05376	9.27E-10	0.08%	1.15E-06	100.00%
PES-MW-10A	Apr-05	0.45	165.834	2.71E-09	0.1%	7	131.38894	5.18E-08	2.6%	185	96.94388	1.91E-06	96.5%	0.67	62.49882	1.07E-08	0.5%	0.110	28.05376	3.92E-09	0.20%	1.98E-06	100.00%
	Nov-05	0.45	165.834	2.71E-09	0.3%	1	131.38894	9.13E-09	1.0%	82	96.94388	8.50E-07	97.2%	0.56	62.49882	8.96E-09	1.0%	0.110	28.05376	3.92E-09	0.45%	8.75E-07	100.00%
PES-MW-10B	Apr-05	3.50	165.834	2.11E-08	4.8%	48	131.38894	3.65E-07	83.4%	5	96.94388	4.73E-08	10.8%	0.18	62.49882	2.88E-09	0.7%	0.045	28.05376	1.60E-09	0.37%	4.38E-07	100.00%
	Nov-05	3.90	165.834	2.35E-08	5.2%	49	131.38894	3.73E-07	82.4%	5	96.94388	5.15E-08	11.4%	0.18	62.49882	2.88E-09	0.6%	0.045	28.05376	1.60E-09	0.35%	4.52E-07	100.00%
PES-MW-11A	Apr-05	0.45	165.834	2.71E-09	0.1%	100	131.38894	7.61E-07	38.6%	117	96.94388	1.20E-06	61.0%	0.18	62.49882	2.88E-09	0.1%	0.066	28.05376	2.35E-09	0.12%	1.97E-06	100.00%
	Nov-05	0.45	165.834	2.71E-09	0.4%	48	131.38894	3.65E-07	54.4%	29	96.94388	2.98E-07	44.4%	0.18	62.49882	2.88E-09	0.4%	0.066	28.05376	2.35E-09	0.35%	6.71E-07	100.00%
PES-MW-12A	Apr-05	0.45	165.834	2.71E-09	0.3%	80	131.38894	6.09E-07	71.2%	23	96.94388	2.37E-07	27.8%	0.18	62.49882	2.88E-09	0.3%	0.080	28.05376	2.85E-09	0.33%	8.55E-07	100.00%
	Nov-05	0.90	165.834	5.43E-09	0.2%	350	131.38894	2.66E-06	93.0%	18	96.94388	1.86E-07	6.5%	0.36	62.49882	5.76E-09	0.2%	0.080	28.05376	2.85E-09	0.10%	2.86E-06	100.00%
PES-MW-12B	Apr-05	1.10	165.834	6.63E-09	0.2%	330	131.38894	2.51E-06	88.2%	31	96.94388	3.17E-07	11.1%	0.45	62.49882	7.20E-09	0.3%	0.180	28.05376	6.42E-09	0.23%	2.85E-06	100.00%
	Nov-05	0.90	165.834	5.43E-09	0.2%	290	131.38894	2.21E-06	91.4%	18	96.94388	1.89E-07	7.8%	0.36	62.49882	5.76E-09	0.2%	0.180	28.05376	6.42E-09	0.27%	2.41E-06	100.00%
PES-MW-13A	Apr-05	0.45	165.834	2.71E-09	0.1%	380	131.38894	2.89E-06	94.9%	14	96.94388	1.48E-07	4.8%	0.18	62.49882	2.88E-09	0.1%	0.042	28.05376	1.50E-09	0.05%	3.05E-06	100.00%
	Nov-05	1.10	165.834	6.63E-09	0.4%	230	131.38894	1.75E-06	93.2%	11	96.94388	1.11E-07	5.9%	0.45	62.49882	7.20E-09	0.4%	0.042	28.05376	1.50E-09	0.08%	1.88E-06	100.00%
PES-MW-14A	Apr-05	0.45	165.834	2.71E-09	0.0%	87	131.38894	6.62E-07	11.0%	515	96.94388	5.31E-06	88.6%	0.85	62.49882	1.36E-08	0.2%	0.180	28.05376	6.42E-09	0.11%	6.00E-06	100.00%
	Nov-05	2.20	165.834	1.33E-08	0.2%	87	131.38894	6.62E-07	10.9%	522	96.94388	5.38E-06	88.5%	1.30	62.49882	2.08E-08	0.3%	0.180	28.05376	6.42E-09	0.11%	6.09E-06	100.00%
PES-MW-14B	Apr-05	0.45	165.834	2.71E-09	0.3%	110	131.38894	8.37E-07	91.1%	7	96.94388	7.12E-08	7.7%	0.18	62.49882	2.88E-09	0.3%	0.140	28.05376	4.99E-09	0.54%	9.19E-07	100.00%
	Nov-05	0.45	165.834	2.71E-09	0.3%	110	131.38894	8.37E-07	91.3%	7	96.94388	6.91E-08	7.5%	0.18	62.49882	2.88E-09	0.3%	0.140	28.05376	4.99E-09	0.54%	9.17E-07	100.00%
PES-INJ-1	19-Nov-01	3.90	165.834	2.35E-08	0.2%	1,400	131.38894	1.07E-05	96.2%	36	96.94388	3.71E-07	3.4%	1.7	62.49882	2.72E-08	0.2%	0.011	28.05376	3.92E-10	0.00%	1.11E-05	100.00%
	18-Feb-02	3.90	165.834	2.35E-08	3.0%	70	131.38894	5.33E-07	68.5%	19	96.94388	1.94E-07	24.9%	1.7	62.49882	2.72E-08	3.5%	0.011	28.05376	3.92E-10	0.05%	7.78E-07	100.00%
	23-May-02	0.39	165.834	2.35E-09	0.4%	47	131.38894	3.58E-07	68.1%	16	96.94388	1.62E-07	30.8%	0.17	62.49882	2.72E-09	0.5%	0.011	28.05376	3.92E-10	0.07%	5.25E-07	100.00%
	29-Aug-02	0.39	165.834	2.35E-09	0.1%	29	131.38894	2.21E-07	12.2%	12	96.94388	1.23E-07	6.8%	0.17	62.49882	2.72E-09	0.2%	41	28.05376	1.46E-06	80.74%	1.81E-06	100.00%
	13-Dec-02	0.25	165.834	1.51E-09	0.1%	37	131.38894	2.82E-07	20.5%	22	96.94388	2.23E-07	16.2%	0.83	62.49882	1.33E-08	1.0%	24	28.05376	8.56E-07	62.23%	1.37E-06	100.00%
	10-Apr-03	0.24	165.834	1.45E-09	0.1%	66	131.38894	5.02E-07	51.8%	18	96.94388	1.86E-07	19.1%	0.63	62.49882	1.01E-08	1.0%	7.6	28.05376	2.71E-07	27.92%	9.70E-07	100.00%
	22-Aug-03	0.24	165.834	1.45E-09	0.1%	20	131.38894	1.52E-07	12.2%	19	96.94388	1.94E-07	15.5%	0.7	62.49882	1.12E-08	0.9%	25	28.05376	8.91E-07	71.30%	1.25E-06	100.00%
	19-Apr-05	1.80	165.834	1.09E-08	2.6%	10	131.38894	7.61E-08	18.4%	15	96.94388	1.51E-07	36.5%	0.72	62.49882	1.15E-08	2.8%	4.6	28.05376	1.64E-07	39.70%	4.13E-07	100.00%

TABLE C.1

MOLAR FRACTION OF CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER

NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY

ANOKA COUNTY PARK

FRIDLEY, MINNESOTA

		PCE[a/]				TCE[a/]				cis+trans-1,2-DCE[a/]				VC[a/]				Ethene				Total CAH[a/]	
Well ID	Date	Concentration (µg/L[b/])	Molar Weight (g/mol)[c/]	Molar Concentration (mol/L[d/])	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Concentration (µg/L)	Molar Weight (g/mol)	Molar Concentration (mol/L)	Molar Fraction (percent)	Molar Concentration (mol/L)	Percent
PES-INJ-2	19-Nov-01	1.9	165.834	1.15E-08	0.2%	630	131.38894	4.79E-06	96.1%	16.5	96.94388	1.70E-07	3.4%	0.85	62.49882	1.36E-08	0.3%	0.011	28.05376	3.92E-10	0.01%	4.99E-06	100.00%
	15-Feb-02	3.9	165.834	2.35E-08	4.4%	45	131.38894	3.42E-07	64.0%	13.7	96.94388	1.41E-07	26.4%	1.70	62.49882	2.72E-08	5.1%	0.011	28.05376	3.92E-10	0.07%	5.35E-07	100.00%
	23-May-02	0.39	165.834	2.35E-09	0.9%	25	131.38894	1.90E-07	71.8%	6.7	96.94388	6.91E-08	26.1%	0.17	62.49882	2.72E-09	1.0%	0.011	28.05376	3.92E-10	0.15%	2.65E-07	100.00%
	29-Aug-02	0.39	165.834	2.35E-09	0.8%	16	131.38894	1.22E-07	42.5%	5.8	96.94388	5.98E-08	20.9%	0.17	62.49882	2.72E-09	0.9%	2.8	28.05376	9.98E-08	34.84%	2.86E-07	100.00%
	13-Dec-02	0.25	165.834	1.51E-09	0.6%	18	131.38894	1.37E-07	53.5%	6.1	96.94388	6.29E-08	24.6%	0.30	62.49882	4.80E-09	1.9%	1.4	28.05376	4.99E-08	19.48%	2.56E-07	100.00%
	11-Apr-03	0.24	165.834	1.45E-09	0.6%	16	131.38894	1.22E-07	52.8%	5.3	96.94388	5.47E-08	23.7%	0.17	62.49882	2.72E-09	1.2%	1.4	28.05376	4.99E-08	21.65%	2.31E-07	100.00%
	22-Aug-03	0.24	165.834	1.45E-09	0.5%	13	131.38894	9.89E-08	31.3%	5.1	96.94388	5.26E-08	16.6%	0.17	62.49882	2.72E-09	0.9%	4.5	28.05376	1.60E-07	50.74%	3.16E-07	100.00%
	19-Apr-05	0.45	165.834	2.71E-09	0.9%	14	131.38894	1.07E-07	35.9%	4.8	96.94388	4.95E-08	16.7%	0.18	62.49882	2.88E-09	1.0%	3.8	28.05376	1.35E-07	45.59%	2.97E-07	100.00%
PES-INJ-3	16-Nov-01	3.9	165.834	2.35E-08	0.4%	760	131.38894	5.78E-06	95.9%	19	96.94388	1.96E-07	3.2%	1.7	62.49882	2.72E-08	0.5%	0.011	28.05376	3.92E-10	0.01%	6.03E-06	100.00%
	18-Feb-02	3.9	165.834	2.35E-08	5.7%	29	131.38894	2.21E-07	53.4%	14	96.94388	1.41E-07	34.2%	1.7	62.49882	2.72E-08	6.6%	0.011	28.05376	3.92E-10	0.09%	4.13E-07	100.00%
	23-May-02	0.39	165.834	2.35E-09	1.1%	21	131.38894	1.60E-07	77.0%	4.1	96.94388	4.22E-08	20.3%	0.17	62.49882	2.72E-09	1.3%	0.011	28.05376	3.92E-10	0.19%	2.07E-07	100.00%
	29-Aug-02	3.9	165.834	2.35E-08	8.8%	10	131.38894	7.61E-08	28.3%	14	96.94388	1.41E-07	52.6%	1.7	62.49882	2.72E-08	10.1%	0.011	28.05376	3.92E-10	0.15%	2.69E-07	100.00%
	13-Dec-02	0.25	165.834	1.51E-09	0.7%	12	131.38894	9.13E-08	43.8%	6.6	96.94388	6.81E-08	32.7%	0.3	62.49882	4.80E-09	2.3%	1.2	28.05376	4.28E-08	20.52%	2.08E-07	100.00%
	11-Apr-03	0.24	165.834	1.45E-09	0.8%	10	131.38894	7.46E-08	40.7%	5.3	96.94388	5.47E-08	29.8%	0.17	62.49882	2.72E-09	1.5%	1.4	28.05376	4.99E-08	27.22%	1.83E-07	100.00%
	22-Aug-03	0.24	165.834	1.45E-09	0.5%	10	131.38894	7.61E-08	27.9%	5.9	96.94388	6.09E-08	22.3%	0.17	62.49882	2.72E-09	1.0%	3.7	28.05376	1.32E-07	48.31%	2.73E-07	100.00%
	19-Apr-05	0.45	165.834	2.71E-09	1.1%	9	131.38894	6.62E-08	25.7%	5.2	96.94388	5.36E-08	20.8%	0.18	62.49882	2.88E-09	1.1%	3.7	28.05376	1.32E-07	51.25%	2.57E-07	100.00%
	17-Nov-05	9.00	165.834	5.43E-08	10.3%	15	131.38894	1.14E-07	21.6%	17.5	96.94388	1.81E-07	34.2%	3.60	62.49882	5.76E-08	10.9%	3.4	28.05376	1.21E-07	22.96%	5.28E-07	100.00%

NOTE: Non-detects are listed as zero for plotting purposes.

[a/] PCE = tetrachloroethene; TCE = trichloroethene; DCE = dichloroethene; VC = vinyl chloride; CAH = clhlorinated aliphatic hydrocarbons

[b/] µg/L = micrograms per liter.

[c/] g/mol = grams per mol.

[d/] mol/L = moles per liter.

FIGURE C.1A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL GWMS-27S
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

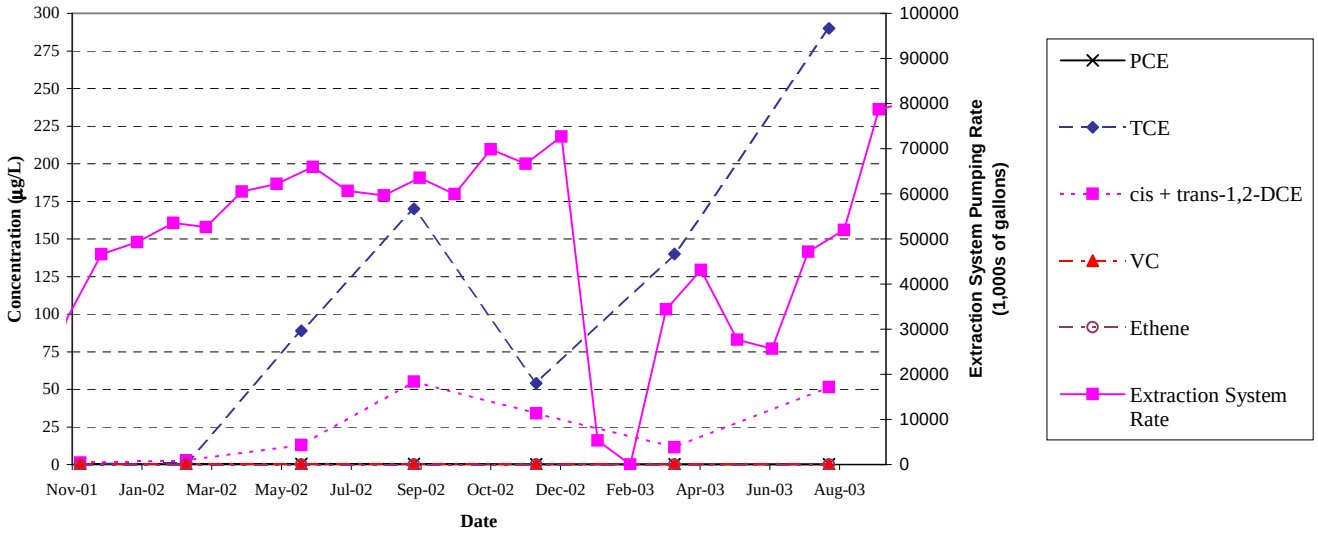


FIGURE C.1B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL GWMS-27S
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

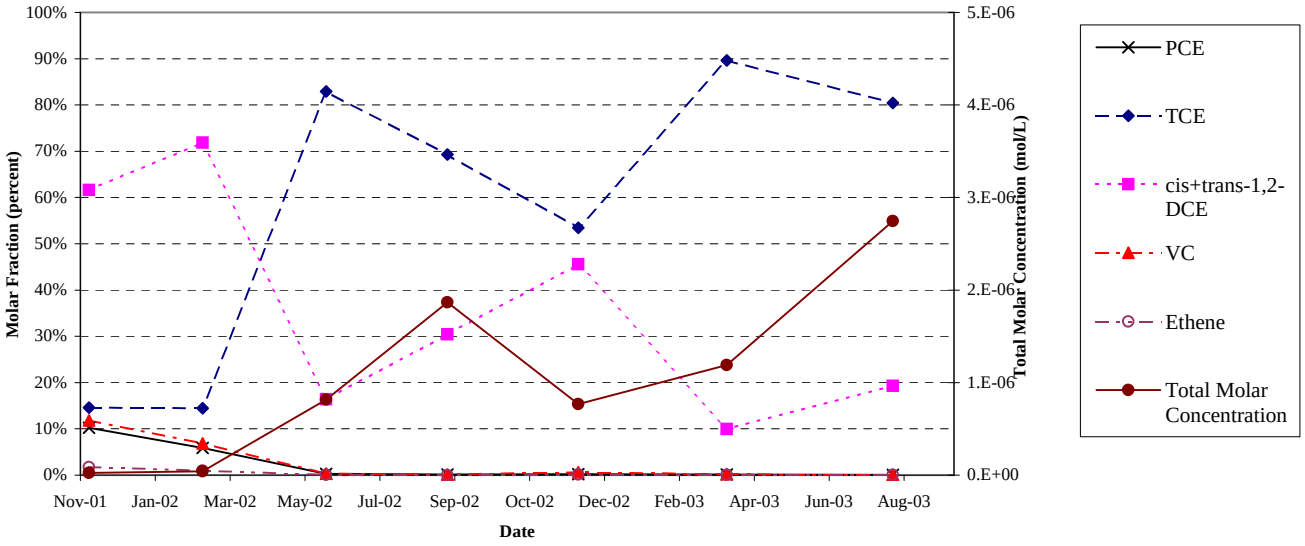


FIGURE C.2A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL GWMS-47S
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

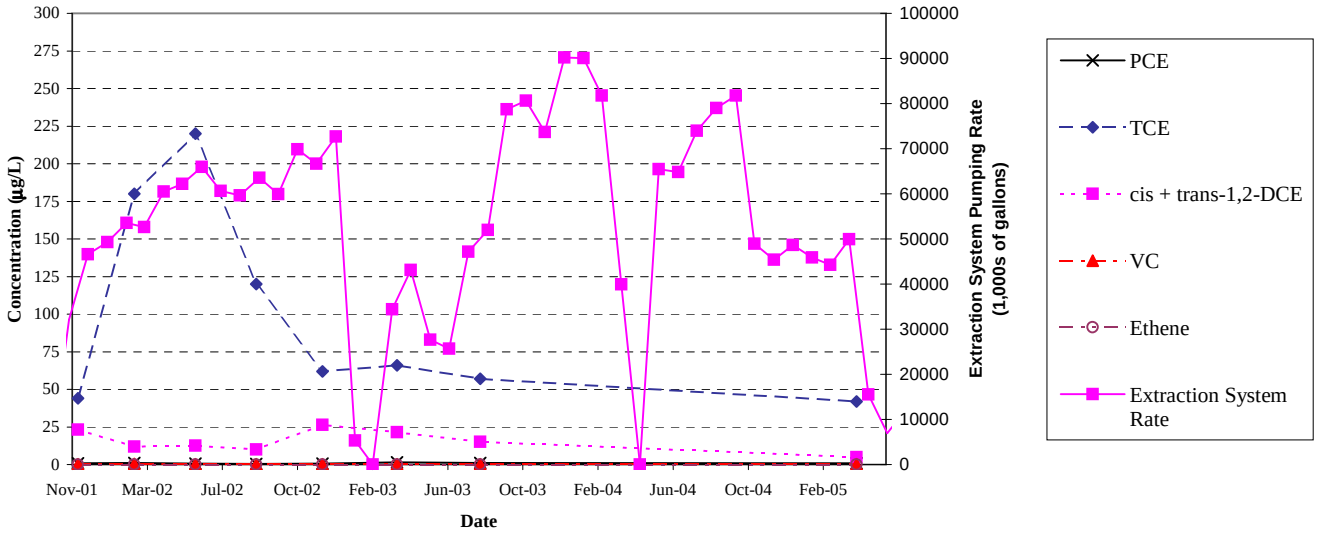


FIGURE C.2B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL GWMS-47S
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

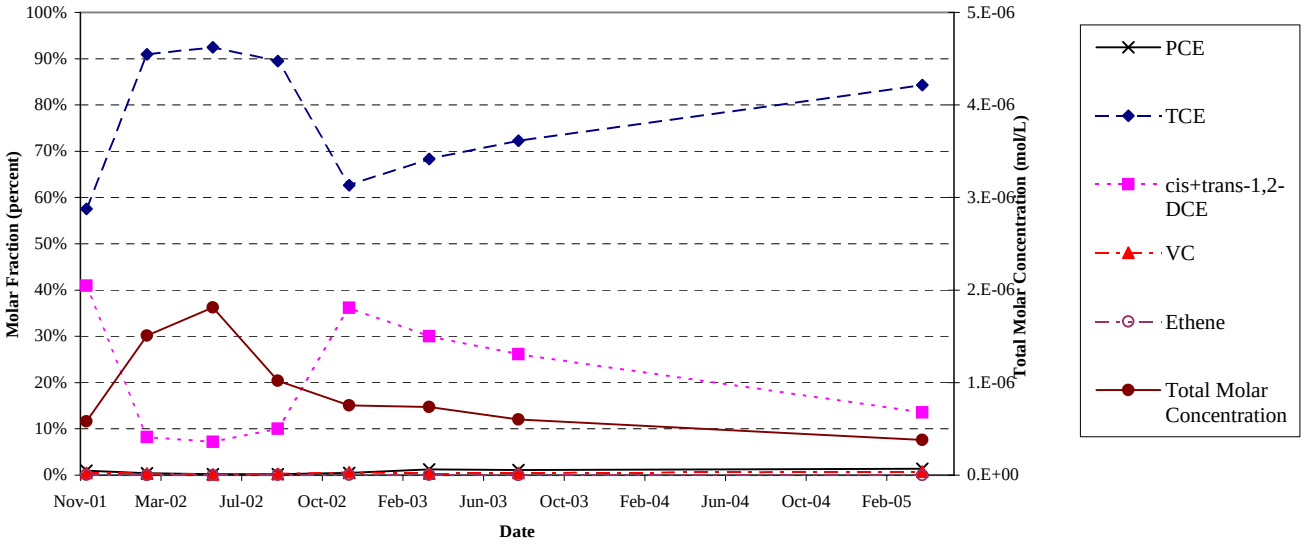


FIGURE C.3A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL GWMS-46S
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

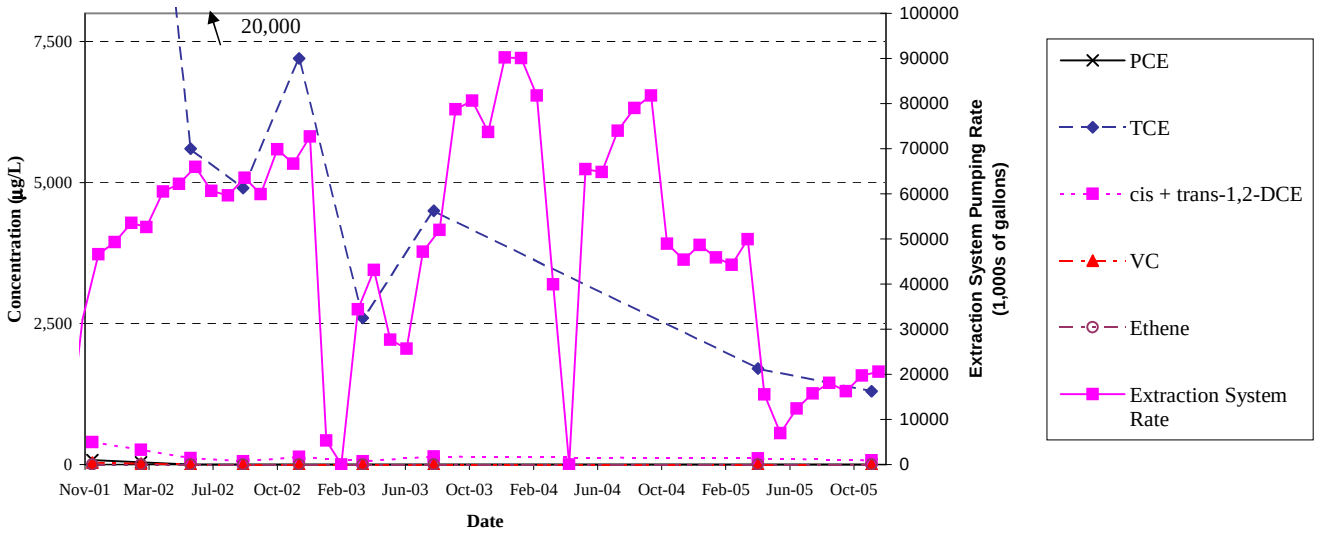


FIGURE C.3B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL GWMS-46S
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

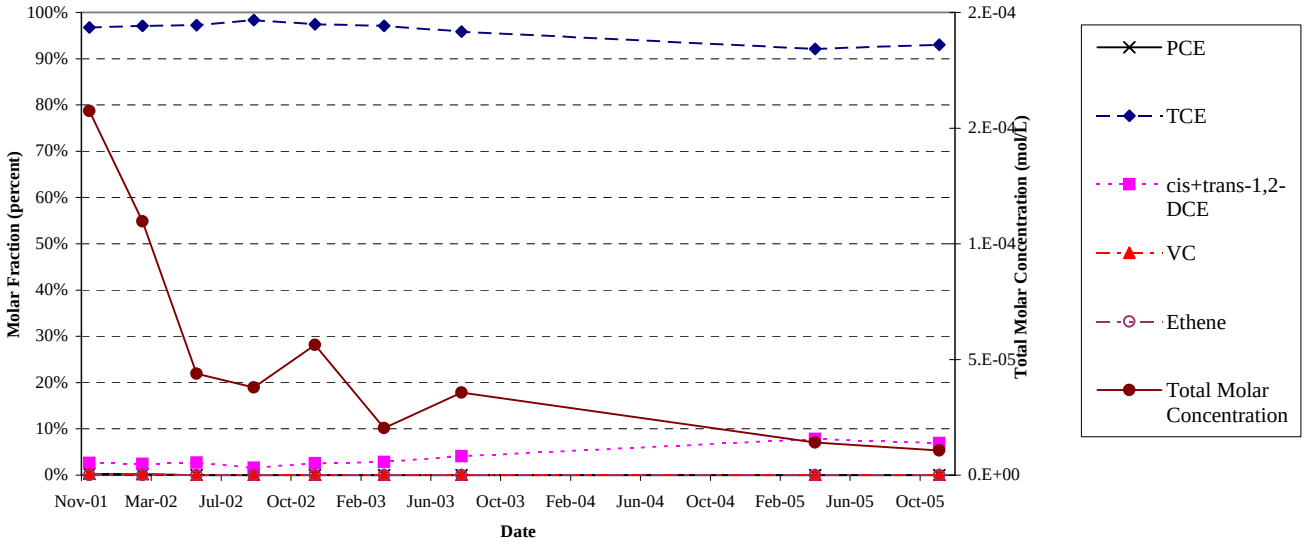


FIGURE C.4A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW-1
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

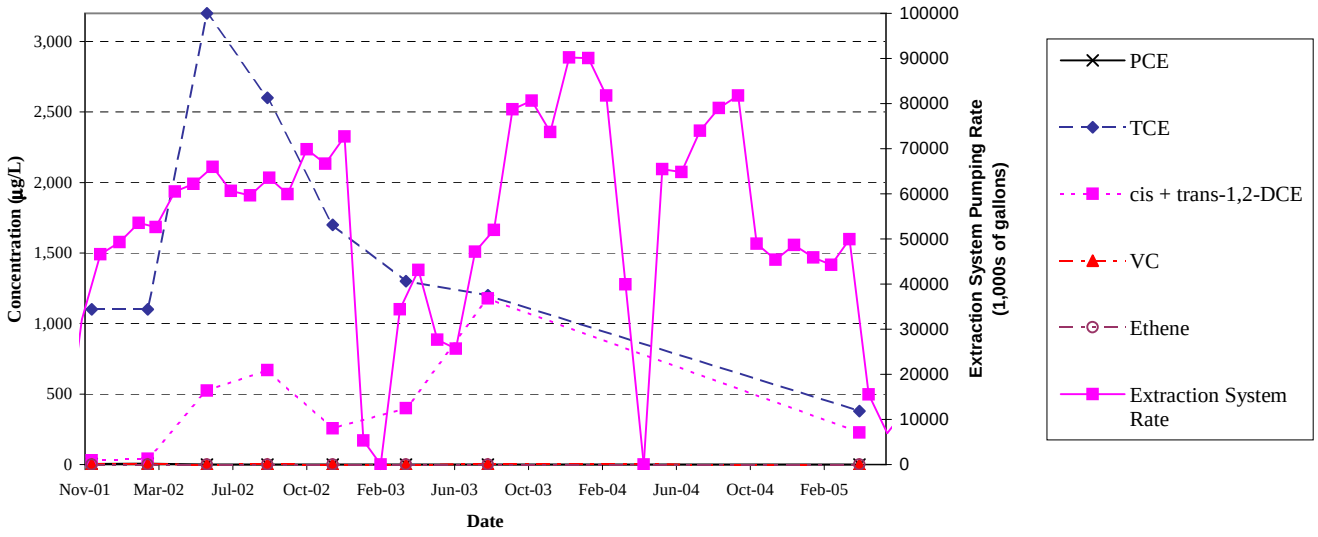


FIGURE C.4B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW-1
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

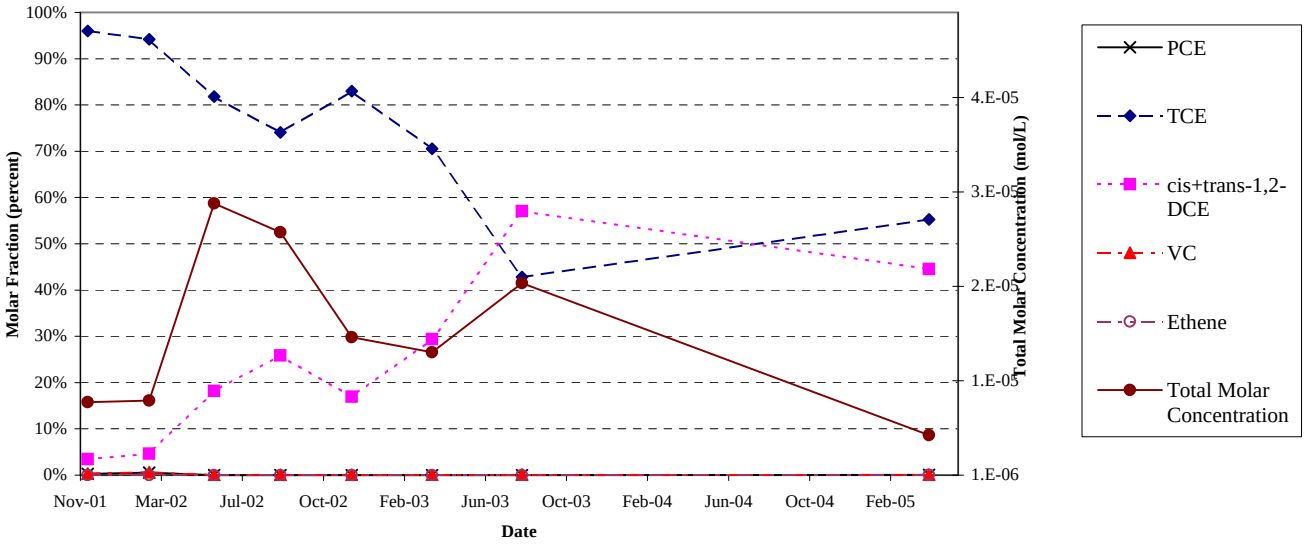


FIGURE C.5A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW-2
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

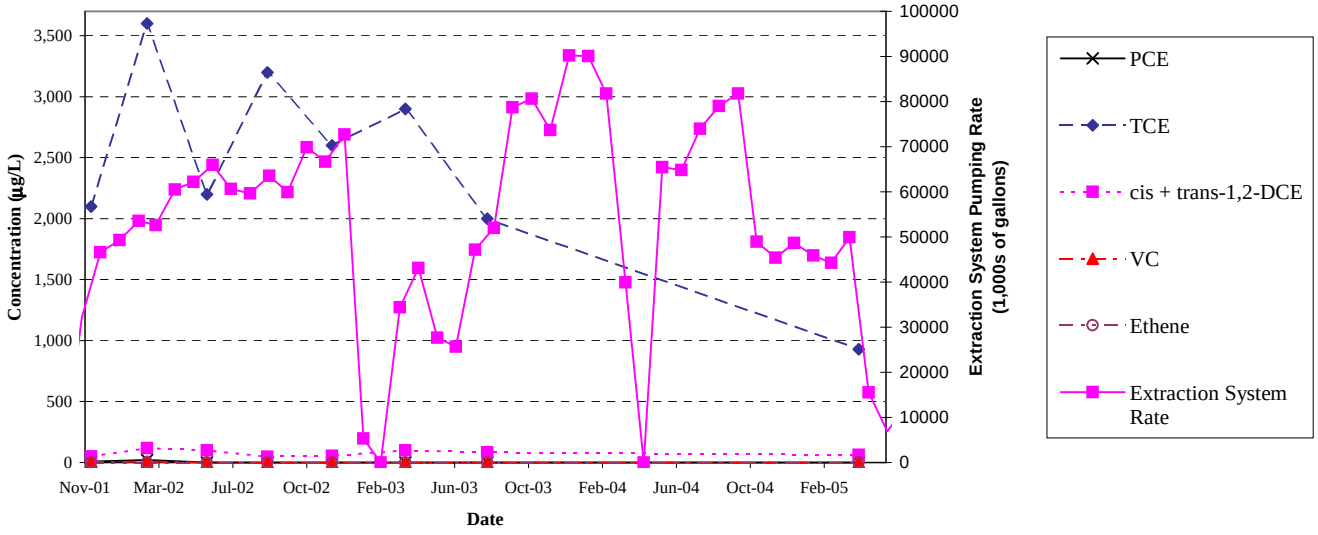


FIGURE C.5B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW-2
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

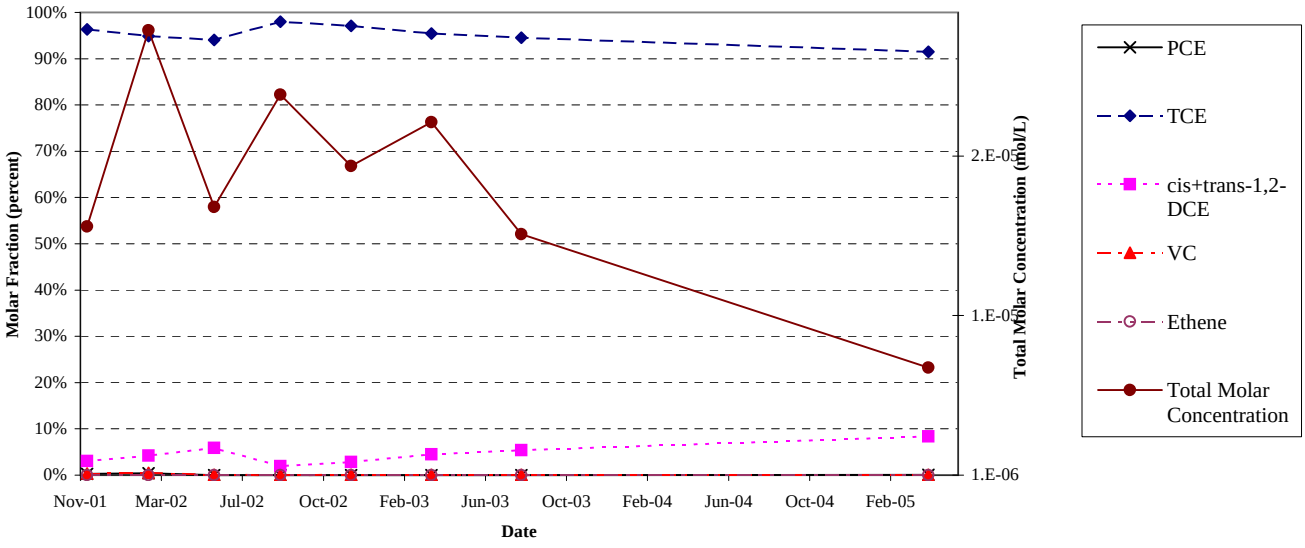


FIGURE C.6A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW-3
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

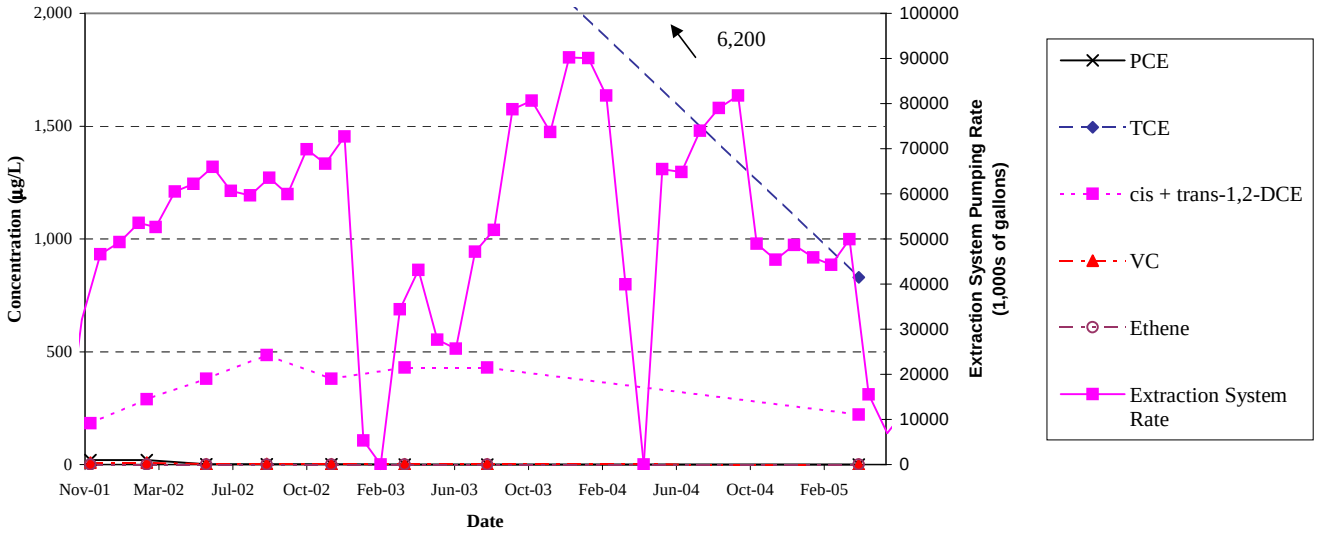


FIGURE C.6B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW-3
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

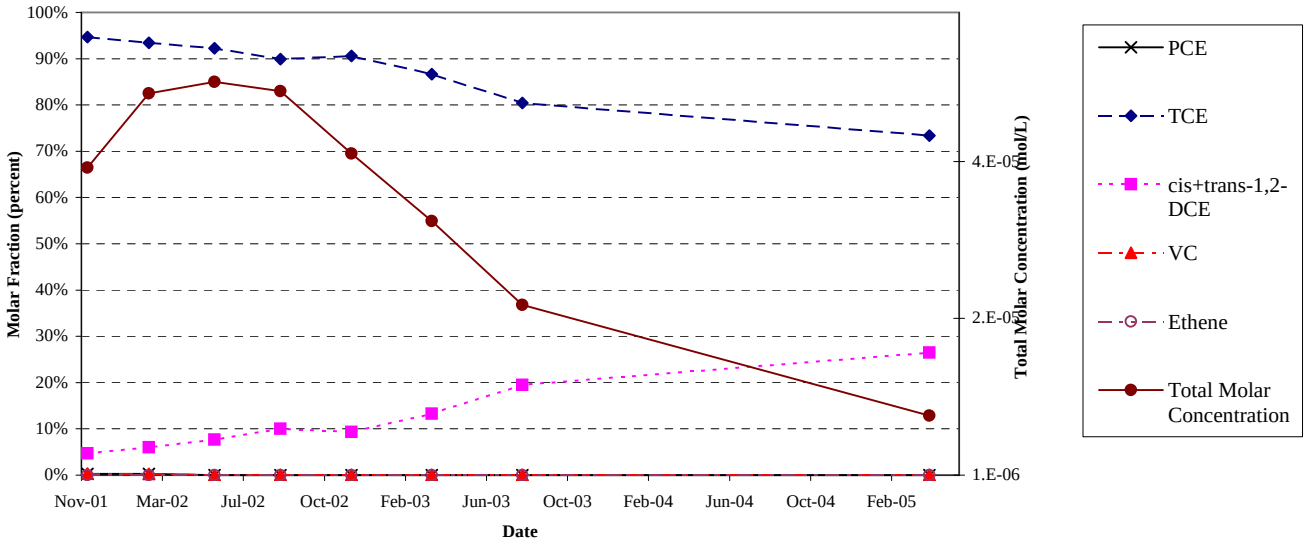


FIGURE C.7A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW-4
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

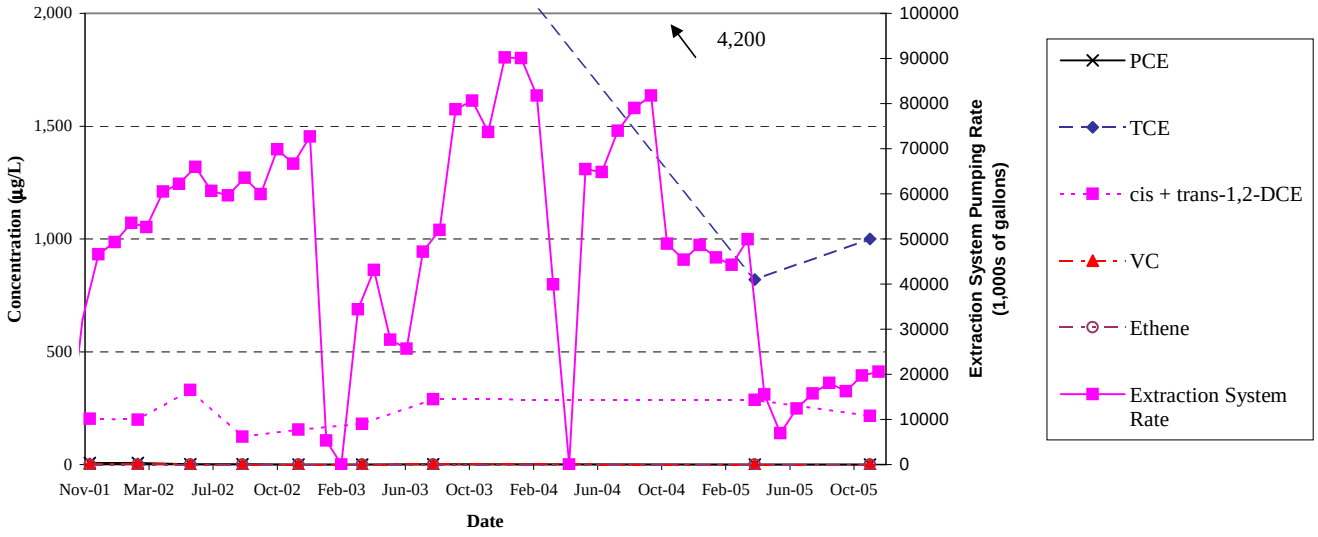


FIGURE C.7B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW-4
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

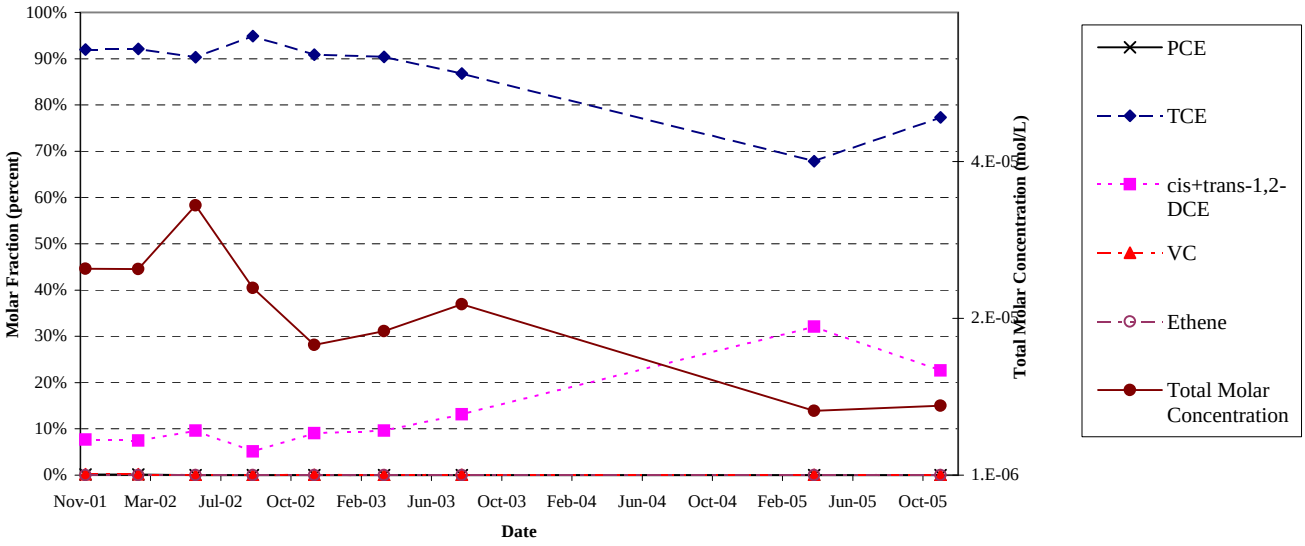


FIGURE C.8A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW-5
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

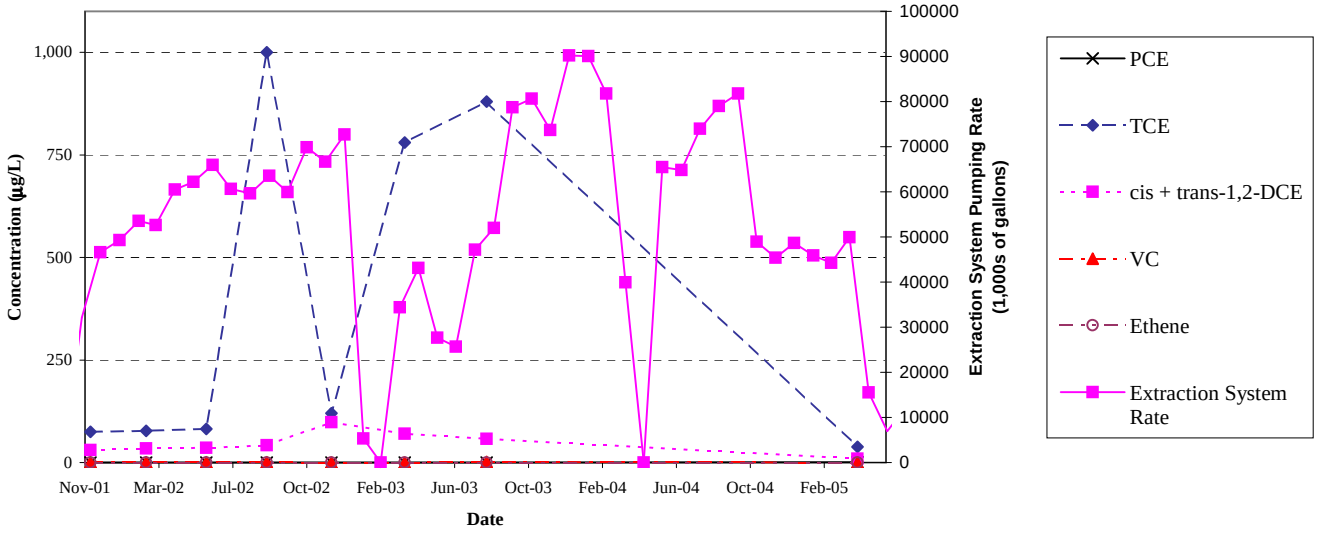


FIGURE C.8B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW-5
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

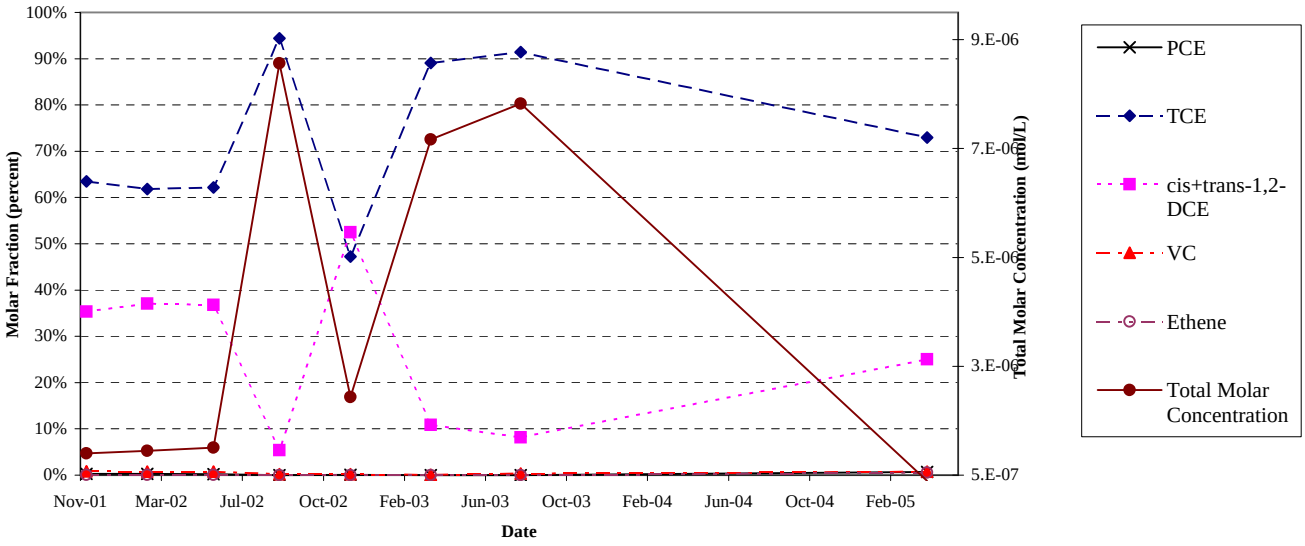


FIGURE C.9A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW-6
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

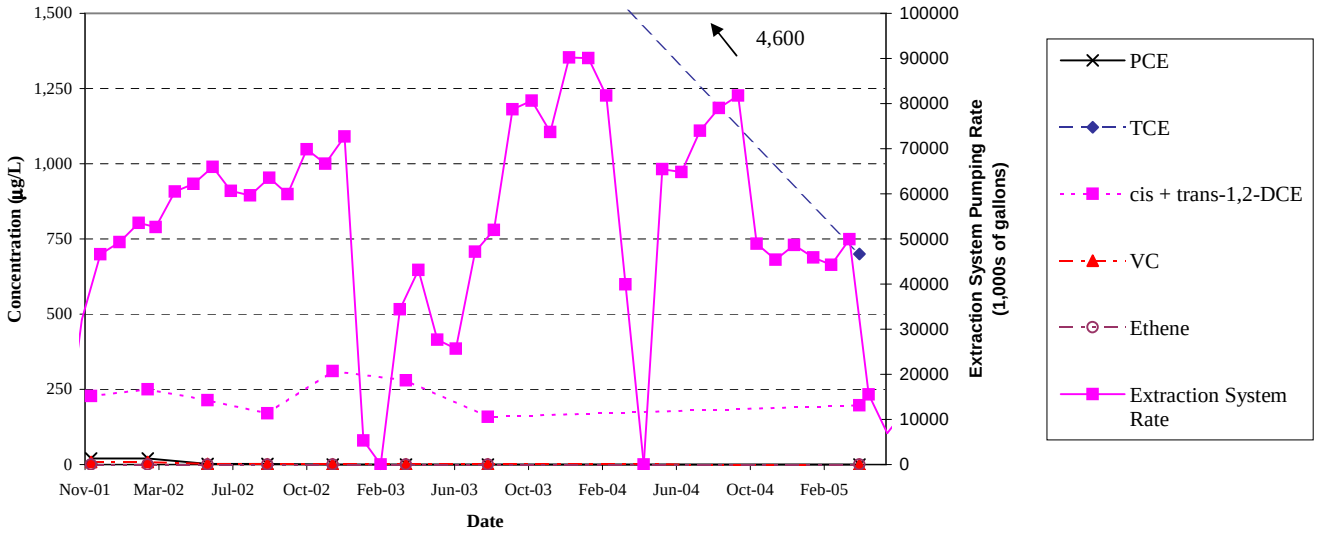


FIGURE C.9B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW-6
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

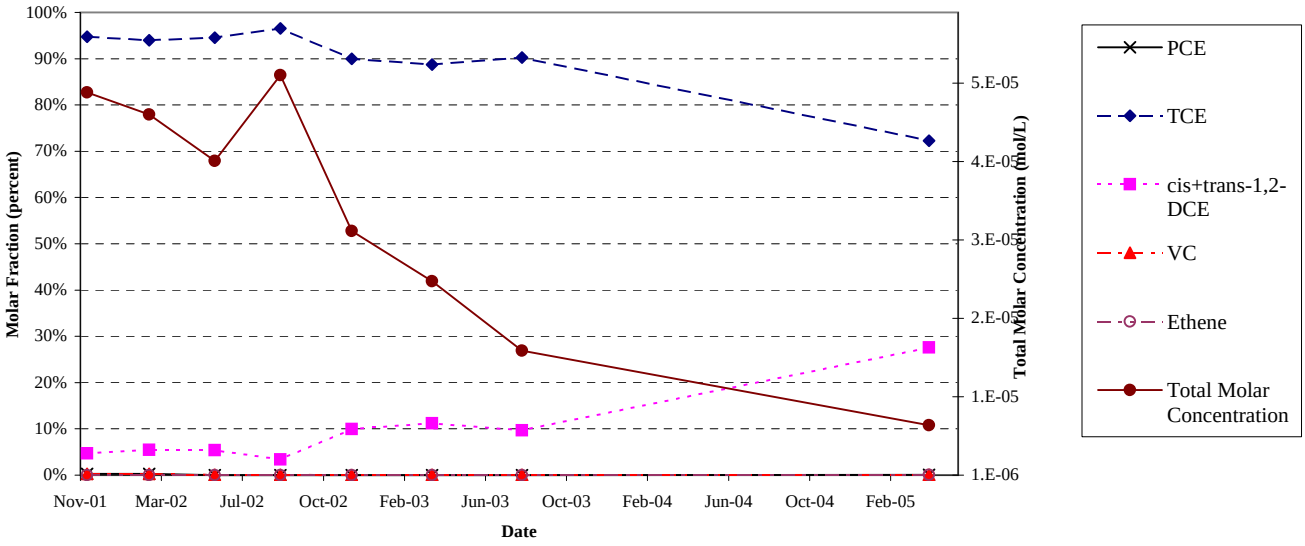


FIGURE C.10A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW-7
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

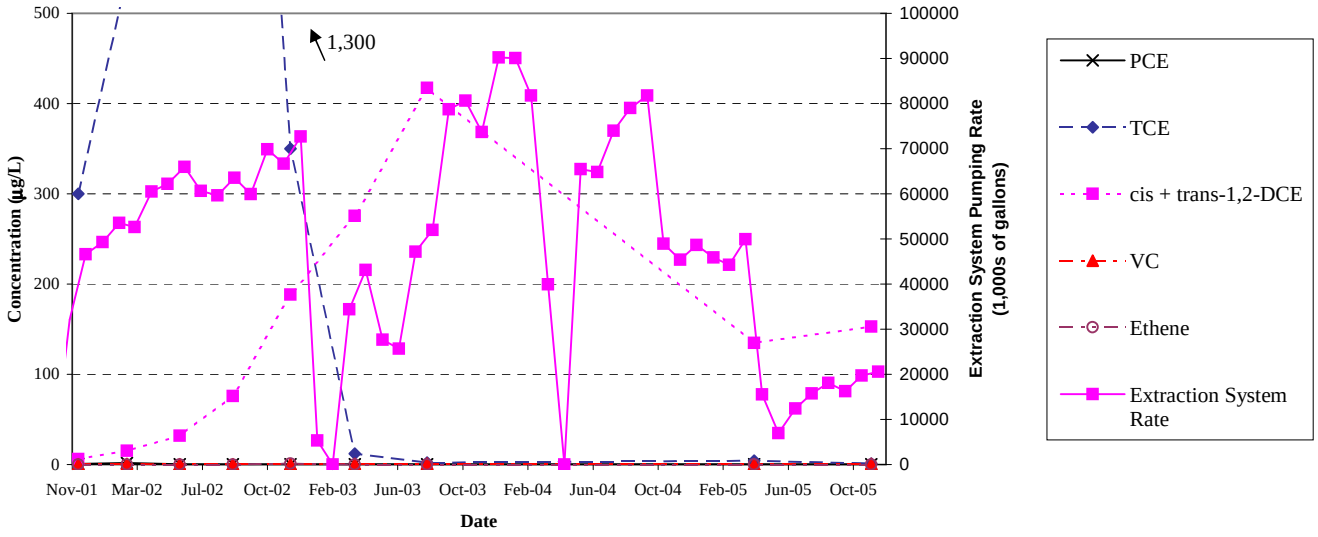


FIGURE C.10B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW-7
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

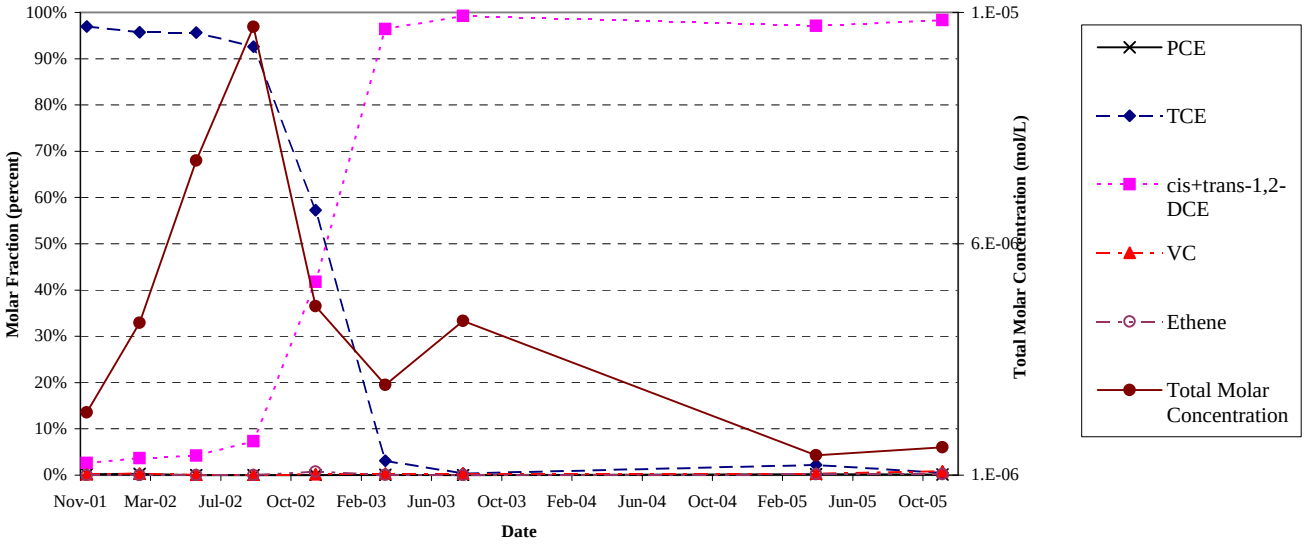


FIGURE C.11A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW-8
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

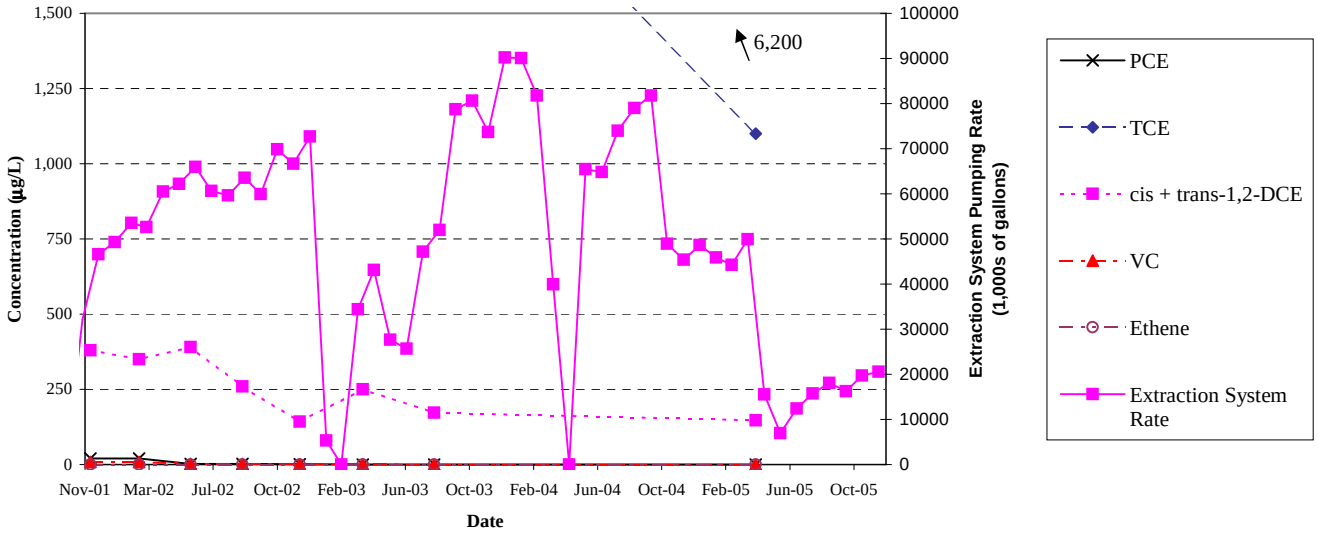


FIGURE C.11B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW-8
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

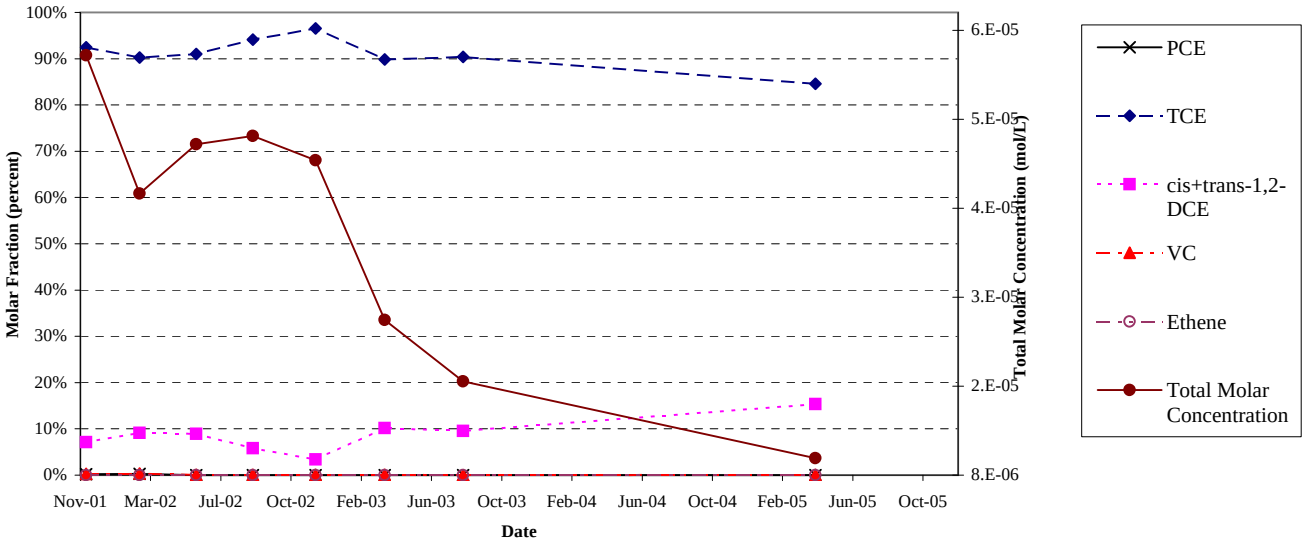


FIGURE C.12A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-MW-9
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

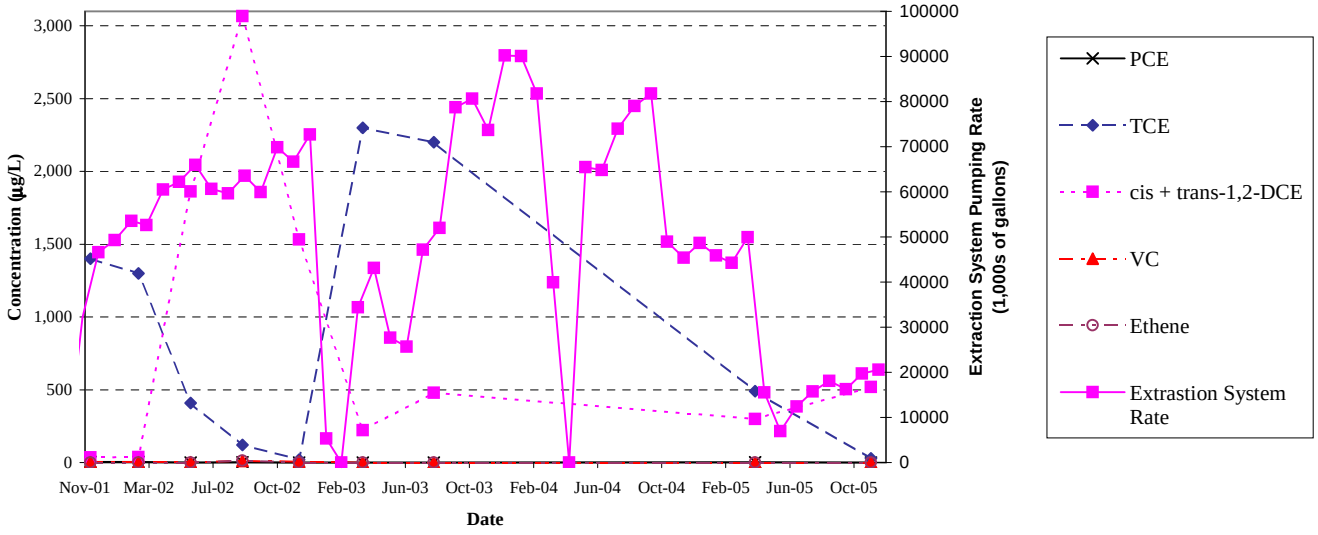


FIGURE C.12B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-MW-9
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

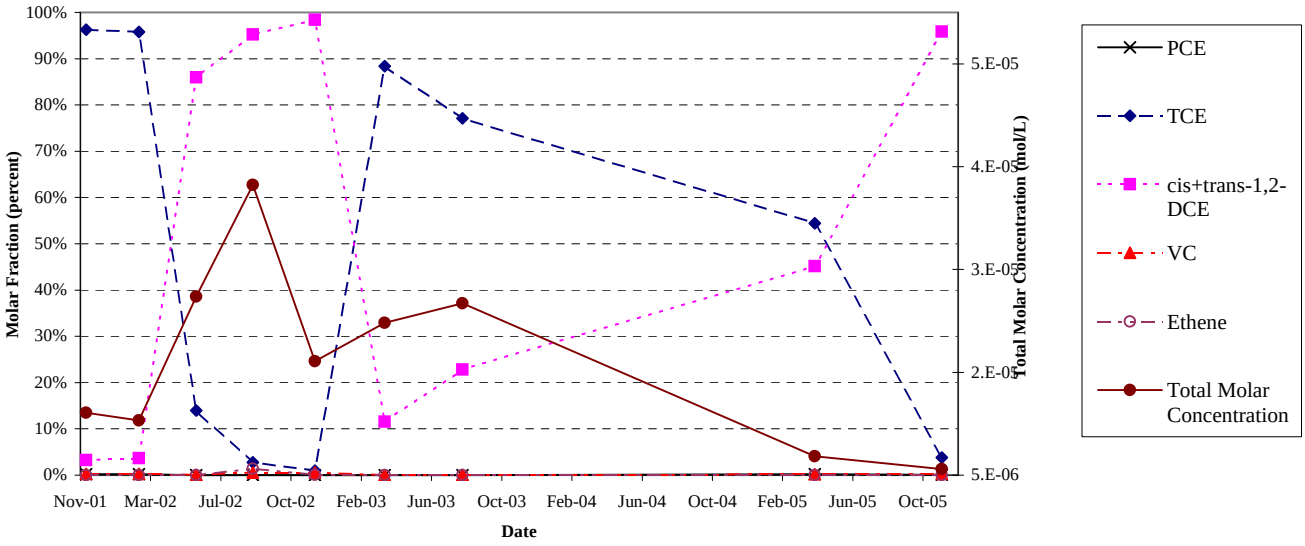


FIGURE C.13A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-CW-1
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

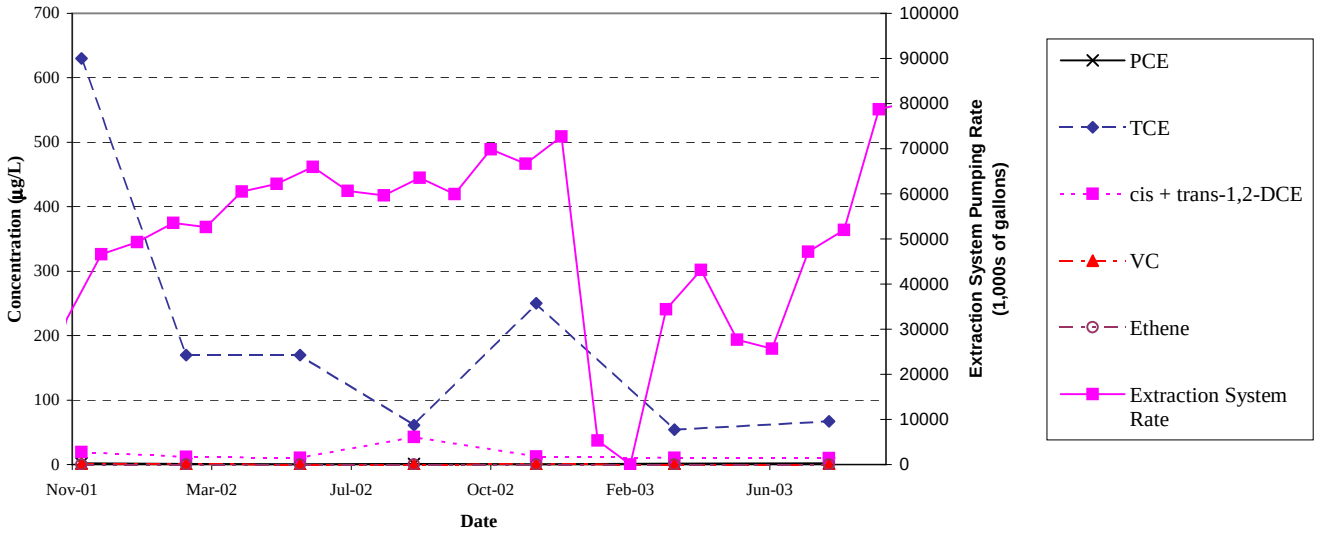


FIGURE C.13B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-CW-1
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

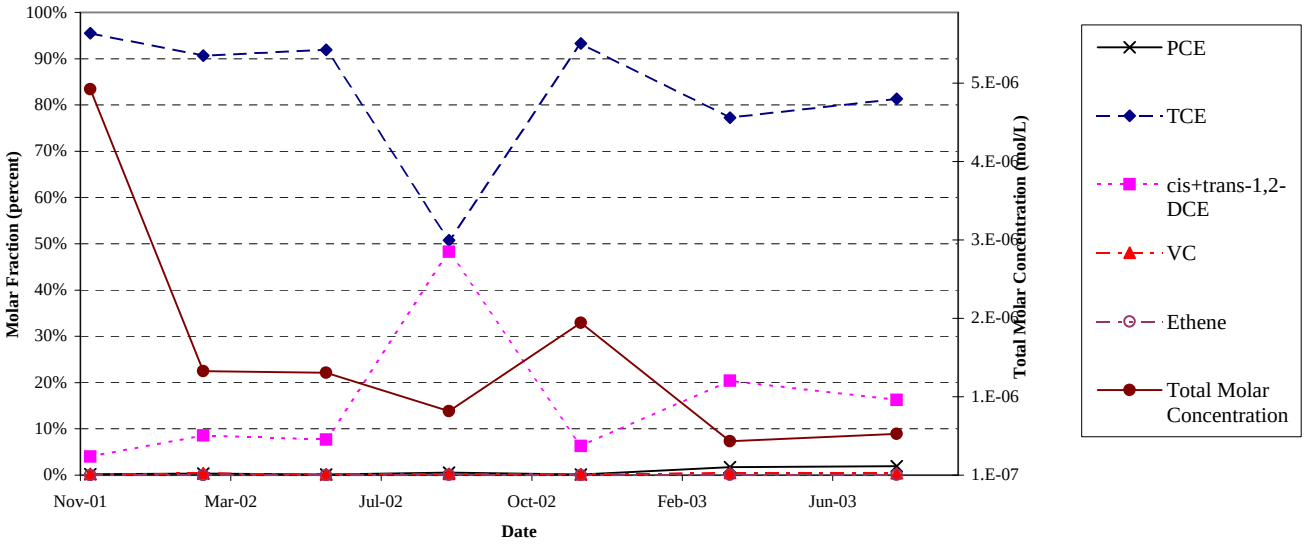


FIGURE C.14A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-CW-2
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

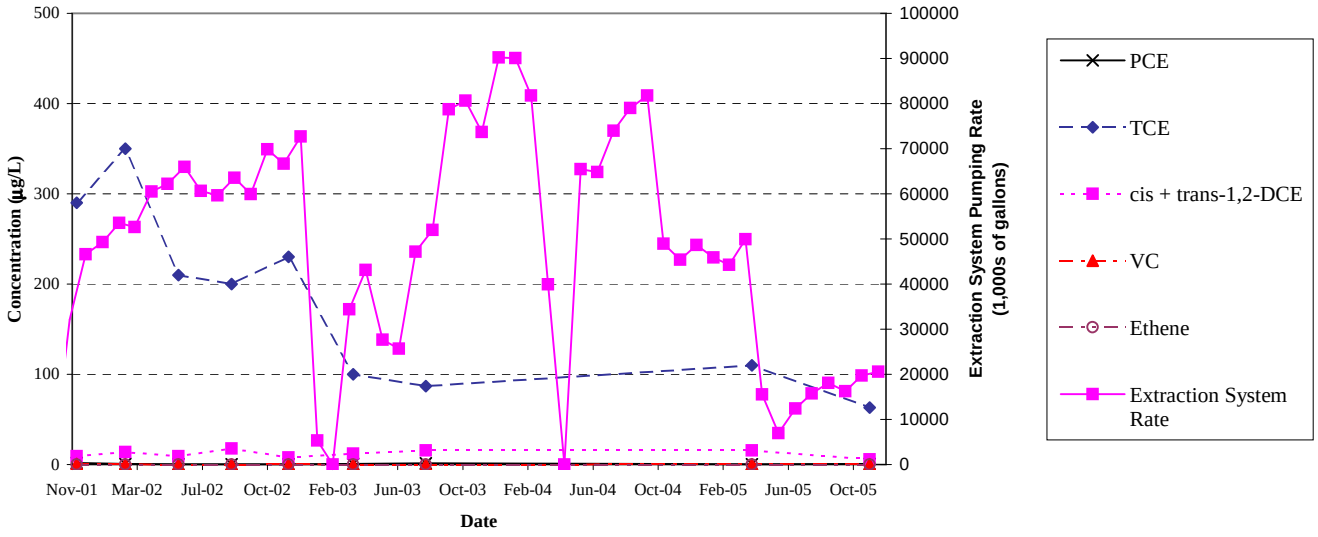


FIGURE C.14B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-CW-2
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

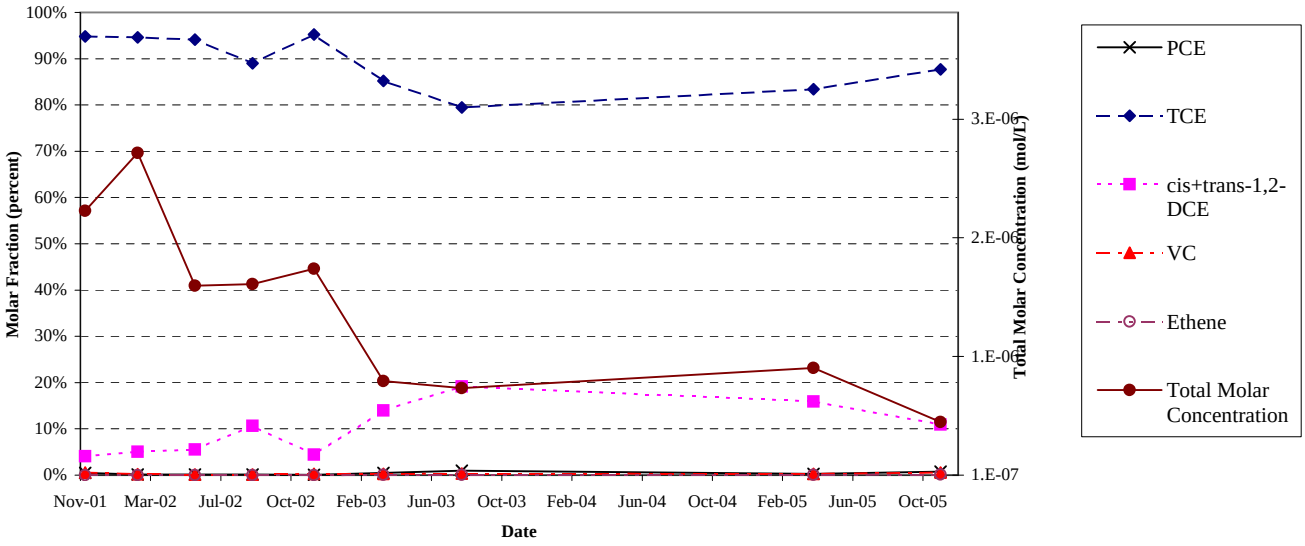


FIGURE C.15A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-CW-3
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

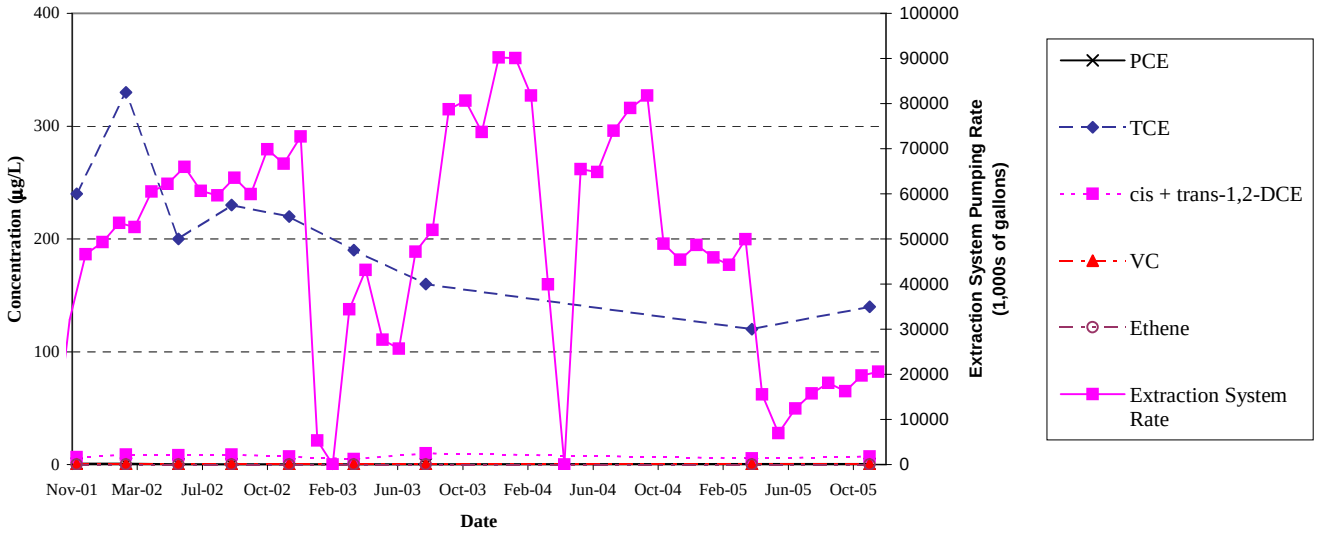


FIGURE C.15B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-CW-3
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

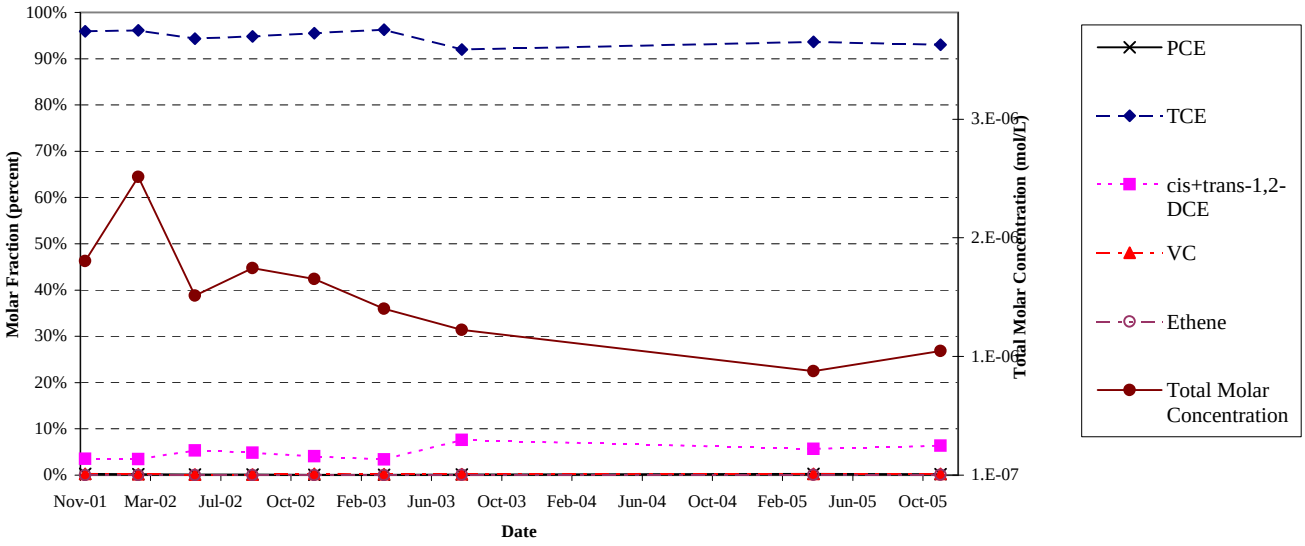


FIGURE C.16A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-INJ-1
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

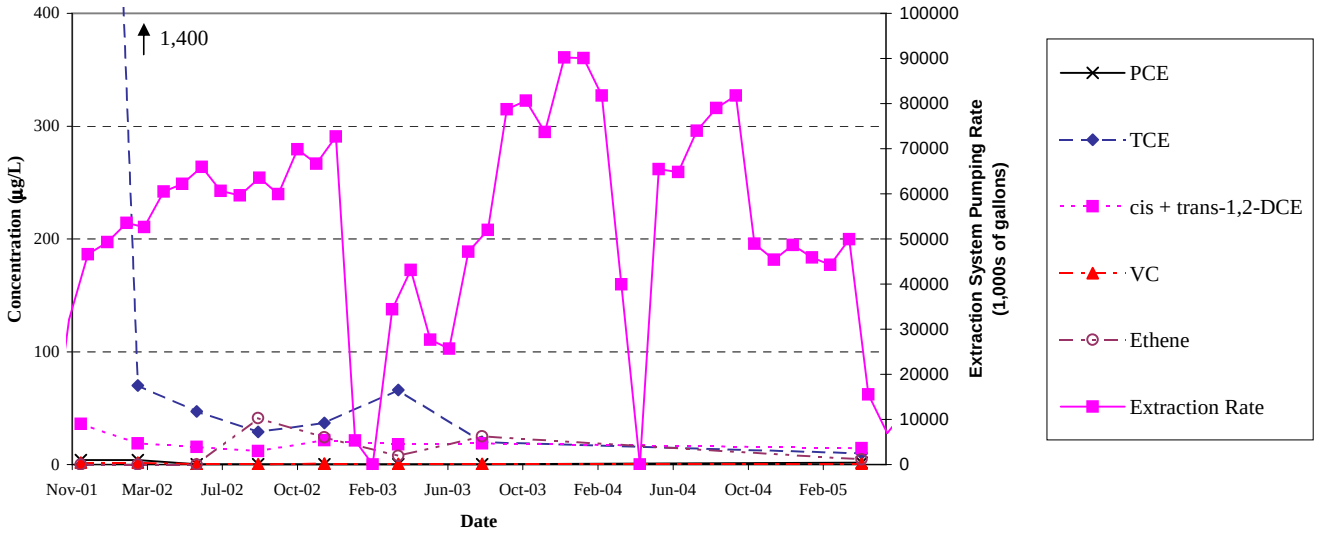


FIGURE C.16B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-INJ-1
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

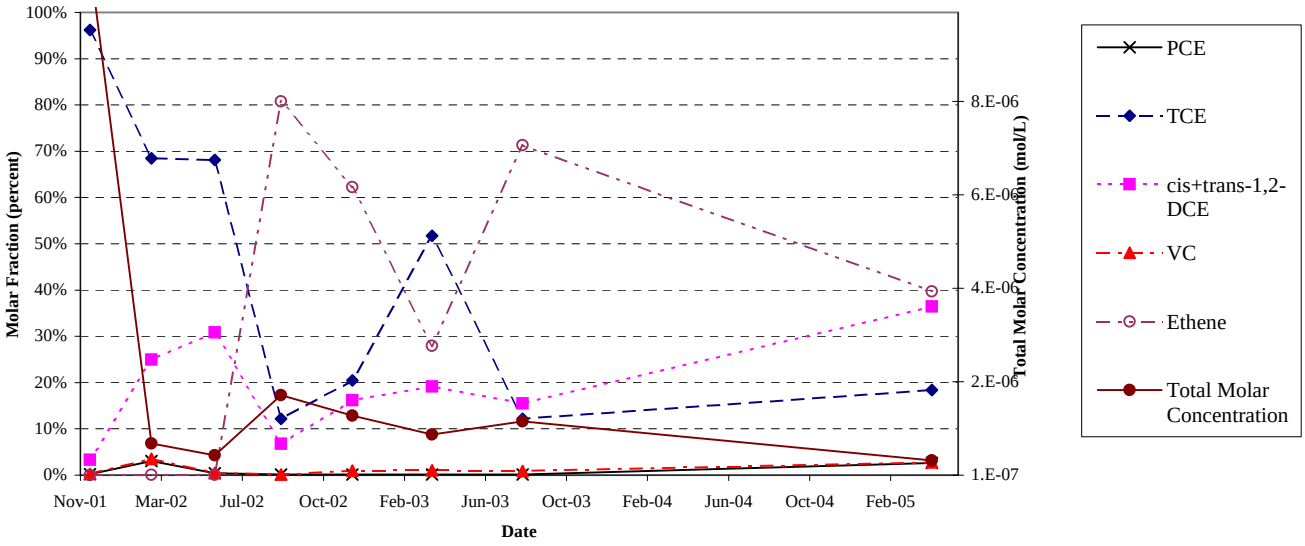


FIGURE C.17A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-INJ-2
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

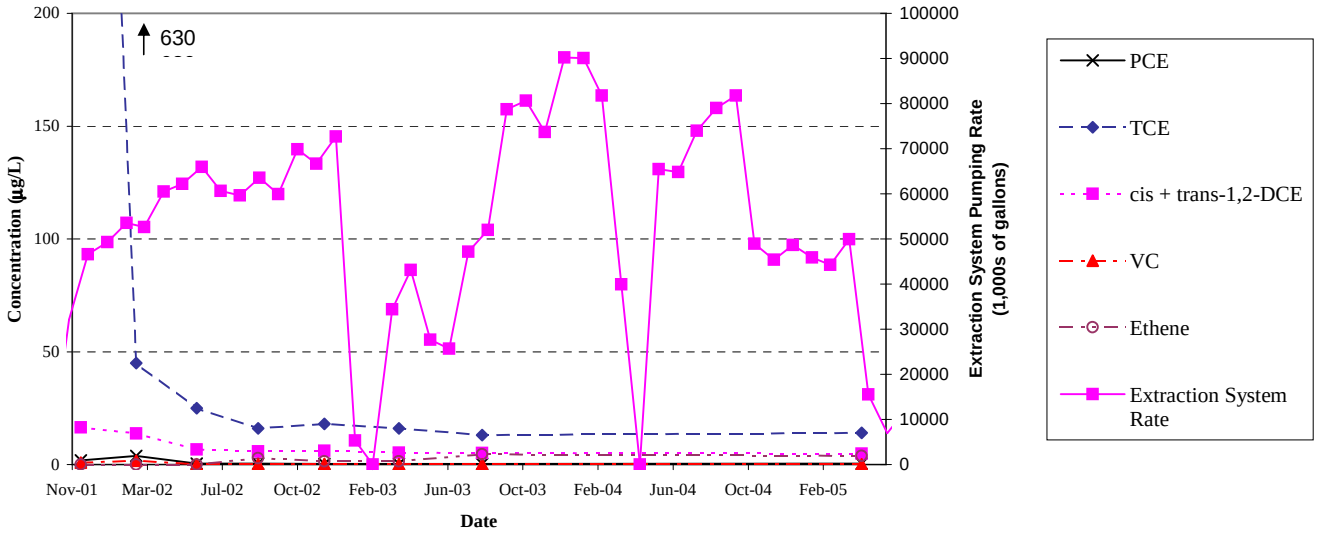


FIGURE C.17B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-INJ-2
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

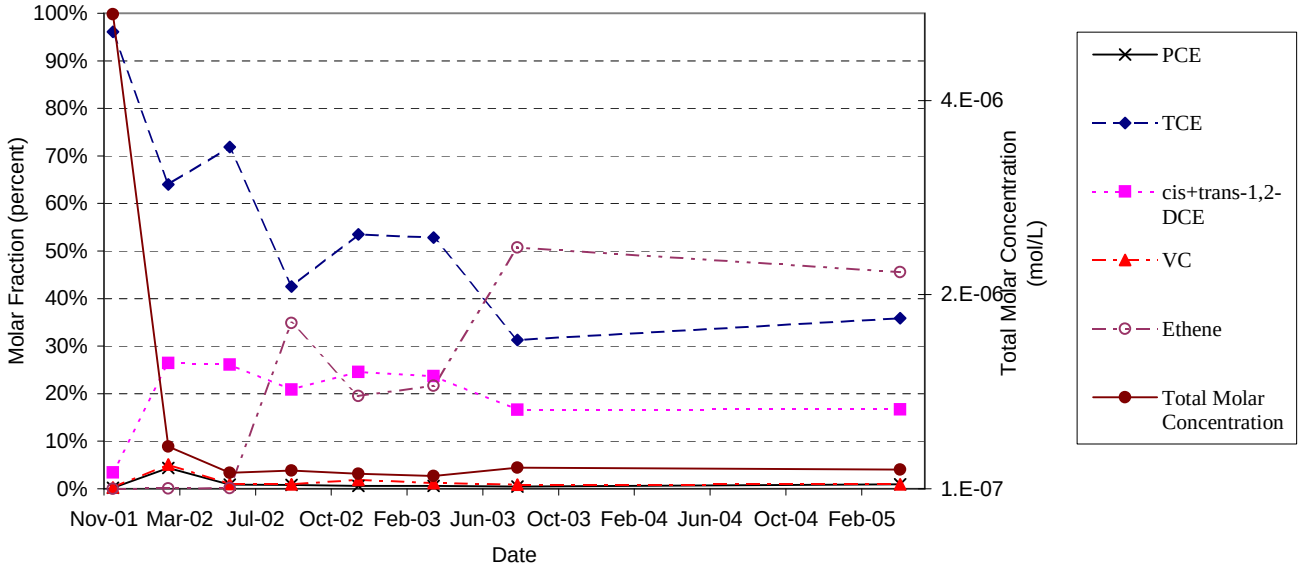


FIGURE C.18A
CONCENTRATIONS OF SELECT CHLORINATED ETHENES OVER TIME
WELL PES-INJ-3
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN

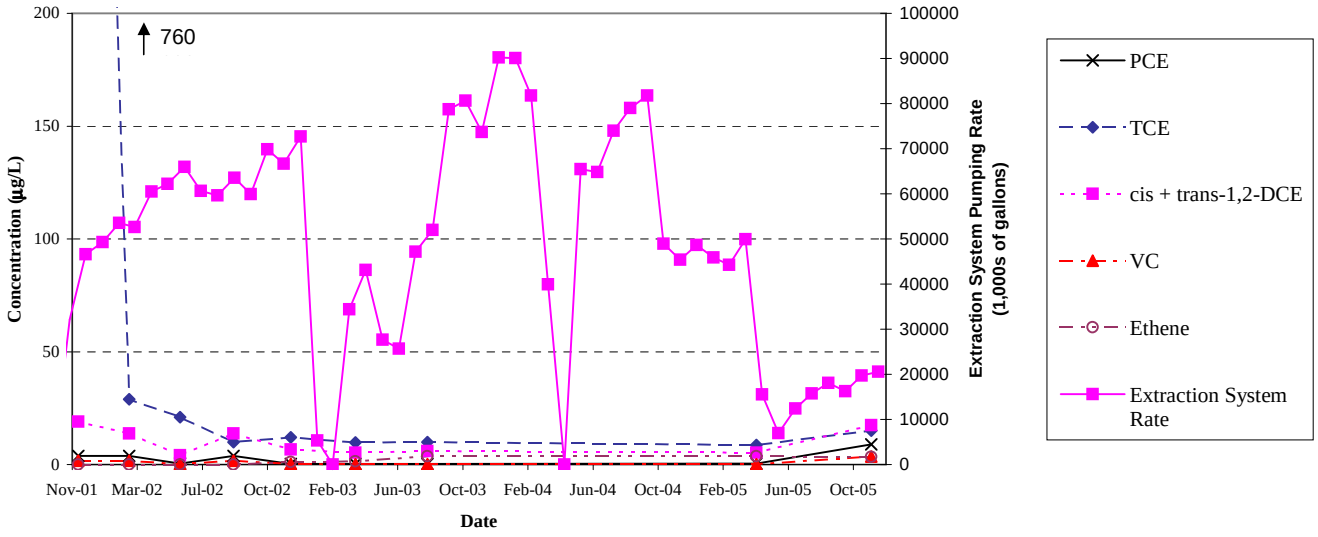
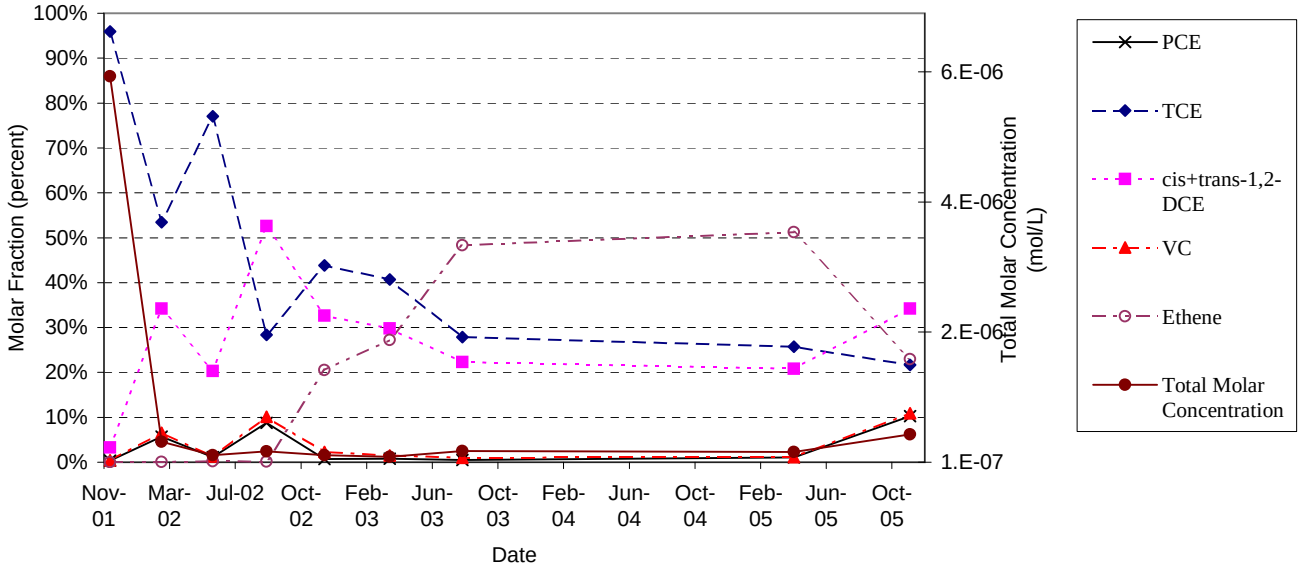


FIGURE C.18B
MOLAR FRACTION OF CHLORINATED ETHENES
AT WELL PES-INJ-3
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK, FRIDLEY MN



APPENDIX D

MPCA SPLIT SAMPLE DATA

TABLE D.1
SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Date	Sampler	PCE[a/] (µg/L)[b/]	TCE[a/] (µg/L)	*cis-* 1,2-DCE[a/] (µg/L)	*trans* 1,2-DCE[a/] (µg/L)	1,1-DCE[a/] (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA[a/] (µg/L)	1,1-DCA[a/] (µg/L)	1,2-DCA[a/] (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Bromodichloro -methane (µg/L)	2-Butanone (µg/L)	Acetone (µg/L)	Benzene (µg/L)	Toluene (µg/L)
MONITORING WELLS																		
GWMS-46S	19-Nov-01	EMR	78 U	**20,000**	200 U	**200**	94 U	34 U	110 U	94 U	0.52 U	0.54 U	0.47 U	0.42 U	210 U	330 U	88 U	84 U
		MPCA	**0.40**	**22,000**	**150**	**200**	**18**	**5.8**	0.20 U	**1.8**	**2.7**	2.0 U	**0.10**	2.0 U	10 U	20 U	2.0 U	**0.3**
	Relative Percent Difference (%)		**99**	**9**	**25**	**0**	**81**	**83**		**98**	**81**		**79**					**100**
PES-MW-1	16-Nov-01	EMR	3.9 U	**1,100**	**14**	**15**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	10 U	16 U	4.4 U	4.2 U
		MPCA	0.2 U	**600**	**16**	**22**	**2.3**	0.5 U	0.2 U	**1.7**	**0.3**	2.0 U	1.0 U	2.0 U	10 U	20 U	2.0 U	0.2 U
	Relative Percent Difference (%)			**45**	**13**	**32**	**51**			**64**	**94**							
	12-Dec-02	EMR	0.50 U	**1,700**	**230**	**26**	**2.5**	0.6 U	0.46 U	**1.4** J	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	1.0 U	0.40 U	**4.1**
		MPCA	20 U	**1,800**	**160**	**30**	50 U	50 U	20 U	20 U	20 U	20 U	0.10 U	20 U	1,000 U	2,000 U	20 U	20 U
	Relative Percent Difference (%)			**6**	**30**	**13**	**95**											**80**
PES-MW-2	15-Nov-01	EMR	7.8 U	**2,100**	**22**	**27**	9.4 U	3.4 U	11 U	9.4 U	10 U	11 U	9.4 U	8.4 U	21 U	33 U	8.8 U	8.4 U
		MPCA	**0.20**	**2,500**	**30**	**47**	**4.6**	**0.5**	0.20 U	**1.9**	**0.30**	2.0 U	1.0 U	2.0 U	10 U	20 U	2.0 U	0.2 U
	Relative Percent Difference (%)		**97**	**16**	**27**	**43**	**51**	**85**		**80**	**97**							
PES-MW-3	14-Nov-01	EMR	20 U	**5,000**	**73**	**110**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
		MPCA	**0.7**	**5,400**	**71**	**140**	**6.6**	**2.0**	0.2 U	**2.1**	**0.7**	2.0 U	1.0 U	2.0 U	10 U	20 U	2.0 U	0.2 U
	Relative Percent Difference (%)		**97**	**7**	**3**	**21**	**71**	**76**		**91**	**97**							
PES-MW-6	15-Nov-01	EMR	20 U	**6,200**	**88**	**140**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
		MPCA	**0.6**	**4,300**	**92**	**170**	**6.7**	**2.3**	0.2 U	**2.4**	**0.8**	2.0 U	1.0 U	2.0 U	10 U	20 U	2.0 U	0.2 U
	Relative Percent Difference (%)		**97**	**31**	**4**	**18**	**71**	**73**		**90**	**97**							
	12-Dec-02	EMR	0.50 U	**3,800**	**240**	**71**	**3.9**	0.60 U	0.46 U	**1.6** J	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	4.0 U	0.4 U	0.44 U
		MPCA	20 U	**4,400**	**180**	**70**	50 U	50 U	20 U	20 U	20 U	20 U	0.10 U	20 U	1000 U	2000 U	20 U	0.20 U
	Relative Percent Difference (%)			**14**	**25**	**1**	**92**			**92**								
PES-MW-7	16-Nov-01	EMR	0.78 U	**300**	**5.2**	0.78 U	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
		MPCA	2.0 U	**390**	**4.0**	**5.0**	5.00 U	5.0 U	2.0 U	5.0 U	2.0 U	2.0 U	1.0 U	2.0 U	100 U	200 U	2.0 U	2.0 U
	Relative Percent Difference (%)			**23**	**23**	**84**												
	12-Dec-02	EMR	0.25 U	**350** J	**180**	**8.3**	**2.0**	0.53 U	0.23 U	**1.0**	0.34 U	0.29 U	0.19 U	0.32 U	**320**	2.0 U	0.20 U	**4.5**
		MPCA	20 U	**310**	**110**	**10**	50 U	50 U	20 U	20 U	20 U	20 U	10 U	20 U	1000 U[e/]	2000 U	20 U	20 U
	Relative Percent Difference (%)			**11**	**39**	**17**	**96**			**95**					**68**			**78**
PES-MW-8	15-Nov-01	EMR	20 U	**6,700**	**160**	**220**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	10 U	82 U	22 U	21 U
		MPCA	**0.7**	**7,900**	**180**	**270**	**6.4**	**3.3**	0.2 U	**4.2**	**0.8**	2.0 U	1.0 U	2.0 U	10 U	20 U	2.0 U	0.2 U
	Relative Percent Difference (%)		**97**	**15**	**11**	**19**	**72**	**61**		**82**	**97**							
PES-MW-9	15-Nov-01	EMR	3.9 U	**1,400**	**15**	**20**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	52 U	16 U	4.4 U	0.42 U
		MPCA	2.0 U	**2,300**	**10**	**23**	5.0 U	5.0 U	2.0 U	5.0 U	2.0 U	2.0 U	1.0 U	2.0 U	100 U	200 U	2.0 U	2.0 U
	Relative Percent Difference (%)			**39**	**33**	**13**												
	11-Dec-02	EMR	0.50 U	20 U	**1,500**	**33**	**6.8**	**5.7**	0.46 U	0.4 U	0.68 U	0.58 U	0.38 U	0.64 U	**180**	**68**	0.4 U	0.44 U
		MPCA	20 U	**20**	**1,300**	**20**	20 U	50 U	20 U	20 U	20 U	20 U	10 U	20 U	1,000 U	2,000 U	20 U	20 U
	Relative Percent Difference (%)			**0**	**13**	**39**	**66**	**89**							**82**	**97**		
INJECTION WELLS																		
PES-INJ-1	19-Nov-01	EMR	3.9 U	**1,400**	**16**	**20**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	10 U	16 U	4.4 U	4.2 U
		MPCA	0.2 U	**1,700**	**22**	**34**	**3.0**	0.5 U	0.2 U	**1.8**	**0.3**	2.0 U	1.0 U	2.0 U	10 U	20 U	2.0 U	0.2 U
	Relative Percent Difference (%)			**18**	**27**	**41**	**36**			**62**	**94**							
	13-Dec-02	EMR	0.25 U	**37** J	**19**	**2.6**	**0.64**	**0.83**	0.23 U	0.20 U	0.34 U	0.29 U	0.19 U	0.32 U	**360**	**130**	0.20 U	0.7 U
		MPCA	20 U	**20**	**20**	10 U	20 U	50 U	20 U	50 U	20 U	20 U	10 U	20 U	**1,500**	**2,500**	20 U	20 U
	Relative Percent Difference (%)			**46**	**5**	**74**	**97**	**98**							**76**	**95**		
PES-INJ-2	19-Nov-01	EMR	1.90 U	**630**	**8.6**	**7.9**	2.3 U	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
		MPCA	2.0 U	**770**	**7.0**	**10**	2.0 U	5.0 U	2.0 U	5.0 U	2.0 U	2.0 U	1.0 U	2.0 U	100 U	200 U	2.0 U	2.0 U
	Relative Percent Difference (%)			**18**	**19**	**21**												

[a/] PCE = tetrachloroethene; TCE = trichloroethene; DCE = dichloroethene; TCA = trichloroethane; DCA = dichloroethane.

[b/] µg/L = micrograms per liter.

[c/] U = Analyte was not detected at a concentration above the method detection limit.

[d/] J = Analyte was detected at a concentration above the method detection limit and below the reporting limit.

APPENDIX E

USGS INJECTION VARIANCE APPLICATION AND SUPPORTING MSDS SHEETS

VARIANCE REQUEST APPLICATION

MINNESOTA DEPARTMENT OF HEALTH
Well Management Section, Metro Square Building
P.O. Box 64975, St. Paul, Minnesota 55164-0975
(651) 215-0811 or 1-800-383-9808
TDD (651) 215-0707 and Fax (651) 215-0978

MDH USE ONLY
TN Number _____
Date Received _____
Amount Received _____
Deposit No. _____
Receipt Codes: General Program - 4921
Disclosure Program - 4932

The party requesting the variance must submit the request in writing, to the address listed on the back of this form, along with the nonrefundable $120 application fee.

ID No. of Water Well Status Report (if applicable) _____

In counties or governmental units which currently have a well program delegation agreement, the variance request must be submitted to both the Minnesota Department of Health and to the delegated program for review.

The variance request must contain the following information. (Please print or type)

A. Name of Applicant (i.e., well/boring/sewer/other owner) Joel Sanders		Company Name (if applicable) US Navy, Southern Division, Naval Facilities Engg Command	
Street Address 2155 Eagle Dr.			
City N. Charleston	State SC	Zip 29406	Telephone No. ( ) 843-820-5562
B. Name of Property Owner (if different from above) Jeff Perry		Company Name (if applicable) Anoka County Parks Department	
Street Address 1350 Bunker Lake Blvd.			
City Andover	State MN	Zip 55304	Telephone No. ( ) 763-767-2896
C. Name of Contractor (if applicable) Rob Caho		Company Name (if applicable) Bergerson-Caswell, Inc. MDH License# 27058	
Street Address 5115 Industrial St.			
City Maple Plain	State MN	Zip 55359	Telephone No. ( ) 763-479-3121

D. Well or Boring Location	Fraction ¼ ¼ ¼	Section No.	Range No.	Township No.	Township Name	County

Street Address of Well or Boring East River Road, Anoka County Park				
City Fridley	State MN	Zip 55421	Fire No.	MN Unique Well No. (if known)

E. Rule(s) from which variance is requested (cite specific rule[s]). (1) 4725.6650 - depth of 8 wells will be 70', which is > 50' allowed

(2) 4725.2050 - Injection of ~ 3,600 gal of food-grade soybean oil; ~ 300 lbs of food-grade lecithin; ~ 7,000 gal of native groundwater; and ~ 30 pounds of non-toxic magnetite of ferrous iron particles

F. Reason(s) rule cannot be met (include supporting evidence). The deeper wells are required for imaging the oil to delineate the distribution of oil. The vegetable oil is used to enhance bioremediation. The lecithin is added as an emulsifier. Native groundwater is added to better emulsify the oil prior to injection. The magnetite or ferrous iron particles are added to do the imaging study. Product information and MSDS sheets for the vegetable oil, lecithin, magnetite, and ferrous iron are included for your review.

G. Alternative or additional protective measures to be taken to assure a comparable degree of protection to health or the environment.

Sampling and analyses of groundwater will be performed at 2, 5, 8, and 12 months as specified in Section 4.4 & 4.7 the Final Work Plan Rev.1, Dt Sep.19, 2001. All the wells will be properly sealed in accordance with MDH requirements after the completion of the study.

H. Well Information	Estimated Depth	Casing Depth	Casing Diameter	Casing Type	Method of Drilling
	Depth to Water	Grout Materials			
	Description of Construction Methods and Anticipated Geologic Conditions.				
	Refer to Section 4.3 of Final Work Plan, Rev. 1, Dated September 19, 2001.				

I. A scaled map showing the location of the well or boring in relation to property lines, structures, utilities, and contamination sources (use additional sheets as necessary and note distances from contamination sources and wells on adjacent properties). Refer to Figure 1-1 of the Final Work Plan for Map

Please include the following information for a variance request from isolation distances.

A. Description of the age, design, size, and type of construction of any existing or potential contaminant sources (such as septic systems; petroleum storage; unused, unsealed wells; etc.). Include contamination sources on adjacent properties.
Refer to Work Plan Section 2.0 for details.
B. Information on the soil type from a soil survey, percolation test, or soil boring report.
Refer to Work Plan Section 2.0, Table 2.1 for details.
C. Other relevant information, such as any testing, inspection, or certification data (please attach reports or data).
Refer to Section 4.0 of the Work Plan

Incomplete applications cannot be processed and will be returned to the applicant. Please submit a complete application including application fees, scaled map, and signatures of well owner and contractor (if applicable). Please include with this request any relevant information necessary to properly evaluate the request and a copy of any review of any contamination sources by a local or state unit of government under other applicable regulations.

The nonrefundable variance fee of $120 along with the variance application, signed by the applicant and the contractor, with supportive information, must be returned to the Well Management Section, Minnesota Department of Health, Metro Square Building, P.O. Box 64975, St. Paul, Minnesota 55164-0975.

This variance is conditioned upon the applicants acceptance of, and compliance with the conditions of this variance. Failure by the applicant to comply with the conditions prescribed in this variance will result in the immediate expiration of this variance.

If the variance is granted, I agree to comply with any conditions required by the Minnesota Department of Health.

Date	First Applicant Name (print) Joel Sanders	First Applicant Signature
Date	Second Applicant Name (print)	Second Applicant Signature
Date	Contractor Name (print)	Contractor Signature

VARIANCE REQUEST APPLICATION

MINNESOTA DEPARTMENT OF HEALTH
Well Management Section, Metro Square Building
P.O. Box 64975, St. Paul, Minnesota 55164-0975
(651) 215-0811 or 1-800-383-9808
TDD (651) 215-0707 and Fax (651) 215-0978

MDH USE ONLY
TN Number _____
Date Received _____
Amount Received _____
Deposit No. _____
Receipt Codes: General Program - 4921
Disclosure Program - 4932

The party requesting the variance must submit the request in writing, to the address listed on the back of this form, along with the nonrefundable $120 application fee.

ID No. of Water Well Status Report (if applicable) _____

In counties or governmental units which currently have a well program delegation agreement, the variance request must be submitted to both the Minnesota Department of Health and to the delegated program for review.

The variance request must contain the following information. (Please print or type)

A. Name of Applicant (i.e., well/boring/sewer/other owner) Joel Sanders		**Company Name (if applicable)** US Navy, Southern Division, Naval Facilities Engg Command	
Street Address 2155 Eagle Dr.			
City N. Charleston	**State** SC	**Zip** 29406	**Telephone No.** ( ) 843-820-5562
B. Name of Property Owner (if different from above) Jeff Perry		**Company Name (if applicable)** Anoka County Parks Department	
Street Address 1350 Bunker Lake Blvd.			
City Andover	**State** MN	**Zip** 55304	**Telephone No.** ( ) 763-767-2896
C. Name of Contractor (if applicable) Rob Caho		**Company Name (if applicable)** Bergerson-Caswell, Inc. MDH License# 27058	
Street Address 5115 Industrial St.			
City Maple Plain	**State** MN	**Zip** 55359	**Telephone No.** ( ) 763-479-3121

D. Well or Boring Location	Fraction	Section No.	Range No.	Township No.	Township Name	County
	¼ ¼ ¼					

Street Address of Well or Boring East River Road, Anoka County Park				
City Fridley	**State** MN	**Zip** 55421	**Fire No.**	**MN Unique Well No. (if known)**

E. Rule(s) from which variance is requested (cite specific rule[s]). (1) 4725.6650 - depth of 8 wells will be 70', which is > 50' allowed

(2) 4725.2050 - Injection of ~ 3,600 gal of food-grade soybean oil; ~ 300 lbs of food-grade lecithin; ~ 7,000 gal of native groundwater; and ~ 30 pounds of non-toxic magnetite of ferrous iron particles

F. Reason(s) rule cannot be met (include supporting evidence). The deeper wells are required for imaging the oil to delineate the distribution of oil. The vegetable oil is used to enhance bioremediation. The lecithin is added as an emulsifier. Native groundwater is added to better emulsify the oil prior to injection. The magnetite or ferrous iron particles are added to do the imaging study. Product information and MSDS sheets for the vegetable oil, lecithin, magnetite, and ferrous iron are included for your review.

G. Alternative or additional protective measures to be taken to assure a comparable degree of protection to health or the environment.

Sampling and analyses of groundwater will be performed at 2, 5, 8, and 12 months as specified in Section 4.4 & 4.7 the Final Work Plan Rev.1, Dt Sep.19, 2001. All the wells will be properly sealed in accordance with MDH requirements after the completion of the study.

H. Well Information	Estimated Depth	Casing Depth	Casing Diameter	Casing Type	Method of Drilling
	75 ft	75 ft	2 in.	PVC	Hollow stem auger
	Depth to Water	Grout Materials			
	Approx. 30 ft bgs	Neat cement grout for backfill; bentonite for seal pack			
	Description of Construction Methods and Anticipated Geologic Conditions.				
	Refer to Section 4.3 of Final Work Plan, Rev. 1, Dated September 19, 2001.				

I. A scaled map showing the location of the well or boring in relation to property lines, structures, utilities, and contamination sources (use additional sheets as necessary and note distances from contamination sources and wells on adjacent properties). Refer to Figure 1-1 of the Final Work Plan for Map

Please include the following information for a variance request from isolation distances.

A. Description of the age, design, size, and type of construction of any existing or potential contaminant sources (such as septic systems; petroleum storage; unused, unsealed wells; etc.). Include contamination sources on adjacent properties.
Refer to Work Plan Section 2.0 for details.
B. Information on the soil type from a soil survey, percolation test, or soil boring report.
Refer to Work Plan Section 2.0, Table 2.1 for details.
C. Other relevant information, such as any testing, inspection, or certification data (please attach reports or data).
Refer to Section 4.0 of the Work Plan

Incomplete applications cannot be processed and will be returned to the applicant. Please submit a complete application including application fees, scaled map, and signatures of well owner and contractor (if applicable). Please include with this request any relevant information necessary to properly evaluate the request and a copy of any review of any contamination sources by a local or state unit of government under other applicable regulations.

The nonrefundable variance fee of $120 along with the variance application, signed by the applicant and the contractor, with supportive information, must be returned to the Well Management Section, Minnesota Department of Health, Metro Square Building, P.O. Box 64975, St. Paul, Minnesota 55164-0975.

This variance is conditioned upon the applicants acceptance of, and compliance with the conditions of this variance. Failure by the applicant to comply with the conditions prescribed in this variance will result in the immediate expiration of this variance.

If the variance is granted, I agree to comply with any conditions required by the Minnesota Department of Health.

Date	First Applicant Name (print) Joel Sanders	First Applicant Signature
Date	Second Applicant Name (print)	Second Applicant Signature
Date	Contractor Name (print)	Contractor Signature

MINNESOTA MDH DEPARTMENT OF HEALTH

COPY

Protecting, maintaining and improving the health of all Minnesotans

March 9, 2005

Refer to: License Number 27058 (TN 3434)

Mr. Daniel Owens
Naval Facilities Engineering Command,
Southern Division
2155 Eagle Drive
North Charleston, South Carolina 29406

Mr. John Henrich
Bergerson-Caswell, Inc.
5115 Industrial Street
Maple Plain, Minnesota 55359

Dear Mr. Owens and Mr. Henrich:

Subject: Variance from Minnesota Rules, Chapter 4725, for Construction of Three Monitoring Wells, Minnesota Unique Well Numbers 725500, 725504, and 725506, in Anoka County Riverfront Park, Located in the NE ¼ of the NE ¼ of the NW ¼ of Section 27, Township 30 North, Range 24 West, Anoka County, Minnesota

This letter is in response to your request for a variance from Minnesota Rules, Chapter 4725, to construct three monitoring wells in Anoka County Riverfront Park, Fridley, Minnesota. Anoka County Riverfront Park is located immediately west of the Naval Industrial Reserve Ordnance Plant (NIROP). The proposed wells are part of the network of monitoring wells used to evaluate the impact and effectiveness of in-situ bioremediation of groundwater contaminated with chlorinated solvents.

Information provided in the variance request indicates that the proposed wells will be constructed with 2-inch flush thread PVC casing and will be 75 feet deep. The reported static water level is at a depth of approximately 30 feet. The proposed well depth is necessary to delineate the distribution and degradation of injected vegetable oil. Variance TN 2408A was approved by the Minnesota Department of Health (MDH) on October 26, 2001, for the oil injection.

Mr. Ed Schneider of the MDH contacted Mr. Rob Caho of Bergerson-Caswell, Inc., and Mr. Venky Venkatesh at CH2M Hill, Inc., who clarified that there will be 5 to 10 feet of screen at the bottom of each well, and that the full depth of the annular space above each screen will be grouted with neat cement. Mr. Venkatesh indicated that the use of steel casing was not desirable, as it would interfere with future downhole geophysical work.

Minnesota Rules, part 4725.6650, subpart 1 requires that a monitoring well may be constructed with flush threaded polyvinyl chloride (PVC) casing and screens only if the screen intersects the water table, the total depth of the well is 50 feet or less, the well is completed in unconsolidated materials, and the flush threaded PVC casing used meets the standards in Schedule 40 as referenced in ASTM Standard 1785-88.

The MDH granted a variance (TN 2408) to the U.S. Navy and Bergerson-Caswell, Inc. on October 11, 2001, for similar monitoring well construction at the subject site.

In accordance with Minnesota Rules, Chapter 4725, and based on the information provided, **your request for a variance is granted to construct the three subject monitoring wells with 2-inch diameter PVC casing to a total depth of 75 feet**. The variance is granted because of the need for monitoring and remediation of the groundwater at the site. The variance is granted with the following conditions:

1. A Monitoring Well Permit Application for each well must be submitted to and approved by the MDH prior to beginning well construction.

2. MDH staff, Mr. Steve Bennett at 651/643-2113 or Mr. Ronald Thompson at 651/643-2108, must be contacted at least 24 hours prior to beginning well construction.

3. The flush threaded PVC casing must meet the standards of ASTM F480-02, and the standards in Schedule 40 as referenced in ASTM Standard D1785-04.

4. The annular space between the casing and the bore hole must be filled with neat-cement grout, pumped through a tremie pipe from within 10 feet of the top of the screen up to the ground surface.

5. All other requirements of Minnesota Rules, Chapter 4725, shall be in effect.

Alternative measures or conditions attached to a variance have the force of law and effect of applicable rule. If a party violates the alternative measures or conditions attached to the variance, the party is subject to enforcement actions and penalties provided in the applicable law or rule.

The variance is conditioned upon the applicable acceptance of and compliance with the conditions of the variance. Failure by the applicant to comply with the conditions prescribed in the variance will result in the immediate expiration of the variance.

If you have any questions, please contact Mr. Schneider at 651/215-0827 or Mr. Bennett at 651/643-2113.

Sincerely,

Patricia A. Bloomer

for Mr. Daniel A. Wilson, Manager
Well Management Section
Environmental Health Division
P.O. Box 64975
St. Paul, Minnesota 55164-0975

DAW:ECS:dg
cc: Jeff Perry, Anoka County Department of Parks and Recreation
David Douglas, Minnesota Pollution Control Agency
Venky Venkatesh, CH2M Hill, Inc.

MINNESOTA MDH DEPARTMENT OF HEALTH

March 30, 2005 *Protecting, maintaining and improving the health of all Minnesotans*

Refer to: License Number 27058 (TN 3434A)

Mr. Daniel Owens
Naval Facilities Engineering Command
Southern Division
2155 Eagle Drive
North Charleston, South Carolina 29406

Mr. John Henrich
Bergerson-Caswell, Inc.
5115 Industrial Street
Maple Plain, Minnesota 55359

Dear Mr. Owens and Mr. Henrich:

Subject: Amendment to Variance TN 3434 for Monitoring Well Construction in Anoka County Riverfront Park, Located in the NE ¼ of the NE ¼ of the NW ¼ of Section 27, Township 30 North, Range 24 West, Anoka County, Minnesota

Variance TN 3434 was issued by the Minnesota Department of Health (MDH) to you on March 9, 2005, to allow construction of three monitoring wells, Minnesota Unique Well Numbers 725500, 725504, and 725506, with 2-inch diameter PVC casing to a total depth of 75 feet. Minnesota Rules, part 4725.6650, subpart 1 requires that a monitoring well may be constructed with flush threaded polyvinyl chloride (PVC) casing and screens only if the screen intersects the water table, the total depth of the well is 50 feet or less, the well is completed in unconsolidated materials, and the flush threaded PVC casing used meets the standards in Schedule 40 as referenced in ASTM Standard 1785-88.

On March 29, 2005, Mr. Rob Caho of Bergerson-Caswell, Inc. contacted Mr. Ed Schneider of the MDH to request that the variance be amended to include five additional monitoring wells, Minnesota Unique Well Numbers 724649, 725501, 725502, 725503, and 725505. Mr. Caho explained that these wells were originally expected to be completed at depths of less than 50 feet. However, recently obtained geological information suggests that some or all of these five wells will need to be completed at depths greater than 50 feet. The wells will be constructed similar to the three originally approved wells, with 2-inch diameter flush thread PVC well casing, 5 to 10 feet of screen at the bottom of each well, and completed at total depths of no more than 75 feet.

The proposed well depth is necessary to delineate the distribution and degradation of injected vegetable oil. The use of steel casing is not desirable, as it would interfere with future downhole geophysical work.

In accordance with Minnesota Rules, Chapter 4725, and based on the information provided, **Variance TN 3434 is amended to allow construction of up to eight monitoring wells constructed with 2-inch diameter flush thread PVC well casing and completed at depths of no more than 75 feet**. The variance is approved for monitoring wells with Minnesota Unique Well Numbers 724649, 725500, 725501, 725502, 725503, 725504, 725505, and 725506. The variance is granted because of the need for monitoring and remediation of the groundwater at the site.

The variance is granted with the following conditions:

1. You must contact MDH staff, Mr. Steve Bennett at 651/643-2113 or Mr. Ronald Thompson at 651/643-2108 at least 24 hours prior to beginning well construction.

2. The flush threaded PVC casing must meet the standards of ASTM F480-02, and the standards in Schedule 40 as referenced in ASTM Standard D1785-04.

3. The annular space between the casing and the bore hole must be filled with neat-cement grout, pumped through a tremie pipe from within 10 feet of the top of the screen up to the ground surface.

4. All other requirements of Minnesota Rules, Chapter 4725, are in effect.

Alternative measures or conditions attached to a variance have the force of law and effect of applicable rule. If a party violates the alternative measures or conditions attached to the variance, the party is subject to enforcement actions and penalties provided in the applicable law or rule.

The variance is conditioned upon the applicable acceptance of and compliance with the conditions of the variance. Failure by the applicant to comply with the conditions prescribed in the variance will result in the immediate expiration of the variance.

If you have any questions, please contact Mr. Schneider at 651/215-0827 or Mr. Bennett at 651/643-2113.

Sincerely,

Daniel A. Wilson

Daniel A. Wilson, Manager
Well Management Section
Environmental Health Division
P.O. Box 64975
St. Paul, Minnesota 55164-0975

DAW:ECS:dg
cc: Jeff Perry, Anoka County Department of Parks and Recreation
David Douglas, Minnesota Pollution Control Agency
Venky Venkatesh, CH2M Hill, Inc.

COPY

MINNESOTA MDH DEPARTMENT OF HEALTH

Protecting, maintaining and improving the health of all Minnesotans

October 26, 2001

Refer to: TN2408a

Mr. Joel Sanders, P.E.
Department of the Navy – Southern Division
Naval Facilities Engineering Command
P.O. Box 190010
2155 Eagle Drive
North Charleston, South Carolina 29419-9010

Dear Mr. Sanders:

Subject: Request for a Variance from Minnesota Rules, Chapter 4725, to Inject Soybean Oil, Lecithin, and Magnetite/Ferrous Iron to Enhance In-Situ Bioremediation in the NE ¼ of the NE ¼ of the NW ¼ of Section 27, Township 30 North, Range 24 West, Anoka County, Minnesota.

This letter is in response to your request for a variance from Minnesota Rules, Chapter 4725, to inject a vegetable oil solution into three wells in Anoka County Riverfront Park, located in Fridley, Anoka County The park is located immediately west of the Naval Industrial Ordnance Plant (NIROP). The purpose of the variance is to allow a pilot-scale investigation to assess the effectiveness of adding vegetable oil to enhance in-situ bioremediation of groundwater contaminated with chlorinated solvents. A plume of contaminated groundwater has been identified in the park.

Details of the injection proposal, bioremediation mechanisms, and groundwater monitoring are included in the "Final Work Plan for Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection", dated September 19, 2001, and prepared by Parson's Engineering Science, Inc. (hereinafter referred to as Final Work Plan). A one-time injection of a total of approximately 3600 gallons of food-grade soybean oil, 300 pounds of food-grade lecithin, and 30 pounds of magnetite/ferrous iron particles mixed with a fatty acid dispersant will be injected in three wells (PES-INJ-1, PES-INJ-2, and PES-INJ-3). Approximately 7000 gallons of native ground water will also be injected. Details of the soybean oil, lecithin, and magnetite materials are included in a September 21, 2001, submittal from Mr. Venky Venkatesh of CH2M Hill Constructors, Inc. This submittal is an attachment to the variance request application. This submittal was further amended, based on a communication via electronic mail on October 22, 2001, from Mr. Venky Venkatesh to Mr. Michael Convery of my staff, to eliminate the use of mineral oil as a dispersant for the magnetite. The dispersion of the vegetable oil solution and effectiveness of bioremediation will be monitored for at least one year after injection using 13 monitoring wells, sampled at roughly 2, 5, 8, and 12 months after injection.

Minnesota Rules, part 4725.2050, prohibits the use of wells or borings for disposal of surface water, groundwater, or any other liquid, gas, or chemical. The purpose of this rule provision is to protect groundwater quality.

In accordance with Minnesota Rules, Chapter 4725, and based on the information provided in your variance request application and attachments, **your request for a variance is granted.** The variance is granted because of the need for remediation of ground water contamination at the site. Enhanced bioremediation is being investigated because hydraulic controls have not been fully effective in reducing contaminant levels, especially in the park. The area of highest ground water contamination within the park appears to be a stagnation point in the ground water flow regime at the site and is not greatly influenced by the ground water extraction occurring at the NIROP facility, upgradient of the park. The variance is granted with the following conditions:

1. You must contact Mr. Steve Bennett of the MDH at (651) 643-2113 at least 24 hours prior to the start of injection.
2. The ground water monitoring plan, as detailed in Sections 4 and 5 of the Final Work Plan, must be followed.
3. The contingency plan, as detailed in Section 6 and in Attachment 2 of Appendix D shall be followed to mitigate generation and migration of vinyl chloride.
4. The Field Application Results Report, top be prepared by Parsons Engineering Science, Inc., shall be submitted to the MDH within 30 days of completion of the report and approval by the U.S. Navy.

All other requirements of Minnesota Rules, Chapter 4725, are in effect.

Alternative measures or conditions attached to the variance have the force of law and effect of applicable rule. If a party violates the alternative measures or conditions attached to the variance, the party is subject to enforcement actions and penalties provided in the applicable law or rule.

The variance is conditioned upon the applicable acceptance of and compliance with the conditions of the variance. Failure of the applicant to comply with the conditions of the variance will result in the immediate expiration of the variance.

If you have any questions, please contact Mr. Ed Schneider at (651) 215-0827 or Mr. Steve Bennett at (651) 643-2113.

Sincerely:

Kathy Svanda

for Daniel A. Wilson, Manager
Well Management Section
Division of Environmental Health
P.O. Box 64975
St. Paul, Minnesota 55164-0975

DAW:MPC:dg
cc: Jeff Perry, Anoka County Parks and Recreation
David Douglas, Minnesota Pollution Control Agency
Tom Bloom, U.S. Environmental Protection Agency
Venky Venkatesh, CH2M Hill Constructors, Inc.
Daniel Griffiths, Parsons Engineering Science, Inc.

Welcome to Central Soya Oil.

This section was designed to provide you with general information regarding Central Soya products and services from the Refined Oil Group.

Products by Application:

Central Soya regards every one of our customers as unique. We offer a wide variety of finished oil formulas that can best meet a particular application or flavor profile standard you are looking for.

In this extensive product line Central Soya offers a match to every general need for soybean oil: frying, baking, sauces/dressings, non-dairy, and industrial applications.

Because of our experience gained through decades of manufacturing, Central Soya is able to provide customized, quality products to our customers (sold on a full production basis or larger quantities). Our depth of experience is available to provide the support you need, backed by the best customer service and technical support in the industry.

When you buy from Central Soya, you get more than just an oil or shortening. You get a new partner in business, because we recognize what affects our customers will probably affect us. So we stand behind every product. We want you to get the complete package, not just a raw material.

Tech Bulletins:

Strict adherence to quality assurance procedures and food safety has always been a Central Soya priority ever since our founding in 1934. We are a world leader in research and development of soy products. As part of its technical support, Central Soya offers the most up-to-date scientific information on fats and oils, as well as the latest in Food Safety procedures and trends. Contact us today to request the information you need.

- Advantages/Selling Points

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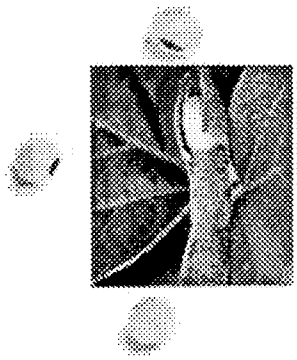
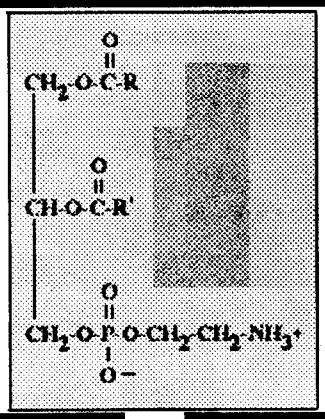
Lecithin in Food



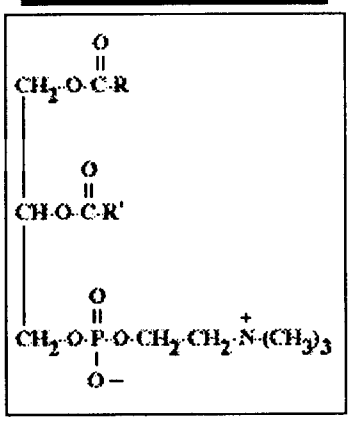
Lecithin is a naturally-occurring group of phospholipids that's found in nearly every living cell. Though the word lecithin is derived from the Greek "lekithos", which means "yolk of an egg," the primary commercial source of lecithin comes from the soybean.

The food industry has long recognized lecithin as a lipophilic emulsifier used in products like margarine and chocolate. But lecithin can be much more than that. Through specific modification techniques, Central Soya has extended the functionality and physical characteristics of lecithin far beyond their natural limitations to include a wider range of functionalities like wetting, dispersion, lubrication, sprayability and ease of handling in dry powder form.

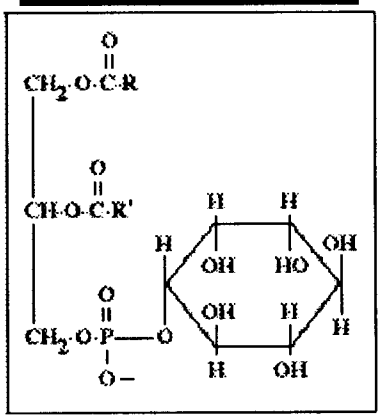
Phosphatidylethanolamine



Phosphatidylcholine



Phosphatidylinositol



R, R' – fatty acid constituents

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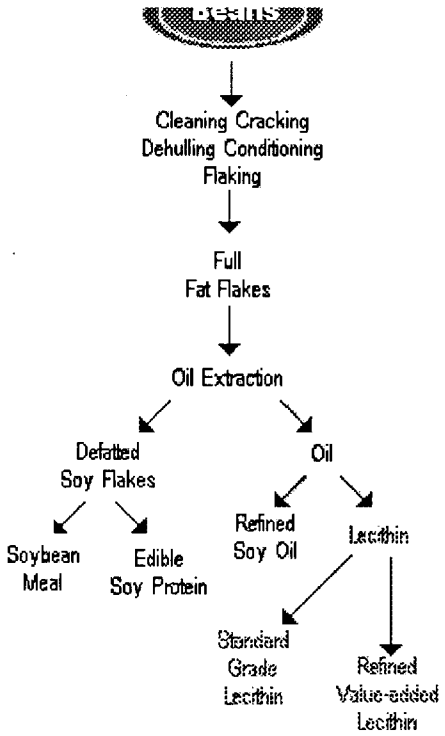
What is Lecithin?

An important ingredient in food processing.

Modified, or "refined," lecithins have

become an invaluable ingredient in today's processed food industry. They provide important surface active properties to a variety of foods such as instant drink mixes, infant formulas, meat sauces and gravies, dispersible oleoresins, pan releases, chewing gum, and no-fat bakery and snack foods.



A natural nutrient.
Lecithin is as natural as soybean oil. It is being actively researched for its relationship to good, long-term health.

Today's health-conscious consumers are spending increasing amounts of time reading labels looking for healthy ingredients. Food processors are finding that lecithin is just such a label-friendly ingredient.

Soybean processing and lecithin.
Central Soya is a fully integrated lecithin supplier, from controlling the quality of the soybeans used through shipping of the finished lecithin. At Central Soya, beans are carefully selected for color and size. They are cleaned to remove impurities, then conditioned, cracked, dehulled and rolled into flakes. Hexane solvent extraction removes the oil from the flake. The addition of water to the crude oil hydrates the phosphatides, making them oil-insoluble. This material is dried and fluidized with soybean oil and fatty acids to produce standard grade lecithin, or is used as source material for refined, value-added lecithin products.

Central Soya has an on-going public relations effort designed to inform consumers of the nutritional benefits of lecithin.

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Lecithin Terminology.

Lecithin products are classified on the basis of the following specifications:

Acetone Insolubles (AI). A measure of the surface-active portion of the lecithin, this material is mainly comprised of phospholipids and gly-colipids. Expressed as a percentage.

Acid Value (AV). Measure of total acidity contributed by ionizable groups of phospholipids and free, fatty acids added to some fluid lecithins to stabilize viscosity. Expressed as meq KOH/kg.

Color. Measured against the Gardner scale. Most lecithin products fall between 11 (having a light honey color) and 17 (having a dark amber color).

Hexane Insolubles (HI). A measure of residual nonfatty material arising during soy processing; composed mainly of soybean meal fines. Modern filtration ensures most products have less than 0.1% HI. Expressed as a percentage.

Moisture (H2O). Measured by the Karl Fisher method, a potentiometric titration specific for water. Powdered and fluid lecithins typically contain less than 1% water.

Peroxide Value (PV). A measure of residual H2O2 from bleaching process. Peroxide is sometimes used at low levels to lighten lecithin color. Expressed as milliequivalents peroxide per kilogram.

pH. Measured as 1% solution in aqueous ethanol. Most lecithins are typically 7.0. Chemically-modified products may range from 6.0-8.0.

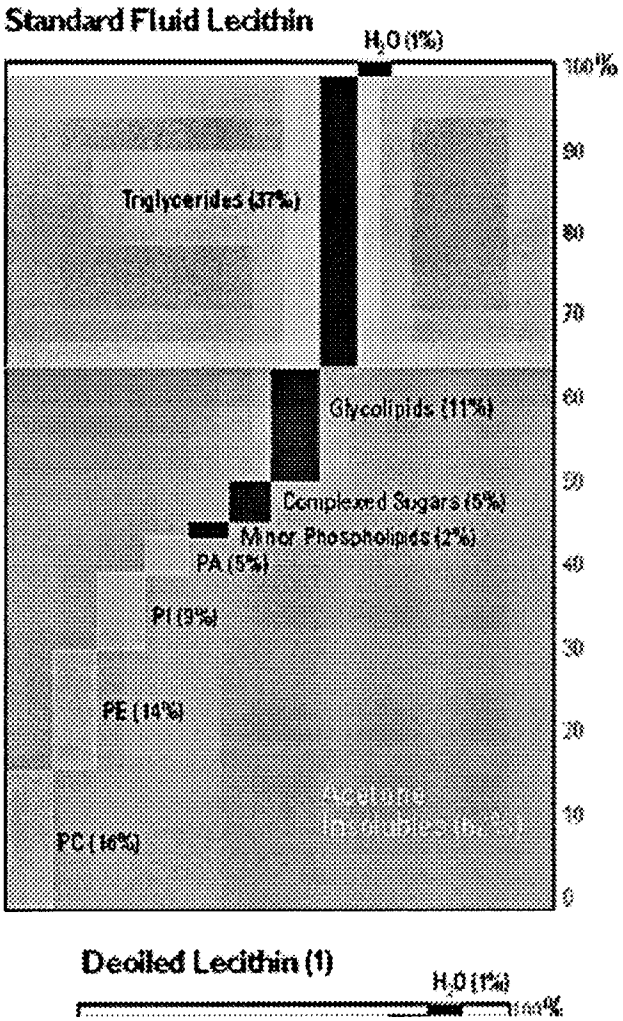
Viscosity. Lecithin is evaluated with a Brookfield rotary viscometer, a widely-used technique. Results are reported in poise or centipoise at 25°C/77°F.

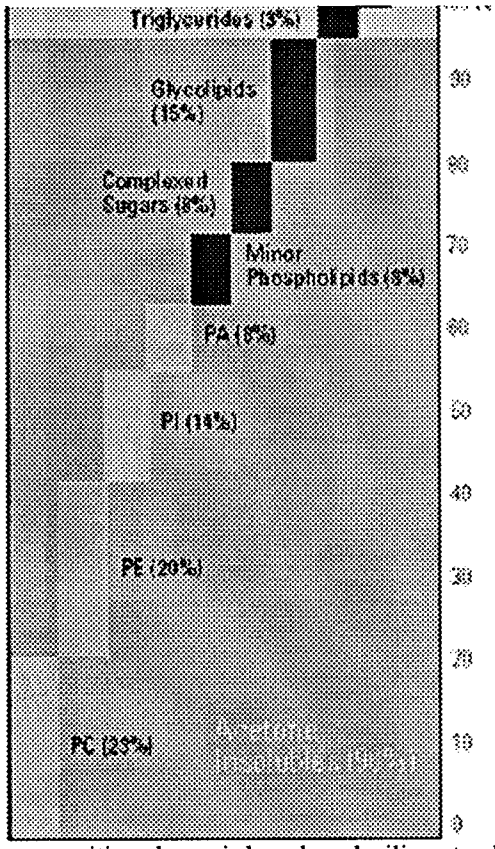
Chemical composition.

Lecithin is a complex mixture of acetone insoluble phospholipids consisting mainly of phosphatidylcholine (PC), phosphatidylethanolamine (PE), phosphatidylinositol (PI), and phosphatic acid (PA), combined with varying amounts of other substances such as triglycerides.

The oil-free granule or powdered form has almost all the triglycerides and fatty acids removed.

top of page





(1) Chemical composition shown is based on deoiling standard lecithin.

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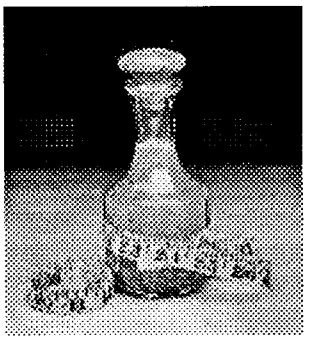
Special Grade Lecithins.

Refined, Value Added Lecithins.
These lecithins offer a range of enhanced functionalities including HLBs as high as 12, improved handling properties, and physical compatibilities.

Centrolex® Series.
Centrolex is a highly concentrated, oil-free lecithin in granule or powder form. It can be used to control fat and moisture in cooked ground meat products like Mexican fillings, chili and sloppy joes as well as in sauces and gravies. Centrolex is widely used as an emulsifier (HLB is 7) in dairy products like ice cream and yogurt, as a lubricity-enhancing ingredient for low fat foods and extruded products, and as a blending aid in baked goods. The series includes various particle sizes, all water-dispersible, oil-soluble and easy to measure and handle without pumps or other liquid handling equipment.

Precept™ Series. Precept deoiled lecithin combines the convenience of a powder with the high HLB benefits (HLBs from 8-10) of refined fluid lecithins. Precept powders are water dispersible and highly concentrated. Precept lecithins are used as emulsifiers in prepared beverages, cream soups and gravies; in bakery products to retain moisture during baking and in icings to improve texture and spread.

Centrophase® Series. Centrophase products are bland, low-viscosity fluid lecithins with a wide range of uses. They can be used as dispersants, wetting agents, emulsifiers, release agents and stabilizers, and are widely used in the food industry for spray release. The Centrophase HR series consists of patented heat-resistant lecithins that retain their light yellow color when exposed to high temperatures and won't develop the burned color associated with standard lecithin.



Centrolene® Series. Centrolene is a water-dispersible, hydroxylated lecithin that serves as an excellent oil-in-water emulsifier. Centrolene is an excellent solubilizer and dispersing agent for oil-soluble colors and flavors in aqueous systems. It also works as a wetting agent for fatty powders and as an emulsifier for low-fat salad dressings.

Centrocap® lecithins are designed for applications like encapsulation where clarity and brilliance are required.

Centrobake® is a powder made from distilled monoglycerides and hydrophilic lecithin. Centrobake is used as a staling inhibitor/dough conditioner in yeast-raised breads, rolls and buns. It also gives excellent shelf life to cakes and doughnuts. Its water dispersibility makes Centrobake an effective way to add richness to diet beverages and puddings.

Centrophil® Series. This series includes a blend of oil-free lecithin and refined specialty oils. The combination provides very low odor and flavor with increased compatibility for specific applications. Centrophil M is a very low-viscosity fluid well suited for spray applications like release or wetting. Centrophil K is a solid, meltable compound used in chewing gum base.

Centrol® CA is a very functional oil/water emulsifier and is commonly used in infant formulas and other dairy replacement systems.

Centromix®E and Centromix CPS are specially formulated to be highly water-dispersible oil-in-water emulsifiers (HLB around 12).

Blendmax® is an enzyme-modified lecithin used for instantizing whole milk powders, oil-in-water emulsions, and for anti-staling in confectioneries, breads, rolls and buns.

Centrol® Series. Products in our Centrol series are stable, easy-to-handle fluid blends of natural phospholipids and soybean oil. Our uniformly high quality makes these products the industry standards for dependability and functionality. Centrol lecithins can be used as emulsifiers, stabilizers, softening or wetting agents and dispersants.

Actiflo®. Actiflo is a fluid lecithin rich in phospholipids. It is prepared in a concentrated, undiluted form by a special process pioneered by Central Soya. Actiflo products are superior water-in-oil emulsifiers well suited for margarine and chocolates.

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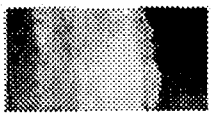
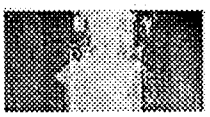
Functional Properties.

Central Soya lecithins offer a variety of functionalities.

Anti-Dusting.

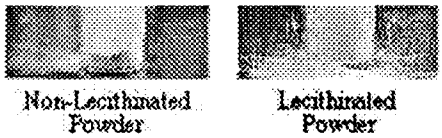
Reduces static to effectively "wet" dusty particles. Special low-viscosity lecithins like Centrophase NV can be sprayed in undiluted form at room temperature

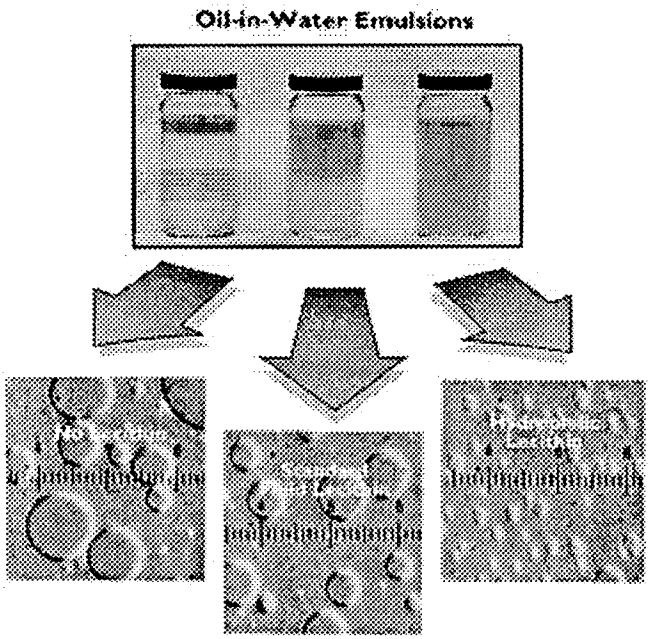




undiluted form at room temperature.

Crystal Formation Modification.
Retards nucleation and crystal growth in fats and monoglycerides.





Emulsifying.
Promotes formation of stable oil-in-water and water-in-oil emulsions by reducing the surface tension between immiscible liquids. The photographs to the right show an improved oil-in-water emulsion using a refined, hydrophilic lecithin.

Lecithin is a mixture of surface-active agents. Most of the surfactant properties of lecithin can be attributed to the phospholipids. These contain a hydrophobic portion with an affinity for fats and oils, and a hydrophilic portion with an affinity for water. Central Soya research and processing technology has created a wide range of surface-active behaviors which enhance the functionality of our lecithin.

The emulsification properties of different lecithin products can be assigned based on the well known hydrophilic-lipophilic balance (HLB). HLB values reflect the size and strength of the hydrophilic (water loving or polar) and the lipophilic (oil loving) groups of emulsifiers.

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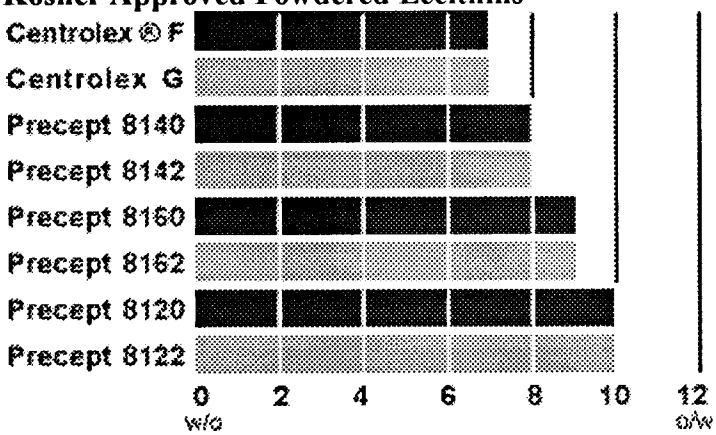
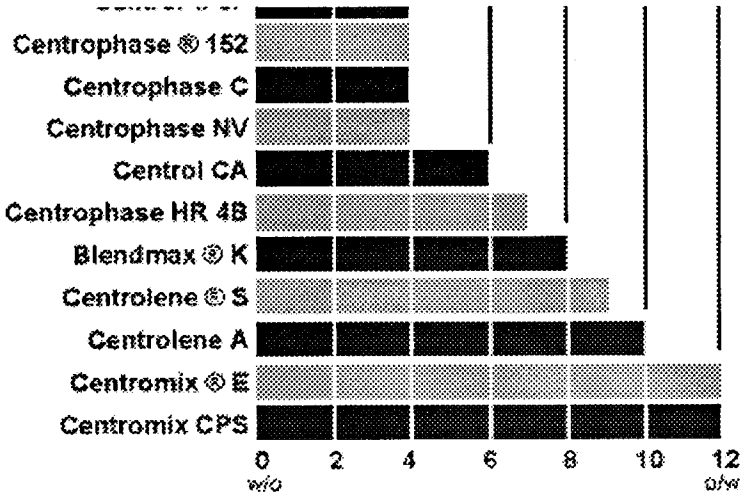
Kosher Approved Powdered Lecithins



Kosher-Approved Fluid Lecithins



Lubrication in Reduced Fat Doughs.
Powdered, deoiled Centrolex® F lecithin will increase the lubricating properties of low fat and no fat doughs. This results in improved dough sheeting properties, less stress on equipment, fewer machine cleanups, and better production yields.

Mixing and Blending Aids.
Decreased time and increased efficiency of mixing unlike ingredients like sugar and shortening by providing lubricity and viscosity reduction at the contact surfaces of incompatible solids as in cream fillings, chocolates and granola mixes.

Release Agents.
Provide easy and complete separation of fried or baked goods from hot and cold cooking surfaces.

The phospholipids form an effective barrier between the two surfaces to eliminate sticking. The lecithin is commonly mixed with triglyceride oil. Low-viscosity lecithins may be used as is.

- **For "as is" application:** Centrophil M, Centrophase NV
- **For dilution with oil:** Centrophase C
- **If heat resistance is required:** Centrophase HR, HR2B, HR4B

Separation Agents.
Prevent adhesion by forming a stable film barrier such as between cheese slices.

Viscosity Modification.
Reduces particle-media friction especially in systems of small, solid particles in a liquid.

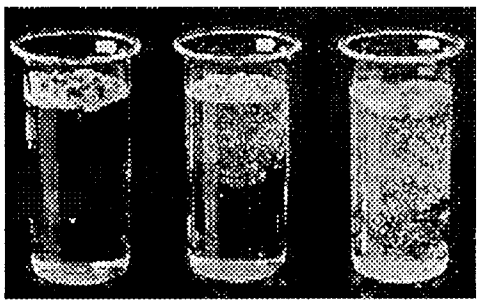
Wetting.
Promotes quick and complete wetting of fatty or hydrophilic powders into aqueous systems.

top of page

Labeling Information.

Consumers have long considered lecithin to be a very desirable ingredient on a food label because of its long-term association with good health.Lecithin is Generally Recognized As Safe (GRAS) under 21 CFR 184.1400 and specifications of the Food

Chemicals Codex. The FDA-preferred labeling is "Soy lecithin" although "Lecithin" is generally considered as the common and usual name. As a convenience to consumers and food processors who are interested in source labeling ingredients, Central Soya voluntarily adds the word "soy" to its lecithin labels.



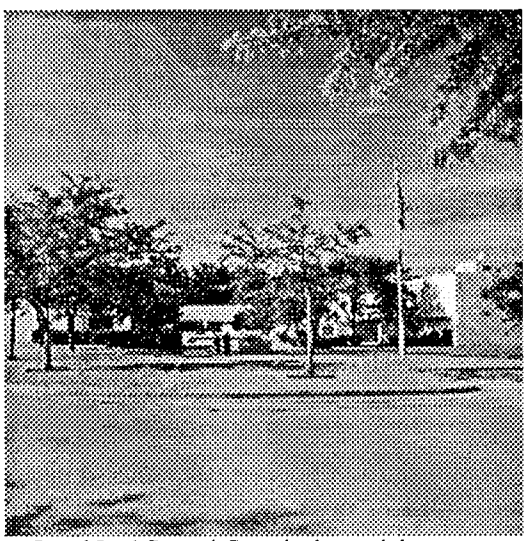
Control | Agglomerated Powder | Agglomerated Powder with Refined Lecithin

Most of our lecithins may be labeled in this manner. The most notable exceptions are those lecithins which either have been hydroxylated ("Hydroxylated Soy Lecithin" or "Hydroxylated Lecithin,") or blended with other surfactants to achieve HLB values over 10.

Our Commitment.

Our commitment to the industry.
Central Soya products are used and trusted by customers throughout the world. They set the industry standards for quality and reliability. Our experience in working with lecithin and our commitment to the industry's development are unequaled.

Our commitment to quality.
At our research center in Fort Wayne, Indiana, lecithins are produced and tested under simulated plant conditions to meet your changing requirements. We also maintain a quality control laboratory at each plant to assure that you receive the best possible products.



Central Soya's Research Center is where we help customers formulate creative solutions to specific problems.

Our commitment to research.
Our product and application laboratories and pilot plants located on our 24-acre site make up one of the country's most modern research facilities. Our research center is staffed by experienced scientists, chemists, engineers, microbiologists and technical

016999

CENTRAL SOYA CO., INC., RTS. 47 & 9, GIBSON CITY, IL. 60936 217/784/8261

CUSTOMER'S NAME

ADDRESS

PRODUCT

12-05-01	02:08 PM	INBOUND	30800 lb	57460 lb GR
12-05-01	03:53 PM	LOOP # 3		30800 lb TA
		LOOP # 3		26660 lb NT

DATE 12-5-01

EMPTY WT.

LOADED WT.

LIC. NO. 250259 (Rear)

TNK. NO. 18916

REMARKS

DRIVER

WEIGHMASTER

AG Trucking, Inc.

P.O. BOX 453 GOSHEN, INDIANA 46526 (219) 642-3351

SHIPPER'S NO. 495789

CONSIGNEE COPY

SHIPPER: Central Soya	PRODUCT: Centromix AR	PUMP ON ☐ YES ☐ NO	DATE 12-7-01
SHIPPED FROM: Albert City, IL	DELIVERY HUB READING: 120387	PUMP OFF ☐ YES ☐ NO	SHIPPER'S WEIGHT
RECEIVER: FMR Inc	PRODUCT BROKER:	CONVEYOR ☐ YES ☐ NO	GROSS: 57460
SHIPPED TO: Fridley Mn	REMARKS:	PNEUMATIC ☐ YES ☐ NO	TARE: 30800
			NET: 26660
			DELIVERY WEIGHT
			GROSS
			TARE
			NET
			TRUCK NO.: 702
			TRAILER NO.: 1876
			DRIVER NO.
			AG ORDER NO.

LIQUID AND PNEUMATIC LOADS

I HAVE CHECKED THE DOCUMENTS PERTAINING TO THIS SHIPMENT AND DO CERTIFY THAT THIS TANK TRUCK IS CONNECTED TO THE PROPER PIPING AND STORAGE FACILITY WHICH HAS BEEN DESIGNATED TO RECEIVE THE NET WEIGHT OF THE COMMODITY SPECIFIED ON THE SHIPPER'S BILL OF LADING. I HAVE FURNISHED INSTRUCTIONS TO THE DRIVER FOR UNLOADING.

DATE:_____ SIGNATURE:_____

RECEIVED IN GOOD ORDER EXCEPT AS NOTED. ANY CLAIMS FOR LOSS AND/OR DAMAGE TO THE SHIPMENT SHALL BE HANDLED SEPARATED FROM THE PAYMENT OF TRANSPORTATION CHARGES AND MUST BE SUBMITTED IN WRITING TO THE CARRIER WITHIN THIRTY (30) DAYS OF THE DATE OF LOSS. NO PAYMENT OF ANY CLAIM WILL BE MADE UNLESS ALL CHARGES DUE AND PAYABLE ON THE SHIPMENT HAVE BEEN MADE.

PREPAID ☐ COLLECT ☐ (CHECK ONE)

SHIPPER SIGNATURE X_____ RECEIVER SIGNATURE X_____ DRIVER SIGNATURE X_____

GIBSON CITY, IL

PROMISED SHIP DATE 12/06/01
CUST PO:

Page.....: 1
DATE.....:11/30/01
PICKER NO: 346141
TIME.....: 15:20

WAREHOUSE SHIPPING DOCUMENT

144072 11/30/01

SCHEDULED SHIP DATE	CUSTOMER NO.	SALES ORDER NO. & DATE
151559	151560	

SOLD TO:	SHIP TO:
EMR INC 251 S FRONTRAGE ST 28 BURR RIDGE IL 60521-616	EMR INC ANOKE PARK FRIDLEY MN 55421

SALES OFFICE: LE
SALESMAN: 54L

COMMENTS	SHIP TERMS AND VIA	F.O.B. POINT/B.O.L. NO.
TO ARRIVE 12/7 ORDERED BY RAGHU	PREPAID AND ADD TO INVOI BEST WAY	GIBSON CITY, IL

LINE NUMBER	ITEM NUMBER / DESCRIPTION AND COMMENTS	SKU U.M.	ORDER QTY. IN O.U. / U.M./FACTOR	QUANTITY TO BE SHIPPED IN SKU'S	QUANTITY SHIPPED IN: ORDER UNITS	QUANTITY SHIPPED IN: SKU'S
2	6233-00-J1 CENTROMIX BR BULK LOT 01335102		LB 27000			
			TOTAL QUANTITY:	27000		

1.
2. MUST BE IN A HEATED TRUCK
3. CALL FOR DELIVERY APPT -CHARLIE DUFFY 612-789-2642
4.
5.

FOR BULK USE	GROSS	TARE	NET	TRAILER NO.	SEAL
	57,460	30,800	26,660	1876	63336

ARRIVAL TIME	WEIGHED IN BY	TIME LOADED	LOADED BY
AM/PM		4:00 AM/PM	63337

HAVE INSPECTED THE COMPARTMENTS OF THE CAR/TRUCK AND FOUND THEM READY TO LOAD:

I ACKNOWLEDGE RECEIPT OF PROPER ANALYSIS TAGS FOR ALL PRODUCTS RECEIVED IN BULK AND I HAVE VERIFIED THE COUNTS AND QUANTITIES SHOWN ON THIS TALLY AND CERTIFY THEM TO BE CORRECT.

RECEIVED BY:

CONTROL NO. 227565

THIS MEMORANDUM is an acknowledgement that a Bill of Lading has been issued and is a certifed copy of the Original Bill of Lading, covering the property named herein.

RECIEVED, subject to the classifications and lawfully filed tariffs or contracts in effect on the date of the receipt by the carrier of the property described in the Original Bill of Lading.

FROM

CENTRAL

and Subsidiaries
AT: Gibson City, IL

SHIPPER'S NO: 144872
CUSTOMER PO:
CARRIER NAME: AG TRUCKING
DATE: 12/06/2001

SOYA

the property described below, in apparent good order, except as noted (contents and condition of contents of packages unknown), marked, consigned, and destined as indicated below, which said carrier (the word carrier being understood throughout this contract as meaning any person or corporation in possession of the property under the contract) agrees to carry to its usual place of delivery at said destination, if on its route, otherwise to deliver to another carrier on the route to said destination. It is mutually agreed, as to each carrier of all or any of said property over all or any portion of said route to destination, and as to each party at any time interested in all or any of said property, that every service to be performed hereunder shall be subject to all the terms and conditions of the Uniform Domestic Straight Bill Of Lading set forth (1) in Uniform Freight Classification in effect on the date hereof, if this is a rail or a rail-water shipment, or (2) in the applicable motor carrier classification or tariff if this is a motor carrier shipment.
Shipper hereby certifies that he is familiar with all the terms and conditions of the said bill of lading, including those on the back thereof, set forth in the classification or tariff which governs the transportation of this shipment, and the said terms and conditions are hereby agreed to by the shipper and accepted for himself and his assigns.

CONSIGNED TO:
EMR INC
ANOKE PARK

FRIDLEY MN 55421

Gross - 57,460
Tare - 30,800
Net - 26,660

ROUTE:

AG TRUCK LINE	CLASS 70

QUANTITY	DESCRIPTION OF ARTICLES	WEIGHT
1	BULK LECITHIN OIL CONC CRUDE/CENTROMIX BR/6233-00-J1	

SHIPMENT NOTES: THIS SHIPMENT CONTAINS FOODSTUFFS

CALL FOR DELIVERY APPT: CHARLIE DUFFY 612-789-2642

MUST BE IN A HEATED TRUCK

NOTE: PRODUCT TO ARRIVE 12/07/01

FREIGHT TERMS: ○ COLLECT ● PREPAID TRAILER: 1876 SEAL: 63336 & 63337

This is to certify that the above named materials are property classified, described, packaged, marked and labeled, and are in proper condition for transportation, according to the applicable regulations of the Department of Transportation.

From Central Soya Company, Inc.
Permanent P.O. Address of Shipper, PO BOX 1400, FORT WAYNE IN 46801-1400

PER: C. Nagle, Central Soya | AGENT PER:

Subject to Section 7 of Conditions of applicable bill of lading, if this shipment is to be delivered to the consignee without recourse on the consignor, the consignor shall sign the following statement:
The carrier shall not make delivery of this shipment without payment of freight and all other lawful charges

CUSTOMER

CENTRAL SOYA

MODIFIED
MATERIAL SAFETY DATA SHEET
for Central Soya Company, Inc., and Subsidiaries
SECTION I

TRADE AND PRODUCT NAME: **NA**	
CHEMICAL NAME: **Soybean Oil**	COMMON NAME **Soybean Oil**
CHEMICAL FAMILY: **Lipid**	FORMULA: CAS #: **8001-22-7**
MANUFACTURER'S NAME: **Central Soya Company, Inc.**	EMERGENCY TELEPHONE NO.: **219-425-5100, ext 5900**
ADDRESS: **1946 West Cook Rd, Fort Wayne, IN 46818**	

It is our opinion that the above named product does not meet the definition of "Hazardous Chemical" as defined in the OSHA "Hazard Communication Standard" regulation 29 CFR 1910.1200. This Material Safety Data Sheet is provided as general information for health and safety guidance.

SECTION II - INGEDIENTS - THRESHOLD LIMIT VALUES

NO.	INGREDIENT	%	OSHA PEL (PERMISSIBLE EXPOSURE LIMITS)	ACGIH TLV-TWA UNITS (TIME WEIGHTED AVERAGE)	ACGIH TLV-STEL UNITS (SHORT TERM EXPOSURE)	ACGIH TLV NOT DETERMINED
1	Soybean Oil "Mist"	NA	15 mg/m3	NA	NA	
	(Health) 0					
	(Flammability) 1					
	(Reactivity) 1					

SECTION III - PHYSICAL AND CHEMICAL CHARACTERISTICS

PRODUCT		SOLUBILITY IN WATER	**Not soluble**
BOILING POINT (°F.)	**NA**	SPECIFIC GRAVITY (H_2O=1)	**Approx. 0.925**
VAPOR PRESSURE (mm Hg.)	**NA**	PERCENT, VOLATILE BY VOLUME (%)	**NA**
VAPOR DENSITY (AIR=1)	**NA**	EVAPORATION RATE (=1)	**NA**
APPEARANCE AND ODOR	**Pale yellow to brownish-yellow liquid**		

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

PRODUCT				
FLASH POINT (Method Used)	**540 deg F (closed cup)**	FLAMMABLE LIMITS **NA**	Lel	Uel

EXTINGUISHING MEDIA: **Foam, carbon dioxide or dry chemical**

SPECIAL FIRE FIGHTING PROCEDURES: **Class B fire; application of water to flaming oil can cause spattering. Oil will float on water.**

UNUSUAL FIRE AND EXPLOSION HAZARDS: **Avoid closed containment of oil - permeated fabrics which under certain conditions might result in spontaneous combustion.**

SECTION V - HEALTH HAZARD DATA

PROBABLE ROUTE OF EXPOSURE: **Eye contact or inhalation under mist conditions.**

EFFECTS OF OVEREXPOSURE: **Not established.**

Ref ACGIH TLV booklet, Appendix D

EMERGENCY AND FIRST AID PROCEDURES: **If inhaled, remove from contaminated atmoshpere. For eye contact, immediately flush eyes with large amounts of running water. Insure rinsing entire surface of eye & under lid.**

SECTION VI - REACTIVITY DATA

STABILITY: **Stable** CONDITIONS TO AVOID: **NA**

INCOMPATABILITY: **None**

HAZARDOUS DECOMPOSITION PRODUCTS: **None**

HAZARDOUS POLYMERIZATION: **Will Not Occur**

CONDITIONS TO AVOID: **NA**

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: **No special hazards except as "nuisance particles" under mist conditions, e.g., spray from broken pipe. Be cautious of heated oil that may affect pressure.**

WASTE DISPOSAL METHOD: **Check local regulations before cleaned-up materials are introduced into sewer systems or waste treatment systems.**

SECTION VIII - SPECIAL PROTECTION INFORMATION

VENTILATION	LOCAL EXHAUST:	SPECIAL:
	MECHANICAL:	OTHER:

RESPIRATORY PROTECTION *(SPECIFY TYPE)*: **None - unless mist condition prevails.**

PROTECTIVE GLOVES:

EYE PROTECTION:

OTHER PROTECTIVE EQUIPMENT:

SECTION IX - SPECIAL PRECAUTIONS AND COMMENTS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING: **None**

OTHER:

All information provided herein is offered in good faith and with the belief it is accurate. In the event of an adverse incident associated with this product, consult with appropriately trained personnel.

For further information on this topic, please contact Bob Harper at Central Soya Company.
Phone: 219-435-5100

CENTRAL SOYA
Lecithin Division

MODIFIED MATERIAL SAFETY DATA SHEET for Central Soya Company, Inc.

SECTION I

TRADE PRODUCT NAME: **CENTROL®**	ISSUE/LATEST REVISION DATE: **5/12/98**
CHEMICAL NAME: **Soy Lecithin (Food Grade)**	COMMON NAME: **Fluid Soy Lecithin**
CHEMICAL FAMILY: **Mixed Phospholipids**	FORMULA: **Complex** CAS #: **8002-43-5**
MANUFACTURER'S NAME: **Central Soya Company, Inc**	TELEPHONE NO.: **(219)425-5100**
ADDRESS: **P O Box 1400, Fort Wayne IN 46801-1400**	

It is our opinion that the above named product does not meet the definition of "Hazardous Chemical" as defined in the OSHA "Hazard Communication Standard" regulation 29 CFR 1910.1200. This Material Safety Data Sheet is provided as general information for health and safety guidance.
NA = not applicable ND = not determined

SECTION II - INGREDIENTS - THRESHOLD LIMIT VALUES

NO.	INGREDIENT	%	OSHA PEL (PERMISSIBLE EXPOSURE LIMITS)	ACGIH TLV-TWA UNITS (TIME WEIGHTED AVERAGE)	ACGIH TLV-STEL UNITS (SHORT TERM EXPOSURE)
	NA				

SECTION III - PHYSICAL AND CHEMICAL CHARACTERISTICS

☒ PRODUCT ☐ INGREDIENT NO.		SOLUBILITY IN WATER	**Dispersible**
BOILING POINT (°F.)	**NA**	SPECIFIC GRAVITY (H_2O=1)	**Approx. 0.98**
VAPOR PRESSURE (mm Hg.)	**NA**	PERCENT, VOLATILE BY VOLUME (%)	**ND**
VAPOR DENSITY (AIR=1)	**NA**	MELTING POINT	**NA**
APPEARANCE AND ODOR	**Thick amber fluid; bland to bean-like odor.**		

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

			LEL	UEL
☒ PRODUCT ☐ INGREDIENT NO.				
FLASH POINT: (Method Used)	**ND**	FLAMMABLE LIMITS:	**ND**	**ND**

EXTINGUISHING MEDIA: **Dry chemical or CO_2 preferable; water may cause spattering or spreading.**
SPECIAL FIRE FIGHTING PROCEDURES: **NA**

UNUSUAL FIRE AND EXPLOSION HAZARDS: **NA**

SECTION V - HEALTH HAZARD DATA

PROBABLE ROUTE OF EXPOSURE: **Ingestion (food additive); contact with skin or eyes.**
EFFECTS OF OVEREXPOSURE: **None known (perhaps mild irritation to eyes).**

EMERGENCY AND FIRST AID PROCEDURES: **As with any foreign liquid in eyes, flush with water; seek medical help if irritation occurs.**

SECTION VI - REACTIVITY DATA

STABILITY: ● **Stable** ○ **Unstable**
CONDITIONS TO AVOID: **NA**
INCOMPATABILITY: (Materials to avoid) **NA**
HAZARDOUS DECOMPOSITION PRODUCTS:
HAZARDOUS POLYMERIZATION: ○ **May Occur** ● **Will Not Occur**
CONDITIONS TO AVOID: **NA**

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: **Small spills - use absorbent material to collect/contain. Large spills - contain and pump into suitable tank.**
WASTE DISPOSAL METHOD: **Check with local, state, federal authorities for proper disposal of large spills.**

SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTIVE (Specify Type): **Disposable dust/mist type mask recommended if product is atomized.**		
VENTILATION	LOCAL EXHAUST: **NA**	SPECIAL: **NA**
Normal	MECHANICAL (General): **Recommended**	OTHER:
PROTECTIVE GLOVES: **Optional**		EYE PROTECTION: **Safety glasses/goggles recommended.**
OTHER PROTECTIVE EQUIPMENT: **NA**		

SECTION IX - SPECIAL PRECAUTIONS AND COMMENTS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING: **NA**
OTHER: **NA**
Trade Product Name: CENTROL®

All information provided herein is offered in good faith and with the belief it is accurate. In the event of an adverse incident associated with this product, consult with appropriately trained personnel.

FerroTec

Form No: QC0095
Revision: E

CERTIFICATE OF COMPLIANCE

PRODUCT: FERROFLUIDS

I certify that the items furnished, were manufactured from the materials of which standard or typical samples are available for examination, chemical or physical testing, or for which test reports or other evidence of conformance to material specifications are available.

Relevant details:

Part number: 90MA1750000

Item Description: MSG W11

Lot Number: F120101A

Saturation Magnetization at 25°C: 166 Gauss

Viscosity at 27°C: 4.6 Centipoise

Inspector 12/07/2001 Date

Ferrotec (USA) Corporation
40 Simon Street
Nashua, NH 03060-3075

Tel: (603) 883-9800
Fax: (603) 883-2308

www.ferrotec.com
info@ferrotec.com

FerroTec

WATER BASED FERROFLUID
MSG W11
F120101A

Saturation Magnetization	166 Gauss
Viscosity at 27°C	4.6 cp
Density at 25°C	1.2446 gm/ml
Initial Susceptibility	0.5139
Surface Tension	40 dynes/cm
pH	11.2

Ferrotec (USA) Corporation
40 Simon Street
Nashua, NH 03060-3075

Tel: (603) 883-9800
Fax: (603) 883-2308

www.ferrotec.com
info@ferrotec.com

July 2001

MATERIAL SAFETY DATA SHEET

SECTION I: PRODUCT IDENTIFICATION

MANUFACTURER'S NAME:	Ferrotec (USA) Corporation
ADDRESS:	40 Simon Street Nashua, N.H. 03061
TELEPHONE:	(603) 883-9800 (X-212)
EMERGENCY ONLY TELEPHONE:	(800) 424-9300 (Domestic) (703) 527-3887 (For International)
CHEMICAL NAME:	Proprietary Product
TRADE NAME & SYNONYMS:	MSG W11
CHEMICAL FAMILY:	Colloidal Dispersion
FORMULA:	Mixture

SECTION II: COMPONENTS

The precise composition of this mixture is proprietary information. A more complete disclosure will be provided to a physician or nurse in the event of a medical emergency.

Magnetite:	2.8 to 3.5% by volume
Water Soluble Dispersant:	2.0 – 4.0 % by volume
Water:	92.5 to 95.2 % by volume
Food Grade Fragrance:	0.05%

SECTION III: CHEMICAL AND PHYSICAL PROPERTIES

Boiling Point (°F)	212° F
Vapor Pressure (mm Hg.)	17 at 20°C
Percent Volatile by Volume	92.5 to 95.2%
Vapor Density (AIR = 1)	<1
Solubility in Water	Complete
Appearance & Odor	Black Fluid, no odor

SECTION IV: FIRE AND EXPLOSION HAZARD AREA

Flash Point (°F):	N/A
Flammable Limits:	uel N/A lel N/A
Extinguishing Media:	N/A
Special Fire Fighting Procedure:	N/A
Unusual Fire and Explosion Hazard.	None

SECTION V: HEALTH HAZARD AREA

Threshold Limit Value:	Not Determined
Effects of Overexposure:	No experience with overexposure. Prolonged or repeated contact with skin or eye may cause irritation. Inhalation of mist or vapor at high temperature may irritate respiratory passages.

Emergency and First Aid Procedures:

Skin Contact:	Wash with soap and water.
Eyes:	Flush with water and consult a physician for treatment.
Inhalation of Smoke or Mist:	Move to fresh air and refer to physician for treatment.

SECTION VI: REACTIVITY DATA

Stability:	Unstable [ ] Stable [x]
Incompatibility (materials to avoid):	Strong oxidizing materials, heat, and flame.
Hazardous Decomposition Products:	Burning may produce carbon monoxide and nitrogen oxides.
Hazardous Polymerization:	May Occur [ ] Will Not Occur [x]

SECTION VII: SPILL OR LEAK PROCEDURES

Steps to be taken in case material is released or spilled:

Remove free liquid. Add absorbent (sand, earth, sawdust) to spill area.
After removing absorbent, wash surface with soap and water to reduce possible slipping hazard.

Waste Disposal Method:

Consult federal, state and local regulations applicable to disposal of wastewater.

SECTION VIII: SPECIAL PROTECTION INFORMATION

Respiratory Protection (Specify Type):

None required unless smoke, mists, or vapors are produced.

Ventilation:

No special ventilation required.

Protective Gloves:

If required to prevent prolonged or repeated skin contact.

Eye Protection:

Safety glasses, if splash is possible.

Other Protective Equipment:

Not needed.

SECTION IX SPECIAL PRECAUTIONS

Precautions to be taken in handling and storing:

Ordinary care in handling chemicals. Wash hands after handling.

Other Precautions:

Avoid contamination of tobacco products. Users should be aware that a very small percentage of the population may display unexpected allergic skin reactions to otherwise innocuous industrial chemicals and raw material.

SECTION X: TRANSPORT INFORMATION

U.S. DOT Bulk Shipping Description:	**Not regulated**
U.S. DOT Non-Bulk Shipping Description:	**Not regulated**
IMDG Code Shipping Description:	**Not regulated**
ICAO Shipping Description:	**Not regulated**
ADR/RID Hazard Class:	**Not regulated**

SECTION XI: COMMENTS

* This product DOES NOT contain any materials considered to be carcinogenic by any recognized sources.

** This material is not sold for use in products for which prolonged contact with skin or implantation in the human body is intended. Ferrotec (USA) Corporation does not recommend this material as safe and effective for such uses and assumes no liability for any such use.

*** This product does not contain any chemical subject to the reporting requirements of Section 313 of Title III of the Superfund Amendment and Reauthorization Act of 1986 and 40 CFR Part 372.

ISP TECHNOLOGIES INC.

Telephone
973 628 4000
1361 Alps Road
Wayne, NJ 07470

Emergency
Medical Information: 612 221 39
Transportation
Emergency: CHEMTREC 1 800 424 93

MATERIAL SAFETY DATA SHEET

MICROPOWDER IRON GRADE S-3700

SECTION 01 - CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

DOMESTIC TRADE NAME: MICROPOWDER IRON GRADE S-3700
EXPORT TRADE NAME: MICROPOWDER IRON GRADE S-3700

CAS REGISTRY NO.: 7439-89-6
CAS REGISTRY NAME: IRON
SYNONYM: METALLIC IRON

MOLECULAR FORMULA: Fe
MOLECULAR WEIGHT: 55.85

SECTION 02 - COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

NONE

SECTION 03 - HAZARDS IDENTIFICATION

```
* * * * * * * * * * * *  E M E R G E N C Y   O V E R V I E W  * * * * * * * * * * * *
*                                                                                     *
*  UNIFORM, GREYISH-BROWN POWDER.                                                     *
*  DUSTING IN AIR WILL PRESENT A MODERATE DUST EXPLOSION HAZARD WITH A                *
*  SPARK SOURCE.  LOW IGNITION ENERGY OF THE POWDER IS A CONTRIBUTING FACTOR          *
*  TO THE FIRE/EXPLOSION HAZARD.                                                      *
*                                                                                     *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

-ACUTE TOXICITY-

ORAL TOXICITY:
RAT LD50: 30,000 MG/KG; NO EVIDENCE OF GROSS PATHOLOGY.

DERMAL TOXICITY:
NO DATA FOUND.

INHALATION TOXICITY:
LITERATURE REFERENCES INDICATE SLIGHT HAZARD FROM INHALATION.

SKIN IRRITATION:
LITERATURE REFERENCES INDICATE NO HAZARD FROM SKIN CONTACT.

SECTION 03 - HAZARDS IDENTIFICATION (CONT.)

EYE IRRITATION:
HUMAN; IRON IN EYE CAUSES RUST RINGS IN CORNEA ASSOCIATED WITH IRRITATION, HYPEREMIA OF CONJUNCTIVA AND INFLAMMATION.

SENSITIZER:
NO DATA FOUND.

DOT CORROSIVE:
NO DATA FOUND.

PRIMARY ROUTE(S) OF ENTRY: INHALATION / CONTACT

-SIGNS AND SYMPTOMS OF EXPOSURE-

SYMPTOMS OF INGESTION:
NO EFFECTS OF EXPOSURE EXPECTED.

SYMPTOMS OF INHALATION:
NO EFFECTS OF EXPOSURE EXPECTED.

SYMPTOMS OF SKIN CONTACT:
NO EFFECTS OF EXPOSURE EXPECTED DUE TO CONTACT. MAY POSSIBLY CAUSE IRRITATION OR DERMATITIS IN SOME INDIVIDUALS UPON PROLONGED CONTACT.

SYMPTOMS OF EYE CONTACT:
NO EFFECTS OF EXPOSURE EXPECTED WITH THE EXCEPTION OF POSSIBLE IRRITATION.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE:
NO DATA FOUND

-OTHER TOXICITY-

OTHER ACUTE TOXICITY:
INTRAVENOUS; RABBIT; 0.5 - 1.0 G/KG CARBONYL IRON POWDER PRODUCED ERYTHROBLASTHEMIA; REVERSIBLE AFTER 1 WEEK.

SUB CHRONIC ORAL TOXICITY:
60-DAY; RAT; 0.1, 1.0, 5.0% DIET; HEMATOLOGIC, HISTOLOGIC EXAMINATIONS AND URINALYSIS RESULTS WERE NORMAL; SLIGHT INCREASE IN WEIGHT.

SUB CHRONIC INHALATION TOXICITY:
NO DATA FOUND

SUB CHRONIC MISCELLANEOUS TOXICITY:
INTRATRACHEAL; RAT TDLo: 506 MG/KG/15 WEEKS; INTERMITTENTLY; NEOPLASTIGENIC.

AQUATIC TOXICITY:
NO DATA FOUND

SECTION 03 - HAZARDS IDENTIFICATION (CONT.)

TUMORIGENICITY:
16-WEEK; SUBCUTANEOUS; MOUSE; 20 MG; 0/20 TUMORS.

MUTAGENICITY:
NO DATA FOUND

REPRODUCTIVE TOXICITY:
NO DATA FOUND

MISCELLANEOUS TOXICITY:
NO DATA FOUND

SECTION 04 - FIRST AID MEASURES

FIRST AID FOR INGESTION:
DRINK PLENTY OF WATER. CALL A PHYSICIAN. NEVER GIVE ANYTHING BY MOUTH TO AN UNCONSCIOUS PERSON.

FIRST AID FOR INHALATION:
NONE REQUIRED.

FIRST AID FOR SKIN CONTACT:
FOR ALL FOREIGN MATERIALS, WASH AFTER EXPOSURE.

FIRST AID FOR EYE CONTACT:
FOR ALL FOREIGN MATERIALS, IMMEDIATELY FLUSH EYES WITH PLENTY OF WATER.

SECTION 05 - FIREFIGHTING MEASURES

FLASH POINT: NO FLASH POINT
AUTOIGNITION TEMP: NO DATA FOUND
FLAMMABLE LIMITS: NO DATA FOUND
FIRE FIGHTING MEDIA: DRY CHEMICAL
SPECIAL FIRE FIGHTING PROCEDURES:
NONE KNOWN
FIRE/EXPLOSION HAZARDS:
STRONG HEAT, SPARKS OR FLAME WILL INITIATE RAPID OXIDATION, WHICH IN THE PRESENCE OF SUFFICIENT AIR, WILL PROCEED SPONTANEOUSLY TO GLOW DULL RED. MAY IGNITE OTHER COMBUSTIBLES. DUSTING IN AIR WILL PRESENT A MODERATE DUST EXPLOSION HAZARD IF THERE IS AN IGNITION SOURCE PRESENT SUCH AS A STATIC ELECTRICAL CHARGE. LOW IGNITION ENERGY OF THE POWDER IS A CONTRIBUTING FACTOR TO THE FIRE/EXPLOSION HAZARD.

SECTION 05 - FIREFIGHTING MEASURES (CONT.)

NFPA HAZARD CODES - HEALTH/FLAMMABILITY/REACTIVITY	0	1	1
HMIS HAZARD CODES - HEALTH/FLAMMABILITY/REACTIVITY	0	1	1

SECTION 06 - ACCIDENTAL RELEASE MEASURES

SPILL/LEAK CLEAN-UP PROCEDURES:
SCOOP UP. AVOID DUSTING. DISPOSE OF WITH SOLID WASTE ACCORDING TO FEDERAL, STATE AND LOCAL REGULATIONS. FLUSH SPILL AREA WITH WATER.

EPA HAZARDOUS SUBSTANCE REPORTABLE QUANTITY: NOT LISTED

SECTION 07 - HANDLING AND STORAGE

PRECAUTIONARY MEASURES:
AVOID CONTACT. AVOID BREATHING DUST. WASH THOROUGHLY AFTER HANDLING. USE DUST MASK WHERE DUSTING CANNOT BE AVOIDED. USE WITH ADEQUATE VENTILATION.
DO NOT CREATE DUST CLOUD IN AIR. GROUND AND BOND ALL PROCESSING, DUST CONTROL AND MATERIALS HANDLING EQUIPMENT TO CONTROL STATIC ELECTRICITY CHARGES. PURGE PROCESSING EQUIPMENT BEFORE USE. PROCESS POWDERS UNDER AN INERT ATMOSPHERE OF LESS THAN 10% OXYGEN. DO NOT ALLOW THE ACCUMULATION OF IRON DUST ON OVERHEAD HORIZONTAL SURFACES.

DISPOSAL METHOD:
DISPOSE OF WITH SOLID WASTE ACCORDING TO FEDERAL, STATE AND LOCAL REGULATIONS.

RCRA CLASS: NOT REGULATED

SECTION 08 - EXPOSURE CONTROLS/PERSONAL PROTECTION

VENTILATION:
USE WITH ADEQUATE VENTILATION.

RESPIRATORY PROTECTION:
DUST MASK WHERE DUSTING CANNOT BE AVOIDED.

EYE PROTECTION:
SAFETY GLASSES.

SKIN PROTECTION:
FLAME RETARDANT CLOTHING REQUIRED.

SECTION 08 - EXPOSURE CONTROLS/PERSONAL PROTECTION (CONT.)

PERSONAL HYGIENE:
WASH THOROUGHLY AFTER HANDLING.

PROTECTIVE MEASURES DURING REPAIR/MAINTENANCE OF EQUIPMENT:
WASH EQUIPMENT THOROUGHLY WITH STEAM OR WARM WATER UNTIL CLEAN. CHECK THE OXYGEN LEVEL WITH AN OXYGEN METER. IN ALL CASES, FOLLOW GOOD INDUSTRIAL SAFETY PRACTICES BEFORE ENTERING EQUIPMENT.

EXPOSURE LIMITS:
FOR INERT OR NUISANCE DUST (PARTICULATES NOT OTHERWISE REGULATED/CLASSIFIED):
OSHA PEL:TWA 15 MG/M3 - TOTAL DUST; 5 MG/M3 - RESPIRABLE FRACTION
ACGIH TLV:TWA 10 MG/M3 - INHALABLE; 3 MG/M3 - RESPIRABLE

SECTION 09 - PHYSICAL AND CHEMICAL PROPERTIES

BOILING POINT: 2750 DEG C
VAPOR PRESSURE: NOT VOLATILE
VAPOR DENSITY (AIR=1): NOT VOLATILE
WATER SOLUBILITY: INSOLUBLE
MELTING/FREEZING POINT: 1535 DEG C
APPEARANCE: UNIFORM POWDER
SPECIFIC GRAV. (WATER=1): NO DATA FOUND
PERCENTAGE VOLATILES: NOT VOLATILE
EVAPORATION RATE: NOT VOLATILE
pH OF SOLUTION: NO DATA FOUND
ODOR: NO DATA FOUND

SECTION 10 - STABILITY AND REACTIVITY

STABILITY: STABLE
HAZARDOUS POLYMERIZATION: WILL NOT OCCUR
CONDITIONS TO AVOID:
OXIDIZES READILY IN MOIST AIR.

INCOMPATIBLE MATERIALS:
REACTS VIOLENTLY WITH ACIDS OR OXIDIZING AGENTS. CHLORINE TRIFLUORIDE, FLUORINE AND NITROGEN DIOXIDE REACT WITH IRON WITH INCANDESCENCE. PHOSPHORUS REACTS WITH IRON WITH INCANDESCENCE WHEN HEATED.

HAZARDOUS DECOMPOSITION PRODUCTS:
NONE KNOWN

SECTION 11 - TRANSPORT INFORMATION

-DOMESTIC DATA-
DOT SHIPPING NAME: NOT REGULATED
DOT HAZARD CLASS: NOT REGULATED
HAZARDOUS INGREDIENT(S): NONE
UN NUMBER: NONE

-EXPORT DATA-
EXPORT SHIPPING NAME: NOT REGULATED
EXPORT HAZARD CLASS: NOT REGULATED
HAZARDOUS INGREDIENT(S): NONE
UN NUMBER: NONE

FerroTec

To: John Lane
USGS

cc:

From: Steve Tatarunis
Ferrotec (USA) Corporation
40 Simon Street
Nashua, NH 03060-3075
tel: 603-598-7216 (direct)
fax: 603-883-2308
internet: statarunis@ferrotec.com

Monday, October 01, 2001 - 3:06 PM

Subj.: Ferrofluid carrier liquid MSDS

Dear John,

Attached is the MSDS for the carrier liquid used in the manufacture of the EFH-1 ferrofluid.

As for the dispersant, in general terms, we can refer to it as being a fatty acid. Hopefully, that will be sufficient for your regulators. If not, we'll consider our next step.

Best Regards,

Steve Tatarunis
Product Manager
Ferrotec (USA) Corporation

EXXON COMPANY, U.S.A.
A DIVISION OF EXXON CORPORATION

DATE ISSUED: 01/24/97
SUPERSEDES DATE: 10/28/96

MATERIAL SAFETY DATA SHEET

EXXON COMPANY, U.S.A. P.O. BOX 2180 HOUSTON, TX 77252-2180

A. IDENTIFICATION AND EMERGENCY INFORMATION

PRODUCT NAME
ISOPAR M

PRODUCT CODE
133468 - 00635

PRODUCT CATEGORY
Petroleum Solvent

PRODUCT APPEARANCE AND ODOR
Clear water-white liquid
Essentially odorless

MEDICAL EMERGENCY TELEPHONE NUMBER
(713) 656-3424

B. COMPONENTS AND HAZARD INFORMATION

COMPONENTS	CAS NO. OF COMPONENTS	APPROXIMATE CONCENTRATION
Distillates (petroleum), hydrotreated light	64742-47-8	100%

This product consists predominantly of C12-C15 isoparaffinic hydrocarbons.

This product, as manufactured by Exxon, does not contain polychlorinated biphenyls (PCB's).

All components of this product are listed on the U.S. TSCA inventory.

See Section E for Health and Hazard Information.

See Section H for additional Environmental Information.

HAZARDOUS MATERIALS IDENTIFICATION SYSTEM (HMIS)

Health	Flammability	Reactivity	BASIS
1	2	0	Recommended by Exxon

EXPOSURE LIMIT FOR TOTAL PRODUCT	BASIS
300 ppm (2300 mg/m3) for an 8-hour workday	Recommended by Exxon

C. PRIMARY ROUTES OF ENTRY AND EMERGENCY AND FIRST AID PROCEDURES

EYE CONTACT
If splashed into the eyes, flush with clear water for 15 minutes or until irritation subsides. If irritation persists, call a physician.

SKIN
In case of skin contact, remove any contaminated clothing and wash skin with soap and water. Launder or dry-clean clothing before reuse. If product is injected into or under the skin, or into any part of the body, regardless of the appearance of the wound or its size, the individual should be evaluated immediately by a physician as a surgical emergency. Even though initial symptoms from high pressure injection may be minimal or absent, early surgical treatment within the first few hours may significantly reduce the ultimate

extent of injury.

INHALATION
If overcome by vapor, remove from exposure and call a physician immediately. If breathing is irregular or has stopped, start resuscitation, administer oxygen, if available.

INGESTION
If ingested, DO NOT induce vomiting; call a physician immediately.

D. FIRE AND EXPLOSION HAZARD INFORMATION

FLASH POINT (MINIMUM)
COMBUSTIBLE - Per DOT 49 CFR 173.120
80.5°C (177°F)
ASTM D 93, Pensky Martens Closed Cup

AUTOIGNITION TEMPERATURE
Approximately 338°C (640°F)
ASTM D 2155

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA) - HAZARD IDENTIFICATION

Health	Flammability	Reactivity	BASIS
1	2	0	Recommended by Exxon

HANDLING PRECAUTIONS
This liquid is volatile and gives off invisible vapors. Either the liquid or vapor may settle in low areas or travel some distance along the ground or surface to ignition sources where they may ignite or explode.

Keep product away from ignition sources, such as heat, sparks, pilot lights, static electricity, and open flames.

FLAMMABLE OR EXPLOSIVE LIMITS (APPROXIMATE PERCENT BY VOLUME IN AIR)
Estimated values: Lower Flammable Limit 1.3% Upper Flammable Limit 6.8%

EXTINGUISHING MEDIA AND FIRE FIGHTING PROCEDURES
Foam, water spray (fog), dry chemical, carbon dioxide and vaporizing liquid type extinguishing agents may all be suitable for extinguishing fires involving this type of product, depending on size or potential size of fire and circumstances related to the situation. Plan fire protection and response strategy through consultation with local fire protection authorities or appropriate specialists.

The following procedures for this type of product are based on the recommendations in the National Fire Protection Association's "Fire Protection Guide on Hazardous Materials", Tenth Edition (1991):

Use dry chemical, foam or carbon dioxide to extinguish the fire. "Water may be ineffective", but water should be used to keep fire-exposed containers cool. If a leak or spill has ignited, use water spray to disperse the vapors and to protect persons attempting to stop a leak. Water spray may be used to flush spills away from exposures. Minimize breathing of gases, vapor, fumes or decomposition products. Use supplied-air breathing equipment for enclosed or confined spaces or as otherwise needed.

NOTE: The inclusion of the phrase "water may be ineffective" is to indicate that although water can be used to cool and protect exposed material, water may not extinguish the fire unless used under favorable conditions by experienced fire fighters trained in fighting all types of flammable liquid fires.

DECOMPOSITION PRODUCTS UNDER FIRE CONDITIONS
Fumes, smoke, carbon monoxide, sulfur oxides, aldehydes and other decomposition products, in the case of incomplete combustion.

"EMPTY" CONTAINER WARNING
"Empty" containers retain residue (liquid and/or vapor) and can be dangerous. DO NOT PRESSURIZE, CUT, WELD, BRAZE, SOLDER, DRILL, GRIND OR EXPOSE SUCH CONTAINERS TO HEAT, FLAME, SPARKS, STATIC ELECTRICITY, OR OTHER SOURCES OF IGNITION; THEY MAY EXPLODE AND CAUSE INJURY OR DEATH. Do not attempt to clean since residue is difficult to remove. "Empty" drums should be completely drained, properly bunged and promptly returned to a drum reconditioner. All other containers should be disposed of in an environmentally safe manner and in accordance with governmental regulations. For work on tanks refer to Occupational Safety and Health Administration regulations, ANSI Z49.1, and

other governmental and industrial references pertaining to cleaning, repairing, welding, or other contemplated operations.

E. HEALTH AND HAZARD INFORMATION

VARIABILITY AMONG INDIVIDUALS
Health studies have shown that many petroleum hydrocarbons and synthetic lubricants pose potential human health risks which may vary from person to person. As a precaution, exposure to liquids, vapors, mists or fumes should be minimized.

EFFECTS OF OVEREXPOSURE (Signs and symptoms of exposure)
High vapor concentrations (greater than approximately 700 ppm, attainable at elevated temperatures well above ambient) are irritating to the eyes and the respiratory tract, and may cause headaches, dizziness, anesthesia, drowsiness, unconsciousness, and other central nervous system effects, including death.

NATURE OF HAZARD AND TOXICITY INFORMATION
Prolonged or repeated skin contact with this product tends to remove skin oils, possibly leading to irritation and dermatitis; however, based on human experience and available toxicological data, this product is judged to be neither a "corrosive" nor an "irritant" by OSHA criteria.

Product contacting the eyes may cause eye irritation.

Product has a low order of acute oral and dermal toxicity, but minute amounts aspirated into the lungs during ingestion or vomiting may cause mild to severe pulmonary injury and possibly death.

This product is judged to have an acute oral LD50 (rat) greater than 5 g/kg of body weight, and an acute dermal LD50 (rabbit) greater than 3.16 g/kg of body weight.

PRE-EXISTING MEDICAL CONDITIONS WHICH MAY BE AGGRAVATED BY EXPOSURE
Petroleum Solvents/Petroleum Hydrocarbons - Skin contact may aggravate an existing dermatitis.

F. PHYSICAL DATA

The following data are approximate or typical values and should not be used for precise design purposes.

BOILING RANGE
218-251°C (424-484°F)

SPECIFIC GRAVITY (15.6°C/15.6°C)
0.79 (6.56 lb/gal)

MOLECULAR WEIGHT
191

pH
Essentially neutral

POUR, CONGEALING OR MELTING POINT
Not available

VISCOSITY
3.42 cSt @ 25°C (77°F) ASTM D 445

VAPOR PRESSURE
Less than 0.1 mm Hg @ 20°C (68°F)
ASTM D 2879

VAPOR DENSITY (AIR = 1)
7.3

PERCENT VOLATILE BY VOLUME
Approximately 50% in 465 minutes @ 1 atm. and 25°C (77°F)

EVAPORATION RATE @ 1 ATM. AND 25°C (77°F) (n-BUTYL ACETATE = 1)
Less than 0.01

SOLUBILITY IN WATER @ 1 ATM. AND 25°C (77°F)
Negligible: 0.0001%

G. REACTIVITY

This product is stable and will not react violently with water. Hazardous polymerization will not occur. Avoid contact with strong oxidants such as liquid chlorine, concentrated oxygen, sodium hypochlorite, calcium hypochlorite, etc., as this presents a serious explosion hazard.

H. ENVIRONMENTAL INFORMATION

CLEAN WATER ACT / OIL POLLUTION ACT
This product may be classified as an oil under Section 311 of the Clean Water Act, and under the Oil Pollution Act. Discharges or spills into or leading to surface waters that cause a sheen must be reported to the National Response Center (1-800-424-8802).

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
Shut off and eliminate all ignition sources. Keep people away. Recover free product. Add sand, earth or other suitable absorbent to spill area. Minimize breathing vapors. Minimize skin contact. Ventilate confined spaces. Open all windows and doors. Keep product out of sewers and watercourses by diking or impounding. Advise authorities if product has entered or may enter sewers, watercourses, or extensive land areas.

Assure conformity with applicable governmental regulations. Continue to observe precautions for volatile, combustible vapors from absorbed material.

THE FOLLOWING INFORMATION MAY BE USEFUL IN COMPLYING WITH VARIOUS STATE AND FEDERAL LAWS AND REGULATIONS UNDER VARIOUS ENVIRONMENTAL STATUTES:

THRESHOLD PLANNING QUANTITY (TPQ), EPA REGULATION 40 CFR 355
(SARA Sections 301-304)
No TPQ for product or any constituent greater than 1% or 0.1% (carcinogen).

TOXIC CHEMICAL RELEASE REPORTING, EPA REGULATION 40 CFR 372 (SARA Section 313)
No toxic chemical is present greater than 1% or 0.1% (carcinogen).

HAZARDOUS CHEMICAL REPORTING, EPA REGULATION 40 CFR 370 (SARA Sections 311-312)

EPA HAZARD CLASSIFICATION CODE:	Acute Hazard	Chronic Hazard	Fire Hazard	Pressure Hazard	Reactive Hazard	Not Applicable
			XXX			

I. PROTECTION AND PRECAUTIONS

VENTILATION
Use only with ventilation sufficient to prevent exceeding recommended exposure limit or buildup of explosive concentrations of vapor in air. No smoking, or use of flame or other ignition sources.

RESPIRATORY PROTECTION
Use supplied-air respiratory protection in confined or enclosed spaces, if needed.

PROTECTIVE GLOVES
Use chemical-resistant gloves, if needed, to avoid prolonged or repeated skin contact.

EYE PROTECTION
Use splash goggles or face shield when eye contact may occur.

OTHER PROTECTIVE EQUIPMENT
Use chemical-resistant apron or other impervious clothing, if needed, to avoid contaminating regular clothing, which could result in prolonged or repeated skin contact.

WORK PRACTICES / ENGINEERING CONTROLS
Keep containers closed when not in use. Do not store near heat, sparks, flame

or strong oxidants. To prevent fire or explosion risk from static accumulation and discharge, effectively ground product transfer system in accordance with the National Fire Protection Association standard for petroleum products.

In order to prevent fire or explosion hazards, use appropriate equipment.

Information on electrical equipment appropriate for use with this product may be found in the latest edition of the National Electrical Code (NFPA-70). This document is available from the National Fire Protection Association, Batterymarch Park, Quincy, Massachusetts 02269.

PERSONAL HYGIENE
Minimize breathing vapor or mist. Avoid prolonged or repeated contact with skin. Remove contaminated clothing; launder or dry-clean before re-use. Remove contaminated shoes and thoroughly clean and dry before re-use. Cleanse skin thoroughly after contact, before breaks and meals, and at end of work period. Product is readily removed from skin by waterless hand cleaners followed by washing thoroughly with soap and water.

J. TRANSPORTATION AND OSHA RELATED LABEL INFORMATION

TRANSPORTATION INCIDENT INFORMATION
For further information relative to spills resulting from transportation incidents, refer to latest Department of Transportation Emergency Response Guidebook for Hazardous Materials Incidents.

U.S. DOT HAZARDOUS MATERIALS SHIPPING DESCRIPTION
Bulk packagings (capacity greater than 119 gallons)
Petroleum Distillate, n.o.s., Combustible Liquid, UN 1268, III

Non-bulk packagings (capacity less than or equal to 119 gallons)
Not regulated

OSHA REQUIRED LABEL INFORMATION
In compliance with hazard and right-to-know requirements, where applicable OSHA Hazard Warnings may be found on the label, bill of lading or invoice accompanying this shipment.

DANGER!

COMBUSTIBLE

Note: Product label may contain non-OSHA related information also.

The information and recommendations contained herein are, to the best of Exxon's knowledge and belief, accurate and reliable as of the date issued. Exxon does not warrant or guarantee their accuracy or reliability, and Exxon shall not be liable for any loss or damage arising out of the use thereof.

The information and recommendations are offered for the user's consideration and examination, and it is the user's responsibility to satisfy itself that they are suitable and complete for its particular use. If buyer repackages this product, legal counsel should be consulted to insure proper health, safety and other necessary information is included on the container.

The Environmental Information included under Section II hereof as well as the Hazardous Materials Identification System (HMIS) and National Fire Protection Association (NFPA) ratings have been included by Exxon Company, U.S.A. in order to provide additional health and hazard classification information. The ratings recommended are based upon the criteria supplied by the developers of these rating systems, together with Exxon's interpretation of the available data.

FOR LUBRICANTS TECHNICAL ASSISTANCE CALL: 1-800-443-9966

FOR FUELS TECHNICAL ASSISTANCE CALL: 713-656-4955

FOR AN MSDS OR ASSISTANCE WITH AN MSDS, DIRECT INQUIRIES TO THE ADDRESS BELOW OR CALL:

MARKETING TECHNICAL SERVICES
EXXON COMPANY, U.S.A.
ROOM 2344
P. O. BOX 2180
HOUSTON, TX 77252-2180
(713) 656-5949

IF YOU HAVE AN IMMEDIATE NEED FOR AN MSDS, DIAL 1-800-298-4007 FOR A FAXED COPY.

414 459 5863

note manufacturer can mix magnetite into vegetable oil. This product contains mineral oil.

January 1999

MATERIAL SAFETY DATA SHEET

SECTION I: PRODUCT IDENTIFICATION

MANUFACTURER'S NAME:	Ferrofluidics Corporation
ADDRESS:	40 Simon Street Nashua, N.H. 03061
TELEPHONE:	**(603) 883-9800 (X212)**
EMERGENCY ONLY TELEPHONE:	**(800) 424-9300 (Domestic)** **(703) 527-3887 (For International)**
CHEMICAL NAME:	Proprietary Product
TRADE NAME & SYNONYMS:	EF HI
CHEMICAL FAMILY:	Colloidal Dispersion
FORMULA:	Mixture

SECTION II: COMPONENTS

The precise composition of this mixture is proprietary information. A more complete disclosure will be provided to a physician or nurse in the event of a medical emergency.

Magnetite:	3-15 % by volume
Oil Soluble Dispersant:	6-30 % by volume
Carrier Liquid:	55-91 % by volume (mineral)

SECTION III: CHEMICAL AND PHYSICAL PROPERTIES

Boiling Point (°F):	**401-491**
Specific Gravity:	**0.92 to 1.47**
Vapor Pressure (mm Hg.):	**1 at 100°F**
Percent Volatile by Volume:	**55-91 %**
Vapor Density (AIR = 1):	**6.4**
Solubility in Water:	**Negligible**
Evaporation Rate at:	**<0.1**
Appearance & Odor:	**Black liquid, Mild odor**

SECTION IV: FIRE AND EXPLOSION HAZARD AREA

Flash Point (°F):	160°
Method:	TCC
Flammable Limits:	uel: 0.6 lel : 7.0 at 77°F
Extinguishing Media:	Co_2, Foam, dry chemical, water spray.
Special Fire Fighting Procedure:	Avoid smoke inhalation. Water spray may cause frothing.
Unusual Fire and Explosion Hazard:	None

SECTION V: HEALTH HAZARD AREA

Threshold Limit Value:	$5mg/m^3$ for oil mist in air (OSHA Regulations 29 CFR 1910-1000)
Effects of Overexposure:	No experience with overexposure. Prolonged or repeated contact with skin or eye contact may cause irritation. Inhalation of mist or vapor at high temperature may irritate respiratory passages.

Emergency and First Aid Procedures:

Skin Contact:	Wash with soap and water.
Eyes:	Flush with water and consult a physician for treatment.
Inhalation of Smoke or Mist:	Move to fresh air and refer to physician for treatment.

SECTION VI: REACTIVITY DATA

Stability:	Unstable [ ] Conditions to Avoid: Prolysis Stable [x]
Incompatibility (materials to avoid):	Strong oxidizing materials, heat, and flame.
Hazardous Decomposition Products:	Burning may produce carbon monoxide and nitrogen oxides.
Hazardous Polymerization:	May Occur [ ] Will Not Occur [x]

SECTION VII: SPILL OR LEAK PROCEDURES

Steps to be taken in case material is released or spilled:

Remove free liquid. Add absorbent (sand, earth, sawdust) to spill area.
After removing absorbent, wash surface with soap and water to reduce possible slipping hazard.

Waste Disposal Method:

Consult federal, state and local regulations applicable to disposal of waste oils.

SECTION VIII: SPECIAL PROTECTION INFORMATION

Respiratory Protection (Specify Type):

None required unless smoke, mists, or vapors are produced.

Ventilation:

No special ventilation required.

Protective Gloves:

If required to prevent prolonged or repeated skin contact.

Eye Protection:

Safety glasses, if splash is possible.

Other Protective Equipment:

Not needed.

SECTION IX SPECIAL PRECAUTIONS

Precautions to be taken in handling and storing:

Ordinary care in handling chemicals. Wash hands after handling.

Other Precautions:

Avoid contamination of tobacco products. Users should be aware that a very small percentage of the population may display unexpected allergic skin reactions to otherwise innocuous industrial chemicals and raw material.

SECTION X: COMMENTS

* This product DOES NOT contain any materials considered to be carcinogenic by any recognized sources.

** This material is not sold for use in products for which prolonged contact with skin or implantation in the human body is intended. Ferrofluidics Corporation does not recommend this material as safe and effective for such uses and assumes no liability for any such use.

*** This product does not contain any chemical subject to the reporting requirements of Section 313 of Title III of the Superfund Amendment and Reauthorization Act of 1986 and 40 CFR Part 372.

Form No: QC0095
Revision: E

Ferrofluidics
a Ferrotec company

CERTIFICATE OF COMPLIANCE

PRODUCT: FERROFLUIDS

I certify that the items furnished, were manufactured from the materials of which standard or typical samples are available for examination, chemical or physical testing, or for which test reports or other evidence of conformance to material specifications are available.

Relevant details:

Part number: 92U4000000

Item Description: EFHI Ferrofluid

Lot Number: F041201C

Saturation Magnetization at 25°C: 400 Gauss(±10%)

Viscosity at 27°C: < 5 Centipoise(±10%)

Inspector 7/5/01 Date

Ferrofluidics Corporation
40 Simon Street
Nashua, NH 03060-3075

Tel: (603) 883-9800
Fax: (603) 883-2308

www.ferrofluidics.com
info@ferrofluidics.com

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Emergency:
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MATERIAL SAFETY DATA SHEET

MICROPOWDER IRON GRADE S-3700

SECTION 01 - CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

DOMESTIC TRADE NAME: MICROPOWDER IRON GRADE S-3700
EXPORT TRADE NAME: MICROPOWDER IRON GRADE S-3700

CAS REGISTRY NO.: 7439-89-6
CAS REGISTRY NAME: IRON
SYNONYM: METALLIC IRON

MOLECULAR FORMULA: Fe
MOLECULAR WEIGHT: 55.85

SECTION 02 - COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

NONE

SECTION 03 - HAZARDS IDENTIFICATION

```
************ EMERGENCY OVERVIEW ************
*                                          *
* UNIFORM, GREYISH-BROWN POWDER.           *
* DUSTING IN AIR WILL PRESENT A MODERATE DUST EXPLOSION HAZARD WITH A *
* SPARK SOURCE. LOW IGNITION ENERGY OF THE POWDER IS A CONTRIBUTING FACTOR *
* TO THE FIRE/EXPLOSION HAZARD.            *
*                                          *
********************************************
```

-ACUTE TOXICITY-

ORAL TOXICITY:
RAT LD50: 30,000 MG/KG; NO EVIDENCE OF GROSS PATHOLOGY.

DERMAL TOXICITY:
NO DATA FOUND.

INHALATION TOXICITY:
LITERATURE REFERENCES INDICATE SLIGHT HAZARD FROM INHALATION.

SKIN IRRITATION:
LITERATURE REFERENCES INDICATE NO HAZARD FROM SKIN CONTACT.

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SECTION 03 - HAZARDS IDENTIFICATION (CONT.)

EYE IRRITATION:
HUMAN; IRON IN EYE CAUSES RUST RINGS IN CORNEA ASSOCIATED WITH IRRITATION, HYPEREMIA OF CONJUNCTIVA AND INFLAMMATION.

SENSITIZER:
NO DATA FOUND.

DOT CORROSIVE:
NO DATA FOUND.

PRIMARY ROUTE(S) OF ENTRY: INHALATION / CONTACT

-SIGNS AND SYMPTOMS OF EXPOSURE-

SYMPTOMS OF INGESTION:
NO EFFECTS OF EXPOSURE EXPECTED.

SYMPTOMS OF INHALATION:
NO EFFECTS OF EXPOSURE EXPECTED.

SYMPTOMS OF SKIN CONTACT:
NO EFFECTS OF EXPOSURE EXPECTED DUE TO CONTACT. MAY POSSIBLY CAUSE IRRITATION OR DERMATITIS IN SOME INDIVIDUALS UPON PROLONGED CONTACT.

SYMPTOMS OF EYE CONTACT:
NO EFFECTS OF EXPOSURE EXPECTED WITH THE EXCEPTION OF POSSIBLE IRRITATION.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE:
NO DATA FOUND

-OTHER TOXICITY-

OTHER ACUTE TOXICITY:
INTRAVENOUS; RABBIT; 0.5 - 1.0 G/KG CARBONYL IRON POWDER PRODUCED ERYTHROBLASTHEMIA; REVERSIBLE AFTER 1 WEEK.

SUB CHRONIC ORAL TOXICITY:
60-DAY; RAT; 0.1, 1.0, 5.0% DIET; HEMATOLOGIC, HISTOLOGIC EXAMINATIONS AND URINALYSIS RESULTS WERE NORMAL; SLIGHT INCREASE IN WEIGHT.

SUB CHRONIC INHALATION TOXICITY:
NO DATA FOUND

SUB CHRONIC MISCELLANEOUS TOXICITY:
INTRATRACHEAL; RAT TDLo: 506 MG/KG/15 WEEKS; INTERMITTENTLY; NEOPLASTIGENIC.

AQUATIC TOXICITY:
NO DATA FOUND

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SECTION 03 - HAZARDS IDENTIFICATION (CONT.)

TUMORIGENICITY:
16-WEEK; SUBCUTANEOUS; MOUSE; 20 MG; 0/20 TUMORS.

MUTAGENICITY:
NO DATA FOUND

REPRODUCTIVE TOXICITY:
NO DATA FOUND

MISCELLANEOUS TOXICITY:
NO DATA FOUND

SECTION 04 - FIRST AID MEASURES

FIRST AID FOR INGESTION:
DRINK PLENTY OF WATER. CALL A PHYSICIAN. NEVER GIVE ANYTHING BY MOUTH TO AN UNCONSCIOUS PERSON.

FIRST AID FOR INHALATION:
NONE REQUIRED.

FIRST AID FOR SKIN CONTACT:
FOR ALL FOREIGN MATERIALS, WASH AFTER EXPOSURE.

FIRST AID FOR EYE CONTACT:
FOR ALL FOREIGN MATERIALS, IMMEDIATELY FLUSH EYES WITH PLENTY OF WATER.

SECTION 05 - FIREFIGHTING MEASURES

FLASH POINT: NO FLASH POINT
AUTOIGNITION TEMP: NO DATA FOUND
FLAMMABLE LIMITS: NO DATA FOUND
FIRE FIGHTING MEDIA: DRY CHEMICAL
SPECIAL FIRE FIGHTING PROCEDURES:
NONE KNOWN
FIRE/EXPLOSION HAZARDS:
STRONG HEAT, SPARKS OR FLAME WILL INITIATE RAPID OXIDATION, WHICH IN THE PRESENCE OF SUFFICIENT AIR, WILL PROCEED SPONTANEOUSLY TO GLOW DULL RED. MAY IGNITE OTHER COMBUSTIBLES. DUSTING IN AIR WILL PRESENT A MODERATE DUST EXPLOSION HAZARD IF THERE IS AN IGNITION SOURCE PRESENT SUCH AS A STATIC ELECTRICAL CHARGE. LOW IGNITION ENERGY OF THE POWDER IS A CONTRIBUTING FACTOR TO THE FIRE/EXPLOSION HAZARD.

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SECTION 05 - FIREFIGHTING MEASURES (CONT.)

NFPA HAZARD CODES - HEALTH/FLAMMABILITY/REACTIVITY	0	1	1
HMIS HAZARD CODES - HEALTH/FLAMMABILITY/REACTIVITY	0	1	1

SECTION 06 - ACCIDENTAL RELEASE MEASURES

SPILL/LEAK CLEAN-UP PROCEDURES:
SCOOP UP. AVOID DUSTING. DISPOSE OF WITH SOLID WASTE ACCORDING TO FEDERAL, STATE AND LOCAL REGULATIONS. FLUSH SPILL AREA WITH WATER.

EPA HAZARDOUS SUBSTANCE REPORTABLE QUANTITY: NOT LISTED

SECTION 07 - HANDLING AND STORAGE

PRECAUTIONARY MEASURES:
AVOID CONTACT. AVOID BREATHING DUST. WASH THOROUGHLY AFTER HANDLING. USE DUST MASK WHERE DUSTING CANNOT BE AVOIDED. USE WITH ADEQUATE VENTILATION.
DO NOT CREATE DUST CLOUD IN AIR. GROUND AND BOND ALL PROCESSING, DUST CONTROL AND MATERIALS HANDLING EQUIPMENT TO CONTROL STATIC ELECTRICITY CHARGES. PURGE PROCESSING EQUIPMENT BEFORE USE. PROCESS POWDERS UNDER AN INERT ATMOSPHERE OF LESS THAN 10% OXYGEN. DO NOT ALLOW THE ACCUMULATION OF IRON DUST ON OVERHEAD HORIZONTAL SURFACES.

DISPOSAL METHOD:
DISPOSE OF WITH SOLID WASTE ACCORDING TO FEDERAL, STATE AND LOCAL REGULATIONS.

RCRA CLASS: NOT REGULATED

SECTION 08 - EXPOSURE CONTROLS/PERSONAL PROTECTION

VENTILATION:
USE WITH ADEQUATE VENTILATION.

RESPIRATORY PROTECTION:
DUST MASK WHERE DUSTING CANNOT BE AVOIDED.

EYE PROTECTION:
SAFETY GLASSES.

SKIN PROTECTION:
FLAME RETARDANT CLOTHING REQUIRED.

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SECTION 08 - EXPOSURE CONTROLS/PERSONAL PROTECTION (CONT.)

PERSONAL HYGIENE:
WASH THOROUGHLY AFTER HANDLING.

PROTECTIVE MEASURES DURING REPAIR/MAINTENANCE OF EQUIPMENT:
WASH EQUIPMENT THOROUGHLY WITH STEAM OR WARM WATER UNTIL CLEAN. CHECK THE OXYGEN LEVEL WITH AN OXYGEN METER. IN ALL CASES, FOLLOW GOOD INDUSTRIAL SAFETY PRACTICES BEFORE ENTERING EQUIPMENT.

EXPOSURE LIMITS:
FOR INERT OR NUISANCE DUST (PARTICULATES NOT OTHERWISE REGULATED/CLASSIFIED):
OSHA PEL:TWA 15 MG/M3 - TOTAL DUST; 5 MG/M3 - RESPIRABLE FRACTION
ACGIH TLV:TWA 10 MG/M3 - INHALABLE; 3 MG/M3 - RESPIRABLE

SECTION 09 - PHYSICAL AND CHEMICAL PROPERTIES

BOILING POINT: 2750 DEG C
VAPOR PRESSURE: NOT VOLATILE
VAPOR DENSITY (AIR=1): NOT VOLATILE
WATER SOLUBILITY: INSOLUBLE
MELTING/FREEZING POINT: 1535 DEG C
APPEARANCE: UNIFORM POWDER
SPECIFIC GRAV. (WATER=1): NO DATA FOUND
PERCENTAGE VOLATILES: NOT VOLATILE
EVAPORATION RATE: NOT VOLATILE
pH OF SOLUTION: NO DATA FOUND
ODOR: NO DATA FOUND

SECTION 10 - STABILITY AND REACTIVITY

STABILITY: STABLE
HAZARDOUS POLYMERIZATION: WILL NOT OCCUR
CONDITIONS TO AVOID:
OXIDIZES READILY IN MOIST AIR.

INCOMPATIBLE MATERIALS:
REACTS VIOLENTLY WITH ACIDS OR OXIDIZING AGENTS. CHLORINE TRIFLUORIDE, FLUORINE AND NITROGEN DIOXIDE REACT WITH IRON WITH INCANDESCENCE. PHOSPHORUS REACTS WITH IRON WITH INCANDESCENCE WHEN HEATED.

HAZARDOUS DECOMPOSITION PRODUCTS:
NONE KNOWN

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SECTION 11 - TRANSPORT INFORMATION

-DOMESTIC DATA-
DOT SHIPPING NAME: NOT REGULATED
DOT HAZARD CLASS: NOT REGULATED
HAZARDOUS INGREDIENT(S): NONE
UN NUMBER: NONE

-EXPORT DATA-
EXPORT SHIPPING NAME: NOT REGULATED
EXPORT HAZARD CLASS: NOT REGULATED
HAZARDOUS INGREDIENT(S): NONE
UN NUMBER: NONE

ABBREVIATIONS

SECTION 01 – CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

CAS REGISTRY NUMBER AND NAME–Chemical abstract service registry number and name as it appears in the EPA Toxic Substances Control Act (TSCA) Chemical Substance Inventory.

SECTION 02 – COMPOSITION/INFORMATION ON HAZARDOUS INGREDIENTS

PEL–Permissible exposure limit for a chemical in the air as established by The Occupational Safety & Health Administration (OSHA).

TLV–Threshold limit value for a chemical in the air as established by The American Conference of Government Industrial Hygienists.

(PEL)TLV:TWA–The time-weighted average exposure for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed without adverse effect.

TLV:STEL–The short term exposure limit is 15-minute time-weighted average exposure which should not be exceeded at any time during a workday, even if the 8-hour TWA is within the TLV.

TLV:C–The ceiling concentration that should not be exceeded even instantaneously.

PEL:ACCEPTABLE CEILING CONCENTRATION–The concentration not to be exceeded during an 8-hour shift, except for a given time period, and not exceeding the concentration given as the acceptable maximum peak.

CARCINOGENIC REFERENCES–Will indicate whether the ingredient has been found to be a (potential) carcinogen by 1) IARC (International Agency for Research on Cancer), 2) NTP (National Toxicology Program) or 3) OSHA (Occupational Safety & Health Administration).

SECTION 03 – HAZARDOUS IDENTIFICATION

ACUTE LD50/LC50–The Lethal Dose/Concentration required to kill 50% of a population of test animals by the route of administration indicated.

SECTION 05 – FIREFIGHTING MEASURES

FLASH POINT–Designated by method CC–Closed Cup–OC–Open Cup.

NFPA HAZARD CODES–The National Fire Protection Association's Hazard Identification System intended to indicate inherent hazards of a chemical under emergency conditions such as fire. The degree of each of three hazards (Health/Flammability/Reactivity) is rated by a numerical designation ranging from low to high of 0 to 4.

HMIS HAZARD CODES–The National Paint & Coatings Association's Hazard Materials Identification System intended to estimate the inherent hazards of a chemical under normal workplace situations. The degree of each of three hazards (Health/Flammability/Reactivity) is rated by a numerical designation ranging from low to high of 0 to 4.

SECTION 07 – HANDLING AND STORAGE

RCRA–Resource Conservation and Recovery Act

SECTION 11 – TRANSPORT INFORMATION

DOT–Department of Transportation

UN NUMBER–United Nations Number

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Redstone Arsenal, AL 35898

Corp QA - M. Maloy Fax-(973) 628-3160

DATE: August 09, 2001
P.O. NUMBER:
FAX NUMBER:

Grade S-3700 MICROPOWDER Iron
1140047
CERTIFICATE OF ANALYSIS
Lot: 7070431

Date of Manufacture: July 04, 1997
Retest Date: July 04, 2002

PROPERTY	SPECIFICATION	ANALYSIS
APPARENT DENSITY(G/CC):	1.5-3.0	1.7
TAP DENSITY(G/CC):	3.5-4.5	3.5
TRUE DENSITY(G/CC):	7.5-7.8	7.8
APPEARANCE @25 DEG C:	UNIFORM POWDER	UNIFORM POWDER
SIEVE ANALYSIS(200 MESH):	0.2 MAX	0.0
AVG PARTICLE SIZE (MICRONS):	1-3	2.3
%IRON(MASS BALANCE):	98 MIN	98.2
COLOR (VISUAL):	GREY	GREY
%CARBON:	<1	0.67
%OXYGEN:	0.7 MAX	0.43
%NITROGEN:	<1	0.69

This COA is printed from a secure computer system ensuring the lot was properly released by the Quality Unit

APPENDIX F

COMMENT RESPONSE MATRICES

RESPONSE TO WRITTEN COMMENTS ON THE DRAFT REPORT FOR A FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NAVAL INDUSTRIAL ORDNANCE PLANT FRIDLEY, MINNESOTA

Item	Section	Page	Comments	Responses
General Response to Comments: There were a number of comments submitted by the reviewing agencies regarding the inconclusive nature of the pilot test results collected to date, the potential (and currently incompletely defined) roll of other contaminant mass reduction mechanisms (e.g., the upgraded extraction system and abiotic degradation related to naturally occurring iron as well as injected iron), and the inadequately defined hydrogeologic system at the site. The majority of these data gaps are presented in the draft report (dated March 2004) and Parsons and the Navy concur with the majority of the comments. Thus, we recommend that the current pilot test system be expanded with the addition of 3 to 4 new well clusters (as recommended in the draft report) and monitored for a minimum of an additional 18 to 24 months in order to investigate these data gaps and to determine the long terms effects of the injected vegetable oil. We also recommend that the subject of an expanded pilot scale application (involving an additional injection) be tabled until after the extended monitoring of the current pilot test system is complete. We believe, as was discussed during the April 2004 meeting, that discussion of the appropriateness of an expanded scale application is premature at this time. As a result, reference to an expanded scale application (termed Phases 1, II, and III of a full scale application in the draft report) will be removed from the recommendation section (Section 5.2). Section 5 has been revised and is attached to this comment response matrix for review. At this time we believe that it would be an inefficient use of time and funds to finalize the draft report (dated March 2004) as the current pilot test system will be monitored for a minimum of an additional 18 to 24 months and that no decision regarding the propriety of an expanded scale application will be made at this time. Thus, we propose to leave the draft report as is, with the exception of Section 5 (conclusions and recommendations), until the partnering team believes that the pilot test data set is adequate to determine the answers to the data gaps eluded to above and to determine the appropriateness of an expanded scale application. After the extended monitoring has been complete and the data gaps can be addressed to the satisfaction of the partnering team, the draft report will be finalized. The final report will contain the current pilot test data set as well as the extended monitoring data set and will thus represent all of the available data and will present the pilot test from inception to completion. In addition, the final report will present recommendations regarding the propriety of applying the organic substrate addition technology at Anoka County Park based upon all of the data collected to date. This comment response matrix will be attached to the final report as an appendix when it is prepared. Parsons and the Navy believe that this approach represents the most efficient and cost effective means to completing this project.				
Minnesota Department of Health Comments				
1.	General	NA	As a general comment, the report was not very conclusive on the success of the pilot study. The best indicators of dechlorination appear to be the appearance of increasing concentrations of cis-1,2-DCE and, more indirectly, the occurrence of indicator conditions that would support dechlorination, such as depleted dissolved oxygen, methanogenesis, ferrous iron and manganese release, and so forth. There are a number of geochemical processes	This pilot project was not a complete success and the report reflects this. This pilot test was successful in that complete reductive dechlorination was induced at locations where sufficient vegetable-oil-derived organic carbon was distributed, as evidenced by decreasing TCE and increasing *cis*-1,2-DCE, VC, and ethene. This pilot project was also successful in enhancing incomplete dechlorination of TCE to *cis*-1,2-DCE at locations where only limited vegetable-oil-derived organic

Item	Section	Page	Comments	Responses
			competing for the same substrate. The pattern of TCE levels was variable, with some of the wells showing increasing TCE levels. We found it difficult to distinguish changes due to dechlorination, preferential partitioning of TCE into the oil phase, reactions with sediment organics, or simple physical displacement due to a "blob" of vegetable oil or movement of the static water level. If DCE was already present in the contaminant mass, even this measure is suspect. We are left with the conclusion that some dechlorination probably occurred, but the extent of dechlorination is unclear.	carbon was distributed. However, the organic carbon was not adequately and uniformly distributed throughout the desired treatment zone. As a result, Parsons does not recommend going forward with an expanded scale application (involving a second injection) at this time. Instead, Parsons recommends expanding the monitoring well network at the existing pilot test area and continuing to monitor the pilot-scale application for a minimum of an additional 18-24 months. After the pilot test system has been monitored for an additional period of time and the system has been completely evaluated, the propriety of an expanded scale application will be revisited. Changes due to dechlorination are evidenced by decreasing concentrations of parent compound (TCE) and increasing concentrations of the daughter compounds (DCE, VC, and ethene).. The occurrence of dechlorination is also indicated by changing molar fraction ratios of parent compounds to daughter compounds (Section 4.4.2). Concentration changes related to partitioning or simple dilution are evidenced by decreasing concentrations of all compounds (parent and daughter). It is very difficult to distinguish dechlorination related to biotic processes and abiotic processes and the report makes no attempt to do so. It is much more valid and more defensible to distinguish degradation related to the injected vegetable oil (degradation within the pilot test area) from degradation related to other processes (degradation outside of the pilot test area). Because degradation within the pilot test area, minus exterior effects (e.g., the extraction system), is directly related to the presence of vegetable oil derived organic carbon (whether the degradation is due to abiotic or biotic processes).
2.	General	NA	The discussion of groundwater flow reversals (and portrayal in figures 4.4 – 4.7) and upward flow from the	Concur. The potentiometric surface maps will be revised to show a more southwesterly flow that is more in line with

Item	Section	Page	Comments	Responses
			Prairie du Chien dolomite probably needs further consideration. The potentiometric lines in these figures can be slightly reconfigured to show a more southwesterly flow, similar to the pattern shown in Figure 4.3 and the pattern shown historically. The fact that the groundwater gradients in this area are so flat makes the pattern very sensitive to measurement variability. The USGS 2003 report cited as a reference in this discussion does not appear to address groundwater flow. We do not have a copy of the TtNUS 2003 report to review those findings. If indeed groundwater flow is completely reversed, it does beg the question where is groundwater going? You may also want to consider rechecking well top elevations to make sure they have not changed during the last two years.	historical flow patterns, and the text will be corrected as necessary. The USGS report reference in this section is incorrect. The USGS report reference will be corrected to read: "USGS 2003a" and will reference the USGS draft report entitled: "Evaluation of the Capture Zones for Recovery Wells at the Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota." Concur. The recommendation to resurvey top of casing elevations at each of the pilot test wells will be added to the recommendations section of the report (Section 5). The groundwater flow reversals near the river as depicted in Figures 4.1, 4.4, 4.5, 4.6, and 4.7 will likely be eliminated when the potentiometric surface contours are re-interpreted. The groundwater flow reversal in the upper portion of the pilot test area as depicted in Figure 4.3 will remain. Groundwater flow within the upper portion of the pilot test area during the May 2002 sampling round (Figure 4.3) was to the northeast, toward the extraction system.
3.	General	NA	There is a comment on Page 2-13 that monitoring wells GWMS-45S and GWPC-53PC were accidentally cross contaminated by backflow through extraction lines. First of all, this is a very unfortunate development, especially involving the Prairie du Chien well. It seems odd to be using groundwater from the Prairie du Chien as part of the injection system. It throws a whole new wrinkle into the assessment of geochemical processes. Although it may be different at this site, water quality in the Prairie du Chien aquifer is generally more mineralized and less oxygenated than groundwater in unconfined, surficial aquifers at major discharge zones as here. Please describe in more detail the causes of this backflow and the quantities of oil involved	The impact to MS-53PC was discovered during groundwater sampling efforts in March 2003. Upon discovery, the vegetable oil in MS-53PC was removed and the well was sampled to determine if there were any significant contaminant impacts to the well. Only trace concentrations of TCE and PCE were detected in groundwater at this well after the vegetable oil was removed, indicating that this well was not impacted significantly. Activities associated with the removal of vegetable oil from MS-53PC are discussed in more detail in a summary technical memorandum prepared by CH2M Hill. This technical memo is attached to this comment response matrix for reference. Vegetable oil has never been detected in well MS-45S. However, it is assumed that this well was

Item	Section	Page	Comments	Responses
			and the efforts to recover the "lost oil".	impacted in the same way as MS-53PC and that the vegetable oil that was introduced to MS-45S has degraded. During the planning phase of this project it was proposed to draw site water for the injection from a shallow well (MS-46S) surrounding the injection area in order to match the geochemical conditions within the shallow aquifer as closely as possible. During the first round of work plan review the regulatory agencies determined that only uncontaminated or lightly contaminated groundwater could be used for the injection. Thus, the Navy was required to use groundwater from MS-53PC and MS-45S for the injection. The geochemistry of the water being drawn from MS-53PC was probably different from the geochemical conditions within the shallow aquifer in the injection area at the time of injection. However, the geochemical conditions within the injection area were rapidly modified after injection by the presence of the vegetable oil, as evidenced by the geochemistry data presented in Table 4.6. Thus, the geochemistry of the injection water did not significantly impact the success of this project.
4.	General	NA	The discussion of data quality issues on Page 34 appears to describe reuse of sampling tubing, inadequate decontamination of tubing or sampling equipment, and possible cross-contamination of subsequent samples. This condition raises obvious quality assurance/quality control questions and concerns. Although the procedures appear consistent to those outlined in the Quality Assurance Project Plan of September 17, 2001, you may want to give serious consideration to use of dedicated equipment in certain wells to avoid a repeat.	Concur. Dedicated equipment was used during the last three rounds of process monitoring to avoid compromising data quality as stated in Paragraph 2, Page 3-4 of the draft report.
5.	General	NA	The USGS report refers to the injection of 110 pounds of colloidal iron and 7.8 pounds of magnetite, which does not appear to be consistent with the 30 pounds of	At the time of the variance application, USGS was performing laboratory tests of both colloidal iron (identified as ferrous iron in the variance request) and magnetite. Since it was not clear

Item	Section	Page	Comments	Responses
			magnetite./ferrous iron discussed in the variance and in the September 2001 work plan. Please provide a description of "colloidal iron" as used in the USGS 2003 report.	which one of these would work better, the variance application referenced both the products. The initial quantity estimated in the variance application was based on early estimates provided by USGS. Based on laboratory tests performed by USGS, the exact quantity was determined prior to the actual injection. Since USGS felt both the products proved to work equally well in the laboratory, they wanted to test both the products in the field. Hence, one of the injection wells (PES-INJ-3) had colloidal iron and the other injection well (PES-INJ-1) had magnetite; and injection well PES-INJ-2 had no colloidal iron or magnetite. Copies of the colloidal iron and magnetite MSDS sheets were included in the variance request letter submitted to MDH. The variance application, variance request letter, MSDS sheets for the colloidal iron and magnetite products, and MDH variance approval letter will be included as Appendix E of the final report for reference.
6.	General	NA	Parts of the tables in Appendices C and D appear to have been cut off and some information appears to be missing. For example, part of the perchloroethene column is missing in Appendix C. Appendix D is simply unclear of what it is comparing.	Concur. The appendix tables were inadvertently mis-formatted. This error will be corrected for the final report.
7.	General	NA	The proposal to add up to 21 monitoring well clusters in Phase II may be a serious concern to Anoka County. Anoka County expressed concern with the number of wells installed for the pilot study in terms of compatibility with public use of the park. This will likely be a major issue if and when discussions of a potential Phase II occur.	It will be necessary to balance the needs of the project with the concerns of Anoka County. This issue will have to be addressed during the planning phase for any future work within the park.
8.	General	NA	As noted above, we were left with a lot of uncertainty regarding the effectiveness of the pilot scale study and the	Refer to response to comment MDH #1.

RESPONSE TO WRITTEN COMMENTS ON
THE DRAFT REPORT FOR A FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NAVAL INDUSTRIAL ORDNANCE PLANT FRIDLEY, MINNESOTA

(Continued)

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			prudence of moving to Phase II.	
Environmental Protection Agency Comments				
1.	Section 2.3	2-4	The Draft Report provides several references to more detailed discussions on site geology and hydrogeology. The Annual Monitoring Reports (AMRs) should be added to this list. The AMRs include detailed discussions of site geology and hydrogeology and are updated annually as necessary to reflect any new data and analysis on site hydrogeological issues, including any developing consensus among the NIROP Technical Team on these issues. Specifically the revised Draft Report should reference the 2003 AMR.	Concur, the final report will reference the most recent AMR as a source for detailed discussions on site geology and hydrogeology.
2.	Section 2.3	2-4	The Draft Report states that "although monitoring wells installed in the shallow drift aquifer at the site have been designated as shallow and intermediate, there appears to be no or very little hydraulic separation between these monitored intervals; hence both of these zones make up the shallow unconfined aquifer at the site." This statement does not appear to be consistent with the current understanding of site hydrogeology. There are areas of the site where the hydraulic separation between shallow and intermediate zone has been observed; and in these areas it may be more appropriate to associate the intermediate zone with the deeper confined or semi-confined aquifer. Revise the Draft Report to provide a more accurate and complete description of site hydrogeology.	Concur. The hydrogeology discussion in the final report will be revised to reference the most recent AMR.
3	Section 2.3.1	2-7	The Draft Report discusses the potential for a significant component of upward vertical flow between the Prairie du Chien (PC) aquifer and the overlying unconsolidated aquifer system. The Draft Report further indicates that "this vertical flow up into the unconsolidated aquifer	Concur. The text will be amended such that it more closely conforms to the site conceptual model advanced by the USGS and to the most recent AMR.

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			system likely represents a potential source of both contaminant mass and groundwater having a different geochemical signature than the unconsolidated aquifer system." Due to the groundwater quality observed in monitoring well MS-53PC, the Draft Report concludes, however, that "upwelling of PC aquifer water into the pilot test area is expected to impact groundwater geochemistry only." This assessment of the potential impact of groundwater discharging from the PC aquifer into the overlying unconsolidated deposits appears to be overestimated. While the higher heads in the PC aquifer and associated discharge into the overly unconsolidated aquifer may be partially responsible for the upward vertical gradients from the deep zone into the intermediate and shallow zones in ACP, the current conceptual model advanced by the United States Geological Survey (USGS) attributes these gradients to other hydraulic phenomena within the unconsolidated zone at the NIROP site. Moreover, the higher heads in the deeper aquifer is unlikely to result in groundwater flow from the PC aquifer, or even the deeper portions of the unconsolidated aquifer system, into the shallow groundwater system. These gradients are more likely to force flow in the intermediate zone in upgradient areas of ACP up into the shallow zone in the downgradient areas of ACP. Revise the Draft Report to provide a more accurate and complete description of site hydrogeology.	
4	Section 2.3.2	2-9	When discussing the effects of the extraction wells on groundwater flow directions and the hydraulic divide observed in ACP, the Draft Report states that "these observations indicate that the extraction system does not directly impact the pilot test area other than to potentially influence hydraulic gradients and produce short-term	On March 10, 2003 the groundwater extraction system was down and the groundwater elevation at MS-46S was 806.04. The extraction system was restarted on March 18th 2003. On April 7, 2003 EMR collected a round of water level data as part of the April 2003 process monitoring event. During this round the groundwater elevation at MS-46S was 804.81.

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			effects on groundwater flow conditions in the extreme upgradient portions of the pilot test area." The Draft Report further states that "as a result, geochemical and contaminant conditions within the pilot test area do not appear to be directly impacted by the extraction system." The Draft Report appears to understate the impact of the extraction system on the pilot study area. The water level surfaces depicted in the 2003 AMR (Figures 4-6 and 4-7) indicate that pumping may reduce water levels at MS-46S by approximately three feet. While seasonal water-level data taken during the pilot test may indicate a large seasonal component in these water-level changes, the recent USGS analysis of data taken during a different seasonal period appears to confirm water level changes of more than one and one-half feet. Moreover, the analysis of vertical gradient presented in the 2003 AMR indicates significant change between pumping and non-pumping conditions in the magnitude and direction of vertical gradients between the shallow and intermediate zone at MS-46. During non-pumping conditions, a slight upward gradient is observed at the MS-46 location, while during pumping conditions a more substantial downward gradient is observed at this location. The full impacts of the pumping system should be acknowledged and the potential impact on the pilot test should be discussed in the Draft Report. As noted in the following comments, the extraction system may have significant impacts on the migration of contaminants through ACP and into the pilot test area. Consequently, it does not appear appropriate to state that "geochemical and contaminant conditions within the pilot	Thus, the impact of the extraction system on MS-46S is likely to be approximately 1.2 feet, assuming that seasonal fluctuations were minimal during this time period The 1.2 foot drop in the water table in the vicinity of MS-46S likely resulted in diminished groundwater potentiometric surface gradients within the pilot test area which would have affected the geochemical conditions and therefore the contaminant conditions within the pilot test area. The reviewer is correct in pointing out this oversight. The text will be corrected and the above discussion will be included. Concur, the vertical flow discussion in the draft report will be amended to reference the most recent understanding of site conditions as presented in the most recent AMR. Concur, the statement that the extraction system does not directly impact geochemical and contaminant conditions within the pilot test area will be removed.

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			test area do not appear to be directly impacted by the extraction system." Revise the Draft Report to acknowledge the potential impact of the extraction system on the pilot test area.	
5	Section 2.4	2-11/2-12	When discussing the higher concentrations of TCE in the central portion of ACP, the Draft Report indicates that isoconcentration maps of the shallow aquifer zone in the 1999 AMR show that "TCE concentrations are significantly lower northeast of East River Road than TCE concentrations present in the ACP." The Draft Report further states that "this zone of elevated concentrations generally corresponds to the location of the groundwater divide, which may represent a stagnation zone. This groundwater stagnation zone may allow elevated concentrations to exist in this area." While the area of elevated concentrations in ACP has previously been thought to potentially result from an area of stagnation, more recent analyses suggests that this area of elevated concentrations may be/have been the result of contamination passing through the extraction system and migrating downgradient into the central portion of ACP. Recent analysis of vertical gradients in ACP, particularly in those areas upgradient to MS-46, indicate that this contamination may have been migrating not only through the shallow aquifer zone but also through the extraction system in the intermediate aquifer zone and subsequently may have been raised by the vertical gradients into the shallow zone. It is also important to note that high levels of contaminants remain evident in the intermediate zone northeast of the East River Road in potential source areas	Concur. Section 2.4 will be revised to reference the most recent AMR. The draft report states that the groundwater potentiometric surface in the upper portion of the pilot test area is relatively flat and that the groundwater flow velocity in this area is relatively slow as a result. Estimated groundwater flow rates were calculated during the course of the pilot test and are presented in Section 4.1.2 (Table 4.2) of the draft report. The draft report also explores the ramifications of the flat potentiometric surface throughout Section 4. Briefly, the limited success of the pilot test is largely due to poor substrate-derived organic carbon distribution. The poor organic carbon distribution is directly related to the low groundwater flow velocity and heterogeneous conditions within the upper portion of the pilot test area.

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			beneath the former manufacturing building. The drop in contaminant levels in ACP observed since the augmentation of the extraction system in 2001 appears to support this alternate explanation of contamination patterns in ACP. Revise the Draft Report to acknowledge this alternate explanation for the patterns of contamination observed in ACP. The Draft Report should similarly use knowledge gained during the pilot study regarding groundwater flow in the study area, including estimates of groundwater velocity, to assess whether the study area is an area of hydraulic stagnation. If found to be an area of hydraulic stagnation, the ramification of this finding on the implementation of the vegetable oil technology should be further explored in the Draft Report.	
6	Section 2.5	NA	The Draft Report discusses the trends in TCE and Dichloroethene (DCE) concentration in ACP prior to and during the pilot test. Several concerns have been noted about this analysis of contaminant trends. The extraction system was upgraded in June, 2001, and this upgrade appears to have had significant impact on contaminant levels in ACP, particularly in the core area of the ACP plume (see the 2003 AMR). The analysis of contaminant trends prior to and during the pilot test should be focused on evaluating the potential impact of these upgrades in the extraction system on the contaminant trends upgradient from and in the pilot study area. The analysis currently included in the Draft Report presents data from wells located throughout the ACP and tends to average contaminant trends from these wells. However,	Concur, The impact of the extraction system on contaminant concentrations in the vicinity of the pilot test area in comparison to the impact of the injected vegetable oil on contaminant concentrations is important when considering the overall effectiveness of the pilot test. However, the effectiveness of the extraction system upgrade in comparison to the effectiveness of the extraction system prior to the upgrade is not as important when considering the effectiveness of the pilot test because the extraction system upgrade was placed online approximately 6 months before the vegetable oil was injected. Therefore the impact of the extraction system prior to the system upgrade is not germane to this evaluation. Concur, Sections 2.4 and 2.5 will be revised to reference the most recent AMR.

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			contaminant levels are significantly less in the peripheral areas of the plume than the core area of the plume. Moreover, the upgrades to the extraction system were designed to address core areas of the plume, which appear to be largely upgradient from the initial pilot study area. The wells located in the core area of the plume, including upgradient and within the general downgradient area of the pilot study, include MS-36S, 18-S, MS-45, and 26-S. The data in the 2003 AMR clearly demonstrate that all of these wells have experienced significant declines in contaminant concentrations since the 2001 upgrade of the extraction system, both prior to and during the pilot test. As indicated in an earlier comment, contaminant trends in the intermediate zone in areas upgradient from the pilot study area may also influence contaminant trends in the shallow zone in the pilot study area. The data from well MS-36I demonstrates a dramatic drop in contaminant levels in the upgradient intermediate zone after implementation of the 2001 extraction system upgrade. Indicating that wells MS-45S and MS-46S were likely impacted by vegetable oil injection, the Draft Report has excluded the data from these wells from the evaluation of the data trends during pilot test. However, the contaminant trends observed in these wells during the pilot test appear consistent with the overall trends observed in the core area of the ACP plume. Based on the data presented, the cause for the decreases observed in these well are not clear and appear to require further evaluation. The analysis of contaminant trends presented in the Draft Report appears to dramatically underestimate the potential	

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			impact of the 2001 upgrade of the extraction system on contaminant trends in the Pilot Study Area. Revise the Draft Report to include a detailed analysis of contaminant trends in the core areas of the plume in ACP prior to and during the pilot test and to provide a more complete analysis of the impact of these trends on the interpretation of pilot test results.	
7	Section 4.1	NA	Since the geochemical data obtained during the pilot test appears to indicate potentially significant variability in flow patterns in the test area. Revise the Draft Report to include an analysis of the boring data obtained during the installation of the pilot-test wells to determine if any significant geologic features can be identified that might influence flow patterns in the pilot-test area.	Concur. Text will be added to Section 4.2 that will present a discussion of the boring log data collected during system installation.
8	Section 4.3	4-24	When discussing the initial distribution of TCE in groundwater, the Draft Report states that "this distribution of TCE concentrations is similar to the distribution of TCE concentration in soil and is (the) reciprocal to the distribution of TOC in soil." This statement appears counterintuitive. While high concentrations of TCE would be expected in soil at locations where groundwater concentrations are high, for any given concentration of TCE in groundwater, the concentration of TCE in soil should be higher in soils with a higher TOC. This is because the higher soil TOC provides for greater adsorption of TCE for any given concentration of TCE in groundwater. Review of the groundwater quality data reported in Table 4-4 and the soil data presented in Table 4.3 indicates that the above statement is also not fully supported by the data.	<u>Paragraphs 1 and 2:</u> The reviewer is correct in that the distribution of TCE in soil, TCE in groundwater, and TOC in soil is counter-intuitive. The following text is considered to be correct and will remain in the report: "The average TCE concentration detected upgradient of PES-MW-4 was approximately 4,100 µg/L, while the average TCE concentration downgradient of PES-MW-4 is approximately 210 µg/L. This distribution of TCE concentrations is similar to the distribution of TCE concentrations in soil and is inversely proportional to the distribution of TOC in soil." The second statement ("This distribution of TCE concentrations is similar to the distribution of TCE concentrations in soil and is inversely proportional to the distribution of TOC in soil.") was meant only as a general observation regarding the areal distribution of TCE in groundwater and soil and TOC in soil. This statement will be removed to avoid potential future confusion.

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			While this statement appears to be correct for the data reported at PES-MW-6, where a high concentration of TCE in groundwater (6,200 µg/l) was observed along with a high concentration of TCE (710 µg/kg) and a relatively low TOC concentration (320 mg/kg) in soil. However, at PES MW-8 the highest concentration of TCE was measured in groundwater (6,700 µg/l), while a relatively low concentration of TCE (130 µg/kg) and high concentration of TOC (1,400 mg/kg) were measured in soil. At PES-MW-2 the groundwater concentration was initially relatively low at 2,100 µg/l, particularly relative to that at PES MW-8. However, the TCE and TOC concentrations in soil were 140 µg/kg and 1,200 mg/kg, respectively, which are very close to the soil concentrations observed at PES MW-8. Thus, the pattern between TCE concentrations in groundwater and soil and TOC in soil appears less certain than initially stated. The Draft Report also states that "spatial distributions of TCE concentrations in soil and in groundwater correspond to observed changes in hydraulic conductivity, groundwater potentiometric surface gradients, and TOC concentrations." The meaning of this statement is unclear and the referenced correspondences should be more fully developed. The Draft Report continues by stating that "these data indicate that VOC migration downgradient through the pilot test area is being retarded and that this retardation may be related to increasing TOC content in soil near the river or changes in the groundwater migration related to changes in hydraulic conductivity." Although somewhat ambiguous, this statement appears to indicate that the contaminant concentration gradients observed within and downgradient	<u>Paragraph 3:</u> TCE concentrations in groundwater in the monitoring wells installed upgradient of PES-MW-3 (including MW-3) are much higher than the TCE concentrations in groundwater at monitoring wells downgradient of MW-4 (including MW-4). The measured hydraulic conductivities upgradient of MW-8 and MW-9 (geometric mean of 176.6 ft/day) are significantly higher than the hydraulic conductivities measured at wells MW-3, MW-8, and MW-9 (geometric mean of 29.5 ft/day). The TOC concentration in soil appears to increase significantly in the direction of the river. The statement: "spatial distributions of TCE concentrations in soil and in groundwater correspond to observed changes in hydraulic conductivity, groundwater potentiometric surface gradients, and TOC concentrations" is only meant to draw all of these pieces of information together and is intended as an observation. It is unknown if these factors are interrelated but it seems likely that they are. In the draft report it is hypothesized that the increasing organic carbon content in the soil matrix in the direction of the river could serve to retard the rate of contaminant mass migration toward the river. However, this statement will be removed as the retardation of the rate of contaminant mass migration is not germane to the evaluation of the pilot test. The migration of parent and daughter products will be retarded to varying degrees based on their differing K_{OC} values and resulting retardation coefficients. In general, retardation will be proportional to the degree of chlorination, with the more highly chlorinated compounds being retarded to a greater degree than the less-chlorinated daughter products. The effects of retardation will likely be evidenced over the long term; the current duration of this pilot test is insufficient to allow a meaningful analysis of the compound-

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			of the pilot study area are due to the advancing contaminant front and it's failure to reach the river. However, given the high groundwater velocities observed in ACP and the length of time the contamination has likely been present in the environment, this does not appear likely. Revise the Draft Report to include further analysis of the role adsorption is currently playing on contaminant migration in ACP and, particularly, in the pilot test area. The impact of adsorption on the migration patterns of contaminant and daughter products during biodegradation and the resulting consequence on data interpretation should be fully defined.	specific migration patterns as parent compounds are degraded and daughter compounds are produced. In an effort to explore the impact of contaminant mass retardation TOC samples will be collected from each of the proposed borings (total of 8 samples). A retardation analysis will be prepared from the TOC in soil data set and will be presented in the final report.
9	Section 4.4.1	4-29	When discussing the significant decrease in TCE concentrations observed in MS-46S following vegetable oil injection, the Draft Report states that "this decrease indicates that this well was impacted by the vegetable oil activities, despite the fact that it is located approximately 20 feet upgradient of the injection wells." The Draft Report fails to provide adequate evidence that MW-46S was impacted by the vegetable oil injection. The TCE concentrations in this well dropped from 20,000 µg/L in November, 2001 before the injection of vegetable oil to 14,000 µg/L in February, 2002 after the injection. The TCE concentration at MW-46S subsequently dropped further to 5,600 µg/L by May, 2002. No discussion of the vegetable oil having spread this far upgradient in the text has been provided. Moreover, the geochemical data (Table 4.6) provides little evidence of the impact of vegetable oil in MS-46S, although geochemical impacts are readily observable in other wells impacted by the vegetable oil.	Concur. The evidence of vegetable oil impact to MS-46S is largely circumstantial. Geochemical evidence of organic carbon impact to this location includes: TOC concentrations increased an order of magnitude after vegetable oil injection, dissolved oxygen concentrations decreased from 0.6 mg/L to non-detect, and oxidation reduction potential decreased from -82 to -276mV. In addition, non-aqueous phase vegetable oil was observed at PES-BG-1, which is located cross-gradient from MS-46S, during the May 2002 sampling round indicating that non-aqueous phase vegetable oil is present as far upgradient as BG-1. Thus, although vegetable oil has not been directly observed at MS-46S, oil has been observed at a location very close to and cross-gradient from MS-46S. In addition, the geochemical data from MS-46S indicate that there was some vegetable-oil-derived organic carbon impact to MS-46S. Thus, the weight of evidence indicates that MS-46S was impacted by vegetable-oil-derived organic carbon. However, a portion of the contaminant concentration reduction observed at MS-46S could be related to the extraction system

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			The widespread reductions in TCE concentration observed in the core of the contaminant plume in ACP after the augmentation of the extraction system may be responsible, at least in part, for the reduction in TCE observed in MS-46S. The Draft Report should be revised to discuss the potential causes for the decreases in contamination observed in MS-46S. Unless a convincing demonstration can be made that the injection of vegetable oil is responsible for the reduction in contaminant concentrations, an acknowledgment that the pilot test may not be responsible for these decreases should be included in the Draft Report. This demonstration should clearly account for the lack of rebound in TCE concentrations in MS-46S after the initial period following the injection of vegetable oil. The drop in TCE concentrations in MS-45S following injection of vegetable has similarly been attributed to impacts of the injection of vegetable oil. The Draft Report should also discuss whether the decreases in contaminant concentrations observed in MS-45S are attributable to the injection of vegetable oil or acknowledge that these decreases in contaminant concentrations may be attributable to underlying trends in contaminant concentrations observed in ACP.	and not to the injected vegetable oil. Text pertaining to the weight of evidence discussion and to the potential role of the extraction system will be added to Section 4.4.1 of the final report. All of the data collected during this pilot test was obtained from wells located downgradient of the injection area and MS-46S. Thus, the lack of contaminant concentration rebound at MS-46S cannot be accounted for due to the lack of data from immediately upgradient of MS-46S. The draft report does not attribute decreases in contaminant concentrations at MS-45S to the vegetable oil injection. The draft report only states that "Wells GWMS-45S and GWMS-46S were likely impacted by the vegetable oil injection pilot test and thus are not included in this evaluation. GWMS-46S was likely directly impacted by vegetable oil during injection, and GWMS-45S and GWMS-53PC were likely accidentally impacted by vegetable oil back-flushing through groundwater extraction lines during substrate injection activities." The evaluation referred to is the evaluation of TCE and DCE concentration reduction rates in Anoka County Park resulting from factors other than the pilot test. Since MS-45S and MS46S may have been impacted by vegetable oil, Parsons does not believe that it is appropriate to include them in this evaluation.
10	Section 4.4.1	4-36 to 4-38	The Draft Report provides an analysis of the average decrease of TCE in the pilot test area and contrasts this decrease with that observed in ACP outside the pilot test area. This discussion should be revised to more fully account for the decreasing contaminant trends occurring in the core of the plume in ACP, including the potential	The wells selected for inclusion in the evaluation of contaminant trends outside of the pilot test were chosen based on their proximity to the pilot test area. Monitoring wells 17-S and 27-S will be excluded from the evaluation as they are not in the "core" of the plume as defined by Figure 4-37 of the 2003 AMR. MS-46S will be removed from the concentration

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			influence of these underlying trends on the decreases in contaminant concentration observed in MS-46S. Presentation of the total concentrations of volatile organic compounds (VOCs) expressed as molar concentrations at pilot test wells may be useful to demonstrate the extent to which the total mass of contaminants in the pilot study area remained constant during the test period. Such an analysis may help to demonstrate that the reductions in contaminant concentrations observed in many pilot test wells were not due to an underlying trend in contaminant mass in the pilot study area. Revise the Draft Report accordingly.	trend evaluation within the pilot test area to eliminate this source of potential bias. Concur. The total molar concentration will be added to Figures 4.10C and 4.11C as well as the figures presented in Appendix C. In addition, text will be added to the final report pertaining to the total molar concentration trend data.
11	Section 4.4.3	4-41	Based on the concentration of TCE measured in vegetable oil collected from PES-INJ-2 in February, 2002 and the changes in TCE concentrations observed in groundwater at this location before and after vegetable oil injection, the Draft Report indicates that the majority of TCE mass at this location was partitioned into the vegetable oil. While this appears to be a reasonable assumption, the Draft Report has also concluded that "these data also indicate that an additional 5,600 µg/L of TCE was added to the system," and that "this additional TCE mass was likely stripped out of the soil matrix by the vegetable oil and partitioned into the vegetable oil NAPL." The basis for this statement is unclear. While TCE mass was likely stripped from the soil matrix, the estimate of an additional 5,600 µg/L that was added to the system does not appear to be well founded. The vegetable clearly shows the ability to concentrate contaminants above groundwater concentrations, but the actual volume of vegetable oil into which the contaminants were partitioned and the relative volume of water from	Concur. This statement will be removed.

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			which the TCE is removed are not known. Consequently, it does not appear possible to estimate the amount of mass that has been removed from the soil matrix. Revise the Draft Report to clarify this analysis or remove it from the text.	
12	Section 4.8	4-80	The Draft Report states that "increases in VC and ethene concentrations observed at monitoring well PES-MW-9 during 2002 indicate that TCE was being completely reductively dechlorinated to the reaction end product ethene at this location during this time period." Since there remained high levels of cis-1,2-DCE at PES-MW-9 during these periods, it appears more appropriate to indicate that a limited amount of TCE was being completely dechlorinated to the end reaction product ethene. Revise the Draft Report language accordingly.	Concur. The text will be revised as suggested.
13	Section 4.8	4-80	When discussing the contaminant trends at PES-MW-9, the Draft Report states that "TCE concentrations increased and cis-1,2-DCE, VC and ethene concentrations decreased in December 2002 and April 2003," and that "this reversal in contaminant concentrations and molar fractions indicates that groundwater flow conditions changed in the vicinity of PES-MW-9." However, water level data do not appear to indicate a change in groundwater flow during this period, particularly during December 2002. Revise the Draft Report to further justify this statement or provide other explanations for the increases in TCE concentrations at PES-MW-9.	Concur, The following statement: "this reversal in contaminant concentrations and molar fractions indicates that groundwater flow conditions changed in the vicinity of PES-MW-9." will be removed and the following text will be inserted in its place: "The cause(s) of this reversal in contaminant concentrations and molar fractions are not well understood, and may include subtle variations in groundwater flow directions that were not detected by the water-level measurement events, or temporal variation in the rate and efficiency with which native microbial populations were degrading the TCE."
14	Section 4.8	NA	Significant quantities of cis-1,2-DCE have been generated during the pilot test at a number of locations, including PES-MW-9. However, the fate of this daughter product	Concur, the potential deficiency in the well network will be acknowledged and the installation of additional sentinel wells will be added to the recommendations section.

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			and subsequent daughter products (i.e., vinyl chloride) has not been clearly established in the Draft Report. Discussions during the April 14, 2004 meeting indicated that a number of processes, abiotic as well as biotic, were available for the destruction of these compounds. Since concern has previously been expressed regarding the generation of vinyl chloride and its discharge to the river, the Draft Report should discuss in greater detail the potential fate of these daughter products. The Draft Report has noted that significant amount of the daughter products have not been detected at the sentinel wells. Based on the apparent flow directions observed in the southeast portion of the pilot test area, it appears that flow directions away from the study area may be in a much more southerly direction than originally anticipated and that the sentinel wells may not be adequately placed to detect daughter products migrating from the pilot test area. Revise the Draft Report to acknowledge this potential deficiency in the sentinel monitoring well network.	
15	Section 4.8	4-82	The Draft Report indicates that the "data indicate that the lack of wide-spread reductive dechlorination at the ACP pilot test site is primarily a function of sub-optimal organic carbon distribution." The report further states that "dissolved phase organic carbon is not being transported to downgradient monitoring wells as rapidly as was expected," and that "the slow migration rates are likely a result of the low hydraulic gradient in the injection area and the transient groundwater flow reversals observed occasionally during the process monitoring activities." However, the assessment that slow groundwater flow is responsible for the failure of dissolve organic carbon to be	Concur. It is possible that organic carbon is being transported out of the injection area but is being consumed prior to reaching the downgradient monitoring wells. This possibility is alluded to in Section 4.5.3.1 and will be restated in Section 4.8 as requested.

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			transported seems inconsistent with the reduction of TCE levels in a number of downgradient wells, although there is little evidence that reductive dechlorination is occurring at these locations. This would appear to suggest that TCE levels are being reduced upgradient and that these volumes of groundwater with reduced TCE concentrations are migrating to the downgradient wells. If there is sufficient groundwater velocity to bring these reduced levels of TCE into downgradient areas, there may be some other reason for dissolved organic carbon not reaching these downgradient areas as well. Revise the Draft Report to discuss other potential causes for the failure for dissolved organic carbon to reach downgradient area.	
16	Section 4.10	4-87	The Draft Report indicates that "the pilot test project can be considered a complete success from the DQO standpoint." The Draft Report also indicates that, based on the DQOs previously established, the first step in evaluating the pilot test is to determine if "the mean concentration at monitoring wells PES-MW-1, PES-MW-6, or PES-MW-7 is below 1,000 µg/L for five consecutive sampling rounds." The Draft Report notes that this requirement is met at PES-MW-7. Although not stated in the report and not required by the DQOs, this requirement has clearly not been met at PES-MW-1 and PES-MW-6. The Draft Report indicates that TCE concentration reduction at PES-MW-7 represents a decline of 99.3%, with the TCE concentration dropping from 300 µg/L to 2.1 µg/L. This reduction does demonstrate that the pilot test was able to reduce significantly the relatively low concentrations of TCE initially found at this location. However, it must be noted that the DQOs would likely have been met at this location,	The fact that the TCE concentration at PES-MW-7 was below 1,000 µg/L prior to vegetable oil injection will be noted in the final report. As the reviewer has noted, the original intent of the first DQO was to show that vegetable oil injection was capable of reducing the TCE concentration at MS-46S from a concentration of 20,000 µg/L to 1,000 µg/L. This represents a 95% reduction in TCE concentration. As also noted by the reviewer, the TCE concentration reduction at MW-7 was 99.3%. Thus, Parsons believes that the intent of this DQO has been satisfied even though the TCE concentration at MW-7 was below 1,000 µg/L prior to injection. Parsons agrees that the first DQO does not provide a good measure of success for this pilot test as it is written. However, Parsons does feel that the first DQO's intent (Reduction of TCE concentrations by 95%) is a valid measure of success. This discussion will be added to the text for clarity.

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			even if the pilot test had not been conducted, since the TCE concentration was already below 1000 µg/L at this location before the start of the test. The DQOs were originally established based on the idea that concentrations of TCE representative of that found at MS-46S (18,000 µg/L) would be found throughout the study area and that the goal was to achieve a reduction of TCE concentrations from this level to below 1,000 µg/L. Thus, while the DQOs have technically been met, these evaluation criteria do not appear to be particularly well suited for evaluating the conditions actually encountered during the test. It is recommended that while indicating that the DQOs have been met, the Draft Report should be revised to indicate that these evaluation criteria do not provide a good measure of the capability of the vegetable oil injection technology. Rather, the Draft Report should emphasize other measures of success when evaluating the pilot test.	
17	Section 5.1	NA	The conclusions present in the Draft Report should be revised as necessary after addressing the concerns and issues raised in the previous Specific Comments.	Concur. The conclusions will be revised appropriately.
18	Section 5.2	NA	Based on discussion at the April 14, 2004 NIROP Technical Team meeting, the recommendations included in the Draft Report should be revised to include only a recommendation for an expanded pilot test. The recommendations should identify the issues and data gaps that should be addressed during the expanded pilot test and include tentative plans for how these issues and data gaps can be addressed.	Concur. The recommendations will be revised appropriately. The data gaps identified within the draft report and during the April 14, 2004 meeting will be addressed by expanding the pilot test monitoring well network and monitoring the system for an additional 18 to 24 months.
Minnesota Pollution Control Agency Comments				

RESPONSE TO WRITTEN COMMENTS ON
THE DRAFT REPORT FOR A FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NAVAL INDUSTRIAL ORDNANCE PLANT FRIDLEY, MINNESOTA

(Continued)

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1	General	NA	Biofouling due to microbial growth has been identified as a problem around the oil injection wells. Oil delivery has been identified as a problem and at meetings it has been said that more numerous injection points may be need. How will permeability reductions due to biofouling impact the movement of ground water through the oil to achieve treatment? The MPCA staff believes that this question was not answered in the Report. The MPCA staff requests that the Navy answer this question.	Significant reductions in hydraulic conductivity can result in the deflection of groundwater movement around the low hydraulic conductivity zone. This would result in much lower treatment efficiency as advective transport of dissolved organic carbon in the downgradient direction would be diminished. These effects are discussed in Section 4.1.2 of the draft report. In addition, Section 4.1.2 of the draft report states that the hydraulic conductivity immediately downgradient of the injection area decreased by approximately one order of magnitude immediately after injection but returned to baseline conditions within the first year of process monitoring. Based on this information, long-term permeability reductions due to oil injection are not anticipated to be problematic.
2	General	NA	It has been stated that organic carbon is not migrating as expected and that organic carbon may be degrading before reaching downgradient wells. How will this problem be addressed? The MPCA staff believes that the Report adequately answers the question.	The TOC distribution issue will not be addressed within the current Phase I pilot test. If an expanded pilot test is implemented, the TOC distribution problem will be addressed by injecting a much more dilute emulsion over a much wider area. Thus, the expanded scale injection will attempt to achieve the required substrate distribution during injection instead of relying so heavily on advective groundwater flow to distribute the TOC after injection. In addition, a mixed injection of both soluble and slowly soluble substrates would likely be employed if an expanded pilot test is installed. The mixed injection would have the added benefit of a soluble and mobile substrate to improve TOC distribution as well as the longevity of a slowly soluble substrate.
3	General	NA	It is stated that Dehalococciodes ethenogenes has not been found at the site even in wells with high biomass. Ethane is present which would indicate conflicting information that the microbe should be present. How will this be resolved? The MPCA staff believes that the Report adequately	No response necessary.

Item	Section	Page	Comments	Responses
			answers this question.	
4	General	NA	*It is stated that the local hydrogeologic system in the vicinity of the pilot test area is not adequately defined. Parsons recommends expanding the monitoring well network and conducting additional process monitoring rounds to make these determinations. How will this issue be resolved? What are Parsons' recommendations?* Please see the follow-up MPCA staff response in Part II of this attachment.	No response necessary.
5	General	NA	The issue of upward flow of ground water from deeper zones was not resolved at the Technical Subcommittee meeting regarding the USGS report. The pilot test was designed assuming horizontal ground water flow. How important is it that this be resolved for the pilot scale test? How does this impact the results? Please see the follow-up MPCA staff response in Part II of this attachment.	No response necessary.
6	General	NA	How will the issue of partitioning of TCE to the oil be evaluated in the TCE reductions observed? Are we creating an LNAPL? What will happen to this material over time? The MPCA staff believes that the Report adequately answers the questions.	No response necessary.
7	General	NA	It seems that the imaging work, proposed to determine how the oil was distributed, is important to the evaluation of the test results (oil delivery and carbon distribution has been identified as a problem). Will the final report include the USGS imaging evaluation?	No response necessary.

Item	Section	Page	Comments	Responses
			The MPCA staff believes that the Report adequately answers the question.	
8	General	NA	Is it likely that the iron added to image to oil distribution is reactive with TCE? Is it reactive? Is it fair to assume that it was added to enhance TCE reduction? Will it be possible to determine what reduction is from the oil and biological activity and what reduction is due to the iron addition (see comments to MS-53PC work plan). How valid is the evaluation of organic substrate addition now that iron has been added to the aquifer? Please see the follow-up MPCA staff response in Part II of this attachment.	No response necessary.
9	General	NA	How will you evaluate the TCE reductions in Anoka County Park due to the addition of additional capture wells upgradient and how will you separate this from the other potential treatment mechanisms at work including biological activity from the oil injection and the introduction of iron? Please see the follow-up MPCA staff response in Part II of this attachment.	No response necessary.
10	General	NA	The results of the monitoring downgradient of the oil injection points are equivocal. While a couple of the wells appear to show the effect of the oil injection (primary fermentation products, an increase in cis-DCE and vinyl chloride) other monitoring wells do not. It is unclear whether this indicates: • An incorrect initial conceptual model of the ground water flow at the site; • That the vegetable oil has altered ground water	No response necessary.

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			flow patterns; • And an actual spatial variation in the aquifer and microbial response to the oil injection The MPCA staff believes that the Report adequately addresses the bulleted items above.	
11	General	NA	Understanding what effect the oil has had on the chlorinated solvents is compromised by the injection of the iron into the ground water. The MPCA staff believes that this item was discussed in the Report; however, the recommendations/conclusion section does not allude to it. The MPCA staff requests that this item be addressed in the recommendations/conclusions section.	Concur. The recommendations/conclusions section will be amended to address the iron issues discussed in detail in Section 4.
12	General	NA	The appearance of hydrogen in CW wells 1, 2, and 3 at 1 nanomolar or higher is confusing. These concentrations of hydrogen indicate a highly reducing environment. However, these wells are downgradient of the injection wells in an aquifer that was characterized before the oil injection study as aerobic, and we should not expect to see hydrogen increases that far away from the test area as a result of the oil injection. The MPCA staff believes that this apparent contradiction was not answered in the Report. The MPCA staff requests that the Navy explain this apparent contradiction.	Concur. The dissolved hydrogen concentrations measured at the contingency wells are indicative of anaerobic sulfate reducing conditions. The hydrogen data contradict the dissolved oxygen, sulfate, sulfide, ferrous iron, and oxidation reduction potential data, which all indicate that geochemical conditions at the contingency wells are weakly aerobic. The reason for this apparent contradiction between data sets is unknown. Dissolved hydrogen data were not collected during the baseline sampling event so dissolved hydrogen conditions prior to vegetable oil injection are unknown. Thus, it can not be directly determined if the elevated hydrogen concentrations measured at the contingency wells are related to the vegetable oil injection or some natural process. However, the geochemical and contaminant data collected from the contingency wells indicate that these well locations were not impacted significantly by the vegetable oil injection. Thus, the weight of evidence implies that the elevated dissolved hydrogen concentrations at the contingency wells is related to

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				some process other than the vegetable oil pilot test. It may be that the contradictory data sets are related to the mixing of water from different aquifer units with different geochemical characteristics in the vicinity of the river, resulting in unstable and contradictory geochemical conditions.
13	General	NA	Earlier discussion centered on the fact that monitoring wells 1 and 6 have not yet exhibited a convincing downward trend, and wells 2, 3, and 4 are showing very little effect of the oil injection on contaminant concentrations. As was discussed last July, declaring success and moving to a full scale system may be premature. The MPCA staff believes that this comment is addressed Report; however, the MPCA staff believes that the interpretation of how successful the pilot study has been is still being debated.	Concur. Parsons feels that this pilot test can only be considered a limited success and full-scale application of this technology is inappropriate at this time. Parsons recommends that monitoring well network of the current pilot test system be expanded and that monitoring of the pilot test system continue for an additional period of time before the decision regarding the propriety of a full scale application can be made.
14	General	NA	While the analysis and presentation of the pilot study results are excellent, the results are confounded by the co-injection of the zero-valent iron and magnetite with the oil. Magnetite has been reported to break down chlorinated aliphatic compounds non-biologically (see *Lee, W., and B. Batchelor, 2002. Abiotic reductive dechlorination of chlorinated ethylenes by iron bearing soil minerals. 1. Pyrite and magnetite. Environ. Sci. Technol. 36:5147-5154*), and the reaction of chlorinated ethylenes with zero-valent iron is well-known. The impact of the vegetable oil on the chlorinated compounds apart from the iron compounds is very difficult to determine, and remains an unknown factor as the scale-up options are considered.	Concur. Parsons recommends that if an expanded pilot-scale application is installed, the injection should involve the injection of organic substrate only, and that any type of iron should be excluded.

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15	General	NA	Studies at the nearby Twin City Arms and Ammunition Plant (TCAAP) also indicate that the disappearance of dichloroethylene (DCE) isomers without the appearance of vinyl chloride is likely due to the presence of magnetite in the ground water sediments (see *Ferrey, et al., 2004. Non-biological removal of cis-dichloroethylene and 1,1-dichloroethylene in aquifer sediment containing magnetite. Environ. Sci. Technol., 38:1746-1752*). This may account for the absence of DCE isomers in the downgradient wells from the pilot study. The MPCA staff requests that the discussion be amended to include the possibility that magnetite may be responsible for DCE isomer degradation at this Site as well.	Concur. The role of magnetite in the degradation of cis-1,2-DCE without the accumulation of VC will be acknowledged. However, the absence of VC does not necessarily mean that all of the DCE degradation is occurring through abiotic processes. DCE degradation via anaerobic or aerobic oxidation results in the complete biotic dechlorination of DCE without the production of VC. In addition, under methanogenic conditions, VC may degrade more rapidly than DCE, resulting in the dechlorination of DCE without the accumulation of VC. Unfortunately this pilot test was designed to demonstrate anaerobic biotic reductive dechlorination and the sampling program was designed accordingly. Thus, the resulting data set is insufficient to accurately assess the role of abiotic degradation. Parsons recommends that the current pilot test system be expanded and monitored for an additional period of time in order to investigate this issue further.
16	General	NA	The effect of iron addition needs more discussion in the Report, particularly in Section 5 where conclusions and recommendations are presented. Because the influence of the iron compounds is unknown, it is not clear how to proceed with the planning and implementation of Phase II and possibly Phase III (conclusions and recommendations section).	Concur. While the role of the iron cannot be quantified, it is likely that a portion of the contaminant mass destruction within the pilot test area is attributable to abiotic processes. This will be acknowledged in Section 5. Parsons recommends that the current pilot test system be expanded and monitored for an additional period of time in an effort to determine the rolls of abiotic and biotic degradation as well as the roll of the expanded extraction system. Parsons recommends that these issues be resolved more completely prior to the implementation of an expanded scale or full-scale application.
17	General	NA	As a general comment, it is confusing why concentrations of trichloroethylene (TCE) increased dramatically in well MW-5 and remained relatively stable in MW-4. If the effect of the oil was to decrease concentrations of this	The impact of vegetable oil is limited to a very small area in the immediate vicinity of the injection area as stated in the draft report (Section 4.5.1). The reason for the TCE concentration increase at MW-5 is currently unknown and is

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			contaminant near the injection wells, the subsequent monitoring data for wells MW-4 and MW-5 either indicate that these wells are not downgradient of the injection wells or that the impact of the oil is limited to a very narrow band near the injection area.	one of the main drivers behind Parsons' recommendation that the current pilot test monitoring be continued, although in a slightly altered form.
18	Section ES.1	ES-4	Please see MPCA staff comment to Section 4.1.1 regarding ground water flow.	See the response to the referenced comment.
19	Section 2.2	2-3	The natural material beneath the fill in the pilot study area also includes silty sand and sandy clay (see Figure 2.1). The significance of these various deposits is that they have a varying degree of ability to transmit water due to hydraulic conductivity differences. Silty sand has much lower hydraulic conductivity than sand and may have an effect on the local ground water flow regime. Lithologic variation of such materials may affect the pilot test results by influencing the ground water flow regime and the distribution of the desired reactants. The MPCA staff requests that the Navy acknowledge this in the Report.	Concur. Text will be added to Section 4.2 that will present a discussion of the boring log data collected during system installation, and the potential influence of the stratigraphy on groundwater flow and pilot test results..
20	Section 2.3.1	2-4 to 2-9	This section discusses the ground water flow conditions that have been determined on a large scale that includes Anoka County Park (ACP). There is general agreement on the "big picture" two-dimensional flow scenario in ACP. It is possible that on a smaller scale there are local variations in the flow regime where horizontal flow may differ due to smaller scale changes in lithology that are not apparent on a larger scale. These variations in flow may impact any evaluations or tests that are carried out on a smaller scale. The MPCA staff requests that the Navy acknowledge this fact in the Report.	Concur. The potential occurrence and significance of small-scale variations in the groundwater flow regime will be acknowledged in Section 2.3.1 of the final report. Concur. The potential role of vertical flow will be

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			There is less agreement on the role of vertical hydraulic head gradients and the vertical movement of ground water from one zone to another, i.e., the three-dimensional flow regime that may have an impact on ACP. How these lithologic variations in the test area affect the three dimensional flow in ACP is not fully understood. The MPCA staff requests that this be noted in the Report.	acknowledged and discussed in more detail in Section 2.3.1 of the final report. Parsons recommends that additional wells be installed within the current pilot test system and that the system be monitored for at least 18 to 24 months in order to investigate this issue further.
21	Section 2.3.1	2-4 to 2-9	The ground water flow regime in ACP is three-dimensional given the presence of vertical head gradients in the park. The pilot test largely assumes a two-dimensional flow regime in which ground water flow is primarily horizontal. It is important to understand the ground water flow regime prior to evaluating the pilot study and prior to developing any remedial options. As stated elsewhere in this letter, the lack of homogeneous lithology and the role of vertical gradients and how these affect ground water flow in ACP is not generally agreed upon. The MPCA staff requests that this be noted in the Report.	Concur. The text will be revised as requested.
22	Section 2.3.1	2-7	The discussion of the vertical movement of water from the Prairie du Chien/Jordan (PC) aquifer is most likely oversimplified. The Report suggests that PC water migrates from depth to the shallow zone. In reality the flow is most likely much more complicated and is not fully understood. Variations in the strength of horizontal gradients and lithologic variations in various zones between the PC and the shallow subsurface will dictate how ground water moves from one zone to another. In some zones there are strong horizontal gradients and more permeable materials. Water traveling up to these zones may tend to be preferentially carried horizontally rather than continue	Concur. The text will be amended to reference the most recent AMR. In addition, the uncertainties regarding vertical flow and its ramifications will be emphasized.

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			upward or there may be a component of both horizontal and vertical flow. PC water may not travel all of the way up into the shallow subsurface. Instead deep and intermediate zone water may be pushed up into shallow zones. In addition, there is variation in the contaminant concentrations from zone to zone. The intermediate and shallow zones generally have higher concentrations. It is important to know the vertical flow relationships because the movement of water between zones may impact the concentrations in other zones. At the present time this is poorly understood and there is not general agreement on this issue. The concept that PC water or low contaminant concentration and differing geochemical character flows freely from the PC into the shallow subsurface may not be valid. The MPCA staff requests that the Navy emphasize the uncertainty of this type of flow occurring in the Report.	
23	Section 2.3.1	2-7	The silt layer identified in the United States Geological Survey (USGS) report has been interpreted to be leaky, allowing some water to move upward as indicated in discussions with the USGS at NIROP Technical Subcommittee meetings. How ground water travels vertically through this interval is not fully understood. The MPCA staff requests that the Navy acknowledge this uncertainty in the Report.	Concur. The text will be amended to reference the most recent AMR.
24	Section 2.3.2	2-9	The Report states that geochemical and contaminant conditions within the pilot study area do not appear to be directly impacted by the extraction system. Although the pilot study area does not appear to be in the capture zone of the system, it is impacted by the system. The system	Concur. Please refer to the response to EPA comment #4. Contaminant concentration trends in wells exterior to the pilot test area are discussed in Section 2.4. In addition, contaminant concentration trends within the pilot test area are compared to

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			intercepts contaminated ground water that would otherwise flow into ACP. Trends in some ACP wells do show a downward trend in contaminant concentration. This section needs to be reworded to acknowledge that ACP has been impacted in a positive way by the extraction system. How much ACP and the pilot study area COC levels in ground water have been impacted by the extraction system is not discussed in this section. The 2003 Annual Monitoring Report (AMR) indicates that in much of ACP the TCE trends have been downward since the additional shallow pumping was added to the system. In ACP wells, where increases in TCE were observed, it is possible that the extended shutdown of the extractions system could have resulted in these increases. This information could be referenced from the 2003 AMR. The MPCA staff requests that the Navy discuss the effects of extraction system operation and shutdown on the study results in the Report.	contaminant concentration trends outside of the pilot test area in Section 4.4.1 in an effort to discriminate between the effects of the vegetable oil pilot test on the one hand, and the combined effects of the extraction system and natural attenuation on the other hand. The run time data for the extraction system will added to the contaminant concentration plots and any correlations/observations will be discussed in Section 4.4.1 of the final report.
25	Section 2.5	2-13	The Report states that MS-46S was directly impacted by the pilot study. However, in Section 4.5.4, the Report states that the geophysical data indicate that geochemical changes related to vegetable oil injection extends downgradient, not up gradient. Also Figure 9 of the USGS tracer study report, "Application of Cross-Borehole Radar to Monitor Field-Scale Vegetable Oil Injection Experiments for Biostimulation," ("Tracer Study Report"), undated, emailed to the MPCA staff on January 8, 2004, does not show that the subsurface oil emulsion reached MS-46S. Instead Figure 9 shows the oil-affected ground water flowing in the opposite direction. The MPCA staff requests that this contradiction be explained in the Report.	On Page 6 of the USGS report the following statement is made: "Based on these results, a qualitative map of the interpreted extent of oil-affected groundwater in November 2002 is inferred (Fig. 9)." This statement indicates that figure 9 represents only an approximation of the extent of vegetable oil in the subsurface. In addition, on page 5 of the USGS report the following statement is made: "Based on the spatial and temporal distribution of slowness anomalies, we infer that the vegetable oil emulsion had not spread horizontally more than 4 or 5 meters from the injection boreholes by November 2002." Figure 9 of the USGS report depicts a lateral spread of only approximately 3 meters. It is apparent that there is some uncertainty in the USGS geophysical data and that the reported lateral extent of the vegetable oil is only an approximation.

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			The Report also identifies MS-45S as being accidentally impacted by vegetable oil back-flushing. Although the Navy has identified MS-53P as being impacted by back-flushing, the Navy has not previously identified MS-45S as being similarly impacted. To the MPCA's knowledge, no effort has been made to remove oil from MS-45S as was done for MS-53P. The MPCA staff requests more information about the back-flushing contamination of MS-45S, efforts made to remove oil from this well, and the effect of this oil addition on pilot study results in the Report.	Thus, the noted contradiction is likely simply the difference between an approximation based on geophysical data (USGS) and an approximation based on geochemical data and field observations (Parsons). This discussion will be added to Section 4.5.4 of the final report. In Section 2.5 (Page 2-13, third paragraph) the report states that: "GWMS-46S was directly impacted by vegetable oil during injection, and GWMS-45S and GWMS-53PC were likely accidentally impacted by vegetable oil back-flushing through groundwater extraction lines during substrate injection activities." Vegetable oil has never been detected in MS-45S, indicating that, apart from the likely accidental impact described above, this well may not have been impacted by the vegetable oil injection. However, MS-53PC was impacted, and the groundwater extraction system installed in MS-53PC during vegetable oil injection was identical to the system installed in MS-45S. Thus, it is a valid assumption that MS-45S may have been impacted in the same way as MS-53PC.
26	Section 2.5	2-12 to 2-13	In its responses to the 2002 NIROP AMR, the MPCA staff requested that a statistical method be investigated to determine trends of chemical concentrations with time. The 2003 NIROP AMR used the Mann-Kendall trend analysis to look at trends in TCE trends in NIROP wells. The MPCA staff requests that the general trends in ACP wells be discussed in this section; that the 2003 AMR be referenced; and a general summary of ACP well trends be included in this section.	Concur. The text will be amended as requested.
27	Section 2.5	2-13	This section mentions that monitoring well MS-45S was directly impacted by oil injection. This is not indicated in the figures in the Tracer Study Report that show vegetable oil distribution. Chemical parameters discussed in	Please refer to the response to MPCA comment #25. The report states that GWMS-45S was likely accidentally impacted in the same way that MS-53PC was impacted, by the

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			subsequent sections of the Report do not seem to corroborate that MS-45S was impacted by oil injection. The MPCA staff requests that the Navy clarify the apparent contradiction. If the well was not impacted by oil injection please, provide possible reasons why the TCE concentration has been dramatically declined in this well.	back flushing of oil through extraction lines, not through migration of vegetable oil through the subsurface. Thus, impact to MS-45S would not appear in the USGS report as the impact to MS-45S was likely limited to a very small quantity of vegetable oil confined to the PVC casing of the well (as in the case of MS-53PC).
28	Section 3.1.4	NA	Please see MPCA staff response to Section 4.5.4 regarding the addition of colloidal iron and dissolved magnetite.	No response necessary.
29	Section 4.1.1	4-2 to 4-16	A review of the water level data is presented in the discussion. The data is presented in a series of figures that is used to construct equipotential maps for the pilot area. The maps show hydraulic head distribution prior to oil injection and during various seasons (spring, summer, fall and winter) during the pilot study. The MPCA staff has reviewed the data and maps and makes the general observations and requests: • A hydraulic head difference exists from higher head to lower head along the line of monitoring wells including MS-27S, PES-CW-1, PES-CW-2, PES-CW-3 and MS-47S. This difference indicates that there is a component of north to south flow that is not accounted for in the maps as presented. The data indicates that, in reality, ground water flow is most likely not perpendicular to the Mississippi River, as is assumed, but flows towards the river in a more south westerly direction. In many of the maps, it appears that ground water flow could be interpreted to be nearly south. In some of the maps some water levels were not collected in certain wells, which makes evaluation more difficult due to lack of data control (an example is Figure 4.2). • An area of relatively flat gradient is present represented	Bullet 1: Concur. Figures 4.1 through 4.4.7 will be revised to indicate a more southerly flow direction as discussed in the April 15 2004 meeting. Bullet 2: Concur. It is likely that there is a component of north-south groundwater flow in the vicinity of the contingency wells, MW-4, and MW-5. This component of north-south flow will be depicted on the revised groundwater potentiometric surface maps. Bullet 3: Concur. The groundwater flow reversals depicted on the current potentiometric surface maps will be eliminated when these figures are revised. Bullet 4: Concur. The groundwater potentiometric surface maps will be revised to incorporate a north-south flow component in the vicinity of the contingency wells, PES-MW-4, and PES-MW-5. Bullet 5: Concur. The hydrogeology discussion will be revised to reference the most recent AMR. In addition, the installation of several nested well clusters will be added to the recommendations section for the current pilot test area. The installation of nested well clusters in already included in the recommendations section for the expanded scale pilot test.

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			by data from monitoring wells PES-MW-4, PES-MW-5, PES-CW-1 and PES-CW-2. It appears that this area of flat gradients is present in all of the maps with the possible exception of the winter of 2002 (Figure 4.2, February 2002) although several water levels were not collected at that time. Some data is not available to complete the map. Hydraulic heads north of this area and south of this area seem to show a drop in hydraulic head from north to south that shows the potential for ground water flow through this area. If high permeability sediments are located in the area of "flat" hydraulic gradients, sufficient horizontal gradient change between north and south of this area may transmit ground water readily from north to south through the "flat" area. • Ground water flow reversals are shown on many of the Report figures, which show ground water flow away from the river towards the pilot area. In most of these figures, the hydraulic head differences are only a mater of several hundredths of a foot. These differences are likely well within measurement error and in reality are too small to cause reverses in ground water flow. Although seasonal changes can occur in ground water flow, the ground water flow regime in this area is most likely well established and flow directions are unlikely to change significantly. The area is beyond the direct hydraulic influence of the pumping system and the Report indicates that the area is not affected by the river stages. Precipitation events, the spring recharge event, and winter freeze up may affect some seasonal changes on the hydraulic heads in monitoring wells, but these effects most likely do not cause flow reversals or great changes in flow direction. Many of these influences are transient and may be short lived and ultimately not result	Bullet 6: Concur. Text will be added to Section 4.2 which will present a discussion of the boring log data collected during system installation.

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			in significant changes in flow directions. A different interpretation of the equipotential maps eliminates the need for reversing flow (see next comment). • A different interpretation of ground water equipotentials can be made using the same head data. The interpretation involves taking into account the north to south change from high head to low head in the last row of wells towards the river and resolves the flow through the area of relatively flat gradients. The interpretation is show in the attached modified figures that show ground water flow from north to south through the area of flat gradient. The horizontal flow regime may be much different than the assumed flow regime upon which the test was based. It is possible that the addition of monitoring wells during the next monitoring phase of the pilot could refine the ground water flow regime. • The effect of any vertical gradients on the flow regime in the test area is unknown. It is possible that the addition of several intermediate monitoring wells, nested with shallow unconfined wells, could verify the vertical ground water flow regime. A review of the vertical flow evaluation in the 2003 AMR might shed light on this issue. • The impact of the lack of homogeneity of lithology in the pilot area and how that might effect the flow regime is not fully understood and discussed. It is possible that additional lithologic information could be collected during the addition of monitoring wells to verify the impact of lithologic changes on the ground water flow regime in the pilot area. It is uncertain how this variation on the assumed flow regime might effect the interpretation of the pilot study, but it is unlikely that the ground flow as interpreted in the	

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			Report is correct. The MPCA staff requests that the Navy evaluate the alternative flow presented by the MPCA staff and determine how that flow scenario might impact the interpretation of the pilot study data. The flow scenario may help to explain some of the study results. As discussed in previous comments, the possible effect of vertical gradients has not been quantified or evaluated. A vertical flow component might also impact the pilot study results. Much of this information could be collected during field work for the extended monitoring of the pilot study.	
30	Section 4.1.2	4-16	The Report indicates that wells PES-MW-3, PES-MW-8 and PES-MW-9 are screened in low permeability materials. There is apparently lithologic variability in the area of these wells that may have prevented or impeded the flow of ground water in a downgradient direction from the injection points. This variability may have impacted the distribution of the desired reactants to these wells from the injection points and may also explain the seeming lack of impact from the vegetable oil injection on some of these wells. (It appears that PES-MW-3 was impacted from the test but that PES-MW-3 and PES-MW-8 were not impacted much.) The MPCA staff requests that the Navy review and discuss how this may have impacted the pilot.	Concur. Text will be added to Section 4.2 which will present a discussion of the boring log data collected during system installation. The lithologic data will be evaluated in terms of its impact on conclusions regarding the groundwater flow regime and the distribution of organic carbon introduced into the subsurface.
31	Section 4.1.2	4-17	The Report states that "the observed impact to hydraulic conductivity is likely a long-term effect of the vegetable oil injection and will likely last until the vegetable oil and associated biomass have been depleted". This is an important consideration for evaluation of a scale-up effort at the site. Based on this observation, the impact on ground water flow on a larger scale may be significant. The	Concur. Impact to hydraulic conductivity is a critical design consideration to any application (expanded pilot or scale up to full scale).

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			MPCA staff requests that the Navy's plans for scaling up the project take this into consideration.	
32	Section 4.1.2	4-20	The MPCA has discussed the potential flow reversal scenario in a comment to Section 4.1.1. The MPCA staff requests that the Navy refer to this comment for this section.	No response necessary.
33	Section 4.1.1	NA	In this section, the Navy identifies periodic changes in ground water flow direction during the pilot study. The Figures 4.1 through 4.7 show that the predominant ground water flow direction in the study area is to the southwest. In Figure 4.3, the Navy shows that the ground water flow direction in May 2002 in the area of the injection wells is toward MS-46S. However, Figure 9 of the Tracer Study Report shows that the direction of movement of the oil-affected ground water is to the southwest toward the river, away from MS-46S. The MPCA staff requests that the Navy explain this apparent contradiction.	Parsons does not see the contradiction. Figure 4.3 depicts the estimated groundwater flow direction during the May 2002 groundwater sampling event. The USGS Figure 9 depicts their interpretation of the subsurface distribution of vegetable oil. The distribution of vegetable oil is predominantly dependant upon the groundwater flow direction during injection and, to a lesser extent, the predominant groundwater flow direction over time. Short lived, low magnitude groundwater flow reversals that take place after injection are not likely to significantly effect the distribution of non-aqueous phase vegetable oil. However, short-term changes in groundwater flow directions may impact the distribution of vegetable-oil-derived soluble organic carbon.
34	Section 4.4.1	4-29	This section states that upgradient well GWMS-46S is impacted by vegetable oil injection activities. This is neither indicated in the figures in the Tracer Study Report that show vegetable oil distribution nor is this supported by various chemical parameters observed in the well. The MPCA staff requests that the Navy clarify the apparent contradiction.	Please refer to the response to EPA comments #9 and #10.
35	Section 4.4.1	4-30	The Report states that the variation in TCE concentration in well MS-46S is perhaps due to variable ground water flow direction. In Figures 4.1- 4.7, MS-46S is upgradient of the pilot test wells with the possible exception of the May 2002	Concur. The individual contributions of the extraction system and the vegetable oil injection pilot test in the reduction of TCE concentrations at MS-46S cannot be determined. Thus, MS-46S will be removed from both TCE concentration

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			map (Figure 4.3). It is questionable that small differences in hydraulic head shown on this map are significant and long lasting enough to cause flow to reverse from the regional trend of flow towards the river. It may be possible that vegetable oil moved, under injection pressures, in an upgradient direct to MS-46S, but the Tracer Study Report on the study to investigate the distribution of vegetable oil using iron additives does not seem to indicate that oil traveled to that well. Chemical parameters discussed in subsequent sections of the Report do not seem to corroborate that MS-45S was impacted by oil injection. It may also be possible that modifications to the pumpout system may have caused changes in concentration in the well. The MPCA staff requests that the Navy further discuss this contradiction.	reduction evaluations (TCE concentration reductions inside and outside of the pilot test area) to eliminate this source of potential bias. Parsons recommends that the pilot test monitoring system be monitored for a minimum of an additional 18 to 24 months in order to further investigate this issue.
36	Section 4.4.1	4-29	The Navy attributes the dramatic decline in the TCE concentration in MS-46S to "vegetable oil injection activities," presumably meaning that injected oil reached the area around this well. However, as cited above, the Tracer Study Report shows that the ground water flow direction is away from MS-46S. Also unlike MW-7, which shows an increasing level of DCEs associates with a decrease in TCE concentrations over the study period, the decline in TCE in MS-46S is occurring with a concurrent decline in DCEs even though the starting TCE concentration in MS-46S is over an order of magnitude higher than that of MW-7. Also in Section 4.5.1, the Navy argues that total organic carbon (TOC) is an indicator of the impact of oil injection in MWs 7 and 9, these wells showing the highest TOCs in the study, up to 26,000 mg/L in MW-7 and up to 240 mg/L in MW-9. The TOC in MS-	Please refer to the response to EPA comments #9 and #10 and the response to MPCA comment #35.

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			46S never exceeds 18 mg/L. These contradictory data suggest that the decline in TCE concentration in MS-46S may not be associated with vegetable oil injection activities. The MPCA staff requests that the Navy explain the apparent contradiction in the data cited above. Also the MPCA staff requests that the Navy identify what "vegetable oil injection activities" it believes are resulting in the decline in the TCE concentration in MS-46S.	
37	Section 4.4.1	4-36	The MPCA staff requests that the Navy acknowledge that the TCE levels in MW-9 increased in the last two sampling events after falling dramatically during a period that showed the expected associated rise in DCEs.	The increase in TCE concentrations at MW-9 is discussed on Page 4-33, second paragraph.
38	Section 4.4.2	4-39	It is not clear from Figure 4.10B that the molar fraction of vinyl chloride increased over the time interval from April, 2003-August, 2003. From the figure, concentrations of vinyl chloride appear near 0% throughout the entire time of the study. The MPCA staff requests that the Navy explain this apparent contradiction.	Concur. The molar fraction of VC increased from 0.0% to 0.6% between April and August 2003. This small increase is likely within the measurement error of the analysis and is so small that it is imperceptible on Figure 4.10B. The sentence reading: "Between April 2003 and August 2003 the molar fraction of TCE decreased while the molar fractions of DCE and VC increased." will be replaced with: "Between April and August 2003 the molar fraction of TCE decreased, the molar fraction of DCE increased, and the molar fraction of VC remained virtually unchanged.".
39	Section 4.5.1	4-43 to 4-47	This section discusses the use of TOC to determine distribution of substrate. An increase in TOC concentration is used to interpret distribution of substrate. In other sections, the Report indicates that well MS-46S has been impacted by vegetable oil injection activities. There is not a significant sustained increase in TOC concentration in well MS-46S observed in the data. It would seem that the lack of increase in TOC does not support that this well is	Actually, an increase of an order of magnitude is a significant change in TOC concentration. This is especially true in this case where, prior to injection, TOC concentrations were too low to support reductive dechlorination (1.8 µg/L) and, after injection, were sufficiently high to support reductive dechlorination (~20 mg/L) as defined by *The Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* (USEPA, 1998).

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			impacted by vegetable oil injection activities. The MPCA staff requests that the Navy discuss this apparent contradiction.	However, the individual contributions of the extraction system and the vegetable oil injection pilot test in the reduction of TCE concentrations at MS-46S cannot be determined. Thus, MS-46S will be removed from both TCE concentration reduction evaluations (TCE concentration reductions inside and outside of the pilot test area) to eliminate this source of potential bias.
40	Section 4.5.1	NA	The data in Table 4.6 appears to indicate that most TOC is found around MWs 7 and 9, with most of the study area, including the area around MWs 6, 1, and 2, having TOC levels an order of magnitude or more lower in other areas of the study area. However, Figure 9 of the Tracer Study Report implies that the oil-affected ground water uniformly covers the area around MWs 6, 1, 7, and 2. The MPCA staff requests that the Navy explain the apparent contradiction regarding the area of influence of the vegetable oil injection.	The aquifer in the area around MWs 1, 2, 6, and 7 was not uniformly impacted by the vegetable oil injection, as can be seen through inspection of Table 4.6 and review of Section 4 of the draft report. Figure 9 of the USGS report represents a "qualitative, interpreted, and inferred" representation of the geochemical conditions present within the pilot test area as stated in the USGS report on Page 6, first sentence. This is not a contradiction, but an over-simplification.
41	Section 4.5.1	4-43	The texts states that the USGS results of the radius of influence testing are summarized in Section 4.5.3; however, the USGS results are discussed in Section 4.5.4. The MPCA staff requests that the text be changed accordingly.	Concur. The text will be revised as requested.
42	Section 4.5.1	4-47	It does not appear that the data on Table 4.6 supports the statement that "TOC data indicate that the zone of influence of the vegetable oil injection within the first few months following injection was limited primarily to the area of wells PESMW-1, PES-MW-6, PES-MW-7 and PES-MW-9". The TOC data for wells PES-MW-1 and PES-MW-6 does not appear to be elevated, particularly in comparison to PES-MW-7 and PES-MW-9. The MPCA	TOC concentrations at MW-1 increased from 1 mg/L prior to injection to 30 mg/L 3 months after injection, and TOC concentrations at MW-6 increased from 1.4 mg/L to 12 mg/L during the same time frame. These increases indicate that these well locations were impacted by vegetable-oil-derived soluble organic carbon. TOC concentrations at MW-7 (26,000 mg/L) 3 months after injection indicate that this well was impacted by non-aqueous phase vegetable oil. The differences

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			staff requests that the Navy resolve the apparent contradiction in the Report.	in TOC concentrations at MW-1, MW-6, MW-7, and MW-9 are not representative of impacted locations verses non-impacted locations, but are representative of differences in the amount of impact to each location.
43	Section 4.5.2	4-47	The presence of hydrogen at 4 nanomolar (nM) in wells 27S and 47S indicate that conditions at these locations are naturally conducive to the reductive dechlorination of chlorinated compounds. How does this observation affect the overall interpretation of the influence of the vegetable oil? If hydrogen is present at locations where we are assuming there is no significant reductive dehalogenation, is it an adequate indicator of the reductive processes at the site?	As stated in the response to MPCA comment #12, the dissolved hydrogen data collected at the contingency wells, and at monitoring wells 27S and 47S contradict most of the other geochemical data collected at each location. In this case, the weight of evidence points to a different conclusion. The mere presence of hydrogen is not enough to indicate that reductive dechlorination is occurring. The evaluation of a site for reductive processes is a weight-of-evidence type of analysis where a number of lines of evidence are combined to come to a conclusion regarding the types and extent of degradation processes occurring. Thus, one line of geochemical evidence, by itself, is typically not sufficient to draw conclusions regarding the degradation processes that are occurring at a particular location, especially if it is contradicted by multiple other lines of evidence
44	Section 4.5.4	4-56	This section does not indicate distribution of vegetable oil in an upgradient direction to well MS-46S. This situation contradicts information in the Report that suggests that vegetable oil injection has impacted the well. The MPCA staff requests that the Navy discuss this apparent contradiction.	Please refer to the responses to EPA comments #9 and #10 and to MPCA comments #25 and #35.
45	Table 4.5	4-37	Calculation of a slope on the data is informative, but must be accompanied by a standard deviation or variance on the slope to provide perspective on the variability of the data. The MPCA staff requests that the analysis be completed accordingly and that the corresponding discussion make	Concur. The R value calculated for each line fit will be provided as an indication of the quality of the line fit.

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			reference to these statistics.	
46	Section 4.6.1.1	4-58	The Report states that there is a change in dissolved oxygen (DO), oxidation-reduction potential (ORP) and dissolved hydrogen data. It should be noted that in April, the spring recharge event occurs in Minnesota. During this event, frozen water stored in the frost zone, snowmelt and any significant spring precipitation may recharge to the water table. It is possible that the influx of this recharge water may impact some of the parameters that are discussed in this section. The MPCA staff requests that the Navy evaluate the recharge event in the Report.	Concur. Surface water recharge is a potential contributor to the geochemical changes observed between December 2002 and April 2003. This potential contributor to the observed geochemical changes will be discussed in Section 4.8.
47	Section 4.8	4-82	A number of factors are indicated that were present for reductive dechlorination to occur. The MPCA staff request that the Navy add a map to the Report that shows the area where these factors were present and where dechlorination occurred.	Concur. The new figure will be Figure 4.20. Subsequent figure numbers (i.e., Figures 4.20, 4.21, 4.22, and 4.23) will be advanced one such that current Figure 4.23 will become 4.24.
48	Section 4.8	4-82	The Report notes the sub-optimal distribution of organic carbon, which is attributed to low hydraulic gradient and transient ground water flow reversals. In previous responses to the Report, the MPCA staff noted that it is unlikely that transient flow reversals occur in the pilot area and that alternative interpretations of ground water flow indicate that hydraulic gradients in the area denoted as a "flat area" of gradient may be influenced by stronger gradients than previously thought. It should be noted that variable lithology may also be a factor in the uneven distribution of organic carbon. The MPCA staff requests that the Navy resolve these issues in the next phase of pilot monitoring.	Concur. The recommendation to install additional nested well clusters will be added to the recommendations pertaining to the current pilot test area in Section 5.

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49	Section 4.9	4-84	The text states "it cannot be determined if the iron injected into PES-INJ-3 had any effect on the chlorinated solvents in the vicinity of PES-INJ-3." As pointed out earlier in the attachment, magnetite is known to degrade chlorinated solvents. Based on the pilot study DQOs, pilot success could be achieved with the success of only one of the three monitoring wells. Pilot success was achieved only in MW-7. Therefore, it is critical to know why success was achieved in only MW-7. The MPCA staff requests that the Navy evaluate the effect of magnetite on the results seen in MW-7. If uncertainty remains after the requested evaluation, the MPCA staff requests that the Navy indicate in the Report what will be done to account for the impact of added iron in further work associated with the pilot study.	The mass of TCE that could have been dechlorinated by the injected magnetite can be estimated by combining the specific reductive capacity of the magnetite (0.37 uM/g of TCE) from Lee and Batchelor (2002) with the mass of magnetite injected (7.9 pounds) from USGS (2003b). The maximum specific reductive capacity of the 7.9 pounds of magnetite is approximately 1.3 millimoles of TCE (7.9 lb*453.6 grams/lb*0.37 uMol/gram* 1 mMol/1000 µMol). Thus, the maximum mass of TCE that could have been dechlorinated by the magnetite is equal to approximately 0.17 grams of TCE (1.3 millimoles multiplied by the molecular weight of TCE of 131.38 grams/mole). The total mass of TCE that was degraded at MW-7 can be approximated by combining the volume of water impacted by the injection at INJ-3 (immediately upgradient of MW-7) with the TCE concentration reduction observed at MW-7. The volume of water affected by the injection at INJ-03 can be estimated by combining the volume of water impacted by the initial injection with the volume of water moving through the system during the pilot test. The volume of water initially impacted by the injection would be approximately equal to the volume of vegetable oil emulsion injected at INJ-03 (3,600 gallons). The volume of water moving through the system can be approximated by multiplying the cross sectional area of the injection volume at INJ-3 of 160 square feet (diameter of the injection area of approximately 16 feet (USGS, 2003a) multiplied by the injection interval of 10 feet) by the effective porosity of the aquifer matrix of 0.25 (Fetter, 1994) and by the estimated groundwater flow rate at INJ-03 of 32 feet/year (Table 4.2) and by the length of the pilot test of 1.8 years (November 2001 to August 2003). The total estimated groundwater flux through the system is approximately 2,304 cubic feet or 65,200 liters of water. Thus, the total volume of water impacted by the

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				injection over the course of the pilot test at INJ-03 is approximately 78,800 liters. The TCE mass present in this volume of water can be conservatively estimated by multiplying 78,800 liters by the TCE concentration reduction observed at MW-7 of 1298 µg/L (1,300 µg/L – 2 µg/L). Thus, a conservative estimate of the TCE mass impacted by the injection at INJ-03 and reduced (as evidenced by the concentration of 2 µg/L at MW-7) is approximately 102 grams. Thus, it can be estimated that the magnetite could have been responsible for the reduction of approximately 0.17 percent of the TCE mass reduction. This discussion will be added to Section 4.9 of the final report. In addition, Parsons does not agree with the statement that the pilot test was only successful at MW-7. The reviewer is correct in the fact that TCE concentrations were below 1,000 µg/L at MW-7 only. However, significant TCE concentration reductions were observed at a number of other wells (e.g., PES-MW-3, PES-MW-6, and PES-WM-8). Thus, the limited success of this pilot test is based on the combined contaminant and geochemical trends at a number of well locations, not just PES-MW-7.
50	Section 5.1.2	5-1	The Report states that geochemical changes from the oil injection are "neither spatially uniform or [sic] temporally consistent" within the pilot study area. The MPCA staff requests that the Navy further explain the factors that might have contributed to this observation.	This observation is based upon the fact that the geochemistry varies both from location to location and through time at each location, thus making the site-wide geochemical data set "neither spatially uniform nor temporally consistent". These inconsistencies are likely related to inconsistent groundwater flow rates and directions, non-uniform vegetable-oil-derived organic carbon distribution, and non-uniform microbial population development. Additional text will be added to Section 5.1.3 regarding the potential factors controlling the observed geochemical inconsistencies.

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51	Section 5.1.3	5-2	The Report states that after vegetable oil injection, there were significant decreases in TCE concentration in well MS-46S. The Tracer Study Report does not indicate that oil was distributed to this well. Chemical parameters that would indicate that the well was impacted by oil did not seem to be present in the data. Although a significant decrease in TCE did occur, it appears that it cannot be attributed to reductive dechlorination due to vegetable oil injection. The MPCA staff requests that the Navy identify and discuss other mechanisms that could have led to the TCE concentration reduction in this well.	Concur. The reductions in TCE at MS-46S cannot be attributed with confidence to reductive dechlorination as stated in the draft report. However, the TCE concentration reductions at MS-46S can be attributed to preferential partitioning of the TCE mass into the non-aqueous phase vegetable oil, as stated in the draft report. The groundwater extraction system likely had some impact on the TCE concentrations observed at MS-46S. However, The individual contributions of the extraction system and the vegetable oil injection pilot test in the reduction of TCE concentrations at MS-46S cannot be determined. Thus, MS-46S will be removed from both TCE concentration reduction evaluations (TCE concentration reductions inside and outside of the pilot test area) to eliminate this source of potential bias.
52	Section 5.1.3	5-3	The Report states that there were increasing TCE concentration trends in four monitoring wells between baseline sampling and the most recent monitoring event. It may be possible that the increases were the result of the extended downtime of the extraction system. The MPCA staff requests that the Navy compare periods of system downtime to TCE concentration increases in ACP wells.	Concur. The runtime data from the extraction system will be added to the trend plots in Appendix C and to Figures 4.10 and 4.11. Discussion regarding the extraction system run time data will be added to the text as appropriate.
53	Section 5.1.5	5-4	The Report states that organic carbon concentrations greater than 20 milligrams per liter (mg/l) are required to meet both the natural demand for electron donor and to provide sufficient electron donor for the dechlorination of chlorinated aliphatic hydrocarbon (CAH) mass. The MPCA staff requests that the Navy list the monitoring wells where this was achieved in the pilot study area and show a map of the area where these conditions were met.	The draft report simply makes the observation that wells that have exhibited evidence of reductive dechlorination of TCE typically have had concentrations of TOC greater than or equal to approximately 20 mg/L. The report does not definitively state that 20 mg/L of TOC are required to meet competing electron acceptor demand and drive reductive dechlorination. Wells where partial or complete reductive dechlorination was observed are listed in Section 4.8. A figure depicting these locations and the approximate extent of reductive dechlorination (and TOC distribution) will be added to Section

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				4.
54	Section 5.1.6	5-5	The Report states that the lack of reductive dechlorination at ACP is primarily a function of inadequate substrate distribution. This factor seems to have greatly limited the success of the pilot study. The MPCA staff does not agree that the failure of distribution is the result of cyclical reversals of ground water flow. There are other more likely factors that have prevented the distribution of substrate. They include variations in lithology that prevent the flow of ground water to certain areas, lack of dissolution of oil into ground water, lack of characterization of the ground water flow regime in the horizontal direction and lack of characterization of the impact of vertical ground water flow into the pilot study area. There may be other factors. The MPCA staff requests that the Navy discuss these other factors and their possible impact on the pilot study.	Concur. The inadequate substrate distribution is likely primarily a result of aquifer heterogeneity and resulting preferential groundwater flow pathways (and consequent zones of inadequate advective groundwater flow) as the draft report states in Section 4.8 of the draft report. The discussion of potential groundwater flow reversals will be removed per the April 15, 2004 meeting. A section will also be added to present stratigraphic data collected during system installation. Parsons does not agree that a lack of vegetable oil dissolution is a likely factor limiting the distribution of organic carbon in the pilot test area given that the volatile fatty acid data (Table 4.7) indicates that the vegetable oil is readily degrading into soluble organic carbon (VFA concentrations exceed 2,000 mg/L at the injection wells). Parsons agrees that the groundwater flow regime (primarily vertical flow) within the pilot test area has not been adequately characterized, and that this lack of characterization makes interpretation of the pilot test data difficult. As a result, Parsons will add a recommendation in Section 5 to install additional well clusters within the pilot test area to improve the characterization of the groundwater flow conditions.
55	Section 5.2	5-5	A number of recommendations are discussed for further monitoring of the existing pilot study wells and for a phased expansion to full scale in ACP. The limited success of the pilot study and a number of uncertainties regarding the horizontal ground water flow regime, vertical ground water flow and variations in lithology were previously noted in the MPCA staff response to the Report. The MPCA staff is not certain how these factors have limited the distribution of substrate and impacted the results. Due	Concur. Recommendations regarding additional well installations and additional monitoring of the current pilot test will be added to Section 5.2.1. Parsons recommends that an additional 3 to 4 well clusters be installed and that monitoring (in a slightly reduced form) be continued for at least 18 to 24 months. The recommendations to move forward with an expanded application (Phases I, II, and III of a full-scale application in

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			to the uncertainties identified by the MPCA staff (and others to the pilot study) at the April 15, 2004 meeting, the NIROP Partnering Team decided that full scale implementation and additional injection not proceed at this time. Instead the team decided to conduct continued monitoring of the existing pilot study area and to install some additional monitoring wells to address some of the uncertainties that have been identified. A Technical Subcommittee meeting will be convened to scope the level of effort for the next monitoring phase and to determine the number and location of additional monitoring wells. For the time being, the MPCA staff cannot approve the phased full-scale implementation. The MPCA staff requests that the Navy revise the Report to reflect the actions adopted by the NIROP Partnering Team at its April 15, 2004 meeting.	the draft report) will be removed. The text will also be revised such that the current pilot test system (with 3-4 well clusters added) will be monitored for at least approximately 18 to 24 months prior to the initiation of the expanded scale application. The extended monitoring data will be used to determine the long-term impacts to groundwater flow conditions and groundwater quality related to the injected vegetable oil, to assess the potential for long term impacts to the river., to assess the roll of abiotic degradation verses biotic degradation, and to assess the roll of the extraction system After this design data has been collected the design phase of the Phase II expanded pilot test may commence.
56	Section 5.2.2	NA	Since the Navy is not proposing to add iron to the vegetable oil for full scale implementation, before the MPCA staff can approve moving ahead with full scale implementation (phased or otherwise), the staff requests that the Navy determine the role played by the addition of iron to success of the pilot study. Since the Navy has asserted that MS-46S was impacted by the vegetable oil injection of the pilot study and the Navy plans to install six monitoring well pairs in the vicinity of this well, the MPCA staff requests that the Navy identify how far upgradient the vegetable oil traveled during the pilot study before choosing the area for Phase I of the full implementation.	Please Refer to the response to MPCA comment #49. Disagree. The Navy feels that the upgradient edge of the injected vegetable oil has been sufficiently bounded as vegetable oil was positively identified at well PES-BG-1 only. Parsons was in error during the April 15th 2004 meeting when it was asserted that vegetable oil had been identified in MS-46S. In actuality vegetable oil was identified in PES-BG-1 (approximately 15 feet cross-gradient from MS-46S) during the May 2002 process monitoring round.
57	Section 5.2.2	5-7	Since the objective of the pumpout wells is to capture the ground water plume leaving NIROP at a TCE	The scope and design of a full-scale application is not within the scope of this document. Therefore, the definition of the

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			concentration of 100 ppb or higher (see the DQO decision rules of Step 5 for Problem C, dated August 21, 2001), the area covered by the full scale should be chosen to be consistent with treating ground water at a TCE concentration of 100 ppb or higher. The number and placement of injection wells needs to be based on this objective so at this juncture the MPCA staff cannot agree on the number of injection wells needed for any full scale remedy.	area within which a full-scale system would be located and the number of injection locations necessary for any future full-scale application will not be addressed at this time.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions and recommendations for the field application to enhance *in-situ* bioremediation of chlorinated solvents via vegetable oil injection at NIROP Fridley, Minnesota.

5.1 CONCLUSIONS

5.1.1 Data Quality Objectives

During the work plan preparation phase of this project a series of DQOs were developed and agreed to collectively by the US Navy and the various regulatory agencies involved in this project. The DQOs provide specific criteria used to determine the success of this pilot test. All of the DQOs were successfully met and in most cases were exceeded. Thus, this pilot test can be considered a success with respect to the DQOs.

5.1.2 Observed Changes in Site Geochemistry

Changes in geochemical conditions during process monitoring indicates that the addition of vegetable oil to the subsurface at ACP has induced environmental conditions conducive to reductive dechlorination upgradient of PES-MW-5. However, these geochemical changes are neither spatially uniform or temporally consistent within the pilot test area.

Baseline geochemical conditions were generally weakly anaerobic to weakly aerobic, with DO concentrations ranging from 0.1 to 2 mg/L and ORP ranging from +123 to -185 mV. Following vegetable oil injection, geochemical conditions upgradient of PES-MW-5 became moderately to strongly anaerobic while conditions downgradient of PES-MW-5 remained weakly aerobic. These observations indicate that subsurface conditions upgradient of PES-MW-5 became more favorable for anaerobic degradation processes, while the area downgradient of PES-MW-5 was either not affected or only weakly affected by the injected vegetable oil. Increases in methane concentrations upgradient of

PES-MW-5 indicate that methanogenesis has become more prevalent in this area. Reductive dechlorination is known to occur most rapidly under methanogenic conditions. Thus, geochemical conditions in this area have become more favorable for reductive dechlorination.

Sulfate data collected during the baseline sampling event indicated that there was significant sulfate mass present in the subsurface within the pilot test area. Thus, the baseline data set indicated that sulfate reduction would be a significant TEAP in the pilot test area and would compete with reductive dechlorination for electron donor. Increasing concentrations of sulfide coupled with decreasing concentrations of sulfate at wells where there is significant TOC present support the assertion that sulfate reduction is occurring in the pilot test area and is likely consuming electron donors at the expense of reductive dechlorination. However, sulfate reduction will only delay the onset or slow the rate of dechlorination as the sulfate mass will likely be depleted within a few months if sufficient TOC is present.

Sulfate reduction and methanogenesis are the dominant TEAPs that have been stimulated at this site, and sulfate and carbon dioxide are competing with CAHs for use as electron acceptors in site groundwater. Sulfate mass is rapidly depleted in the presence of sufficient organic carbon. Thus, sulfate reduction is considered to be a temporary competing TEAP to reductive dechlorination at locations where sufficient TOC mass is present. Methanogenesis is expected to continue to be an active TEAP within the pilot test area and to continue to compete with reductive dechlorination for electron donor mass.

5.1.3 Actual/Significant Changes in Contaminant Concentrations

After vegetable oil injection there were significant decreases in the concentration of TCE observed at the injection wells and at monitoring wells GWMS-46S, PES-MW-4, PES-MW-6, PES-MW-8, and PES-MW-9. Concentrations of TCE at the remaining wells upgradient of PES-MW-5 increased initially, typically peaking in May or August 2002, then decreased through August 2003. However, the decreasing trend in TCE was not uniform for all of the wells within the pilot test area. Increasing trends in the concentration of TCE were observed at monitoring locations GWMS-27S, GWMS-47S,

PES-MW-1, and PES-MW-5 between baseline sampling and the most recent process monitoring event. However, an increase in *cis*-1,2-DCE concentrations detected in several monitoring wells (PES-MW-1, PES-MW-3, PES-MW-4, PES-MW-6, PES-MW-7, and PES-MW9) suggests that reduction of TCE to *cis*-1,2-DCE has occurred due to substrate addition. In addition, the detection of low concentrations of VC and ethene at some wells indicates that TCE is being reductively dechlorinated to ethene in limited areas close to the injection wells.

The greatest decrease in contaminant concentrations occurred at the GWMS-46S, where TCE decreased from a baseline concentration of 20 mg/L to a concentration of approximately 5 mg/L; and at the injection locations, where contaminant concentrations decreased from the 1 mg/L range to tens of µg/L. However, there is some ambiguity regarding the mechanism(s) responsible for the observed TCE concentration decreases at MS-46S and within the rest of the pilot test area. Significant TCE concentration decreases have been observed at well locations installed outside of the pilot test area that are likely to be related to upgrades to the extraction system. In addition, the roll of abiotic degradation mechanisms have not been completely defined within the pilot test area.

5.1.4 Daughter Product Formation and Persistence

The presence of the daughter products *cis*-1,2-DCE, VC, and ethene which were not used in facility operations, provides direct evidence that TCE is being reductively dechlorinated. Increasing concentrations of *cis*-1,2-DCE coupled with decreasing concentrations of TCE at wells installed close to the injection area (upgradient of PES-MW-5) indicate that partial degradation of TCE to *cis*-1,2-DCE is occurring in this area. The detection of low concentrations of VC and ethene in the same area indicate that limited complete reductive dechlorination is limited to close proximity to the injection area (wells PES-MW-7 and PES-MW-9). Complete dechlorination appears to correlate to areas where TOC is greater than 20 mg/L. Therefore, the lack of complete dechlorination at the majority of the pilot test wells is likely due to a lack of sufficient TOC.

5.1.5 Degree of Electron Donor Utilization for Reductive Dechlorination

A significant percentage of the substrate mass is utilized for microbially mediated redox processes other than reductive dechlorination of chlorinated compounds. In particular, geochemical data indicate that sulfate reduction and methanogenesis may utilize a significant percentage of substrate (i.e., this mass is not being used to enhance reductive dechlorination of CAHs). However, reduction of TCE to *cis*-1,2-DCE (and in some cases to VC and ethene) observed at the injection wells and monitoring locations PES-MW-7 and PES-MW-9 are direct indications that reductive dechlorination is occurring in groundwater at the site. It may be that organic carbon concentrations greater than 20 mg/L are required to meet both the natural demand for electron donor and to provide sufficient electron donor for the dechlorination of CAH mass.

5.1.6 Substrate Distribution and Potential for Future Reductive Dechlorination

Wells where evidence of reductive dechlorination of TCE has occurred exhibit the following characteristics:

- DO concentration less than 1 mg/L;
- ORP less than -100 mV;
- Carbon dioxide concentration greater than 100 mg/L;
- Sulfate concentration less than 50 mg/L;
- TOC concentration equal to or greater than approximately 20 mg/L;
- Measurable concentrations of VFAs equal to or greater than 50 mg/L;
- Ferrous iron concentration greater than 2 mg/L;
- Methane concentration greater than 1 mg/L; and
- Total biomass concentration greater than approximately 50 pmoles PLFA/mL.

These conditions have not been uniformly induced across the treatment area, but have been limited mostly to the immediate injection area. Geophysical data collected by the USGS suggests that vegetable oil NAPL is distributed only within the injection area, and that groundwater impacted by the injected vegetable oil is distributed as far downgradient as PES-MW-2. In order to stimulate reductive dechlorination, sufficient organic

substrate is required to create anaerobic reducing conditions while stimulating microbial growth of dechlorinating microorganisms. Therefore, the lack of reductive dechlorination at ACP is primarily a function of inadequate substrate distribution.

The potential for future biologically mediated reductive dechlorination and mass reduction will be a function of substrate distribution. It was assumed that dissolution of the vegetable oil would create a reaction zone extending tens of feet downgradient from the injection zone. The more-limited extent of the reaction zone is likely related to the presence of a low hydraulic gradient and cyclical reversals of groundwater flow.

Significant TCE concentration reductions were observed at several locations within and upgradient from the pilot test area. However, the rolls of the various reduction mechanisms (e.g., the upgraded extraction system, abiotic degradation related to iron in the soil as well as added iron, and biotic degradation related to the injected vegetable oil) are not well understood. The observed TCE concentration reductions are likely due to a combination of all of the various mechanisms operating on this site.

5.2 RECOMMENDATIONS

The recommendations section of this report is divided into two subsections. The first subsection presents recommendations for continued monitoring of the pilot test area, and the second subsection addresses an expanded pilot scale application of enhanced anaerobic bioremediation at ACP.

5.2.1 Recommendations for Additional Monitoring at the Pilot Test Site

The continued presence of measurable vegetable LNAPL within the injection area indicates that there is significant vegetable oil remaining in this area. Thus, the vegetable oil injected during the pilot test will act as a source of organic carbon for some time. It is expected that, even after the vegetable oil is depleted, the microbial biomass that has developed within the injection area will provide a secondary source of organic carbon as it breaks down. Therefore, the beneficial effects of the pilot test can be expected to continue for several years. Thus, Parsons recommends continuation of groundwater monitoring within the pilot test area to determine long-term effects of the injected vegetable oil on water quality and the hydraulic properties of the aquifer matrix; and to

monitor changes in geochemistry, microbial population, and CAH concentrations as the oil becomes depleted.

In addition, the extraction system upgrades that were completed and placed on line during the summer of 2001 appear to have had some positive impact to contaminant concentrations within the park. Unfortunately it is impossible to conclusively separate the effects of the newly upgraded extraction system from the effects of the vegetable oil pilot with the dataset currently available. Parsons recommends that future monitoring of the pilot test system be expanded to select locations outside of the pilot test area so that the impacts of the upgraded extraction system and the injected vegetable oil can be separated.

During the course of the pilot test there were significant TCE concentration reductions observed at some well locations indicating that the pilot test was at least partially successful. However, there is considerable ambiguity regarding the mechanism(s) responsible for the observed TCE concentration reductions. It is likely that the TCE concentration reductions are a result of a combination of abiotic degradation mechanisms related to naturally occurring iron present in the soil column as well iron added during the injection and biotic mechanisms related to the injected vegetable oil. It is important to determine what mechanisms are active at Anoka County Park and within the pilot test system prior to evaluating the propriety of an expanded scale application. Therefore Parsons recommends that the current pilot test be monitored for at least an additional 18 to 24 months to investigate this issue further.

Finally, it has been determined by other parties (primarily the USGS) that there may me a significant component of vertical flow within Anoka county park that may be influencing groundwater and contaminant mass migration rates and directions. In addition, it has become apparent through the continuing efforts of the USGS that groundwater flow within the pilot test area may be in a more southerly direction instead of southwest. As a result, there may be a portion of the pilot test area that is not being monitored sufficiently. Thus, Parsons recommends that approximately 4 additional well clusters be installed in a line extending from the injection area due south. Each of the proposed monitoring well clusters should consist of two monitoring wells with differing

screen intervals (shallow and intermediate). Parsons further recommends that the proposed well clusters be added to the extended monitoring program to determine the effects of the pilot test due south of the injection area.

Parsons recommends that the current pilot test system be monitored for a minimum of an additional 18 to 24 months (3 to 4 sampling events) in order to further investigate the data gaps described above.

Specific recommends for continued monitoring of the current pilot test system include:

- Installation of 4 additional well clusters in a line extending from the injection area to the river in a southerly direction. Each well cluster should consist of a shallow well and an intermediate well.
- Collection of slug test data, groundwater elevation data, and vegetable oil LNAPL thickness data within and immediately downgradient of the injection area on a semi-annual basis; and
- Collection of groundwater samples for field and laboratory analysis data on a semi-annual basis from wells within and outside of the pilot test area. Analytical parameters should include: purging stabilization parameters (DO, temperature, ORP, specific conductance, and pH), VOCs, carbon isotope fractionation, and other geochemical parameters (sulfate, TOC, VFAs, methane, ethane, ethene, ferrous iron, nitrate, carbon dioxide, and chloride).

Analysis for the above-listed parameters will allow continued monitoring of groundwater and aquifer matrix conditions, substrate and organic carbon distribution, geochemical changes, and changes in contaminant concentration and molar fraction over time in order to evaluate the data gaps presented above as well as to determine the long term effects of the injected vegetable oil.

5.2.2 Recommendations for an expanded Scale Application at Anoka County Park.

The pilot-scale vegetable oil injection was partially successful in that reductive dechlorination of TCE was enhanced and complete dechlorination of TCE was observed in limited areas. However, due to the uncertainties related to site specific hydraulics, effects of the extraction system, the roll of abiotic degradation, and long term effects of

the vegetable oil injection pilot Parsons does not recommend proceeding with an expanded scale application at this time. Instead Parsons recommends that the current system be monitored for at least an additional 18 to 24 months and that the appropriateness of an expanded pilot test be evaluated at that time.

RESPONSE TO COMMENTS ON THE RESPONSE TO COMMENTS ON THE DRAFT REPORT FOR A FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NAVAL INDUSTRIAL ORDNANCE PLANT FRIDLEY, MINNESOTA

Item	Section	Page	Comments	Responses
Minnesota Department of Health Comments				
			Supplemental comments have not been received to date.	None.
Environmental Protection Agency Comments				
1.	Section 2.3	2-4	The response appears to be adequate.	No response necessary.
2.	Section 2.3	2-4	The response appears to be partially adequate. While the response indicates that the hydrogeology discussion in the final report will be revised to reference the most recent AMR, the response does not indicate whether the statement identified in the comment will be modified. Specifically, it is recommended that the final report include a more complete description of the site hydrogeology and acknowledge that the shallow and intermediate zones are hydraulically connected in some areas.	The referenced statement will be revised to conform to the current understanding of the site conceptual model as presented in the most recent AMR. The final report will include a more complete description of site stratigraphy and hydrogeology, including any new data collected. However, the Navy does not believe that it is necessary or an efficient use of funds to reproduce the hydrogeologic discussion from the AMR in the final vegetable oil pilot test report.
3	Section 2.3.1	2-7	The response appears to be adequate.	No response necessary.
4	Section 2.3.2	2-9	The response appears to be adequate.	No response necessary.
5	Section 2.4	2-11/2-12	The response appears to be partially adequate. While the response indicates that Section 2.4 will be revised to reference the most recent AMR, it does not indicate how the text cited by the comment will be revised. It should be revised to reflect the current understanding of site hydrology indicated by the site AMR and other documents such as the USGS study of site hydrology. In addition , the request that the report should assess	The referenced statement cannot be revised at this time as the site conceptual model may change between now and when the report is finalized. The referenced statement will be revised to conform to the understanding of the site conceptual model as presented in the most current AMR when the report is finalized.. The assessment of groundwater flow within the pilot test area will continue to be addressed through the collection

Item	Section	Page	Comments	Responses
			whether the pilot study area is actually an area of hydraulic stagnation based on the estimates of groundwater velocities identified in the Draft Report does not appear to be adequately addressed. The response did not directly indicate if the pilot study area is an area of stagnation. However, the response did indicate that "the poor organic carbon distribution is directly related to the low groundwater flow velocity and heterogeneous conditions within the upper portion of the pilot test area." The groundwater flow velocities reported in Table 4.2 of the Draft Report indicate average flow velocities in the area of the injection wells before injection of between 522 and 630 ft/yr. Average pre-injection flow velocities in the area downgradient of the injection wells were reported to be between 1,228 and 6,754 ft/yr. These groundwater flow velocities do not appear to indicate an area of hydraulic stagnation, and it is not clear how average groundwater flow velocities could account for the poor distribution of organic carbon noted in the response to comment.	of additional groundwater elevation data during future process monitoring events and the installation of additional monitoring wells as stated in the revised Section 5 (attached to the final response to comments matrix). The groundwater flow velocity data presented in Table 4.2 of the draft report is divided into three areas related to the horizontal gradients observed during the baseline sampling event (as stated in Section 4.1.1 of the draft report). The area termed the "upgradient portion of the plot test area" extends from the background wells (PES-BG-1, PES-BG-2, and PES-BG-3) to monitoring well PES-MW-3, and is characterized by a relatively flat groundwater potentiometric surface (Figure 4.1 of the draft report). The pre-injection groundwater flow velocity for this area is approximately 438 ft/year (Section 4.1.2 and Table 4.2 of the draft report). This calculated groundwater flow rate is representative of the entire upgradient portion of the pilot test area, not the injection area. The groundwater flow rate upgradient from PES-MW-2 could not be calculated because the groundwater potentiometric surface in this area is extremely flat. Measured differences in groundwater elevation between wells in this area are within the range of potential measurement errors (i.e., < 0.01 ft), and in some cases attempts to interpret groundwater flow directions using these measurements result in the depiction of unlikely (and potentially erroneous) groundwater flow reversals (e.g., between PES-BG-2 and PES-BG-3). Thus, it is difficult to determine the groundwater flow rate within the injection area prior to injection. However, it is apparent that the groundwater

Item	Section	Page	Comments	Responses
				flow rate in this area is very low as it is directly proportional to the hydraulic gradient as determined by Darcy's Law. The observed flat groundwater potentiometric surface and proportionally slow groundwater flow rate in the injection area persisted throughout the pilot test (with the notable exception of December 2002). Therefore, the injection area does appear to be a "stagnation zone" (i.e., a zone of substantially reduced groundwater flow velocity), and this characteristic may have impacted the distribution of organic carbon.
6	Section 2.5	NA	The response does not appear to be adequate. While acknowledging that "the impact of the extraction system on contaminant concentrations in the vicinity of the pilot test area ... is important when considering the overall effectiveness of the pilot test," the response concludes by stating that "the impact of the extraction system prior to the system upgrade is not germane to this evaluation." This conclusion appears to be based on the fact that the extraction well test placed on line approximately 6 months before vegetable oil was injected. However, the impact of modifications to the extraction system on contaminant concentrations throughout the Anoka County Park and in the pilot study area are not immediate and require analysis of the long-term trends resulting from these modifications. Moreover, during the period of the pilot test, the extraction system was not operated for extended periods due to equipment malfunctions. These periods of loss of contaminant capture may also have secondary impacts on groundwater quality in the pilot study area. As requested in the original	The response will be amended to state "Therefore the impact of the extraction system prior to the start of the vegetable oil pilot test is not germane to this evaluation." The Navy agrees that the long-term impact of the extraction system is an important factor in determining the success of the pilot test. Thus, the Navy has proposed that carbon isotope data be collected from a series of monitoring wells within and outside of the pilot test area to determine the impact of the extraction system (refer to the work plan addendum for a complete discussion of the proposed carbon isotope work). While an analysis of contaminant trends prior to and after the system upgrade would be interesting and would likely be beneficial from the standpoint of extraction system optimization, the Navy does not believe that an analysis of historic contaminant concentration trends is relevant to the evaluation of the success of the pilot test. The Navy believes that contaminant concentration trends during the pilot test are much more relevant to the pilot test evaluation. Therefore, the Navy will conduct an analysis of contaminant concentration trends within and outside of

Item	Section	Page	Comments	Responses
			comment, the Pilot Study Report should include a detailed analysis of contaminant trends in the core areas of the plume in ACP prior to and during the pilot test and should provide a more complete analysis of the impact of these trends on the interpretation of pilot test results.	the pilot test area starting in December 2001 and continuing through the end of the pilot test.
7	Section 4.1	NA	The response appears to be adequate. The response indicates that a discussion of the boring data collected during the system installation will be included in the final report. However, a presentation and analysis of these data is not currently provided. These data may be useful for better explaining the limited success of the pilot test at this point in the pilot test and may help to define a program of continued monitoring and investigation. Such an analysis may be helpful in developing the expanded monitoring program currently recommended in the revised Section 5, Conclusions and Recommendations.	A portion of the stratigraphic data collected during the system installation is presented in the work plan addendum in the form of a site conceptual cross section. It is proposed that additional stratigraphic data be collected during the installation of three new monitoring well clusters. The newly collected data and the previously collected data will be presented in a technical memorandum which will be prepared following the next process monitoring event.
8	Section 4.3	4-24	The response appears to be adequate.	No response necessary.
9	Section 4.4.1	4-29	The response appears to be partially adequate. The response has acknowledged the uncertainties regarding the impact of the injection of vegetable oil on contaminant concentrations in upgradient areas represented by groundwater quality from MS-46S. However, the response indicates that it is not appropriate to include the groundwater quality data from MS-46S in the evaluation of contaminant trends in groundwater entering the pilot test area. The geochemical impacts observed at MS-46S were minimal and provide little justification for assuming	The Navy does not agree that the observed geochemical impacts to GWMS-46S can be considered to be “minimal”. The Navy considers order of magnitude increases in TOC and methane concentrations and large changes in ORP conditions indicative of organic carbon impact (-82 mV decreased to -276 mV) to be significant. Thus, the Navy does not consider the inclusion of MS-46S in the upgradient (e.g., un-impacted) data set to be appropriate. The addition of PES-BG-2 to the groundwater sampling protocol is proposed in the work plan addendum. PES-BG-2 is located approximately 15

Item	Section	Page	Comments	Responses
			the pilot test has had a long-term and significant impact on groundwater quality in the area of MS-46S. There is little other data available to determine the quality of groundwater entering the pilot test study. If Parsons does not feel it is appropriate to use the data from MS-46S for the evaluation of upgradient groundwater quality, an additional upgradient well should be installed as part of the pilot scale test recommended in the revised Section 5, Conclusions and Recommendations.	feet upgradient of MS-46S and is therefore less likely to have been impacted by the injected vegoil and thus likely represents background conditions. The Navy does not believe that the installation of a new background monitoring point is necessary at this time.
10	Section 4.4.1	4-36 to 4-38	The response appears to be adequate. However, it may be valuable to provide total molar concentration plots at this point in time rather than waiting until generation of the final report. These plots may be helpful for evaluating some of the outstanding issues and for addressing these issues adequately in the extended monitoring program now being planned.	Concur, the total molar concentration plots will be provided during the meeting scheduled for October 6th.
11	Section 4.4.3	4-41	The response appears to be adequate.	No response necessary.
12	Section 4.8	4-80	The response appears to be adequate.	No response necessary.
13	Section 4.8	4-80	The response appears to be adequate.	No response necessary.
14	Section 4.8	NA	The response appears to be partially adequate. While the response acknowledges the potential deficiency in the downgradient monitoring well network and agrees to the installation of additional wells, the response does not agree to discuss the additional processes, abiotic as well as biotic, that may be acting to reduce concentrations of TCE daughter products	The Navy agrees that both abiotic and biotic processes are important factors that must be considered during the evaluation of the pilot test, as stated in the draft report and the previous version of the comment response matrix. The Navy proposes to analyze groundwater samples from selected monitoring wells within and outside of the pilot test area for a number of parameters that are designed to

Item	Section	Page	Comments	Responses
			downgradient from the pilot test area. Based on discussions held during the April 14, 2004 meeting these additional processes may be instrumental in reducing concentrations daughter products and should be fully discussed in the final report.	help clarify the relative importance of abiotic and biotic degradation as well as the role of the extraction system. Proposed sampling locations and analytes are presented in the work plan addendum. The discussion of additional processes requested in the comment will be facilitated by this additional groundwater sampling and analysis.
15	Section 4.8	4-82	The response appears to be adequate.	No response necessary.
16	Section 4.10	4-87	The response appears to be adequate.	No response necessary.
17	Section 5.1	NA	The response appears to be adequate.	No response necessary.
18	Section 5.2	NA	The response appears to be adequate.	No response necessary.
New -1	Revise d Section 5	NA	In Section 5.1.6, when discussing the limited extent of the reaction zone observed during the test, the revised Section 5 indicates that "the more-limited extent of the reaction zone is likely related to the presence of a low hydraulic gradient and cyclical reversals in groundwater flow." However, as indicated in Specific Comment No. 5, groundwater flow velocities observed in the area downgradient of the injection wells are substantial and do not appear to offer a significant impediment to the transport of organic carbon. Moreover, the presence of TCE degradation products in downgradient wells in the absence of high organic carbon concentrations appear to suggest sufficient hydraulic gradients to induce adequate groundwater flow for the distribution of organic carbon. The revised Section 5 should more fully	Refer to the response to comment 5 for discussion regarding groundwater flow rates within the injection area. The substantial groundwater flow velocities presented in the draft report are not representative of the injection area. The Navy agrees that the analytical data collected from the downgradient monitoring wells indicates that some organic carbon is reaching these locations. However, as stated in the draft report (Section 4.5.1), significant organic carbon loading is limited to PES-MW-1, PES-MW-6, PES-MW-7, and to a lesser extent PES-MW-9 (i.e., significant organic carbon loading is limited to the immediate vicinity of the injection area). Lower concentrations of TOC were also sporadically detected in most of the other monitoring wells during the course of the pilot test (primarily during the December 2002 event).

Item	Section	Page	Comments	Responses
			discuss the impact of observed groundwater flow velocities on the anticipated distribution of organic carbon.	Thus, a limited mass of organic carbon was being transported away from the injection area. However, the mass of organic carbon being delivered to most of the monitoring wells is insufficient to deplete concentrations of completing electron acceptors and stimulate reductive dechlorination, as evidenced by the stable concentrations of sulfate and high concentrations of TCE remaining in most of the downgradient wells. The Navy will continue to investigate groundwater flow and the distribution of organic carbon through the installation of new well clusters and the performance of two additional rounds of process monitoring.
New -2	Revise d Section 5	NA	The revised Section 5.2.1 recommends that "future monitoring of the pilot test system be expanded to select locations outside of the pilot test area so that the impacts of the upgraded extraction system and the injected vegetable oil can be separated." However, the proposed expansion of the monitoring network and proposed additional monitoring do not appear to include any activities designed to achieve this objective. The installation of an additional well(s) may be necessary to resolve the impact of upgradient contaminant concentration trends on the pilot test results.	The recommendations in Section 5.2.1 are general recommendations for future site activities. Specific project tasks designed to fulfill the recommendations presented in Section 5 are discussed in detail in the work plan addendum. The Navy believes that performance of these specific tasks will be sufficient to achieve the objective stated in the comment.
New -3	Revise d Section 5	NA	The revised Section 5.2.1 indicates that "it is important to determine what mechanisms are active at Anoka County Park and within the pilot test area prior to evaluating the propriety of an expanded scale application." The revised Section 5.2.1, therefore, further recommends that "the current pilot test be monitored for at least an additional 18 to 24 months to	The recommendations in Section 5.2.1 are general recommendations for future site activities. Specific project tasks designed to fulfill the objectives and recommendations presented in Section 5 are discussed in detail in the work plan addendum. The work plan addendum text discusses how the proposed activities will facilitate achieving the objective of determining the

Item	Section	Page	Comments	Responses
			investigate this issue further." However, based on the activities outlined and the discussion provided in revised Section 5, it is not clear how the activities proposed for the extended monitoring period will achieve the objective of determining the mechanisms that are active in Anoka County Park and within the pilot test. The revised Section 5 should clearly discuss how these objectives will be achieved during the proposed period of extended monitoring.	mechanisms that are active in Anoka County Park and within the pilot test area.
New -4	Revised Section 5	NA	The revised Section 5.2.1 recommends the continued collection of groundwater elevation data on a semi-annual basis. Given the uncertainties regarding flow conditions and directions with in the pilot test area, a semi-annual frequency does not appear adequate to resolve these uncertainties. More frequent collection of groundwater elevation data should be considered.	Disagree, the groundwater flow conditions (e.g., direction and rate) within the pilot test area have been relatively consistent from event to event. The only changes noted were related to the elevation of the water table over time (e.g., the water table is higher in all wells during particular rounds). Thus, the Navy does not believe that it is necessary to continue to monitor the system quarterly since the groundwater flow direction and rate appeared to be relatively stable throughout all four of the seasons.
Minnesota Pollution Control Agency Comments				
NA	NA	NA	The MPCA staff hereby approves the MPCA Responses to Comments as modified pursuant to Attachment I of this letter. Attachment 1 applies to items 23, 29, and 55 only. Therefore, all other items were removed from this response to comment matrix. The reader is referred to the original comment response matrix for the remaining items.	No response necessary.
23 and bull	Section 2.3.1	2-7	The MPCA staff requests that the Navy ensure that the tasks related to the Annual Monitoring Report be tasked out to the appropriate contractor for	Concur, The Navy has proposed that additional well clusters be installed within the pilot test area in order to evaluate the vertical gradients in this area. The vertical

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et 5 of item 29			completion, e.g., that a contractor be tasked to determine how vertical gradients impact the flow regime in the pilot test area and how ground water travels vertically through the silt layer identified in the United States Geological Survey report.	gradient data collected from the newly installed well clusters during the Fall of 2004 will be evaluated and presented in a technical memorandum to be prepared after the completion of this sampling event. Additional vertical gradient data will be collected approximately 6 months later and will be evaluated and presented in either a technical memorandum or the final results report.
55	Section 5.2	5-5	The MPCA staff requests that the Navy change the last sentence in the "Responses" column to read, "After the design data has been collected, the Navy will propose the design of Phase II to the NIROP Partnering Technical Subcommittee for the Technical Subcommittee's evaluation. The Technical Subcommittee will make a recommendation to the Partnering Team for discussion and approval before the expanded pilot test commences."	Concur, the change will be made as requested.

APPENDIX G

FINAL MAY 2006 TECHNICAL MEMORANDUM

TECHNICAL MEMORANDUM

May 2006

To: Dan Owens and Cliff Casey, NFESC; Venky Venkatesh, CH2M Hill Constructors, Inc.

From: Dan Griffiths and Bruce Henry, Parsons

Subject: Preliminary Results for the Anoka County Park Organic Substrate Addition Pilot Test, Fridley, Minnesota

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This technical memorandum presents a summary of data collected during extended monitoring activities conducted at the vegetable oil injection pilot test during the Spring and fall of 2005, as well as relevant historic pilot test data. This technical memorandum has been prepared for the Naval Facilities Engineering Command (NAVFAC), Southern Division, and CH2M Hill Constructors (CCI) by the Parsons Corporation (Parsons).

INTRODUCTION

During the reporting phase of this project it was determined that this pilot test was a success in that each of the data quality objectives (DQOs) were met and contaminant mass reduction was enhanced in the vicinity of the vegetable oil injection area. However, it was also determined that vegetable-oil-derived organic carbon was not effectively distributed within the pilot test area and that complete reductive dechlorination was only induced in a relatively small area (Parsons, 2004).

The activities associated with the extended monitoring program, presented in the work plan addendum technical memorandum dated January 6th 2005 and presented in this technical memorandum, were designed to improve the characterization of the pilot test area and to address the data gaps identified in the final work plan addendum (Parsons, 2005).

EXTENDED MONITORING ACTIVITIES

Extended process monitoring activities at the vegetable oil pilot test site were conducted in accordance with the final work plan addendum (January 6th 2005), the Final Work Plan (Parsons, 2001a), final Quality Assurance Project Plan (QAPP), (Parsons, 2001b), and guidance provided by the United States Environmental Protection Agency (USEPA (1998)).

The extended process monitoring activities were conducted in three phases. The first phase consisted of a membrane interface probe (MIP) survey within the pilot test area to investigate the stratigraphy and vertical distribution of volatile organic compound (VOC) mass from the ground surface to a total depth of approximately 60 to 70 feet below ground surface (bgs). The second phase used the data generated during the MIP survey to place eight new monitoring wells and ten soil borings within approximately 100 feet of the injection area. The third phase began after the new monitoring well clusters are

installed and consisted of a groundwater sampling event at the newly installed wells, existing pilot test wells, and selected existing monitoring wells located outside of the pilot test area. A second groundwater sampling event was conducted approximately 7 months after the first event, in November 2005. The data collected during the field activities associated with the extending monitoring of the vegetable oil pilot test area are presented in the following subsections.

MEMBRANE INTERFACE PROBE SURVEY

An MIP survey was conducted within the pilot test area in order to improve the characterization of the stratigraphy and distribution of VOCs in the subsurface. During the MIP survey it was determined that an area of relatively high VOC concentrations is present in the proximity of the pilot test area, and that this area of high chlorinated VOC concentrations extends further than expected to the south and west. Therefore, all of the contingency MIP borings and one additional MIP boring were installed for a total of 38 MIP points (Figure 1). In addition, it was discovered that the direct push equipment employed during the MIP survey was capable of drilling deeper than expected. Thus, select MIP borings were advanced to a maximum depth of 70 feet below ground surface (bgs) instead of the proposed maximum depth of 50-60 feet. This data indicates that the direct push drilling technology is a viable drilling method at Anoka County Park to depths of at least 70 feet.

During the course of the MIP survey, discrete groundwater samples were collected from the background MIP location and sixteen MIP locations drilled within or in close proximity to the injection area. A total of 45 discrete groundwater samples were collected from select vertical intervals corresponding to high and low chlorinated VOC concentrations and areas where high flame ionization detector (FID) readings were observed. The discrete groundwater samples were collected at each location using direct push discrete sampling equipment. Each sample was collected directly from the aquifer formation through the sampling point without purging a significant quantity of groundwater. These samples were analyzed for VOCs via USEPA Method 8260B, total organic carbon (TOC) via USEPA method SW9060, and methane, ethane, and ethene via Microseeps Internal standard operating procedure (SOP) AM-20GAX in order to qualitatively validate the MIP results. The data set generated from the analysis of these samples was used in conjunction with data generated during the MIP program and the soil sampling program to determine the extent of the area directly impacted by vegetable oil and to investigate the distribution of CAH reductive dechlorination products within the injection area. The completed MIP borings are summarized in Table 1. The MIP profiles generated during this program are attached to this technical memorandum as Appendix A.

SOIL BORING INSTALLATIONS

A total of ten soil borings were installed as part of the extended monitoring activities related to the vegetable oil pilot test. Seven soil borings (PES-SB-1 through PES-SB-7) were advanced in the immediate vicinity of the three injection wells. These soil borings

were used to collect stratigraphic, geochemical, mineralogical, and microbial data in the vicinity of each injection well and to determine the extent of the injection area. Three additional soil borings (PES-SB-8 through PES-SB-10) were installed immediately downgradient of the injection area in order to investigate anomalies in the geophysical data set generated by the United States Geological Survey (USGS). The completed soil boring installation activities are summarized in Table 2 and are presented in detail in the following subsections. Boring logs prepared during drilling are presented in Appendix A.

MONITORING WELL INSTALLATIONS

A total of eight new monitoring wells were installed using hollow stem auger (HSA) drilling techniques during the extended monitoring program. One of the proposed monitoring wells (PES-MW-13A) is located approximately 55 feet upgradient of MS-46S and approximately 65 feet upgradient of the injection area (Figure 2). The data collected from this location is representative of soil and groundwater that have not been impacted by the injected vegetable oil and iron tracers. The remaining seven monitoring wells were installed south and downgradient from the injection area as shown on Figure 2. Proposed monitoring well clusters PES-MW-10, PES-MW-12, PES-MW-14 consist of two wells installed at two vertical intervals within the shallow drift aquifer (Figure 2), while monitoring wells PES-MW-11A and PES-MW-13A consist of single wells installed slightly below the bottom of the silt/clay unit (Figure 2). The new monitoring wells, with the exception of PES-MW-13A, were installed to investigate potential vegetable oil impacts in a more southerly direction from the injection area and to investigate the potential for vertical groundwater flow. The installation details associated with the new monitoring wells are summarized in Table 2.

Each monitoring well installed during the extended monitoring program was constructed of 2-inch inside diameter (ID) schedule 40 polyvinyl chloride (PVC) casing and 0.020-inch slot screen. Each monitoring well was installed with approximately 10 feet of factory slotted screen which was flush threaded to the appropriate length of solid casing. A filter pack consisting of clean size 10-20 silica sand was installed from the bottom of each borehole to approximately 2 feet above the top of the screen interval. A 2-foot thick pure bentonite seal was installed above the sand pack, and a concrete-bentonite sanitary seal was installed from the top of the bentonite seal to ground surface. The installation details associated with the new monitoring wells are summarized in Table 2.

During drilling and well installation activities, soil samples were collected from the screen interval of each proposed monitoring well and shipped to an offsite laboratory for analysis. The boring logs compiled during the extended monitoring program are included as Appendix B. Select boring logs have been complied and presented in three dimensions on a fence diagram presented as Figure 3. Groundwater elevation data collected during the November 2005 sampling event is presented on Figure 4.

MEMBRANE INTERFACE PROBE SURVEY RESULTS

The MIP rig employed at Anoka County Park was provided and operated through a subcontract by KB Labs Incorporated. KB Labs' MIP rig was equipped with approximately 70 feet of direct push rod with a heating block on the bottom. As the MIP rod was advanced, a heating block at the tip of the probe heated the soil and groundwater in the immediate vicinity of the probe tip. As the heating block heated the soil and groundwater, the resultant "soil gas" was drawn through a membrane and into an inert gas loop where it was drawn through a series of detectors at ground surface. The detectors included an electron capture detector (ECD) to detect total chlorinated VOCs, a photoionization detector (PID) to detect total VOCs, and an FID to detect methane and less volatile organic compounds that are not detected by the PID. In addition, a dipole array was installed in the MIP probe which collected electrical conductivity data from the soil matrix. Using this suite of detectors, a complete vertical profile of relative soil grain size, total chlorinated and non-chlorinated VOC concentrations, and methane concentrations was generated for each MIP location. The MIP locations are depicted on Figure 2.

During the course of the MIP survey it was discovered that the soil conductivity logs that were being produced by the dipole array did not match up to soil boring logs collected during the installation of the pilot test system in 2001. After the new soil borings and monitoring wells were installed the soil conductivity profiles were compared to the newly generated boring logs and the historic logs. The newly generated boring logs matched the historic logs relatively well. However, the soil conductivity logs did not match the new or historic boring logs. Therefore, we conclude that the soil conductivity logs collected during the MIP survey do not represent stratigraphic conditions at the site and will not be used for any purpose.

The data collected during the MIP survey indicates that the concentration of total VOCs present beneath the pilot test area is insufficient to cause a deflection on the PID instrument associated with the MIP system. There were no PID detections in any of the profiles collected with the exceptions of MIP-31 and MIP-36. Therefore, the MIP discussion with regard to VOC concentrations will be based on data collected with the ECD. The MIP profiles are attached to this technical memorandum as Appendix A.

ELECTRON CAPTURE DETECTOR DATA

The ECD data collected during the MIP survey is summarized on Table 3, is depicted on Figure 5, and is presented in detail in Appendix A. The complete data set collected by KB labs was also provided under a separate cover (KB Labs, 2005). Review of the horizontal distribution of ECD response indicates that elevated concentrations of chlorinated VOCs are present throughout the pilot test area. Elevated concentrations of chlorinated ethenes were detected at all MIP locations, indicating that the VOC "hot spot" was not bounded in any direction during the MIP survey.

Review of the vertical distribution of ECD response indicates that at most MIP locations installed upgradient of PES-MW-10A/B, elevated concentrations of chlorinated solvents were present below approximately 28 to 30 feet bgs and above 40 to 42 feet bgs. The exceptions to this observation include MIP points MIP-3, MIP-6, MIP-10, MIP-11, and MIP-14. Downgradient of PES-MW-10A/B the ECD data collected at the majority of the MIP points indicate that elevated concentrations of chlorinated VOCs are present below a depth of approximately 35 feet bgs and do not extend below approximately 50 feet bgs. In some cases elevated concentrations of chlorinated VOCs extended below the bottom of the total advancement depth of the point. Therefore, the vertical distribution of elevated chlorinated VOC concentrations is not completely defined at these locations.

Immediately after the completion of the MIP survey, discrete groundwater samples were collected from direct push borings installed immediately adjacent to a selection of MIP bore holes. The discrete groundwater samples were collected in an effort to quantify the ECD and FID response data collected during the MIP survey. The ECD response and associated discrete sampling data are summarized in Table 4. Generally the ECD response for a given depth compares relatively well to the associated total chlorinated VOC concentration as reported by the discrete sampling results within each borehole, with the exception of results from MIP-5, MIP-8, and MIP-19. However, the correlation of ECD response to discrete sampling data does not hold up between boreholes as indicated by the variability in the correlation factor data presented on Table 4. These observations indicate that the ECD response data appears to be a useful tool to qualitatively determine the vertical distribution of chlorinated solvents within a particular borehole. However, the ECD data does not appear to be a very useful tool to determine the horizontal distribution of chlorinated VOC concentrations except in a very qualitative "presence-absence" way. Therefore, the distribution of ECD response data with respect to the size of the detections will not be discussed, as this data does not appear to correlate to changes in chlorinated VOC concentrations.

FLAME IONIZATION DETECTOR DATA

The FID response data generated during the MIP survey (Table 4 and Appendix B) is representative of concentrations of methane and other less volatile organic compounds that are not detected by the PID or the ECD. Thus, FID response can be considered to be indicative of the presence of organic material in the subsurface because the presence of methane can be inferred to result from the biodegradation of organic matter. Organic material in the subsurface at the pilot site consists of a combination of naturally occurring organic material in the soil matrix as well as vegetable oil injected as part of the pilot test. Therefore, the FID data collected during the MIP survey is representative of both naturally occurring as well as vegetable oil derived organic carbon. However, vegetable oil was injected at relatively high concentration at this site so it was expected that the response to vegetable oil derived organic carbon would be much larger than the response to naturally derived organic carbon signature.

Relatively low FID detections in the range of approximately 1E+05 to 6E+05 microvolts (uV) were observed sporadically throughout the pilot test area at locations

that are unlikely to be impacted by vegetable oil derived organic carbon (i.e., cross gradient points MIP-18 and MIP-36, as well as downgradient points MIP-27, MIP-32, and MIP-37). These observations indicate that the FID detector was detecting organic carbon that is likely to be naturally occurring, with a response of approximately 6E+05 uV. Within and downgradient from the injection area FID detections were much higher, ranging from approximately 1E+06 uV to 1E+07 uV, indicating that the vegetable oil derived organic carbon is responsible for an increase in FID response of approximately one to two orders of magnitude.

Relatively high FID detections were observed in a large area which includes the injection area and extends southwest as far down gradient as MIP-26 (Figure 6). This relatively large area corresponds roughly to the area of elevated TOC discussed in later sections (Figure 9). The coincidence of the area of elevated FID readings and the area of elevated TOC concentrations indicates that the FID was likely detecting dissolved phase organic carbon, dissolved methane, as well as non-aqueous phase vegetable oil. Thus, the area of elevated FID detections represents an area that is impacted by vegetable oil derived organic carbon, both directly and indirectly.

The vertical distribution of FID detections at all locations is highly heterogeneous. Within the un-impacted locations this heterogeneity indicates that naturally occurring organic carbon is present only within particular vertical intervals. For example, at MIP-36 (Appendix A) elevated FID readings are limited to two very narrow vertical intervals located at 28 feet and 30 feet bgs. Review of the boring log from PES-BG-2, located approximately 8 feet away, indicates that these vertical intervals consist of silty sand which is slightly finer than the fine to medium sand present above and below this vertical interval. This fine grained unit likely contains higher concentrations of naturally occurring organic carbon than the surrounding sands, which would result in a higher FID reading. Large ECD peaks are also present in the MIP-36 profile at the same depth intervals indicating that the fine grained unit contains elevated concentrations chlorinated VOCs as well as TOC. The heterogeneous distribution of FID peaks in borings within the injection area indicates that the injected vegetable oil also has a heterogeneous vertical distribution.

SOIL SAMPLING RESULTS

Continuous soil samples were collected from the soil borings and monitoring well borings from the ground surface to the bottom of each borehole. Boring logs were prepared by an experienced field geologist at each boring location. The boring logs compiled during the extended monitoring program are included as Appendix B.

A total of 36 soil samples were collected during drilling activities and analyzed for VOCs via USEPA method 8260B. Soil samples were collected from soil borings PES-SB-1, PES-SB-2, and PES-SB-3 to characterize the soil conditions in the immediate vicinity of the injection wells. At each soil boring location, subsurface soils impacted by vegetable oil were typically stained dark brown or black and smelled of degrading vegetable oil. At soil boring PES-SB-1 and PES-SB-3, the soil was heavily impacted by

vegetable oil from a depth of approximately 33 feet bgs to 39 feet bgs and from 39 feet to 48 feet bgs, respectively. These impact intervals correspond to the closest injection well screen intervals (PES-INJ-01 and PES-INJ-03, respectively). At soil boring PES-SB-2, which was installed immediately adjacent to PES-INJ-02, vegetable oil impacts extended from just below the top of the PES-INJ-02 injection interval at 40 feet to 6 feet below the bottom of the PES-INJ-02 injection interval at 50 feet. At all locations vegetable oil impacts were more pronounced in coarser, more transmissive units, indicating that the injection fluids migrated predominantly through the more permeable sand units.

Soil borings PES-SB-4 and PES-SB-5, were drilled upgradient of PES-INJ-2 to define the upgradient edge of the injection area, while PES-SB-6, and PES-SB-7 were drilled down gradient of PES-INJ-2 to define the down gradient edge of the injection area. Evidence of vegetable oil impact was not observed in PES-SB-4 and PES-SB-5, indicating that the injected vegetable oil did not travel more than approximately 8 to 10 feet upgradient during or after injection. This conclusion is contradicted somewhat by the high FID detections at MIP-02 (installed approximately 25 feet upgradient of PES-SB-5). On the downgradient side of the injection area vegetable oil impacts were observed at PES-SB-6, PES-SB-7, PES-SB-8, and PES-SB-9 indicating that vegetable oil or high concentrations of vegetable oil derived organic carbon migrated as far down gradient as approximately 23 feet. Impacts were observed in these wells primarily as soil intervals with mild to moderate degrading vegetable oil odor. Impacts were observed at these downgradient locations as deep as approximately 55 feet bgs (PES-SB-9). Two intervals containing “weak to mild odor” were observed during drilling at PES-MW-10B at 50 feet bgs and 53 feet bgs. These observations may indicate that these depth intervals were impacted by vegetable oil or high concentrations of vegetable oil derived organic carbon. These observations indicate that during and potentially shortly after injection the vegetable oil or high concentrations of vegetable oil derived organic carbon continued to spread laterally along the coarser more transmissive units as far down gradient as approximately 23 to 25 feet. This data does not indicate that the injected vegetable oil spread vertically (upward or downward) to a significant extent.

The boring logs compiled during the drilling activities were combined with the historic boring logs and used to develop a fence diagram which depicts the stratigraphic data collected during drilling in three dimensions (Figure 3). Review of the boring log data and the fence diagram indicates that the stratigraphy beneath the pilot test site is relatively consistent on a large scale. The soil beneath the pilot test area consists predominantly of fine to medium sand and silty sand which extends from approximately 5 feet bgs to below the maximum drilling depth of 70 feet bgs. At approximately 30 feet bgs there is a fine grained of unit of variable thickness which consists predominantly of silt and clay. This fine grained unit ranges in thickness from less than one foot to a maximum of approximately 6 feet and is continuous throughout the pilot test area. There are also a number of smaller, less continuous, fine grained units present beneath the pilot test area. In particular, there appears to be a relatively large, thin silt/clay unit present at a depth of approximately 60 feet beneath and downgradient from the injection area. It is

likely that these fine grained units impact and therefore to some extent control groundwater flow characteristics locally within the pilot test area.

TOTAL ORGANIC CARBON ANALYSES IN SOIL

During drilling operations soil samples were collected from soil borings drilled within the injection area and from outside the injection area in order to determine the spatial extent of soils impacted by vegetable oil and to compare the TOC content of impacted soils and un-impacted soils. The soil TOC results are summarized in Table 5. Soil TOC concentrations measured at the background boring PES-MW-13A ranged from approximately 330 mg/kg to approximately 830 mg/kg, indicating that there is naturally occurring organic carbon present within the soil matrix. This concentration range compares well with soil TOC data collected prior to the injection of the vegetable oil in 2001, indicating that PES-MW-13A has not been impacted by vegetable oil derived organic carbon.

TOC concentrations in soil collected within the injection area ranged from approximately 300 mg/kg to a maximum of 6,200 mg/kg. The high concentrations of TOC detected in the injection area were detected in vertical intervals that were visibly impacted by vegetable oil, indicating that significant vegetable oil derived organic carbon remains within the injection area to drive biological processes, including reductive dechlorination. TOC concentrations within the injection area vary widely between boreholes and even vertically within individual boreholes. This vertical and horizontal variation indicates that vegetable oil derived TOC is distributed heterogeneously within the injection area.

At locations PES-SB-7 and PES-MW-12B soil samples were collected from silty clay or clay units and analyzed for TOC (as well as a number of other parameters discussed in later sections). The silty clay unit sampled at PES-SB-7 was located at a depth of approximately 32 to 34 feet bgs, while the cohesive clay unit sampled at PES-MW-12B was located at 62 to 63 feet bgs. The clay units at both locations and depths contained high concentrations of TOC (2,900 mg/kg at PES-SB-7 and 5,900 mg/kg at PES-MW-12B). There is no evidence of vegetable oil impact between 32 and 34 feet bgs at PES-MW-7 and PES-MW-12B is located several hundred feet downgradient of the injection area and is thus unlikely to be impacted by vegetable oil. Thus, the high concentration of TOC present in the silt units at PES-SB-7 and PES-MW-12B likely to be naturally occurring. Groundwater samples were collected in close proximity to these sampling intervals (MIP-14 at 36 ft bgs for PES-SB-7 and MW-12B) and analyzed for TOC as well as a number of other parameters. TOC concentrations in groundwater at these locations were relatively low, below 8 mg/L in both cases, indicating that the high concentration of naturally occurring TOC present in the soil matrix is insoluble and thus not bioavailable to drive biological processes (including reductive dechlorination). This data indicates that these fine grained units are capable of absorbing significant amounts of contaminant mass and may serve as secondary sources of contaminant mass over time.

PLFA AND MICROBIAL POPULATION CHARACTERIZATION ANALYSES IN SOIL

Biomass is represented by the total amount of phospholipid fatty acids (PLFA) present and provides a quantitative measure of the viable microbial biomass present. Elevated concentrations of biomass are an indicator of enhanced microbial activity and are an indirect indicator of changes in food supply (organic carbon) or changes in environmental conditions. The microbial population can also be identified through targeted gene detection analysis in order to determine if the microbial population present in a particular location is capable of dechlorinating chlorinated solvent mass and to what extent. A series of soil samples were collected from the injection area, upgradient of the injection area, and downgradient from the injection area in order to compare the microbial populations (both total population and which microbes are present) in each area. These samples were analyzed for total microbial biomass (PLFA) as well as targeted gene detection to determine the presence or absence of 4 phylogenic groups (Eubacteria, methanogens, sulfate and iron reducing bacteria, and methanotrophs); four bacterial genera that are known to be capable of dechlorinating chlorinated solvents (*Dehalococcoides* (DHC), *Desulfuromonas* (DSM), *Dehalobacter* (DHB), and *Desulfitobacterium* (DSB) and one additional genera that is known to dechlorinate tetrachloroethene (PCE) and trichloroethene (TCE) to *cis*-1,2-dichloroethene (DCE) (*Geobacter* (GEO)). In addition, two functional genes which identify particular species of DHC were identified and quantified. The BAV1 vinyl chloride reductase (BVC) functional gene is indicative of the species BAV1 which was isolated and identified by Frank Löffler's group at the Georgia Institute of Technology (He et. al., 2003) as a species of DHC that is capable of completely dechlorinating TCE to ethene. The second functional gene, also isolated and identified by Frank Löffler's group (He et. al., 2003), is TCE R-dase (TCER) which has been shown to be indicative of a DHC species that is capable of dechlorinating TCE completely. A third strain of methanotrophic bacteria was also identified and quantified through the analysis for soluble methane monooxygenase (sMMO). sMMO is an enzyme that is produced by methanotrophic bacteria when TCE is being broken down to non-toxic organic hypoxides through a destructive process called cometabolic oxidation (He et. al., 2003).

A total of 14 samples were collected and analyzed for targeted gene detection and PLFA, while an additional 9 samples were collected and analyzed for PLFA only. The PLFA and targeted gene detection analysis results are presented in Table 6. 11 of the 23 samples collected were impacted by vegetable oil or high concentrations of vegetable oil derived organic carbon as evidenced by visual and olfactory observations reported during drilling operations (Appendix B). The total biomass measured in the impacted samples was approximately two orders of magnitude higher than the total biomass measured in the un-impacted samples. The observed increase in microbial biomass is a result of an increase in microbial food supply supplied by the injected vegetable oil. The increased biomass is paralleled by increases in all of the identified phylogenic groups. Each phylogenic group increased by approximately one to four orders of magnitude with the largest increases observed in the sulfate/iron reducers and methanotrophs. This data

indicates that the injected substrate was successful in promoting anaerobic microbial population development within and downgradient from the injection area.

DHC and DHB were positively identified in nearly all samples analyzed including both vegetable oil impacted and non-impacted samples. The population of DHC in the impacted samples was approximately one order of magnitude higher than the population measured in the non-impacted samples while DHB populations in the impacted samples were approximately two to three orders of magnitude higher than background. DSM was positively identified in only one sample (PES-SB-6). DSB was positively identified in approximately half of the samples analyzed and does not appear to be affected by the presence or absence of vegetable oil. GEO was also detected at concentrations near the method detection limit in the impacted samples but not in the un-impacted samples. This data indicates that several microbial strains that are known to be capable of dechlorinating VOC mass are present naturally in site soils and that the injected vegetable oil has been effective at increasing the populations of DHC, DHB, and to a lesser extent GEO. Thus, the microbial population within the pilot test area is capable of completely dechlorinating chlorinated VOC mass.

During the functional gene portion of the targeted gene detection analysis BVC was detected at low concentrations in nearly all of the impacted samples and in approximately one half of the un-impacted samples. TCER was also detected at low concentrations in three of the impacted samples and in only one of the un-impacted samples. sMMO was also detected in all but one of the impacted samples and in four of seven of the un-impacted samples. Moderate to high concentrations of sMMO (with respect to the un-impacted samples) were detected at locations PES-SB-1, PES-SB-7, and PES-MW-10B, indicating that it is possible that chlorinated solvent mass is being destroyed by methanotrophic bacteria through cometabolic oxidation at these locations.

During the April 2005 sampling event groundwater samples were collected from a selection of monitoring wells and submitted to Microbial Insights Inc. for targeted gene detection analysis. The results of the targeted gene detection in groundwater analyses are summarized in Table 6 for easy comparison to the soil results. Comparison of targeted gene detection results in water and soil from similar locations (e.g., PES-SB-2 to PES-INJ-2, PES-SB-7 to PES-MW-1, PES-MW-10B soil to PES-MW-10A water, PES-SB-4 to MS-46S, and PES-MW-10B soil to PES-MW-10B water) provides an insight into the relative representativeness of groundwater samples. Soil samples are considered to be most representative of the true microbial population present because the bulk of the microbial population grows on the soil matrix. Groundwater samples are generally considered to provide a good approximation of the microbial population and are generally preferred over soil samples due to the ease and low cost associated with groundwater sampling in comparison to soil sampling. However, review of Table 6 indicates that on this site groundwater samples are biased low and do not represent the microbial population present in the subsurface.

VOLATILE ORGANIC COMPOUND ANALYSES IN SOIL

A total of 36 soil samples were collected during drilling activities and analyzed for VOCs via US EPA method 8260B (Table 5). TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and acetone were the only VOCs that were detected at concentrations above the method detection limit. VOC concentrations varied widely across the site, both vertically and horizontally. TCE concentrations ranged from non detect to 7,700 µg/kg (PES-SB-2) while *cis*-1,2-DCE and trans-1,2-DCE concentrations ranged from non detect to 2,100 µg/kg and 91 µg/kg, respectively. Samples that were impacted by vegetable oil, as indicated by visual and olfactory inspection, contained substantial concentrations of *cis*-1,2-DCE, and in some cases *trans*-1,2-DCE, indicating that at least partial dechlorination is occurring.

VOC samples were collected from several intervals at locations PES-SB-1, PES-SB-4, PES-SB-7, PES-MW-10B, PES-MW-11A, PES-MW-13A, and PES-MW-14B. At each location soil samples were collected from fine grained units, typically silty sands or clays, and coarser units, typically fine to medium sands, in an effort to determine which units contained higher VOC concentrations. At all locations sampled the finer grained, lower permeability units contained higher concentrations of VOCs than the coarser grained units. For example, at PES-SB-7 a clay unit located at 32 to 34 feet bgs contained 2,100 µg/kg of TCE while a sand unit immediately below (34 to 36 feet bgs) contained only 50J µg/kg. This phenomena is repeated at PES-MW-10B where a silt unit at 36 to 42 feet bgs contains 1,600 µg/kg of TCE while a sand unit at 49 feet bgs contains no detectable concentrations of TCE. This data indicates that the VOC concentrations are higher in the fine grained silt/clay units and that these soils may contain as much, or more, contaminant mass than the more transmissive sand units. Thus, the fine grained units will likely serve as secondary sources of contaminant mass for some time.

The removal of TCE mass from the silty clay units beneath the NIROP site will be an extremely slow process because removal rate will be limited by the rate of diffusion, which is typically several orders of magnitude slower than advective-dispersive processes. Thus, the application of a remedial option in the more permeable unit(s) will not accelerate site cleanup time significantly because the time to achieve MCLs on this site is dependant on the rate at which contaminant mass diffuses out of the fine grained units, not on the rate at which the remedial option of choice destroys contaminant mass.

AQUEOUS AND MINERAL INTRINSIC BIOREMEDIATION ASSESSMENT ANALYSES IN SOIL

Aqueous and Mineral Intrinsic Bioremediation Assessment (AMIBA) analyses consist of analyses for chromium extractable sulfides, acid extractable sulfides, weak acid extractable iron, strong acid extractable iron, weak and strong acid extractable manganese, and total oxidized iron (Kennedy *et al*., 2000). This suite of analyses, in addition to bioavailable ferric iron and bioavailable manganese, is designed to assess the potential for a reductive dechlorination pathway known as biogeochemical reductive dechlorination (BiRD) and to assess the potential for abiotic degradation through

mineralization. The BiRD process is termed "biogeochemical" because microbial processes are used to facilitate geochemical conditions that cause the precipitation of mineral ferrous iron monosulfide (FeS) in the aquifer matrix. The primary microbial processes that are necessary to produce FeS are iron reduction and sulfate reduction. In a normal aquifer system, both of these processes occur in the presence of sufficient organic carbon, ferric iron, and sulfate. These processes are occurring within the pilot test area due to the presence of vegetable-oil-derived organic carbon.

A total of 11 samples were collected for AMIBA analysis. 6 of the 11 samples collected were impacted by vegetable oil or high concentrations of vegetable oil derived organic carbon as evidenced by visual and olfactory inspection. Comparison of the impacted and non-impacted sample sets indicates that bioavailable iron, bioavailable manganese, and chromium extractable sulfide have been depleted slightly in the impacted samples. This data indicates that the impacted soil matrix has been depleted of bioavailable metals and sulfide, and therefore the capacity for abiotic degradation has been reduced slightly. However, the observed reduction in these species is relatively small in relation to the total mass present in the un-impacted samples. Therefore, the impacted soils' capacity to support abiotic degradation may remain relatively unchanged.

Review and comparison of all of the bioavailable iron and the strong acid extractable iron data is interesting and provides some insights into the relationship between the total mass of iron present in the soil (represented by strong acid extractable iron), and how much of that iron mass is accessible to the microbial community for use. In most of the samples collected strong acid extractable iron concentrations are one to nine times higher than the respective bioavailable iron concentration. This relationship is likely related to that fact that iron mineral dissolution is related to the surface area accessible to the microbial population and the microbial population present within a particular sample. It is also important to understand that the mass of bioavailable iron is rate dependant in that iron will continue to be stripped over time. Thus, as the time scale of the bioavailable iron analysis is extended, more of the total iron present in the soil matrix will become bioavailable. The time scale for the current bioavailable iron data set was 30 days. If the analysis time scale were extended for a much longer period of time most or all of the total iron present in the soil could become bioavailable. Therefore, the limiting factor on this site may be sulfide because the total sulfide mass in the soil matrix (as represented by chromium extractable sulfide) has been depleted by approximately 56% in the first 30 months following injection.

GROUNDWATER SAMPLING RESULTS

SITE HYDROLOGY

During the groundwater sampling event in November 2005 a round of groundwater elevation measurements was collected within the pilot test area as well as a number of monitoring wells installed outside of the pilot test area. The data collected during this round (Table 8) was used to develop a groundwater potentiometric surface map which is depicted on Figure 4. The groundwater mound in the park, historically known as the

"stagnation zone", is clearly evident in the 2005 potentiometric surface map and continues to control groundwater flow in the pilot test area.

Groundwater elevation data collected at the newly installed monitoring wells (PES-MW-10A, PES-MW-11A, PES-MW-12A, PES-MW-13A, and PES-MW-14A) have resulted in the improvement of the definition of the groundwater potentiometric surface within the pilot test area. Groundwater flow is interpreted to be more southerly in and immediately downgradient from the injection area than previous interpretations. This more southerly flow appears to continue to monitoring wells PES-MW-9 and PES-MW-11A where groundwater flow appears to turn to a more westerly heading.

The reinterpretation of the groundwater potentiometric surface did impact interpreted groundwater flow direction. However, the slope of the groundwater potentiometric surface map remained similar to past interpretations. In 2005 (April and November) the groundwater surface was relatively flat in the upgradient portion of the pilot test area (upgradient of monitoring well PES-MW-3) and in the downgradient portion of the pilot test area (downgradient of PES-MW-4. The groundwater surface between well PES-MW-3 and well PES-MW-4 slopes strongly to the south-southwest. This stair-step pattern in the groundwater surface is likely a result of the discontinuous silt unit that has been detected in the area during drilling operations (Figure 3).

Historically, vegetable oil thickness measurements have also been collected during each process monitoring round. Since injection measurable vegetable oil thicknesses have been detected routinely at PES-INJ-02 and PES-INJ-03 and sporadically at PES-INJ-01. During more recent sampling events the vegetable oil thickness measured in PES-INJ-3 has been greater than that measured in PES-INJ-1 and PES-INJ-2. During the 2005 sampling events separate phase vegetable oil was not detected at PES-INJ-01 and PES-INJ-02, while vegetable oil was detected at PES-INJ-03 (the thickness of the vegetable oil could not be determined during the November round). The observed decrease in measurable vegetable oil at PES-INJ-03 and the absence of measurable vegetable oil at PES-INJ-01 and PES-INJ-02 indicates that the vegetable oil is being gradually consumed.

Table 9 presents the results of pre- and post-injection aquifer testing and estimates of groundwater seepage velocity. The geometric mean for hydraulic conductivity values measured for PES-MW1 and the injection wells in the upgradient portion of the study area (upgradient of PES-MW-8 and PES-MW-9) was 177 feet per day (ft/day) (0.062 centimeters per second [cm/sec]). Hydraulic conductivity measurements conducted in wells PES-MW-3, PES-MW-8, and PES-MW-9 indicate that a zone of low hydraulic conductivity, relative to the injection area and the area around the contingency wells, is present in the vicinity of these well locations. The geometric mean for hydraulic conductivity values measured at PES-MW-3, PES-MW-8, and PES-MW-9 was 29.6 ft/day (0.010 cm/sec). The only location tested downgradient from this zone of lower conductivity prior to injection was PES-CW1. The hydraulic conductivity calculated for PES-CW-1 was approximately 196 ft/day (0.069 cm/sec). Mean groundwater flow

velocities, calculated from data collected prior to injection, ranged from approximately 438 feet per year (ft/yr) to 2,545 ft/yr.

Comparison of the pre-injection aquifer testing data with the post-injection aquifer testing data (Table 9) indicates that values of hydraulic conductivity calculated immediately after injection for the injection wells was approximately an order of magnitude lower than pre-injection values of hydraulic conductivity for these same wells. This decrease in hydraulic conductivity was likely due to the presence of vegetable oil within the aquifer matrix that effectively lowers the relative permeability of the aquifer matrix.

Values of hydraulic conductivity calculated from data collected 1 year after injection are similar to those calculated from the pre-injection testing round. This indicates that the decrease in hydraulic conductivity observed immediately after injection was transient, and that the hydraulic conductivity of the aquifer matrix in the vicinity of the injection wells (PES-MW-1) has returned to baseline conditions. This may be due to a lowering of residual oil saturation due to degradation and/or migration and dispersion of the vegetable oil.

A second post-injection round of slug testing was conducted during the April 2003 process monitoring event. Slug test data collected in April 2003 indicate that the hydraulic conductivity within the injection wells is very low relative to the baseline sampling event. This decrease in hydraulic conductivity within the injection wells is due to the presence of vegetable oil within the well casings and within the aquifer matrix surrounding the wells. The low hydraulic conductivities measured within the injection wells is also likely due to microbial growth (biofouling) within and around the injection wells. Immediately downgradient from the injection area (PES-MW-1, PES-MW-6, and PES-MW-7) hydraulic conductivities measured in April 2003 are similar to those measured during the baseline event (Table 9). These data indicates that the decrease in hydraulic conductivity is limited to the area immediately surrounding the injection wells.

Six of the new monitoring wells were installed in two well clusters (PES-MW-10A/B, PES-MW-12A/B, and PES-MW-14A/B) in order to determine if vertical groundwater flow is a significant factor within the pilot test area. The vertical hydraulic gradient was calculated at each monitoring well cluster by dividing the difference in head by the vertical interval between the wells within each cluster. The vertical hydraulic gradient at monitoring well clusters PES-MW-10 and PES-MW-14 were both weak (approximately 0.004 ft/ft) and upward indicating that there may be a small component of upward flow in the vicinity of these well clusters. The vertical gradient at cluster PES-MW-12 was very small (0.002 ft/ft) and in the downward direction.

VOLATILE ORGANIC COMPOUND ANALYSES IN GROUNDWATER

Groundwater VOC data is the primary line of evidence in determining the success of the vegetable oil pilot test. During the first extended monitoring program process monitoring round all of the original pilot test monitoring wells, the eight newly installed

monitoring wells, and seven monitoring wells outside of the pilot test area were sampled for VOCs. Table 10 presents the latest round of VOC data as well as historic data for the previously sampled monitoring wells.

Review of the entire VOC data set indicates that TCE remains the most commonly detected contaminant across the site and that TCE is typically present at greater concentration than any other contaminant compound within each monitoring well. TCE concentrations have been decreasing at all of the wells (except for the newly installed wells) since 2002. *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE, and 1,1-DCA have also been detected routinely during the last 36 months at much lower concentrations than TCE. VC, acetone, and 2-butanone have also been detected sporadically both historically and during the most recent sampling event in November 2005.

TCE concentrations detected during the baseline sampling event, conducted prior to vegetable oil injection, are depicted on Figure 7. Review of groundwater analytical data (summarized in Table 10) from the baseline sampling event in November 2001 indicates that four contaminants were detected at concentrations above associated method detection limits: PCE, TCE, *cis*-1,2-DCE, and *trans*-1,2-DCE. PCE was detected at only one location (GWMS-47S) at a low concentration of 0.92 micrograms per liter (ug/L). TCE was detected at elevated concentrations at all wells within the pilot test area, except GWMS-27S, with a maximum concentration of 20,000 ug/L detected at location MS-46S (see Figure 1 for well locations). TCE concentrations were generally highest (>1,000 µg/L in most cases) in the upgradient portions of the pilot test area, east of PES-MW-4. TCE concentrations detected in the downgradient portions of the pilot test area were significantly lower, generally below 300 µg/L, with the exception of PES-CW-1 (630 ug/L). *cis*-1,2-DCE, a breakdown product of TCE, was detected at most locations at concentrations significantly less than TCE. This data suggests that limited degradation of TCE to *cis*-1,2-DCE occurred naturally at the site prior to vegetable oil injection.

Review of groundwater analytical data (Table 10) collected after vegetable oil injection indicates that TCE concentrations detected in groundwater have been variable over time, but generally have declined at the three injection wells (PES-INJ-1, PES-INJ-2, and PES-INJ-3) and at all of the pilot test wells with the exception of GMW-27S. At the majority of these wells TCE concentrations increased initially, typically peaking during the May or August 2002 sampling rounds, then decreased through November 2005. TCE concentrations detected during the most recent sampling event in November of 2005 are depicted on Figure 8. Comparison of the pre-injection plume map presented in Figure 7 to the most recent plume map presented in Figure 8 indicates that TCE concentrations have decreased substantially since injection, with the largest decreases observed in and downgradient from the injection area.

2-butanone and acetone have been detected sporadically at elevated concentrations during all of the process monitoring events in several wells including PES-INJ-1, PES-INJ-2, PES-INJ-3, PES-MW-6, PES-MW-7, PES-MW-8, and PES-MW-9. Concentrations of both analytes were relatively low during the first round of process monitoring with a maximum concentration of 490 µg/L for 2-butanone and 240 µg/L for

acetone. During later process monitoring rounds concentrations of 2-butanone and acetone were highly variable and in some cases relatively high. However, 2-butanone and acetone have never been detected at concentrations approaching the MPCA Health Risk Limits of 4,000 µg/L for 2-butanone and 700 µg/L for acetone outside of the injection area and monitoring wells PES-MW-7 and PES-MW-9.

VC has not been detected at concentrations above the method detection limit in any of the contingency wells (PES-CW1, PES-CW2, PES-CW3, GWMS-47S), or the new downgradient monitoring well cluster PES-MW-12A/B, during the course of the pilot test.

GEOCHEMICAL ANALYSES IN GROUNDWATER

Biodegradation of organic carbon, whether natural or anthropogenic, brings about measurable changes in the chemistry of groundwater in the affected area. Concentrations of compounds used as electron acceptors (e.g., dissolved oxygen [DO], nitrate, sulfate, and carbon dioxide) are depleted, and byproducts of electron acceptor reduction (e.g., carbon dioxide, ferrous iron, sulfide, reduced manganese, and methane) are elevated. By measuring these changes, it is possible to evaluate what biological processes are occurring at a particular site. The geochemical data collected during the course of the pilot test is presented in Table 11.

During the Spring 2005 sampling event TOC concentrations sufficient to support reductive dechlorination (>20 milligrams per liter (mg/L) (USEPA, 1998)) were detected at the injection wells and at monitoring wells PES-MW-4, PES-MW-7, PES-MW-10A, and PES-MW-14A. The TOC data set collected from the monitoring wells during the Spring 2005 sampling round was combined with the TOC data set collected during the discrete sampling program (also in the Spring of 2005) and used to develop a TOC contour map (Figure 9). The TOC data depicted on Figure 9 indicates that there is a relatively large area of elevated TOC present to the south and southwest of the injection area. Within the relatively large area impacted by elevated (>10 mg/L) TOC concentrations is a smaller core of highly elevated TOC concentrations (>50 mg/L) which extends as far down gradient as PES-MW-4 and PES-MW-14A. TOC concentrations within this area are present at concentrations sufficient to drive reductive dechlorination (USEPA, 1998). The TOC mass depicted on Figure 9 is most likely related to and derived from the vegetable oil injected as part of this pilot test. Comparison of the TOC plume map depicted in Figure 9 with the TCE plume map depicted in Figure 8 indicates that the area of high TOC concentration in Figure 9 roughly corresponds to the area of low TCE concentrations (<50 µg/L) in Figure 8.

Between the April 2005 and November 2005 sampling events TOC concentrations decreased at most locations sampled and the horizontal extent of TOC concentrations exceeding 10 mg/L decreased significantly (Figure 10). The reductions in TOC concentrations observed downgradient of the injection area are not likely to be a result of or indicative of organic carbon depletion in the injection area because TOC concentrations in the injection area increased at PES-INJ-03 during the same time period.

It is more likely that the observed reductions in TOC concentrations downgradient of the injection area are related to seasonal fluctuations in groundwater flow and TOC transport rates.

At monitoring locations where TOC concentrations are elevated (the injection wells, PES-MW-7, PES-MW-10A, and PES-MW-14A) geochemical conditions are moderately to strongly reducing as indicated by the presence of elevated concentrations ferrous iron, reduced manganese, sulfide, and methane. The presence of these reduced species indicates that iron reduction, manganese reduction, sulfate reduction and methanogenesis are occurring at, or in close proximity to, these locations. These reducing conditions are conducive to anaerobic biological processes including anaerobic reductive dechlorination.

Ethane and ethene concentrations present in wells known to be un-impacted by vegetable oil (MS-27S, MS-47S, PES-CW-1, PES-CW-2, PES-CW-3) range up to approximately 35 nanograms per liter (ng/L) and 50 ng/L, respectively. During the Spring 2005 sampling event ethane concentrations at least twice the concentration measured in non-impacted wells (70 ng/L) were detected in the injection wells and in monitoring wells MS-45S, MS-46S, PES-MW-1, PES-MW-7, PES-MW-10A, PES-MW-11A, PES-MW-12B, PES-MW-14A, and PES-MW-14B. During the same sampling event ethene concentrations at least twice the concentration measured in un-impacted wells (100 ng/L) were detected in the injection wells and in monitoring wells PES-MW-1, PES-MW-6, PES-MW-10A, PES-MW-12B, PES-MW-14A, and PES-MW-14B. This data indicates that complete reductive dechlorination may be occurring at these locations or immediately upgradient of these locations (in the case of PES-MW-1 and PES-MW-6). Methane, ethene, and ethane samples were not collected during the November 2005 sampling event.

GROUNDWATER SAMPLING RESULTS FROM MS-53PC

Monitoring well MS-53PC was redeveloped and one groundwater sample collected as recommended in the August 2003 Report (CCI, 2003). In April of 2005, the TOC concentration in MS-53 PC was 110 mg/L and the total VFA concentration was 792 mg/L (Table 12). Background concentrations of TOC as measured during the baseline event were below 5 mg/L and VFA concentrations measured at wells upgradient of the injection system are below 4 mg/L. Therefore, the high concentrations of TOC and VFAs measured at MS-53PC indicate that this well was impacted with vegetable oil during injection. However, TCE was the only VOC detected in MS-53PC in April 2005 and it was detected at a concentration of 0.83J µg/L, which is lower than the TCE concentration detected during the June 2003 sampling event. The concentration of TCE detected in MS-53-PC during the June 2003 sampling event was 2.1 and 1.19 µg/L in the screened interval. This suggests that, although monitoring well MS-53PC was impacted during the vegetable oil injection, the TCE concentration at this well did not increase. No further action is recommended for monitoring well MS-53PC.

SUMMARY

During the Spring 2005 field program a total of 38 MIP points were installed with 48 discrete groundwater samples collected to confirm or further investigate the data collected during the MIP program. After the MIP program was complete 8 new wells and 10 new soil borings were installed to investigate the soil conditions within and downgradient from the injection area to improve the definition of groundwater flow conditions in the pilot test area and to investigate geochemical and VOC conditions in the area south of the injection wells. Following the completion of the drilling program a full round of groundwater sampling was conducted.

During the course of the MIP program it was found that direct push drilling is well suited for drilling activities at Anoka County Park. The direct push rig deployed in support of this project was capable of reaching depths of up to approximately 75 feet below ground surface and was limited by the supply of drilling rod and not by the capabilities of the rig. It is also likely small diameter monitoring wells could be installed in addition to the MIP work, soil sampling, and discrete groundwater sampling conducted during this project. Small diameter monitoring wells could be installed in lieu of standard monitoring wells during future drilling programs at a fraction of the cost due to cost savings related to decreased mobilization and drilling costs, decreased investigation derived waste production, and decreased well material costs.

Groundwater elevation data collected during the 2005 program from the existing pilot test wells, the newly installed pilot test wells, and a selection of wells installed outside of the pilot test area indicates that groundwater flow near the injection area is more southerly than previously interpreted. As a result, the effects of the injected vegetable oil are migrating with groundwater flow in a more south-southwest direction. This newly interpreted groundwater flow regime is supported by the TOC plume maps presented on Figures 9 and 10 and the November 2005 plume map presented on Figure 8. The groundwater elevation data collected in 2005 from the newly installed monitoring well clusters also indicates that there is the potential for upward vertical groundwater flow at wells PES-MW-10 and PES-MW-14, and downward groundwater flow at PES-MW-12.

The ECD data collected during the MIP survey indicates that chlorinated VOC mass is present in the subsurface between approximately 28 feet and 42 feet bgs in the upgradient portion of the pilot test area (upgradient of PES-MW-10) and between approximately 35 feet and 50 feet bgs downgradient of PES-MW-10. This distribution was confirmed by discrete groundwater sampling conducted immediately after the completion of the MIP program. The VOC in soil data collected during the drilling program further indicates that VOC concentrations in the finer grained, less transmissive units are significantly higher than VOC concentrations present in the coarser grained, more transmissive units. This data indicates that significant contaminant mass is present in the fine grained silt-clay units. Thus, any remedial strategies implemented in this area that are designed primarily to remove/destroy contaminant mass should be targeted to the finer grained units present between approximately 30 feet and 50 feet bgs where the majority of the contaminant mass resides. In addition, groundwater flow and contaminant migration

within the fine grained units are likely to be controlled by diffusion based mechanics as apposed to the more permeable units where advective flow mechanics likely control contaminant migration. As a result, the success of any remedial option chosen for application within this area will be dependant upon the rate at which contaminant mass diffuses out of the fine grained units.

The TOC in soil data and observations collected during the drilling program indicate that the injected vegetable oil was distributed heterogeneously both vertically and horizontally within the injection area. TOC concentrations in soil detected within the injection area ranged from approximately 2,000 to 6,000 mg/kg, indicating that significant vegetable oil derived organic carbon mass remains in the system to drive biological degradation processes. TOC data collected in groundwater during the discrete sampling program and during the groundwater sampling program indicates that a relatively large area of elevated TOC concentrations was present around the injection area and extended approximately 80 feet to the south-southwest during the April 2005 sampling event. TOC concentrations in this area were high enough to support reductive dechlorination (>20 mg/L (USEPA, 1998)). During the November 2005 sampling event this area of elevated TOC was smaller than in April 2005, possibly as a result of seasonal fluctuations in groundwater flow and TOC transport. Geochemical conditions within this area of elevated TOC (the injection wells, PES-MW-1, PES-MW-4, PES-MW-7, PES-MW-10A, and PES-MW-14A) are indicative of anaerobic geochemical conditions capable of supporting reductive dechlorination. The TOC data collected in April 2005 also indicates that monitoring well MS-53PC was inadvertently impacted by vegetable oil during injection activities in 2001.

Targeted gene detection analysis of soil samples collected during the 2005 program indicates that DHC and DHB were positively identified in nearly all samples analyzed including both vegetable oil impacted and un-impacted samples. The population of DHC in the impacted samples was approximately one order of magnitude higher than the population measured in the non-impacted samples, while DHB populations in the impacted samples were approximately two to three orders of magnitude higher than background. Dechlorinating bacteria DSB, DSM, and GEO were also positively identified at lower concentrations. Thus, the microbial population within the pilot test area is capable of completely dechlorinating chlorinated VOC mass. In addition, moderate to high concentrations of sMMO (with respect to the un-impacted samples) were detected at locations PES-SB-1, PES-SB-7, and PES-MW-10B, indicating that it is possible that chlorinated solvent mass is being destroyed by methanotrophic bacteria through cometabolic oxidation at these locations. This data indicates that several microbial strains that are known to be capable of dechlorinating chlorinated VOC mass are present naturally in site soils, that the injected vegetable oil has been effective at increasing the populations of DHC, DHB, and to a lesser extent GEO. The injected vegetable oil has also been successful in promoting contaminant mass destruction through cometabolic oxidation. Samples of groundwater were also collected for targeted gene detection analysis. Comparison of the targeted gene detection data collected in soil

and in groundwater indicates that the analysis of groundwater from this site does not adequately represent the microbial population in the subsurface.

A total of 11 samples were collected for AMIBA analysis during the 2005 drilling program. Comparison of the impacted and un-impacted sample sets indicates that bioavailable iron, bioavailable manganese, and chromium extractable sulfide have been depleted slightly in the impacted samples. This data indicates that the impacted soil matrix has been depleted of bioavailable metals and sulfide and therefore the capacity for abiotic degradation has been reduced slightly. However, the observed reduction in these species is relatively small in relation to the total mass present in the un-impacted samples. Therefore, the impacted soils' capacity to support abiotic degradation remains relatively unchanged.

Groundwater VOC data collected during the 2005 sampling rounds indicate that VOC concentrations continued to decrease both within and outside of the pilot test area. Comparison of the pre-injection TCE plume map presented on Figure 7 and the November 2005 TCE plume map presented on Figure 8 indicates that TCE concentrations decreased most dramatically within and down gradient from the pilot test area. Review of the VOC data presented in Table 10 and geochemistry data presented in Table 11 indicates that at locations were adequate TOC is present partial, potentially complete, reductive dechlorination is occurring. Elevated ethane and ethene concentrations at these locations further indicates that complete reductive dechlorination may be occurring. These observations indicate that the vegetable oil pilot has been successful in enhancing VOC mass destruction beneath Anoka County Park.

Data collected during the most recent round of field activities indicates that significant contaminant mass is present as sorbed mass located in the fine grained silt/clay units beneath the park. As a result of the presence of this sorbed contaminant mass, the remedial time frame and effectiveness associated with any remedy designed to remove contaminant mass from the subsurface (including organic substrate addition) will be dependant upon the rate at which the contaminant mass diffuses out of the silt/clay units and into the more transmissive sand units where it can be removed or destroyed. Theoretically the rate at which contaminant mass diffuses out of the finer grained units could be maximized by removing the contaminant mass from the more transmissive units and thereby increasing the steepness of the contaminant concentration gradient from the less permeable unit to the more permeable unit. However, the time frame necessary for contaminant mass to diffuse out of the fine grained units is likely to be on the order of hundreds of years. Therefore, it is unlikely that any remedial technology will be successful in significantly accelerating the time it will take to reach remedial goals at the site because contaminant mass will continue to diffuse out of the fine grained units for some time to come.

Since the remedial time frame for groundwater contamination at Anoka County Park appears to be fixed by the diffusion rate from the fine grained units it is likely that the attainment of the remedial goal to remove or destroy all contaminant mass from the subsurface will be technically unattainable within a reasonable period of time. However,

the remedial goal to protect potential contaminant receptors by limiting contaminant mass loading to those receptors remains as a potentially attainable remedial goal at the site. The success of the vegetable oil pilot test indicates that the substrate addition technology is a viable technology to meet this remedial goal. The data collected during the course of this pilot test has shown that the injected vegetable oil has been effective at immobilizing contaminant mass through the partitioning of contaminant mass into the immobile vegetable oil (Parsons, 2004) as well as enhancing the destruction of contaminant mass through biologically supported degradation processes. The ability of vegetable oil to immobilize contaminant mass has the potential to reduce contaminant loading in the short term while the ability of organic substrate addition to promote biologically mediated contaminant mass destruction will reduce contaminant mass loading in the long term.

Parsons suggests that the Navy continue to perform limited groundwater monitoring in the pilot test area in order to track the future progress of the pilot test and to define the life cycle of the injected substrate. Future sampling events could be combined with the base wide sampling events in order to decrease the monitoring costs and to produce site wide sampling rounds that are internally comparable. The sampling locations and analytical parameters could be scaled back to only those locations and parameters important for tracking the progress of the pilot test (Table 13). It is recommended that the following sampling be retained and repeated approximately annually in order to continue to track the effectiveness of the system and to track the depletion of the vegetable oil derived organic carbon:

TABLE 13
RECOMMENDATIONS FOR FUTURE ANNUAL SAMPLING
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well Identification	Well Stabilization Parameters [a/]	VOCs (8260B)	TOC (SW9060)
PES-INJ-03	X	X	X
PES-MW-4	X	X	X
PES-MW-5	X	X	X
PES-MW-7	X	X	X
PES-MW-9	X	X	X
PES-MW-10A	X	X	X
PES-MW-11A	X	X	X
PES-MW-12A	X	X	X
PES-MW-13A	X	X	
PES-MW-14A	X	X	X
PES-CW-2	X	X	
PES-CW-3	X	X	
MS-46S	X	X	
MS-47S	X	X	

[a/] Well stabilization parameters include dissolved oxygen, temperature, pH, oxidation reduction potential, and turbidity.

In addition it is recommended that a slightly expanded sampling program be implemented during the site wide sampling round immediately prior to a five year ROD review in order to prepare a more complete representation of "current" site conditions. Parsons recommends that PES-MW-1 and PES-MW-6 be added to the pre-ROD review sampling protocol in order to assess groundwater conditions immediately downgradient from the injection area. Parsons also recommends that the B interval wells be added at well clusters PES-MW-10, PES-MW-12, and PES-MW-14 in order to assess water quality downgradient from and slightly below the injection area.

TABLE 14
RECOMMENDATIONS FOR SAMPLING PRIOR TO A 5-YEAR ROD REVIEW
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well Identification	Well Stabilization Parameters [a/]	VOCs (8260B)	TOC (SW9060)
PES-MW-1	X	X	X
PES-MW-6	X	X	X
PES-MW-10B	X	X	X
PES-MW-12B	X	X	X
PES-MW-14B	X	X	X

Note: Sampling recommendations presented in this table are in addition to the sampling recommendations presented in Table 13.

[a/] Well stabilization parameters include dissolved oxygen, temperature, pH, oxidation reduction potential, and turbidity.

During the coming months the NIROP team will be required to make a series of decisions regarding the future of remedial activities at Anoka County Park. These decisions will be made based upon the results of the vegetable oil pilot test, research being conducted by the USGS with regard to the hydraulic system, and the impact of the extraction system currently operating on site. The vegetable oil pilot test has been successful in enhancing the destruction of chlorinated solvent mass in the subsurface and has thus been successful in reducing the overall toxicity of the groundwater plume. Vegetable oil has also been shown to be effective at stripping contaminant mass from the soil matrix through its surfactant properties and immobilizing contaminant mass through its preferential partitioning properties (Parsons, 2004). Therefore, Parsons recommends that organic substrate addition in general and vegetable oil injection specifically be considered as a future remedial option at this site.

In 1990 the record of decision (ROD) for groundwater at the NIROP facility was signed. The ROD specified that contaminated groundwater located offsite and downgradient of the NIROP facility in Anoka County Park would be allowed to dissipate naturally (TTNUS, 2005). During the 1998 5-year ROD review it was determined that VOC concentrations in Anoka County Park were not decreasing as rapidly as expected

and it was recommended that the Navy determine what could be done to reduce residual groundwater contamination in Anoka County Park (TTNUS, 2005). As a result of this recommendation the Navy embarked on this organic substrate addition pilot test program. In addition, the Navy started a groundwater extraction system expansion program in order to more fully capture the VOC plume emanating from the NIROP facility. Over the last several years of groundwater monitoring in Anoka County Park VOC concentrations at wells installed within and outside of the pilot testing area have been decreasing (TTNUS, 2006). The VOC concentration decreases observed outside of the pilot test area are likely a result of more complete capture afforded by the expanded extraction system and natural attenuation mechanisms active in the Park (TTNUS, 2006). Since VOC concentrations in Anoka County Park have been decreasing over the last several years, Parsons suggests that the Navy continue to monitor VOC concentrations at wells installed in the Park to determine if the VOC concentration reductions are sustainable. If VOC concentrations continue to decrease in the Park then the tenants of the ROD should be fulfilled and active remediation in the Park may be unnecessary to be protective of identified potential contaminant receptors. In the event that VOC concentrations in the Park increase significantly over a significant period of time the NIROP partnering team could re-consider the need for more active remediation measures.

In the event that a more active approach becomes warranted, Parsons suggests that future active remedial activities at Anoka County Park be designed to reduce the potential impact to receptors and therefore reduce the environmental risk and impact associated with the contaminant mass remaining in the subsurface instead of attempting to remove or destroy all of the remaining contaminant mass. To this end Parsons suggests that the NIROP team limit future remedial activities at the site to defined contaminant hot spots or source areas instead of attempting to treat large areas (for example attempting to treat an area within a particular interpreted VOC concentration contour). The control or elimination of contaminant mass present as hot spots will allow the environmental risk associated with the site to be reduced most significantly and most efficiently in terms of cost and in terms of impact to activities and access to the site.

REFERENCES

Bouwer, E.J., 1994. Bioremediation of chlorinated solvents using alternate electron acceptors. In: *Handbook of Bioremediation*. CRC Press, Boca Raton, FL.

CH2M Hill Constructors Incorporated (CCI), 2002. *Project Completion Report (Revision 00), Pilot –Scale Study to Enhance In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at Anoka County Riverfront Park, Naval Industrial Reserve Ordnance Plant Fridley*. January.

Chapelle, F.H., 1993. *Ground-Water Microbiology and Geochemistry*: John Wiley & Sons, Inc., New York, 424 p.

Evans, D., 1995. *Contaminant Transport by groundwater Flow.* Atlanta Geological Society Continuing Education Work Shop Presentation Handouts.

He, J., Ritalahti, K. M., Aiello, M. R., Löffler, F. E., 2003. Complete Detoxification by an Anaerobic Enrichment Culture and Identification of the Reductively Dechlorinating Population as a Dehalococcoides Species. *Applied and Environmental Microbiology,* February, 2003, , p. 996-1003.

Kennedy, L., Everett, J., and Gonzales, J., 2000. *Aqueous and Mineral Intrinsic Bioremediation Assessment (AMIBA) Protocol.*

Lyman, W.J., Reidy, P.J., and Levy, B., 1992. *Mobility and Degradation of Organic Contaminants in Subsurface Environments*: C.K. Smoley, Chelsea, MI, 395 p.

Parsons, 2001a. *Final Work Plan for Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at the Naval Industrial Reserve Plant (NIROP) Fridley, Minnesota*. September.

Parsons, 2001b. *Final Quality Assurance Project Plan for Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents Via Vegetable Oil Injection at The Naval Industrial Reserve Ordnance Plant (NIROP), Fridley, Minnesota*. September.

Parsons, 2004. *Draft Report for a Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at Naval Industrial Ordnance Plant Fridley, Minnesota*.

Parsons, 2005. *Addendum to the Final Work Plan for Field Application to Enhance In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at the Naval Industrial Reserve Plant (NIROP) Fridley, Minnesota*. January.

Song, D.L., Conrad. M.E., Sorenson ,K.S., and Alverez-Cohen, L. 2002. Stable Carbon Isotope Fractionation During Enhanced In-Situ Bioremediation of Trichloroethene: *Environmental Science and Technology,* vol. 36, No. 10, p. 2262-2268.

Tetra Tech NUS Inc. 2005. *2004 Annual Monitoring Report, Naval Industrial Reserve Ordnance Plant, Fridley Minnesota.* November.

Tetra Tech NUS Inc. 2006. *2005 Annual Monitoring Report, Naval Industrial Reserve Ordnance Plant, Fridley Minnesota.* April.

US Environmental Protection Agency (USEPA), 1998. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*: EPA/600/R-98/128, September; http://www.epa.gov/ada/reports.html.

Vogel, T.M., C.S. Criddle, and P.L. McCarty, 1987. Transformations of halogenated aliphatic compounds. *Environmental Science and Technology* 22:722-736.

TABLES

TABLE 1
SUMMARY OF MEMBRANE INTERFACE PROBE POINT INSTALLATIONS
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well/Borehole Identification	Well/Boring Diameter (Inches)	Total Depth (feet bgs)[a/]	Ground Surface Elevation (feet amsl)[b/]	Elevation Top of Casing (feet amsl)	Survey Northing (State Plane)	Survey Easting (State Plane)
MIP-1	1	60	NM[c/]	NM	1,077,426.77	2,810,933.36
MIP-2	1	60	NM	NM	1,077,392.94	2,810,924.37
MIP-3	1	60	NM	NM	1,077,386.69	2,810,892.06
MIP-4	1	55	NM	NM	1,077,389.93	2,810,890.64
MIP-5	1	60	NM	NM	1,077,393.87	2,810,889.35
MIP-6	1	60	NM	NM	1,077,385.27	2,810,882.59
MIP-7	1	74	NM	NM	1,077,387.07	2,810,908.80
MIP-8	1	60	NM	NM	1,077,382.04	2,810,914.14
MIP-9	1	61	NM	NM	1,077,378.44	2,810,910.70
MIP-10	1	60	NM	NM	1,077,374.97	2,810,906.82
MIP-11	1	60	NM	NM	1,077,393.04	2,810,910.18
MIP-12	1	60	NM	NM	1,077,378.63	2,810,925.62
MIP-13	1	70	NM	NM	1,077,367.15	2,810,898.56
MIP-14	1	62	NM	NM	1,077,364.96	2,810,894.05
MIP-15	1	60	NM	NM	1,077,354.34	2,810,904.24
MIP-16	1	60	NM	NM	1,077,348.53	2,810,893.98
MIP-17	1	60	NM	NM	1,077,351.98	2,810,908.44
MIP-18	1	60	NM	NM	1,077,378.73	2,810,935.81
MIP-19	1	60	NM	NM	1,077,340.37	2,810,897.87
MIP-20	1	60	NM	NM	1,077,322.76	2,810,900.43
MIP-21	1	70	NM	NM	1,077,314.20	2,810,903.44
MIP-22	1	60	NM	NM	1,077,215.88	2,810,882.20
MIP-23	1	70	NM	NM	1,077,347.80	2,810,907.97
MIP-24	1	60	NM	NM	1,077,343.98	2,810,907.95
MIP-25	1	60	NM	NM	1,077,323.60	2,810,884.91
MIP-26	1	60	NM	NM	1,077,308.01	2,810,878.27
MIP-27	1	60	NM	NM	1,077,292.13	2,810,865.27
MIP-28	1	60	NM	NM	1,077,383.47	2,810,925.54
MIP-29	1	60	NM	NM	1,077,258.88	2,810,896.58
MIP-30	1	60	NM	NM	1,077,281.18	2,810,903.57
MIP-31	1	67	NM	NM	1,077,311.17	2,810,911.70
MIP-32	1	62	NM	NM	1,077,305.95	2,810,929.81
MIP-33	1	60	NM	NM	1,077,345.89	2,810,925.22
MIP-34	1	60	NM	NM	1,077,354.24	2,810,924.29
MIP-35	1	66	NM	NM	1,077,213.64	2,810,866.11
MIP-36	1	60	NM	NM	1,077,377.46	2,810,925.30
MIP-37	1	67	NM	NM	1,077,271.25	2,810,921.46
MIP-38	1	61	NM	NM	1,077,308.49	2,810,952.02

[a/] feet bgs indicates depth in feet below ground surface.

[b/] feet amsl indicates elevation in feet above mean sea level.

[c/] NM indicates elevation not measured.

TABLE 2
SUMMARY OF MONITORING WELL AND SOIL BORING CONSTRUCTION
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well/Borehole Identification	Completion Date	Well/Boring Diameter (Inches)	Screened Interval/TD (feet bgs)[a/]	Ground Surface Elevation (feet amsl)[b/]	Elevation Top of Casing (feet amsl)	Survey Northing (State Plane)	Survey Easting (State Plane)
Newly Installed Monitoring Wells							
PES-MW-10A	4/1/2005	2/8	45.0 - 55.0	NM[d/]	832.17	1,077,342.33	2,810,904.47
PES-MW-10B	3/31/2005	2/8	65.0 - 75.0	NM	832.11	1,077,345.35	2,810,906.36
PES-MW-11A	3/29/2005	2/8	45.0 - 55.0	NM	832.28	1,077,320.34	2,810,900.39
PES-MW-12A	4/5/2005	2/8	35.0 - 45.0	NM	833.89	1,077,205.43	2,810,881.86
PES-MW-12B	4/5/2005	2/8	55.0 - 65.0	NM	833.80	1,077,208.68	2,810,882.56
PES-MW-13A	3/28/2005	2/8	35.0 - 45.0	NM	832.15	1,077,420.00	2,810,927.99
PES-MW-14A	4/4/2005	2/8	45.0 - 55.0	NM	831.74	1,077,291.98	2,810,872.98
PES-MW-14B	4/4/2005	2/8	65.0 - 75.0	NM	831.84	1,077,295.69	2,810,871.97
Newly Installed Soil Borings							
PES-SB-1	8/29/2000	NA[c/]/8	60	NM	NA	1,077,385.69	2,810,895.57
PES-SB-2	8/29/2000	NA/8	60	NM	NA	1,077,373.21	2,810,905.91
PES-SB-3	9/7/2000	NA/8	60	NM	NA	1,077,359.27	2,810,907.97
PES-SB-4	9/7/2000	NA/8	60	NM	NA	1,077,379.96	2,810,914.05
PES-SB-5	9/9/2000	NA/8	60	NM	NA	1,077,376.71	2,810,909.98
PES-SB-6	9/7/2000	NA/8	60	NM	NA	1,077,368.49	2,810,898.43
PES-SB-7	9/7/2000	NA/8	60	NM	NA	1,077,365.37	2,810,894.23
PES-SB-8	9/9/2000	NA/8	60	NM	NA	1,077,357.14	2,810,883.76
PES-SB-9	9/9/2000	NA/8	60	NM	NA	1,077,357.62	2,810,895.39
PES-SB-10	9/9/2000	NA/8	60	NM	NA	1,077,353.26	2,810,903.79

[a/] feet bgs indicates depth in feet below ground surface.

[b/] feet amsl indicates elevation in feet above mean sea level.

[c/] NA indicates data not available.

[d/] NM indicates elevation not measured.

TABLE 3
SUMMARY OF MIP SURVEY DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Location	Depth Range (ft bgs)[a/]	Peak depth(s) (ft bgs)	ECD peak hit (uV)[b/]	FID range (ft bgs)	FID peak depth (ft bgs)	FID peak (uV)
MIP Points Upgradient of MPES-MW-10A/B						
MIP-01	30.5-49.0	32.0-36.0	3.50E+05	NA[c/]	NA	ND[d/]
MIP-02	27.0-47.0	33.5	1.20E+06	26.7-28.5	26.5	1.80E+06
		36.0	2.50E+05		27.0	2.20E+06
MIP-03	29.5-59.5	39.0	3.90E+05	30.5-32.5	31.0	8.00E+06
		42.0	3.00E+05			
		45.0	3.20E+05			
		51.0	2.80E+05			
MIP-04	38.0-53.0	32.5	4.00E+05	NA	NA	ND
		35.0	3.50E+05			
		37.5	5.20E+05			
MIP-05	28.5-49.0	30.0	1.80E+06	30.0-32.0	30.0	4.80E+05
		32.5	8.00E+05			
MIP-06	34.5-TD (60) [e/]	37.0	3.00E+05	31.0-34.0	32.0	1.50E+06
		48.0	3.90E+05		33.0	9.00E+05
		54.0	3.00E+05			
MIP-07	27.5-46.0	27.5	8.00E+05	27.5	27.5	1.80E+05
		31.0	7.00E+05			
MIP-08	28.5-TD (60)	37.0	1.00E+06	31.0	31.0	4.00E+05
		39.0	1.00E+06			
		41.0	9.00E+05			
MIP-09	28.5-50.0	31.0	1.00E+06	NA	NA	ND
		36.0	8.00E+05			
MIP-10	36.0-52.0	41.0	2.00E+05	32.0	32.0	5.50E+05
		43.0	2.00E+05			
		50.0	1.50E+05			
MIP-11	28.5-TD (60)	44.0	7.00E+05	NA	NA	ND
		51.5	1.00E+06			
		56.5	6.00E+05			
		59.0	6.00E+05			
MIP-12	27.0-40.0	27.0	1.00E+06	NA	NA	ND
		35.0	3.50E+06			
MIP-13	31.0-51.0	33.0	1.70E+06	31.0-50.5	47.5	6.00E+06
					51.0	5.50E+06
MIP-14	29.5-TD (62)	36.0	5.00E+05	32.0-54.0	32.0	6.00E+05
		49.0	4.00E+05		38.0	6.00E+05
		58.0	5.00E+05		49.0	2.80E+06
					54.0	8.00E+05
MIP-15	30.5-42.0	36.0	1.60E+06	54.0-57.0	54.0	5.00E+06
					56.0	3.00E+06
MIP-16	30.5-42.0	34.0	1.50E+06	34.0-56.0	34.0	5.00E+05
		36.0	2.30E+06		53.0	2.00E+06
					56.0	3.00E+05
MIP-17	30.0-52.5	32.5	8.00E+05	NA	NA	ND
		39.0	7.00E+05			
		42.0	6.00E+05			
MIP-18	26.5-48.0	29.0	7.00E+05	28.0	28.0	1.50E+05
		33.5	4.00E+05			
		37.0	4.00E+05			
MIP-23	30.0-48.0	35.5	2.50E+06	NA	NA	ND
		40.0	2.00E+06			
MIP-28	28.0-TD (60)	35.0	6.00E+05	53.0-54.0	53.5	1.00E+05
		42.0	5.50E+05			
MIP-33	28.0-46.0	28.0	1.50E+06	NA	NA	ND
		35.5	7.50E+05			
		41.0	5.00E+05			

TABLE 3
SUMMARY OF MIP SURVEY DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

MIP-34	27.0-43.5	28.5	1.30E+06	NA	NA	ND
		33.0	7.50E+05			
MIP-36	27.5-33.0	28.5	8.00E+06	27.5-30.0	28.0	6.00E+05
		30.5	5.50E+06		30.0	6.00E+05
		32.0	2.00E+06			
MIP Points Down Gradient of MPES-MW-10A/B						
MIP-19	31.0-TD (60)	34.0	6.00E+05	38.0-54.0	42.5	4.00E+06
		38.0	9.50E+05		44.5	7.00E+06
		44.5	8.00E+05		49.0	2.00E+06
		48.0	9.00E+05		53.0	4.50E+06
		55.0	4.00E+05			
		58.0	8.00E+05			
MIP-20	31.0-58.0	34.0	4.50E+05	55.5-57.0	56.0	7.50E+06
		42.0	7.50E+05		57.0	3.00E+06
		58.0	3.50E+05			
MIP-21	31.5-52.5	35.0	6.00E+05	47.5-58.0	55.0	8.50E+06
		40.0	1.00E+06		56.0	1.10E+07
		42.5	1.80E+06		57.5	5.00E+06
		47.0	1.00E+06			
MIP-22	33.0-TD (60)	41.0	3.00E+05	NA	NA	ND
		47.0	3.00E+05			
		59.0	6.00E+05			
MIP-24	31.0-48.0	34.0	1.20E+06	47.5-55	48.0	8.00E+05
		36.0	1.70E+06		52.5	2.10E+06
		39.0	1.20E+06		53.5	1.60E+06
					55.0	9.00E+05
MIP-25	31.0-TD (60)	34.0	3.20E+05	39.0-52.0	40.0	2.00E+05
		39.0	3.80E+05		44.0	1.55E+05
		48.0	2.50E+05		49.0	2.00E+05
		56.0	2.00E+05		52.0	3.00E+05
MIP-26	31.0-51.0	35.0	5.80E+05	54.5-55.5	55.0	8.00E+06
MIP-27	31.0-54.0	35.0	4.00E+05	35.0-41.0	38.5	1.50E+06
		37.0	4.20E+05	50.0-57.5	57.0	2.10E+05
		46.0	3.00E+05			
MIP-29	44.0-59.0	49.0	7.00E+05	NA	NA	ND
		55.0	5.50E+05			
MIP-30	35, 38.0-58.0	35.0	5.00E+05	42.0-45.0	44.0	7.00E+05
		47.0	3.20E+06			
MIP-31	33.0-57.0	43.0	4.50E+06	NA	NA	ND
		45.0	4.00E+06			
		48.0	2.00E+06			
MIP-32	31.5-56.0	40.0	5.00E+06	35.0, 40.0, 46.5	35.0	1.90E+05
		47.0	4.00E+06		40.0	2.00E+05
					46.5	1.80E+05
MIP-35	43-TD (66)	43.0	2.00E+05	NA	NA	ND
		50.0	2.80E+05			
		57.0	3.20E+05			
		63.0	4.50E+05			
		66.0	3.50E+05			
MIP-37	38.0-62.5	47.0	6.00E+05	39.5-46.5	44.0	4.50E+05
		51.0	5.00E+05			
MIP-38	40.0-TD (61)	41.0	3.00E+05	NA	NA	ND
		43.0	3.70E+05			
		45.0	9.00E+05			
		48.0	7.50E+05			
		53.0	5.00E+05			

[a/] ft bgs - feet below ground surface
[b/] uV = microvolts
[c/] NA = not applicable
[d/] ND = not detected
[e/] TD = total depth

TABLE 4
SUMMARY OF MIP AND DISCRETE GROUNDWATER SAMPLING DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Date	Sampling Depth (ft bgs)	ECD Response (uV)	Correlation Factor (unitless)	Total Cl VOCs (µg/L)	PCE[a/] (µg/L)[b/]	TCE[a/] (µg/L)	*cis*-1,2-DCE[a/] (µg/L)	*trans*-1,2-DCE[a/] (µg/L)	Vinyl Chloride (µg/L)	FID Response (uV)	TOC Concentration (mg/L)	Methane (µg/L)	Ethene (µg/L)	Ethane (µg/L)
MIP-01	14-Mar-05	30.0	3.00E+05	149	**2,007**	0.45 U	**1,900**	**49**	**51**	**0.52 J**	ND	4.6	NA	NA	NA
		50.0	3.00E+05	1279	**235**	0.45 U	**220**	**6.6**	**3.2**	0.18 U	ND	3.9	NA	NA	NA
MIP-03	14-Mar-05	31.0	1.56E+05	233	**671**	0.90 U	**38**	**610**	**12**	**3.4**	8.00E+06	**420**	NA	NA	NA
		39.0	3.42E+05	291	**1,174**	2.2 U	**940**	**170**	**44**	0.9 U	ND	**14**	NA	NA	NA
		43.0	2.93E+05	439	**667**	1.1 U	**630**	**13**	**14**	0.45 U	ND	4.8	NA	NA	NA
MIP-04	14-Mar-05	38.0	4.00E+05	277	**1,444**	2.2 U	**1300**	**65**	**59**	0.90 U	ND	4.4	NA	NA	NA
	14-Mar-05	43.0	3.20E+05	389	**822**	0.45 U	**790**	**13**	**14**	0.18 U	ND	4.7	NA	NA	NA
	15-Mar-05	50.0	2.00E+05	434	**460**	0.90 U	**430**	**16**	**6.2**	0.36 U	ND	**10**	26	2.9	3.0
MIP-05	15-Mar-05	30.0	1.00E+06	1679	**596**	0.45 U	**520**	**40**	**31**	0.18 U	4.00E+05	1.7	2.7	0.36	0.55
		40.0	3.61E+05	396	**912**	0.90 U	**860**	**19**	**25**	0.36 U	ND	1.7	9.3	0.85	0.75
MIP-08	17-Mar-05	31.0	3.00E+05	187	**1,607**	9 U	**1,400**	**58**	**68**	3.6 U	4.00E+05	3.2	20	12	9.4
		35.0	4.50E+05	263	**1,710**	9 U	**1,500**	**60**	**69**	3.6 U	ND	3.1	13	6.0	5.8
		41.0	8.00E+05	783	**1,022**	4.5 U	**920**	**32**	**29**	1.8 U	ND	1.7	9.4	4.9	4.6
		48.0	5.50E+05	1202	**458**	4.5 U	**400**	**9.6**	**7.4**	1.8 U	ND	1.9	15	7.0	7.8
MIP-09	17-Mar-05	31.0	1.00E+06	596	**1,678**	2.2 U	**1,500**	**79**	**81**	0.9 U	ND	2.9	13	2.2	1.9
		36.0	8.00E+05	421	**1,899**	4.5 U	**1,700**	**74**	**84**	1.8 U	ND	2.3	13	5.0	3.7
		45.0	2.50E+05	526	**476**	2.2 U	**440**	**9.9**	**7.6**	0.9 U	ND	2.7	8.2	0.55	0.89
MIP-10	17-Mar-05	32.0	ND	None	**310**	1.1 U	**280**	**10**	**9.8**	0.45 U	5.00E+05	2.4	83	0.24	0.36
		43.0	2.50E+05	341	**733**	2.2 U	**680**	**17**	**18**	0.9 U	ND	3.1	15	1.6	1.6
		48.0	ND	None	**425**	0.90 U	**400**	**9.6**	**7.4**	0.36 U	ND	**150**	14000	1.4	0.53
MIP-13	16-Mar-05	33.5	2.00E+06	2494	**802**	0.45 U	**170**	**590**	**41**	**0.51 J**	ND	**3.0**	4900	9.4	7.6
		43.0	2.50E+05	310	**807**	0.45 U	**160**	**630**	**14**	**2.2**	ND	**37**	11000	0.90	0.49
		47.5	2.00E+05	801	**250**	0.45 U	**4.5**	**240**	**3.8**	**0.96 J**	6.00E+06	**130**	20000	2.7	1.5
MIP-14	16-Mar-05	36.0	4.50E+05	300	**1,499**	0.45 U	**120**	**1,300**	**66**	**6.5**	ND	**7.2**	14000	15	11
		42.0	1.00E+05	145	**688**	2.2 U	**630**	**25**	**15**	0.9 U	ND	1.8	4300	0.56	0.47
		46.0	3.50E+05	1076	**325**	1.1 U	**300**	**10**	**4.7**	0.45 U	ND	2.0	70	15	16
		49.0	4.00E+05	1607	**249**	0.45 U	**180**	**62**	**2.4**	0.18 U	2.50E+06	3.2	660	4.6	4.9
MIP-15	17-Mar-05	36.0	1.50E+06	579	**2,589**	11 U	**2,300**	**99**	**89**	4.5 U	ND	3.2	53	0.41	0.52
		42.0	2.50E+05	370	**675**	2.2 U	**630**	**15**	**12**	0.9 U	ND	3.1	1900	5.1	4.4
		54.0	ND	None	**158**	0.45 U	**19**	**130**	**1.7**	**3.1 J**	5.00E+06	**170**	30000	4.9	8.5
MIP-16	15-Mar-05	36.0	2.00E+06	1887	**1,060**	0.45 U	**850**	**150**	**54**	**0.4 J**	ND	2.2	3100	13	8.3
		45.0	ND	None	**323**	0.45 U	**280**	**33**	**4.9**	**0.20 J**	2.50E+05	2.3	7000	13	14
		53.0	ND	None	**135**	0.45 U	**71**	**57**	**2.3**	0.18 U	2.00E+06	4.6	1700	3	3.5
MIP-17	15-Mar-05	39.0	7.50E+05	386	**1,941**	0.45 U	**1,800**	**66**	**67**	**0.53 J**	ND	1.7	15	13	5.2
		42.0	6.00E+05	915	**656**	0.45 U	**620**	**14**	**12**	0.90 U	ND	2.3	560	12	12
		46.0	3.50E+05	897	**390**	0.45 U	**370**	**8.6**	**6.5**	0.18 U	ND	2.4	230	3.7	3.9
		50.0	ND	None	**227**	0.45 U	**200**	**19**	**3.6**	0.18 U	ND	3.8	7.5	1.1	1.0
MIP-19	15-Mar-05	38.0	9.50E+05	766	**1,240**	0.45 U	**250**	**930**	**50**	**2.4**	7.00E+05	5.8	18000	21	15
		42.0	2.00E+05	322	**621**	0.45 U	**17**	**580**	**18**	**0.59 J**	2.00E+06	4.3	20000	3.6	2.8
		47.0	5.00E+05	2670	**187**	0.45 U	**8.4**	**170**	**4.0**	**0.97 J**	ND	**16**	28000	6	7.3
		52.0	2.00E+05	733	**273**	0.45 U	**23**	**240**	**4.8**	**0.93 J**	4.00E+06	5.6	17000	14	18
MIP-21	15-Mar-05	43.0	1.80E+06	935	**1,926**	4.50 U	**1,500**	**330**	**55**	1.8 U	ND	1.9	1900	72	37
		56.0	ND	None	**151**	**0.77 J**	**130**	**14**	**1.7**	0.18 U	1.00E+07	3.9	30	7.2	7.8
MIP-23	15-Mar-05	36.0	2.50E+06	1427	**1,752**	0.45 U	**1,400**	**240**	**85**	1.8 U	ND	0.8	5000	24	6.7
MIP-24	16-Mar-05	36.5	1.00E+06	516	**1,939**	0.45 U	**1,800**	**62**	**69**	**0.97 J**	ND	1.7	110	7.8	5.6
		53.0	ND	None	**179**	0.45 U	**12**	**160**	**1.8**	**1.4**	2.00E+06	**230**	19000	0.14	0.05
MIP-31	16-Mar-05	43.0	4.00E+06	3460	**1,156**	0.45 U	**1,100**	**24**	**26**	**0.23 J**	ND	2.6	39	1.3	1.4
MIP-32	16-Mar-05	40.0	1.00E+06	873	**1,145**	0.45 U	**1,100**	**20**	**17**	1.8 U	2.00E+05	**18**	39	48	47

[a/] PCE = tetrachloroethene; TCE = trichloroethene; DCE = dichloroethene; TCA = trichloroethane; DCA = dichloroethane.

[b/] µg/L = micrograms per liter.

[c/] U = Analyte was not detected at a concentration above the method detection limit.

[d/] J = Analyte was detected at a concentration above the method detection limit and below the reporting limit

TABLE 5
SUMMARY OF SOIL ANALYTICAL DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Sample Depth (feet bgs)[a/]	Stratigraphy	Total Organic Carbon (mg/kg)[d/]	TCE[b/] (µg/kg)[c/]	*cis*-1,2-DCE[b/] (µg/kg)	*trans*-1,2-DCE (µg/kg)	Vinyl Chloride (µg/kg)	1,2-DCA[b/] (µg/kg)	Carbon Tetrachloride (µg/kg)	Acetone (µg/kg)	2-Butanone (µg/kg)	Bromomethane (µg/kg)
PES-SB-1	16-Mar-05	32 - 35	Cohesive silt, mild odor, staining	**410**	**220**	**100**	17 U	17 U	24 U	19 U	67 U	84 U	29 U
	16-Mar-05	35 - 36	Cohesive Silt, mild odor, staining	**830**	**510**	**490**	17 U	17 U	24 U	19 U	67 U	84 U	29 U
	16-Mar-05	37 - 38	Sandy Silt, mild odor, staining	**330**	**80**	**2,100**	**83**	17 U	24 U	19 U	69 U	87 U	29 U
PES-SB-2	15-Mar-05	37 - 38	Sandy silt, strong odor, heavy staining	**6,200**	**7,700**	**850**	**56 J**[e/]	17 U	23 U	20 U	69 U	87 U	19 U
PES-SB-3	14-Mar-05	42	Non-plastic silt with fine sand, moderate odor, staining	**1,700**	**2,400**	**610**	**75**	17 U	24 U	19 U	67 U	84 U	19 U
PES-SB-4	24-Mar-05	30	Sandy silt, no odor, no staining	**480 J**	**1,000**	22 U	**19 J**	16 U	24 U	19 U	65 U	81 U	28 U
	24-Mar-05	31	Sandy Silt, no odor, no staining	**3,700**	**710**	23 U	17 U	17 U	24 U	19 U	66 U	83 U	28 U
	24-Mar-05	42 - 44	Fine sand, no odor, no staining	**160 J**	**110**	24 U	17 U	17 U	23 U	20 U	69 U	87 U	29 U
PES-SB-5	7-Apr-05	42 - 44	Fine - medium sand, no odor, no staining	**230 J**	**77**	24 U	17 U	17 U	25 U	20 U	**130 J**	87 U	29 U
PES-SB-6	7-Apr-05	36 - 38	Fine sand, strong odor	**550**	23 U	**43 J**	17 U	17 U	24 U	19 U	66 U	84 U	28 U
PES-SB-7	23-Mar-05	32 - 34	Tight clay with medium sand	**2,800**	**2,100**	**57 J**	**91**	18 U	26 U	20 U	71 U	90 U	30 U
	7-Apr-05	34 - 36	Cohesive Sandy Silt, no odor	**340 J**	**50 J**	**210**	**18 U**	18 U	26 U	20 U	70 U	88 U	30 U
	3-Mar-05	46 - 48	Find sand, strong odor	**300 J**	24 U	24 U	18 U	18 U	25 U	20 U	70 U	88 U	30 U
PES-SB-8	17-Mar-05	46	Silt, no odor, some staining	**280**	NA	NA	NA	NA	NA	NA	NA	NA	NA
	17-Mar-05	48 - 50	Fine Sand and Silt, mild odor	**230 J**	**81**	24 U	17 U	17 U	25 U	19 U	68 U	85 U	19 U
	17-Mar-05	51	Fine Sand and Silt, no odor	**280 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA
	17-Mar-05	56	Fine - coarse sand, no odor	**330 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA
PES-SB-9	7-Apr-05	34 - 36	Fine sand with silt, mild-strong odor	**350 J**	**85**	**150**	17 U	17 U	25 U	19 U	67 U	85 U	29 U
	21-Mar-05	46	Fine - medium sand with silt, mild odor, weak staining	**1,200**	NA	NA	NA	NA	NA	NA	NA	NA	NA
	21-Mar-05	51	Silty sand, mild odor	**210 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA
	21-Mar-05	56	Fine - coarse silty sand, mild odor	**350 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA
PES-SB-10	22-Mar-05	51	Fine sand, no odor	**290 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA
	22-Mar-05	56	Fine - medium sand, no odor	**240 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA
PES-MW-10B	31-Mar-05	36 - 38	sandy silt, no odor	**610**	**1,600**	22 U	**25 J**	16 U	23 U	18 U	64 U	81 U	27 U
	31-Mar-05	40 - 42	sandy silt, no odor	**1,000**	**1,600**	23 U	**24 J**	16 U	24 U	19 U	65 U	82 U	28 U
	31-Mar-05	49 - 50	fine sand, no odor	**370 J**	24 U	24 U	17 U	17 U	25 U	20 U	69 U	87 U	29 U
	31-Mar-05	70 - 71	Fine - medium sand, no odor	**220 J**	24 U	24 U	17 U	17 U	25 U	20 U	68 U	85 U	29 U
PES-MW-11A	29-Mar-05	42 - 44	Sandy silt, no odor	**470 J**	**1,800**	22 U	**26 J**	16 U	23 U	18 U	64 U	81 U	27 U
	29-Mar-05	48 - 50	fine sand, no odor	**310 J**	**100**	24 U	17 U	17 U	25 U	20 U	69 U	87 U	30 U
PES-MW-12B	5-Apr-05	62 - 63	Cohesive tight clay. no odor.	**5,900**	**190**	25 U	18 U	18 U	26 U	20 U	**140 J**	89 U	30 U
PES-MW-13A	28-Mar-05	26 [f/]	Sandy silt, no odor	**610**	**200**	22 U	16 U	16 U	23 U	18 U	64 U	80 U	27 U
	28-Mar-05	27	sandy silt, no odor	**460 J**	**89**	22 U	17 U	16 U	23 U	18 U	64 U	81 U	27 U
	28-Mar-05	42	Fine sand, no odor	**330 J**	**59**	23 U	17 U	17 U	24 U	19 U	66 U	84 U	28 U
PES-MW-14B	4-Apr-05	40 - 42	Sandy silt, no odor	**580**	**220**	**130**	16 U	16 U	23 U	18 U	63 U	79 U	27 U
	4-Apr-05	42	Sandy silt, no odor	**510**	**200**	**250**	**22 J**	16 U	23 U	18 U	64 U	81 U	27 U
	4-Apr-05	68 - 70	Fine sand, no odor	**370 J**	23 U	23 U	17 U	17 U	24 U	19 U	**360**	84 U	28 U

[a/] feet bgs = feet below ground surface.

[b/] TCE = trichloroethene; DCE = dichloroethene; DCA = dichloroethane.

[c/] µg/kg = micrograms per kilogram.

[d/] mg/kg = milligrams per kilogram.

[e/] J indicates that the analyte was detected at a concentration above the method detection limit but below the reporting limit resulting in an estimated value.

TABLE 6
SUMMARY OF PLFA AND TARGETED GENE DETECTION DATA IN SOIL AND GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

						Dechlorinating Bacteria					DHC Functional Genes			Phylogenic Groups				
Sample Location	Sample Date	Sample Depth (feet bgs)[a/]	Stratigraphic Classification	Evidence of Organic Carbon Impact	Total Organic Carbon (mg/kg)[b/]	DHC [c/] (cells/gram)[d/]	DSM [c/] (cells/gram)	DHB [c/] (cells/gram)	DSB [c/] (cells/gram)	Geobacter (cells/gram)	BVC [c/] (cells/gram)	TCER [c/] (cells/gram)	sMMO [c/] (cells/gram)	Eubacteria (cells/gram)	Methanogens (cells/gram)	Sulfate+Iron Reducers (cells/gram)	Methanotrophs (cells/gram)	Total Biomass (cells/gram)
Soil Samples Impacted by Vegetable Oil																		
PES-SB-1	16-Mar-05	32-35	Silt	Mild Odor	**410**	**2.00E+04**	<1.75E+03 [e/]	**1.64E+07**	**5.32E+08**	**7.77E+03**	**4.33E+01 J**	<8.76E+02	**3.76E+05**	**4.73E+08**	**3.11E+07**	**7.92E+06**	**2.13E+09**	**1.21E+08**
PES-SB-2	15-Mar-05	37-38	F-M Sand	Strong Odor	**6,200**	**9.76E+04**	<1.70E+03	**2.73E+07**	<1.70E+03	**6.70E+02**	**2.47E+03**	**3.01E+02 J**	**7.36E+02**	**2.26E+09**	**1.09E+04**	**1.48E+06**	**4.98E+09**	**1.29E+07**
PES-SB-3	14-Mar-05	42	Silty Fine Sand	Moderate Odor, Staining	**1,700**	**1.20E+03**	<1.82E+03	**4.47E+07**	<1.82E+03	<1.37E+03	**2.19E+01 J**	**2.40E+02 J**	**1.23E+03 J**	**1.62E+09**	**6.61E+06**	**3.50E+07**	**7.95E+09**	**1.09E+08**
PES-SB-6	23-Mar-05	36-38	Fine Sand	Strong Odor	**550**	**1.25E+04**	**1.24E+03 J** [f/]	**2.94E+07**	**8.30E+07**	**1.40E+03**	**1.19E+02 J**	**4.40E+03**	**1.08E+01 J**	**8.36E+08**	**4.31E+05**	**6.08E+05**	**2.95E+09**	**1.58E+08**
PES-SB-7	23-Mar-05	46-48	Fine Sand	Strong Odor	**300 J**	**6.48E+04**	<1.59E+03	**9.08E+07**	**3.25E+06**	**1.44E+02 J**	**4.94E+02 J**	<7.96E+02	**1.55E+07**	**2.84E+09**	**5.21E+06**	**7.96E+05**	**3.77E+10**	**1.93E+08**
PES-SB-9	21-Mar-05	46	Silty Fine Sand	Moderate Odor, Staining	**1,200**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**4.83E+08**
PES-SB-9	21-Mar-05	51	Silty Fine Sand	Mild Odor	**210 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**4.21E+07**
PES-SB-9	21-Mar-05	56	F-C Sand	Mild Odor	**350 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1.02E+07**
PES-SB-10	22-Mar-05	46	Fine Sand	Strong Odor	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**2.60E+08**
PES-MW-10B	31-Mar-05	49-50	Fine Sand	Mild Odor	**370 J**	<9.98E+02	<2.00E+03	**1.78E+03 J**	**5.58E+06**	**7.11E+02**	<9.98E+02	<9.98E+02	**2.40E+08**	**1.13E+09**	**6.04E+08**	**3.99E+06**	**3.25E+08**	**2.45E+08**
PES-SB-3	14-Mar-05	32	Sandy Silt	Very Mild Odor	NA	**2.45E+04**	<1.69E+03	**6.41E+04**	<1.69E+03	**1.26E+03**	**2.11E+02 J**	<8.43E+02	<1.69E+03	**6.67E+06**	<1.69E+03	<1.29E+03	**1.39E+05**	**4.52E+05**
Soil Samples Un-Impacted by Vegetable Oil																		
PES-SB-4	24-Mar-05	42-44	Fine Sand	None	**160 J**	<4.0E+02	<7.99E+02	**4.99E+04**	**1.24E+05**	<6.00E+02	<4.00E+02	<4.00E+02	<7.99E+02	**7.43E+07**	**4.05E+04**	<6.00E+02	**3.46E+05**	**1.98E+06**
PES-SB-5	25-Mar-05	42-44	F-m Sand	None	**230 J**	**4.17E+03**	<1.54E+03	**1.04E+05**	<1.54E+03	<1.15E+03	**1.55E+01 J**	<7.69E+02	<1.54E+03	**5.81E+07**	<1.54E+03	<1.15E+03	**3.42E+05**	**5.30E+05**
PES-SB-8	17-Mar-05	46	Silty Fine Sand	None	**280**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**2.37E+05**
PES-SB-8	17-Mar-05	51	Fine Sand and Silt	None	**280 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**6.26E+05**
PES-SB-8	17-Mar-05	56	F-C Sand	None	**330 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**2.11E+05**
PES-SB-10	22-Mar-05	51	Fine sand	None	**290 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1.49E+08**
PES-SB-10	22-Mar-05	56	F-M Sand	None	**240 J**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**7.98E+06**
PES-MW-10B	31-Mar-05	70-71	F-M Sand	None	**220 J**	**1.38E+03**	<1.97E+03	**1.06E+05**	**5.14E+06**	<1.48E+03	<9.84E+02	<9.84E+02	**6.61E+05**	**3.14E+08**	**6.89E+05**	<1.48E+03	**1.03E+07**	**1.53E+06**
PES-MW-11A	29-Mar-05	48-50	Fine Sand	None	**310 J**	**1.38E+03**	<8.71E+02	**6.83E+05**	**4.03E+06**	4.88E+00 J	<4.36E+02	**5.46E+02**	**1.44E+01 J**	**4.60E+08**	**6.74E+05**	<6.53E+02	**3.66E+07**	**7.50E+05**
PES-MW-12B	5-Apr-05	62-63	Tight Clay	None	**5,900**	**6.24E+07**	<1.83E+03	**5.90E+04**	**4.27E+05**	<1.38E+03	<9.17E+02	<9.17E+02	**9.34E+02**	**2.43E+08**	**9.08E+04**	**1.94E+02 J**	**3.38E+05**	**6.11E+05**
PES-MW-14B	4-Apr-05	68-70	Fine Sand	None	**370 J**	**2.04E+06**	<1.90E+03	**1.97E+04**	**1.41E+07**	<1.43E+03	**6.57E+02 J**	<9.51E+02	**1.03E+04**	**3.55E+08**	**4.62E+06**	<1.43E+03	**6.27E+06**	**7.54E+05**
PES-MW-13A	28-Mar-05	42	Fine Sand	None	**330 J**	**5.54E+04**	<1.46E+03	**1.84E+05**	<1.46E+03	<1.09E+03	**3.99E+01 J**	<7.28E+02	<1.46E+03	**3.54E+05**	<1.46E+03	<1.09E+03	**3.85E+05**	**1.26E+05**
Groundwater Samples Impacted by Vegetable Oil																		
PES-INJ-02	19-Apr-05	40.0 - 50.0	NA	NA	**2,400**	<2.5E-01	<5.0E-01	**9.82E+02**	**3.69E+04**	<3.75E-01	<2.50E-01	<2.50E-01	**1.65E+02**	**2.54E+05**	**3.87E+03**	<3.75E-01	**6.58E+03**	**7.14E+06**
PES-MW-10A	15-Apr-05	45.0 - 55.0	NA	NA	**190**	<2.5E-01	<5.0E-01	**2.87E+04**	**1.68E+05**	**5.85E+00**	<2.50E-01	<2.50E-01	<5.0E-01	**7.46E+07**	**2.23E+05**	**1.22E+04**	**1.36E+06**	**3.18E+06**
PES-MW-14A	12-Apr-05	55.0 - 65.0	NA	NA	**50**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**3.33E+05**
Groundwater Samples Un-Impacted by Vegetable Oil																		
18S	18-Apr-05	27.8 - 37.8	NA	NA	**3.8**	<2.5E-01	<5.0E-01	**1.34E+04**	**1.20E+05**	<3.75E-01	<2.50E-01	<2.50E-01	<5.0E-01	**3.34E+06**	**3.09E+03**	**1.09E+02**	**5.76E+05**	**2.47E+04**
26S	15-Apr-05	30.0 - 40.0	NA	NA	**2.2**	<2.5E-01	<5.0E-01	**4.13E+02**	**6.23E+03**	<3.75E-01	<2.50E-01	<2.50E-01	<5.0E-01	**1.16E+05**	**2.42E+03**	<3.75E-01	**2.61E+03**	**1.28E+04**
GWMS-46S	18-Apr-05	24.0 - 34.0	NA	NA	**3.7**	<2.5E-01	<5.0E-01	**1.52E+03**	**1.85E+04**	**3.86E-02 J**	<2.50E-01	<2.50E-01	<5.0E-01	**2.75E+06**	**4.75E+03**	**3.29E+01**	**4.18E+04**	**3.64E+03**
PES-MW-1	15-Apr-05	35.0 - 45.0	NA	NA	**3.0**	<2.5E-01	<5.0E-01	**3.11E+04**	**2.24E+05**	**8.61E-01**	<2.50E-01	<2.50E-01	**1.52E+04**	**1.05E+08**	**1.34E+05**	**3.19E+04**	**1.03E+06**	**1.13E+05**
PES-MW-6	15-Apr-05	35.0 - 45.0	NA	NA	**2.6**	**3.23E+00**	<5.0E-01	**3.16E+04**	**1.81E+05**	**8.61E-01**	<2.50E-01	<2.50E-01	<5.0E-01	**9.03E+07**	**1.02E+05**	**1.14E+04**	**1.16E+06**	**6.93E+04**
PES-MW-7	15-Apr-05	40.0 - 50.0	NA	NA	**29**	**4.79E+00**	**1.84E+00**	**1.87E+04**	**2.09E+05**	**2.68E+00**	<2.50E-01	<2.50E-01	<5.0E-01	**9.77E+05**	**2.21E+05**	**1.85E+03**	**7.27E+05**	**4.03E+05**
PES-MW-9	13-Apr-05	30.0 - 40.0	NA	NA	**3.6**	**4.19E+00**	<5.0E-01	**1.49E+03**	**9.34E+04**	<3.75E-01	<2.50E-01	<2.50E-01	<5.0E-01	**6.34E+07**	**7.08E+03**	**3.46E+01**	**1.78E+04**	**2.06E+04**
PES-MW-10B	14-Apr-05	65.0 - 75.0	NA	NA	**3.3**	**8.95E-01**	<5.0E-01	4.31E+02	9.99E+02	<3.75E-01	<2.50E-01	<2.50E-01	<5.0E-01	**2.55E+05**	**6.60E+03**	<3.75E-01	**2.33E+04**	**2.88E+04**
PES-MW-12A	12-Apr-05	35.0 - 45.0	NA	NA	**6.0**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**1.12E+05**

[a/] feet bgs = feet below ground surface.

[b/] mg/kg = micrograms per kilogram.

[c/] DHC = Dehalococcoides; DSM = Desulfuromonas; DHB = Dehalobacter; DSB = Desulfitobacterium; BVC = BAV-1 VC R-Dase; TCER = TCE R-Dase; sMMO = Soluble Methane Monooxygenase

[d/] cell/gram = live microbial cells per gram of soi

[e/] <1.75E+03 indicates that the analyte was not detected above the indicated method detection limit

[f/] J indicates that the analyte was detected at a concentration above the method detection limit but below the reporting limit resulting in an estimated valu

TABLE 7
SUMMARY OF AQUEOUS AND MINERALOGICAL INTRINSIC BIOREMEDIATION ASSESSMENT RESULTS
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Sample Depth (feet bgs)[a/]	Stratigraphic Classification	Evidence of Organic Carbon Impact	Total Organic Carbon (mg/kg)[d/]	$BAFe^{3+}$ [b/] (mg/kg)[c/]	WAEFe [b/] (mg/kg)	SAEFe [b/] (mg/kg)	$O\text{-}Fe^{total}$ [b/] (mg/kg)	BAMn [b/] (mg/kg)	WAEMn [b/] (mg/kg)	SAEMn [b/] (mg/kg)	AVS [b/] (mg/kg)	CES [b/] (mg/kg)
Samples Impacted by Vegetable Oil														
PES-SB-1	16-Mar-05	35	Silt	Mild Odor	**410**	**423**	**550**	**540**	<5.9	**15.6**	<100	<200	**1,600**	**6300**
PES-SB-2	15-Mar-05	38	F-M Sand	Strong Odor	**6,200**	**1,430**	**250**	**4,400**	**100**	**41.5**	<100	<200	**1,300**	**2,200**
PES-SB-3	14-Mar-05	42	Silty Fine Sand	Strong Odor, staining	**1,700**	**1,040**	**150**	**5,800**	<5.8	**4.5**	<100	<200	<1200	**1,500**
PES-SB-3	14-Mar-05	60	Silty Fine Sand	Mild Odor	NA	<6.0	**150**	**1,960**	<6.0	**1,890**	<100	<200	**1,200**	**1,900**
PES-SB-9	21-Mar-05	36	Silty Fine Sand	Moderate Odor	**350 J**	**929**	**600**	**6,500**	<5.8	**1.6**	<100	<200	<1200	**1400**
PES-SB-10	22-Mar-05	46	Fine Sand	Strong Odor	NA	**1,540**	**1,100**	**7,000**	**7.4**	**12.1**	<100	<200	<1200	**3200**
					Average Concentrations	**1,072** [g/]	**467**	**4,367**	**11.6**	**15** [g/]	<100	<200	**983**	**2,750**
Samples Un-Impacted by Vegetable Oil														
PES-SB-1	16-Mar-05	56	Silty Fine Sand	None	NA	**1,100**	**150**	**7,900**	**282**	**114**	<100	<200	**2,200**	**11,000**
PES-SB-2	15-Mar-05	60	Fine Sand	None	NA	**990**	**150**	**4,700**	<6.0	**12.0**	<100	<200	**1,300**	**1,800**
PES-SB-4	24-Mar-05	44	Fine Sand	None	**160 J**	**544**	**200**	**5,000**	<6.0	**20.3**	<100	<200	<1200	**4,100**
PES-SB-4	24-Mar-05	54	Fine Sand	None	NA	**1,020**	**150**	**1,800**	<6.1	**29.7**	<100	**7,000**	<1200	**14,000**
PES-SB-8	17-Mar-05	50	Silty Fine Sand	None	**230 J**	**2,920**	**300**	**2,700**	**656**	**96.2**	<100	<200	<1200	<1200
					Average Concentrations	**1,315**	**190**	**4,420**	**124**	**54**	<100	<200 [g/]	**1,060**	**6300**

[a/] feet bgs = feet below ground surface.

[b/] $BAFe^{3+}$ = bioavailable ferric iron; $WAEFe^{3+}$ = weak acid extractable ferric iron; $SAEFe^{3+}$ = strong acid extractable ferric iron; $WAEFe^{2+}$ = weak acid extractable ferrous iron; $SAEFe^{2+}$ = strong acid extractable ferrous iron; $O\text{-}Fe^{total}$ = total oxidized iron; BAMn = bioavailable manganese; WAEMn = weak acid manganese; SAEMn = strong acid extractable manganese; AVS = acid volatile sulfide; CES = chromium extractable sulfide.

[c/] mg/kg = micrograms per kilogram.

[d/] <25 indicates that the analyte was not detected above the indicated method detection limit.

[f/] J indicates that the analyte was detected at a concentration above the method detection limit but below the reporting limit resulting in an estimated value.

[g/] One value that is significantly different from the population was discluded from this calculation.

TABLE 8
SUMMARY OF GROUNDWATER ELEVATION DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well/Borehole Identification	Date	Elevation Datum (Feet amsl)[a/]	Depth to Water (Feet btoc)[b/]	Depth to Oil (Feet btoc)	Groundwater Elevation[c/] (Feet amsl)
MONITORING WELLS					
18-S	11-Apr-05	833.86	25.53	N.E. [e/]	808.33
	4-Nov-05		27.88	N.E.	805.98
26-S	11-Apr-05	834.06	25.98	N.E.	808.08
	4-Nov-05		28.30	N.E.	805.76
GWMS-27S	11-Apr-05	832.74	27.35	N.E.	805.39
	4-Nov-05		29.72	N.E.	803.02
GWMS-45S	11-Apr-05	832.13	24.10	N.E.	808.03
	4-Nov-05		26.37	N.E.	805.76
GWMS-46S	11-Apr-05	831.67	24.41	N.E.	807.26
	4-Nov-05		26.14	N.E.	805.53
GWMS-47S	11-Apr-05	834.83	30.47	N.E.	804.36
	4-Nov-05		32.62	N.E.	802.21
GWMS-49S	11-Apr-05	834.16	N.M. [d/]	N.E.	N.M.
	4-Nov-05		32.61	N.E.	801.55
MWW-13	11-Apr-05	833.33	28.53	N.E.	804.80
	4-Nov-05		30.31	N.E.	803.02
PES-MW-1	11-Apr-05	832.49	24.66	N.E.	807.83
	4-Nov-05		26.92	N.E.	805.57
PES-MW-2	11-Apr-05	832.41	24.66	N.E.	807.75
	4-Nov-05		26.93	N.E.	805.48
PES-MW-3	11-Apr-05	832.80	25.72	N.E.	807.08
	4-Nov-05		N.M.	N.E.	N.M.
PES-MW-4	11-Apr-05	832.57	27.91	N.E.	804.66
	4-Nov-05		N.M.	N.E.	N.M.
PES-MW-5	11-Apr-05	832.60	27.94	N.E.	804.66
	4-Nov-05		30.01	N.E.	802.59
PES-MW-6	11-Apr-05	832.41	24.63	N.E.	807.78
	4-Nov-05		26.90	N.E.	805.51
PES-MW-7	11-Apr-05	832.58	24.81	N.E.	807.77
	4-Nov-05		27.07	N.E.	805.51
PES-MW-8	11-Apr-05	832.64	25.00	N.E.	807.64
	4-Nov-05		27.26	N.E.	805.38
PES-MW-9	11-Apr-05	832.85	25.18	N.E.	807.67
	4-Nov-05		27.48	N.E.	805.37
PES-MW-10A	11-Apr-05	832.17	24.47	N.E.	807.70
	4-Nov-05		26.74	N.E.	805.43
PES-MW-10B	11-Apr-05	832.11	24.33	N.E.	807.78
	4-Nov-05		26.62	N.E.	805.49
PES-MW-11A	11-Apr-05	832.28	24.04	N.E.	808.24
	4-Nov-05		26.93	N.E.	805.35
PES-MW-12A	11-Apr-05	833.89	29.53	N.E.	804.36
			31.71	N.E.	802.18
PES-MW-12B	11-Apr-05	833.80	29.48	N.E.	804.32
			N.M.	N.E.	N.M.

TABLE 8
SUMMARY OF GROUNDWATER ELEVATION DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Well/Borehole Identification	Date	Elevation Datum (Feet amsl)[a/]	Depth to Water (Feet btoc)[b/]	Depth to Oil (Feet btoc)	Groundwater Elevation[c/] (Feet amsl)
PES-MW-13A	11-Apr-05	832.15	24.17	N.E.	807.98
	4-Nov-05		26.46	N.E.	805.69
PES-MW-14A	11-Apr-05	831.74	24.25	N.E.	807.49
	4-Nov-05		26.53	N.E.	805.21
PES-MW-14B	11-Apr-05	831.84	24.28	N.E.	807.56
	4-Nov-05		26.56	N.E.	805.28
PES-CW-1	11-Apr-05	832.01	27.17	N.E.	804.84
	4-Nov-05		29.36	N.E.	802.65
PES-CW-2	11-Apr-05	833.02	28.25	N.E.	804.77
	4-Nov-05		30.55	N.E.	802.47
PES-CW-3	11-Apr-05	835.47	30.89	N.E.	804.58
	4-Nov-05		33.09	N.E.	802.38
PES-BG-1	11-Apr-05	832.75	24.87	N.E.	807.88
	4-Nov-05		27.12	N.E.	805.63
PES-BG-2	11-Apr-05	832.73	24.91	N.E.	807.82
	4-Nov-05		27.18	N.E.	805.55
PES-BG-3	11-Apr-05	832.56	24.72	N.E.	807.84
	4-Nov-05		26.95	N.E.	805.61
INJECTION WELLS					
PES-INJ-1	11-Apr-05	832.42	24.64	N.E.	807.78
	4-Nov-05		26.84	N.E.	805.58
PES-INJ-2	11-Apr-05	832.87	25.14	N.E.	807.73
	4-Nov-05		27.38	N.E.	805.49
PES-INJ-3	11-Apr-05	832.71	25.28	25.04	807.65

[a/] Feet amsl indicates elevation in feet above mean sea level.

[b/] Feet btoc indicates depth in feet below top of casing.

[c/] Water elevations corrected for presence of oil using a specific gravity of 0.92.

[d/] N.M. = not measured.

[e/] N.E. = not encountered.

TABLE 9
PRE- AND POST-INJECTION HYDRAULIC CONDUCTIVITIES AND AVERAGE GROUNDWATER VELOCITIES
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Monitoring Well	Test Date	Rising or Falling Test	Screened Interval (ft bgs)[a/]	Casing Inside Diameter (inches)	Static Water Level (feet btoc)	Hydraulic Conductivity (K) (ft/day)[b/]	(cm/sec)[c/]	(gpd/ft^2)[d/]	Estimated Effective Porosity	Hydraulic Gradient (ft/ft)[e/]	Maximum Groundwater Velocity (ft/yr)[f/]
Pre-Injection Slug Tests in the Injection Area											
PES-INJ-1	12/7/01	Both	35-45	3.0	28.37	210	7.43E-02	1,574	0.25	0.002	522
PES-INJ-2	12/7/01	Both	30-40	3.0	28.84	221	7.79E-02	1,651	0.25	0.002	548
PES-INJ-3	12/7/01	Both	40-50	3.0	28.73	254	8.96E-02	1,898	0.25	0.002	630
PES-MW-1	12/7/01	Both	35-45	2.0	28.55	177	6.23E-02	1,321	0.25	0.002	438
GEOMETRIC MEAN						**214**	**7.54E-02**	**1,597**	**0.25**	**0.00**	**530**
Pre-Injection Slug Tests Down Gradient From the Injection Area											
PES-MW-3	12/6/01	Both	35-45	2.0	29.66	23	8.15E-03	173	0.25	0.059	1,988
PES-MW-4	12/6/01	Both	30-40	2.0	31.20	14	5.03E-03	107	0.25	0.059	1,228
PES-MW-8	12/7/01	Both	30-40	2.0	28.70	78	2.77E-02	587	0.25	0.059	6,754
GEOMETRIC MEAN						**30**	**1.04E-02**	**221**	**0.25**	**0.059**	**2,545**
PES-CW-1	12/6/01	Both	30-40	2.0	31.38	**196**	**6.92E-02**	**1,467**	**0.25**	**0.002**	**572**
December 2002 Post-Injection Slug Tests in the Injection Area											
PES-INJ-1	12/14/02	Both	35-45	3.0	28.73	11	3.87E-03	82	0.25	0.002	27
PES-INJ-2	12/14/02	Rise	30-40	3.0	28.82	7.9	2.79E-03	59	0.25	0.002	20
PES-INJ-3	12/14/02	Both	40-50	3.0	28.73	13	4.59E-03	97	0.25	0.002	32
GEOMETRIC MEAN						**10**	**3.67E-03**	**78**	**0.25**	**0.002**	**26**
December 2002 Post-Injection Slug Tests Down Gradient From the Injection Area											
PES-MW-1	12/16/02	Rise	35-45	2.0	26.67	83	2.93E-02	622	0.25	0.041	4,974
PES-MW-6	12/16/02	Rise	35-45	2.0	26.60	70	2.46E-02	522	0.25	0.041	4,179
PES-MW-7	12/16/02	Rise	35-45	2.0	26.79	110	3.87E-02	820	0.25	0.041	6,560
GEOMETRIC MEAN						**86**	**3.04E-02**	**643**	**0.25**	**0.04**	**5,147**
April 2003 Post-Injection Slug Tests in the Injection Area											
PES-INJ-1	4/5/03	Both	35-45	3.0	27.73	1.0	3.39E-04	7.2	0.25	0.002	2.4
PES-INJ-2	4/4/03	Both	40-50	3.0	28.23	8.4	2.96E-03	63	0.25	0.002	21
GEOMETRIC MEAN						**2.8**	**1.00E-03**	**21**	**0.25**	**0.00**	**7.0**
April 2003 Post-Injection Slug Tests Down Gradient From the Injection Area											
PES-MW-1	4/4/03	Both	35-45	2.0	27.77	124	4.36E-02	925	0.25	0.041	7,399
PES-MW-6	4/4/03	Both	35-45	2.0	27.71	68	2.40E-02	509	0.25	0.041	4,071
PES-MW-7	12/16/02	Both	35-45	2.0	26.79	85	2.99E-02	633	0.25	0.041	5,069
GEOMETRIC MEAN						**86**	**3.04E-02**	**644**	**0.25**	**0.041**	**5,156**
August 2003 Post-Injection Slug Tests in the Injection Area											
PES-INJ-1	8/28/03	Both	35-45	3.0	27.73	0.3	9.00E-05	1.9	0.25	0.002	0.6
PES-INJ-2	8/27/03	Both	40-50	3.0	28.23	2.7	9.60E-04	20	0.25	0.002	6.8
GEOMETRIC MEAN FOR POST-INJECTION TESTS						**0.8**	**2.94E-04**	**6.2**	**0.25**	**0.00**	**2.1**
August 2003 Post-Injection Slug Tests Down Gradient From the Injection Area											
PES-MW-1	8/27/03	Both	35-45	2.0	27.77	94	3.31E-02	702	0.25	0.020	2,741
PES-MW-6	8/27/03	Both	35-45	2.0	27.71	94	3.32E-02	704	0.25	0.023	3,159
PES-MW-7	8/27/03	Both	35-45	2.0	26.79	66	2.34E-02	496	0.25	0.012	1,161
GEOMETRIC MEAN FOR POST-INJECTION TESTS						**81**	**2.87E-02**	**607**	**0.25**	**0.018**	**2,094**

[a/] ft bgs = feet below ground surface.
[b/] ft/day = feet per day.
[c/] cm/sec = centimeters per second.
[d/] gpd/ft^2 = gallons per day per square foot.
[e/] ft/ft = foot per foot.
[f/] ft/yr = feet per year.
[g/] Pre-injection mean calculations are for wells upgradient of PES-MW8 and PES-MW9.
[h/] Pre-injection mean calculations are for wells PES-MW3, PES-MW8, and PES-MW9.
[i/] Pre-injection calculations are for well PES-CW1.

TABLE 10
SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Date	PCE[a/] (µg/L)[b/]	TCE[a/] (µg/L)	*cis-* 1,2-DCE[a/] (µg/L)	*trans* 1,2-DCE[a/] (µg/L)	1,1-DCE[a/] (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA[a/] (µg/L)	1,1-DCA[a/] (µg/L)	1,2-DCA[a/] (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Bromodichloro -methane (µg/L)	2-Butanone (µg/L)	Acetone (µg/L)	Benzene (µg/L)	Toluene (µg/L)
MONITORING WELLS																	
18-S	18-Apr-05	0.45 U	**400**	**96**	**27**	**0.87 J**	**0.37 J**	0.90 U	**0.89 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**39**	0.41 U	0.67 U
MS-26S	15-Apr-05	**0.63 J**	**230**	**48**	**2.7**	**0.61 J**	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
GWMS-27S	12-Nov-01	0.39 U[c/]	0.44 U	0.99 U	0.38 U	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	**3.3**	**12**	0.42 U
	11-Feb-02	0.39 U	**0.76 J**[d/]	**2.4**	0.38 U	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	21-May-02	0.39 U	**89**	**12**	**0.97**	0.47 U	0.17 U	0.53 U	**1.2**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.39 U	**170**	**50**	**5.1**	**0.62 J**	0.17 U	0.53 U	**0.62 J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	9-Dec-02	0.25 U	**54**	**33**	**0.99 J**	**0.58 J**	0.30 U	0.23 U	**0.94 J**	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	7-Apr-03	0.24 U	**140 J**	**10**	**1.5**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	18-Aug-03	**0.30 J**	**290**	**45**	**6.4**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	**23**	0.11 U	0.11 U
MS-36S	22-Apr-05	0.45 U	**21**	**270**	**51**	0.57 U	**1.7**	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
MS-44S	18-Apr-05	0.45 U	**77**	**19**	**2.3**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**4.0 J**	0.41 U	0.67 U
GWMS-45S	18-Apr-05	0.45 U	**180**	**550**	**62**	**2.3**	**0.28 J**	0.90 U	**1.5**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**5.7**	0.41 U	0.67 U
GWMS-46S	19-Nov-01	78 U	**20,000**	200 U	**200**	94 U	34 U	110 U	94 U	0.52 U	0.54 U	0.47 U	0.42 U	210 U	330 U	88 U	84 U
	18-Feb-02	39 U	**14,000**	**120**	**140**	47 U	17 U	53 U	47 U	52 U	54 U	47 U	42 U	100 U	160 U	44 U	42 U
	22-May-02	1.9 U	**5,600**	**55**	**61**	**4.6**	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	28-Aug-02	0.78 U	**4,900**	**29**	**29**	**2.5**	**0.92 J**	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.8 U	2.1 U	**5.0 J**	0.88 U	0.84 U
	11-Dec-02	1.2 U	**7,200**	**65**	**73**	**6.4**	1.5 U	1.2 U	1.0 U	1.7 U	1.4 U	0.95 U	1.6 U	4.3 U	10 U	1.0 U	1.1 U
	9-Apr-03	0.24 U	**2,600**	**24**	**32**	**2.6**	**0.6 J**	0.23 U	**1.0**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	20-Aug-03	0.24 U	**4,500**	**57**	**85**	**3.5**	**1.3 J**	0.23 U	**1.8**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	18-Apr-05	0.45 U	**1,700**	**55**	**51**	**1.7**	**0.45 J**	0.90 U	**1.8**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
	17-Nov-05	0.45 U	**1,300**	**35**	**36**	**2.0**	**0.43 J**	0.90 U	**1.7**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
GWMS-47S	14-Nov-01	**0.92**	**44**	**22**	**1.1**	0.47 U	0.17 U	0.53 U	**0.89**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	12-Feb-02	**1.1 J**	**180**	**9.9**	**2.1**	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	21-May-02	**0.60**	**220**	**9.3**	**3.3**	**0.50**	0.17 U	0.53 U	**1.1**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.39 U	**120**	**6.6**	**3.3**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	10-Dec-02	**0.64 J**	62 U	**25**	**1.4**	0.26 U	0.30 U	0.23 U	0.20 U	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	8-Apr-03	**1.5**	66 U	**20**	1.4 U	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	19-Aug-03	**1.1**	**57**	**14**	**1.2**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	11-Apr-05	**0.87 J**	**42**	**4.1**	0.89 U	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
MS-53PC	11-Apr-05	0.45 U	**0.83 J**	0.83 U	0.19 U	0.75 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.7 U	0.41 U	0.67 U
PES-MW-1	16-Nov-01	3.9 U	**1,100**	**14**	**15**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.40 U	4.7 U	4.2 U	10 U	16 U	4.4 U	4.2 U
	15-Feb-02	7.8 U	**1,100**	20 U	**20 J**	9.4 U	3.4 U	11 U	9.4 U	10 U	11 U	9.4 U	8.4 U	21 U	33 U	8.8 U	8.4 U
	22-May-02	0.78 U	**3,200**	**450**	**75**	**4.5**	0.34 U	1.1 U	**1.6**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	28-Aug-02	0.39 U	**2,600**	**630**	**39**	**3.8**	**1.3 J**	0.53 U	**1.5**	0.52 U	0.54 U	0.47 U	0.42 U	12 U	8.2 U	0.44 U	0.42 U
	12-Dec-02	0.50 U	**1,700**	**230**	**26**	**2.5**	0.6 U	0.46 U	**1.4 J**	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	1.0 U	0.40 U	**4.1**
	10-Apr-03	0.24 U	**1,300**	**370**	**30**	**2.0**	0.17 U	0.23 U	**1.2**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	21-Aug-03	0.24 U	**1,200**	**1100**	**79**	**3.2**	**1.4 J**	0.23 U	**2.3**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	15-Apr-05	0.45 U	**380**	**210**	**16**	**0.99 J**	0.18 U	0.90 U	**1.0**	0.36 U	0.49 U	0.37 U	0.56 U	4.30 U	**2.5 J**	0.41 U	0.67 U
PES-MW-2	15-Nov-01	7.8 U	**2,100**	**22**	**27**	9.4 U	3.4 U	11 U	9.4 U	10 U	11 U	9.4 U	8.4 U	21 U	33 U	8.8 U	8.4 U
	14-Feb-02	20 U	**3,600**	50 U	**68**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
	22-May-02	0.78 U	**2,200**	**62**	**39**	**3.1**	**0.59**	1.1 U	**1.7**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	**9.3**	0.88 U	0.84 U
	28-Aug-02	0.78 U	**3,200**	**21**	**26**	**2.0 J**	0.34 U	1.1 U	**1.3 J**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	11-Dec-02	0.50 U	**2,600**	**24**	**32**	**3.0**	0.60 U	0.5 U	**1.4 J**	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	4.0 U	0.40 U	0.44 U
	9-Apr-03	0.24 U	**2,900**	**46**	**55**	**2.7**	**0.53 J**	0.23 U	**1.6**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	20-Aug-03	0.24 U	**2,000**	**27**	**57**	**2.2**	**0.39 J**	0.23 U	**2.0**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	14-Apr-05	0.45 U	**930**	**45**	**18**	**1.5**	0.18 U	0.90 U	**0.93 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-3	14-Nov-01	20 U	**5,000**	**73**	**110**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
	13-Feb-02	20 U	**6,100**	**120**	**170**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
	21-May-02	1.9 U	**6,200**	**220**	**160**	**5.3**	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	27-Aug-02	1.9 U	**5,900**	**390**	**95**	**4.7 J**	**2.2 J**	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	10-Dec-02	1.2 U	**5,000**	**260**	**120**	**5.7**	1.5 U	1.2 U	1.0 U	1.7 U	1.4 U	0.95 U	1.6 U	4.3 U	10 U	1.0 U	1.1 U
	8-Apr-03	0.24 U	**3,800**	**300**	**130**	**3.7**	**1.1 J**	0.2 U	**2.3**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	20-Aug-03	0.24 U	**2,400**	**320**	**110**	**3.0**	**0.90 J**	0.23 U	**2.8**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	14-Apr-05	0.45 U	**830**	**170**	**51**	**1.8**	**0.34 J**	0.90 U	**1.4**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-4	14-Nov-01	7.8 U	**3,300**	**83**	**120**	9.4 U	3.4 U	11 U	9.4 U	10 U	11 U	9.4 U	8.4 U	21 U	33 U	8.8 U	8.4 U
	12-Feb-02	7.8 U	**3,300**	**88**	**110**	9.4 U	3.4 U	11 U	9.4 U	10 U	11 U	9.4 U	8.4 U	21 U	33 U	8.8 U	8.4 U
	21-May-02	0.78 U	**4,200**	**140**	**190**	**4.1**	0.34 U	1.1 U	**3.5**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	27-Aug-02	0.78 U	**3,100**	**56**	**67**	**2.2**	0.34 U	1.1 U	**1.7 J**	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	10-Dec-02	0.50 U	**2,100**	**72**	**82**	**2.6**	0.60 U	0.46 U	**1.9 J**	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	4.0 U	0.40 U	0.44 U
	8-Apr-03	0.24 U	**2,300**	**80**	**100**	**2.1**	0.17 U	0.23 U	0.17 U	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	19-Aug-03	**0.73 J**	**2,600**	**130**	**160**	**2.8**	**0.86 J**	0.23 U	**3.2**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	12-Apr-05	0.45 U	**820**	**200**	**86**	**1.5**	**0.33 J**	0.90 U	**2.2**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**180**	0.41 U	0.67 U
	14-Nov-05	0.45 U	**1,000**	**140**	**76**	**1.9**	0.18 U	0.90 U	**2.0**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U

TABLE 10
SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Date	PCE[a/] (µg/L)[b/]	TCE[a/] (µg/L)	*cis-* 1,2-DCE[a/] (µg/L)	*trans* 1,2-DCE[a/] (µg/L)	1,1-DCE[a/] (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA[a/] (µg/L)	1,1-DCA[a/] (µg/L)	1,2-DCA[a/] (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Bromodichloro -methane (µg/L)	2-Butanone (µg/L)	Acetone (µg/L)	Benzene (µg/L)	Toluene (µg/L)
PES-MW-5	14-Nov-01	0.39 U	**75**	**29**	**1.8**	0.47 U	0.17 U	0.53 U	**0.76**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	12-Feb-02	0.39 U	**77**	**32**	**2.1**	0.47 U	0.17 U	0.53 U	0.74 **J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	21-May-02	0.39 U	**82**	**34**	**1.8**	0.47 U	0.17 U	0.53 U	**0.67**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	27-Aug-02	0.39 U	**1,000**	**21**	**21**	**1.0**	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	10-Dec-02	0.25 U	120 U	**94**	**4.4**	0.26 U	0.3 U	0.23 U	**2.8**	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	8-Apr-03	0.24 U	**780**	**53**	**17**	0.22 U	0.17 U	0.23 U	**0.97 J**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	19-Aug-03	**0.28 J**	**880**	**28**	**30**	**1.7**	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	12-Apr-05	0.45 U	**38**	**8.7**	**0.92 J**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**9.1**	0.41 U	**0.73 J**
PES-MW-6	15-Nov-01	20 U	**6,200**	**88**	**140**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	21 U
	15-Feb-02	20 U	**5,800**	**100**	**150**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	52 U	82 U	22 U	4.2 U
	23-May-02	1.9 U	**5,100**	**84**	**130**	**3.2**	**1.7**	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	28-Aug-02	1.9 U	**6,600**	**87**	**83**	**3.2 J**	**1.4 J**	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	**17 J**	2.2 U	2.1 U
	12-Dec-02	0.50 U	**3,800**	**240**	**71**	**3.9**	0.60 U	0.46 U	**1.6 J**	0.68 U	0.58 U	0.38 U	0.64 U	1.7 U	4.0 U	0.4 U	0.44 U
	10-Apr-03	0.24 U	**3,000**	**180**	**100**	**2.7**	**0.77 J**	0.23 U	**2.5**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.1 U	0.11 U
	21-Aug-03	0.24 U	**2,000**	**97**	**61**	**2.8**	**0.59 J**	0.23 U	**2.1**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	15-Apr-05	0.45 U	**700**	**170**	**27**	**1.7**	**0.27 J**	0.90 U	**0.87 J**	0.36 U	0.49 U	0.37 U	0.91 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-7	16-Nov-01	0.78 U	**300**	**5.2**	0.78 U	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	14-Feb-02	1.9 U	**540**	**7.9**	**7.4**	2.3 U	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	**74**	8.2 U	2.2 U	2.1 U
	22-May-02	0.39 U	**980**	**14**	**18**	**2.2**	**0.36**	0.53 U	**1.6**	0.52 U	0.54 U	0.47 U	0.42 U	**130**	**340**	0.44 U	0.42 U
	28-Aug-02	**0.48 J**	**1,300**	**65**	**11**	**2.1**	**0.42 J**	0.53 U	**0.98 J**	0.52 U	0.54 U	0.47 U	0.42 U	**66**	**55**	0.44 U	0.42 U
	12-Dec-02	0.25 U	**350 J**	**180**	**8.3**	**2.0**	0.53 U	0.23 U	**1.0**	0.34 U	0.29 U	0.19 U	0.32 U	**320**	2.0 U	0.20 U	**4.5**
	10-Apr-03	0.24 U	12 U	**270**	**5.5**	**0.99 J**	**0.69 J**	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.32 U	**1,800**	**65**	0.11 U	0.11 U
	21-Aug-03	0.24 U	**2.1**	**410**	**7.2**	0.22 U	**0.90 J**	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	**89**	**14**	0.11 U	0.11 U
	15-Apr-05	0.45 U	**4.1**	**130**	**4.7**	0.57 U	**0.29 J**	0.90 U	**0.89 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**4.9 J**	0.41 U	0.67 U
	17-Nov-05	0.45 U	**1.0**	**150**	**2.7**	0.57 U	**0.80 J**	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	**0.88 J**
PES-MW-8	15-Nov-01	20 U	**6,700**	**160**	**220**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	10 U	82 U	22 U	21 U
	14-Feb-02	20 U	**4,700**	**150**	**200**	23 U	8.5 U	26 U	23 U	26 U	27 U	23 U	21 U	10 U	82 U	22 U	21 U
	22-May-02	1.9 U	**5,400**	**180**	**210**	**4.8**	**2.2**	2.6 U	**4.0**	2.6 U	2.7 U	23 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	27-Aug-02	1.9 U	**5,700**	**130**	**130**	**4.0 J**	**1.8 J**	2.6 U	**3.8 J**	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	**19 J**	2.2 U	2.1 U
	12-Dec-02	1.2 U	**5,500**	**70**	**73**	1.3 U	1.5 U	1.2 U	1.0 U	1.7 U	1.4 U	0.95 U	1.6 U	4.3 U	10 U	1.0 U	1.1 U
	9-Apr-03	0.2 U	**3,000**	**120**	**130**	**3.0**	**0.81 J**	0.23 U	**2.8**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	21-Aug-03	**0.32 J**	**2,200**	**76**	**96**	**3.3**	0.17 U	0.23 U	**1.9**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	14-Apr-05	0.45 U	**1,100**	**90**	**57**	**1.6**	**0.34 J**	0.90 U	**1.5**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-9	15-Nov-01	3.9 U	**1,400**	**15**	**20**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	52 U	16 U	4.4 U	0.42 U
	13-Feb-02	3.9 U	**1,300**	**17**	**20**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	52 U	16 U	4.4 U	4.2 U
	22-May-02	0.78 U	**410**	**1,800**	**63**	**8.2**	**1.2**	1.1 U	**1.5**	1.0 U	1.1 U	0.94 U	0.84 U	**91**	**150**	0.88 U	0.84 U
	27-Aug-02	1.9 U	**120**	**3,000**	**67**	**9.6**	**12**	2.6 U	2.3 U	2.6 U	2.7 U	2.30 U	2.1 U	**290**	**180**	2.2 U	2.1 U
	11-Dec-02	0.50 U	20 U	**1,500**	**33**	**6.8**	**5.7**	0.46 U	0.4 U	0.68 U	0.58 U	0.38 U	0.64 U	**180**	**68**	0.4 U	0.44 U
	9-Apr-03	0.24 U	**2,300**	**180**	**42**	**2.7**	0.17 U	0.23 U	**1.3**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	20-Aug-03	0.24 U	**2,200**	**370**	**110**	**3.2**	**0.71 J**	0.23 U	**2.8**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	13-Apr-05	2.2 U	**490**	**270**	**30**	**1.0**	0.90 U	4.5 U	**0.77 J**	1.8 U	2.40 U	1.8 U	2.8 U	22 U	12 U	2.0 U	3.4 U
	16-Nov-05	0.45 U	**28**	**500**	**18**	**3.2**	0.18 U	0.90 U	**1.0**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-CW-1	13-Nov-01	1.9 U	**630**	**12**	**7.5**	2.3 U	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	11-Feb-02	0.78 U	**170**	**9.5**	**2.4**	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	20-May-02	0.39 U	**170**	**8.2**	**2.3**	0.47 U	0.17 U	0.53 U	**0.86**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.89 **J**	**61**	**39**	**3.8**	0.47 U	0.17 U	0.53 U	**0.65 J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	9-Dec-02	**0.53 J**	**250 J**	**9.6**	**2.9**	**0.67** J	0.30 U	0.23 U	**0.99 J**	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	7-Apr-03	**1.5**	**54**	**9.6**	**0.93 J**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	18-Aug-03	**2.0**	**67**	**8.9**	**0.97 J**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
PES-CW-2	13-Nov-01	1.9 U	**290**	**7.3**	1.9 U	2.3 U	0.85 U	2.6 U	2.3 U	2.3 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	11-Feb-02	0.78 U	**350**	**9.0**	**4.8**	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	20-May-02	0.39 U	**210**	**7.0**	**2.1**	**0.71**	0.17 U	0.53 U	**1.4**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.39 U	**200**	**14**	**3.7**	**0.47 J**	0.17 U	0.53 U	**0.73 J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	9-Dec-02	0.25 U	**230 J**	**6.4**	**1.5**	0.26 U	0.30 U	0.23 U	1.0 U	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	7-Apr-03	**0.75 J**	**100**	**11**	**1.1**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	**0.75 J**
	19-Aug-03	**1.3**	**87**	**14**	**1.5**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	11-Apr-05	0.45 U	**110**	**4.9**	0.89 U	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**12**	0.41 U	0.67 U
	14-Nov-05	**0.66 J**	**63**	**6.4**	0.89 U	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U

TABLE 10
SUMMARY OF VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Date	PCE[a/] (µg/L)[b/]	TCE[a/] (µg/L)	*cis-* 1,2-DCE[a/] (µg/L)	*trans* 1,2-DCE[a/] (µg/L)	1,1-DCE[a/] (µg/L)	Vinyl Chloride (µg/L)	1,1,1-TCA[a/] (µg/L)	1,1-DCA[a/] (µg/L)	1,2-DCA[a/] (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Bromodichloro -methane (µg/L)	2-Butanone (µg/L)	Acetone (µg/L)	Benzene (µg/L)	Toluene (µg/L)
PES-CW-3	13-Nov-01	0.78 U	**240**	**5.7**	0.76 U	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	12-Feb-02	0.78 U	**330**	**6.5**	**2.3**	0.94 U	0.34 U	1.1 U	0.94 U	1.0 U	1.1 U	0.94 U	0.84 U	2.1 U	3.3 U	0.88 U	0.84 U
	20-May-02	0.39 U	**200**	**7.0**	**1.3**	**0.77**	0.17 U	0.53 U	**1.4**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	26-Aug-02	0.39 U	**230**	**5.8**	**2.9**	0.47 U	0.17 U	0.53 U	**0.88 J**	0.52 U	0.54 U	0.47 U	0.42 U	1.0 U	1.6 U	0.44 U	0.42 U
	10-Dec-02	0.25 U	**220 J**	**6.0**	**0.98 J**	**0.58 J**	0.30 U	0.23 U	**1.0**	0.34 U	0.29 U	0.19 U	0.32 U	0.86 U	2.0 U	0.20 U	0.22 U
	8-Apr-03	0.24 U	190 U	4.7 U	0.25 U	0.22 U	0.17 U	0.23 U	**0.72 J**	0.17 U	0.25 U	0.19 U	0.32 U	0.86 U	2.0 U	0.11 U	0.11 U
	19-Aug-03	0.24 U	**160**	**8.6**	**1.2**	0.22 U	0.17 U	0.23 U	**0.76 J**	0.17 U	0.25 U	0.19 U	0.11 U	0.86 U	2.0 U	0.11 U	0.11 U
	11-Apr-05	0.45 U	**120**	**4.5**	0.89 U	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
	14-Nov-05	0.45 U	**140**	**6.0**	**1.1**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-10A	15-Apr-05	0.45 U	**6.8**	**180**	**4.8**	0.57 U	**0.67 J**	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	**870**	**66**	0.41 U	0.67 U
	16-Nov-05	0.45 U	**1.2**	**81**	**1.4**	0.57 U	**0.56 J**	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	**250**	**9.7**	0.41 U	0.67 U
PES-MW-10B	14-Apr-05	**3.5**	**48**	**3.7**	0.89 U	0.57 U	0.18 U	0.90 U	**0.83 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**2.4 J**	0.41 U	0.67 U
	15-Nov-05	**3.9**	**49**	**4.1**	0.89 U	0.57 U	0.18 U	0.90 U	**0.77 J**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-11A	13-Apr-05	0.45 U	**100**	**110**	**6.5**	0.57 U	0.18 U	0.90 U	**1.1**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	**3.7 J**	0.41 U	0.67 U
	15-Nov-05	0.45 U	**48**	**28**	0.89 U	0.57 U	0.18 U	0.90 U	**1.1**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
PES-MW-12A	12-Apr-05	0.45 U	**80**	**20**	**3.0**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	**1.3**	0.56 U	**11**	**24**	0.41 U	**0.79 J**
	15-Nov-05	0.90 U	**350**	**13**	**5.0**	1.1 U	0.36 U	1.8 U	1.5 U	0.72 U	0.98 U	0.74 U	1.1 U	8.6 U	4.6 U	0.82 U	1.3 U
PES-MW-12B	20-Apr-05	1.1 U	**330**	**22**	**8.7**	1.4 U	0.45 U	2.2 U	1.9 U	1.9 U	1.2 U	0.92 U	1.4 U	11 U	5.8 U	1.0 U	1.7 U
	15-Nov-05	0.90 U	**290**	**12**	**6.3**	1.1 U	0.36 U	1.8 U	1.5 U	0.72 U	0.98 U	0.74 U	1.1 U	8.6 U	4.6 U	0.82 U	1.3 U
PES-MW-13A	22-Apr-05	0.45 U	**380**	**8.1**	**6.2**	0.57 U	0.18 U	0.90 U	**1.2**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
	16-Nov-05	1.1 U	**230**	**5.8**	**5.0**	1.4 U	0.45 U	2.2 U	1.9 U	1.9 U	1.2 U	0.92 U	1.4 U	11 U	5.8 U	1.0 U	1.7 U
PES-MW-14A	12-Apr-05	0.45 U	**87**	**490**	**25**	**1.0**	**0.85 J**	0.90 U	**0.81 J**	0.36 U	0.49 U	**1.8**	0.56 U	4.3 U	**190**	0.41 U	**0.74 J**
	15-Nov-05	2.2 U	**87**	**510**	**12**	2.8 U	**1.3 J**	4.5 U	3.8 U	1.8 U	2.4 U	1.8 U	2.8 U	22 U	12 U	2.0 U	3.4 U
PES-MW-14B	20-Apr-05	0.45 U	**110**	**1.3**	**5.6**	0.57 U	0.18 U	0.90 U	**1.4**	0.36 U	0.49 U	**0.38 J**	0.56 U	4.3 U	**3.1 J**	0.41 U	0.67 U
	16-Nov-05	0.45 U	**110**	**5.5**	**1.2**	0.57 U	0.18 U	0.90 U	**1.4**	0.36 U	0.49 U	0.37 U	0.56 U	4.3 U	2.3 U	0.41 U	0.67 U
INJECTION WELLS																	
PES-INJ-1	19-Nov-01	3.9 U	**1,400**	**16**	**20**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	10 U	16 U	4.4 U	4.2 U
	18-Feb-02	3.9 U	**70**	**15**	3.8 U	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	**340**	16 U	4.4 U	4.2 U
	23-May-02	0.39 U	**47**	**13**	**2.7**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**420**	**360**	0.44 U	**1.1**
	29-Aug-02	0.39 U	**29**	**9.6**	**2.3**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**370**	**270**	0.44 U	0.42 U
	13-Dec-02	0.25 U	**37 J**	**19**	**2.6**	**0.64**	**0.83**	0.23 U	0.20 U	0.34 U	0.29 U	0.19 U	0.32 U	**360**	**130**	0.20 U	0.7 U
	10-Apr-03	0.24 U	**66**	**16**	**2.0**	0.22 U	**0.63 J**	0.23 U	0.22 U	0.17 U	0.25 U	0.19 U	0.32 U	**320**	**66**	0.11 U	0.11 U
	22-Aug-03	0.24 U	**20**	**17**	**1.8**	0.22 U	**0.7 J**	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	**450**	**170**	0.11 U	**0.9 J**
	19-Apr-05	1.80 U	**10**	**11**	3.6 U	2.30 U	0.72 U	3.60 U	3.0 U	1.40 U	2.00 U	1.50 U	2.20 U	**1,900**	**640**	1.60 U	**2.7** U
PES-INJ-2	19-Nov-01	1.90 U	**630**	**8.6**	**7.9**	2.3 U	0.85 U	2.6 U	2.3 U	2.6 U	2.7 U	2.3 U	2.1 U	5.2 U	8.2 U	2.2 U	2.1 U
	15-Feb-02	3.9 U	**45**	9.90 U	3.8 U	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	**390**	16 U	4.4 U	4.2 U
Veg. Oil	12-Feb-02	1,100 U	**6,200**	680 U	850 U	800 U	1,000 U	480 U	620 U	800 U	610 U	670 U	660 U	940 U	650 U	590 U	**2,000 J**
	23-May-02	0.39 U	**25**	**3.8**	**2.9**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**670**	**150**	0.44 U	**0.45**
	29-Aug-02	0.39 U	**16**	**3.4**	**2.4**	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**590**	**160**	0.44 U	0.42 U
	13-Dec-02	0.25 U	**18 J**	**3.4**	**2.7**	0.34 U	0.30 U	0.23 U	0.20 U	0.34 U	0.34 U	0.19 U	0.32 U	**1,200**	**320**	0.20 U	**9.4**
	11-Apr-03	0.24 U	**16**	**3.1**	**2.2**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.32 U	**870**	**92**	0.11 U	**3.8**
	22-Aug-03	0.24 U	**13**	**3.0**	**2.1**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	**1,100**	**170**	0.11 U	**2.4**
	19-Apr-05	0.45 U	**14**	**2.9**	**1.9**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	**820**	**150**	0.41 U	**1.1**
PES-INJ-3	16-Nov-01	3.9 U	**760**	9.9 U	**9.1**	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	10 U	16 U	4.4 U	4.2 U
	18-Feb-02	3.9 U	**29**	9.9 U	3.8 U	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	**490**	**240**	4.4 U	4.2 U
Veg. Oil	12-Feb-02	1,100 U	**7,800**	680 U	850 U	800 U	1,000 U	480 U	620 U	720 U	610 U	670 U	660 U	940 U	650 U	590 U	770 U
	23-May-02	0.39 U	**21**	**3.7**	0.39 U	0.47 U	0.17 U	0.53 U	0.47 U	0.52 U	0.54 U	0.47 U	0.42 U	**770**	**610**	0.44 U	0.42 U
	29-Aug-02	3.90 U	**10**	9.9 U	3.8 U	4.7 U	1.7 U	5.3 U	4.7 U	5.2 U	5.4 U	4.7 U	4.2 U	**440**	**710**	4.4 U	4.2 U
Veg. Oil	29-Aug-02	570 U	**4,900**	550 U	560 U	620 U	940 U	520 U	530 U	610 U	610 U	540 U	470 U	**3,300**	**2,800**	470 U	640 U
	13-Dec-02	0.25 U	**12 J**	**3.8**	**2.8**	0.26 U	0.30 U	0.23 U	0.20 U	0.34 U	0.29 U	0.19 U	0.32 U	**560**	**680**	0.20 U	0.22 U
Veg. Oil	9-Dec-02	1,100 U	**3,500**	680 U	850 U	800 U	1,000 U	480 U	620 U	720 U	610 U	670 U	660 U	**4,000**	**1,600 J**	590 U	**4,800**
	11-Apr-03	0.24 U	**9.8**	**3.1**	**2.2**	0.22 U	0.17 U	0.23 U	0.20 U	0.17 U	0.25 U	0.19 U	0.32 U	**900**	**400**	0.11 U	0.11 U
	22-Aug-03	0.24 U	**10**	**3.5**	**2.4**	0.22 U	0.17 U	0.23 U	0.2 U	0.17 U	0.25 U	0.19 U	0.11 U	**1,200**	**470**	0.11 U	0.11 U
	19-Apr-05	0.45 U	**8.7**	**3.3**	**1.9**	0.57 U	0.18 U	0.90 U	0.75 U	0.36 U	0.49 U	0.37 U	0.56 U	**960**	**480**	0.41 U	0.67 U
	17-Nov-05	9.0 U	**15.0 J**	17 U	18 U	11 U	3.6 U	18 U	15 U	7.2 U	9.8 U	7.4 U	11 U	**1,500**	**2,600**	8.2 U	**24**
PRE-INJECTION OIL SAMPLES																	
PES-INJ-2A-OIL	11-Dec-02	1,000 U	920 U	670 U	840 U	790 U	1,000 U	470 U	610 U	710 U	600 U	650 U	650 U	880 U	640 U	580 U	750 U
PES-INJ-2-OIL	11-Dec-02	1,000 U	950 U	670 U	840 U	790 U	1,000 U	470 U	610 U	710 U	600 U	650 U	650 U	900 U	640 U	580 U	750 U

[a/] PCE = tetrachloroethene; TCE = trichloroethene; DCE = dichloroethene; TCA = trichloroethane; DCA = dichloroethane.

[b/] µg/L = micrograms per liter.

[c/] U = Analyte was not detected at a concentration above the method detection limit.

[d/] J = Analyte was detected at a concentration above the method detection limit and below the reporting limit.

TABLE 11
SUMMARY OF GROUNDWATER GEOCHEMICAL DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Methane (µg/L)[a/]	Ethane (µg/L)	Ethene (µg/L)	TOC[b/] (mg/L)[c/]	Dissolved Oxygen (mg/L)	Dissolved Hydrogen (nM)[d/]	Nitrate (mg/L)	Nitrite (mg/L)	Ferrous Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Ammonia (mg/L)	Total Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Chloride (mg/L)	Redox Potential (mV)[e/]	pH (SU)[f/]	Temperature (°C)[g/]	Specific Conductivity (µs/cm)[h/]
MONITORING WELLS																					
18-S	4/18/2005	NM[j/]	NM	NM	3.8	R[l/]	NM	NM	NM	1.44	2.0	180	0.01	NM	NM	35	NM	-87	7.49	11.9	1,238
MS-26S	4/15/2005	NM	NM	NM	2.2	R	NM	NM	NM	0.19	0.9	160	0.06	NM	NM	25	NM	-96	7.52	12.8	1,309
MS-27S	12-Nov-01	46 J[i/]	1.6 U	1.4 U	3.7	0.34	Na[l/]	<0.2[k/]	<0.2	0.05	0.1	19	<0.01	0.12	119	1.25	20	-123	9.81	12.5	1,136
	11-Feb-02	36	1.6 U	1.4 U	1.4	0.02	Na	<0.13	<0.077	0.22	<0.6	43	0.02	0.06	163	18	75	-371	8.06	11.4	575
	21-May-02	2.0 U	1.6 U	1.4 U	<1.7	0.33	3.3	<0.13	<0.077	0.90	<0.6	170	0.02	0.02	340	35	55	-315	7.00	10.8	1,068
	26-Aug-02	2.7 J	1.6 U	1.4 U	9.9	0.06	2.2	<0.13	<0.077	0.83	<0.6	170	<0.01	0.01	425	60	70	-85	6.36	12.8	1,052
	9-Dec-02	4.3	0.064	0.036	16	0.26	3.0	<0.057	<0.018	0.73	<0.6	170	<0.01	0.05	357	45	60	60	7.17	9.8	645
	7-Apr-03	2.6	0.022	0.023	2.8	0.23	5.2	<0.058	<0.018	0.82	<0.6	150	0.03	0.01	272	30	60	-77	7.24	10.4	1,011
	18-Aug-03	4.5	0.033	0.056	1.2 J	1.34	2.4	<0.058	<0.018	0.86	1.1	140	0.01	0.02	340	55	75	-47	NM	15.4	142
MS-36S	22-Apr-05	NM	NM	NM	3.4	R	NM	NM	NM	0.05	0.1	60	0.51	NM	NM	15	NM	-184	8.18	15.1	1,538
MS-44S	18-Apr-05	NM	NM	NM	0.4	R	NM	NM	NM	0.17	2.2	170	<0.01	NM	NM	25	NM	-50	7.07	11.5	1,380
GWMS-45S	18-Apr-05	20	0.095	0.071	7.0	R	NM	NM	NM	1.08	1.4	160	0.06	NM	NM	25	NM	-94	7.59	11.2	1,130
GWMS-46S	19-Nov-01	2.0 U	1.6 U	1.4 U	1.8	0.57	Na	<0.2	<0.2	2.2	1.9	210	0.01	0.07	391	50	15	-82	7.04	10.1	1,134
	18-Feb-02	2.0 U	1.6 U	1.4 U	3.6	0.96	Na	<0.13	<0.077	1.9	1.0	340	0.01	0.09	85	10	25	-276	6.95	10.7	1,048
	22-May-02	2.0 U	1.6 U	1.4 U	2.3	<0.01	1.1	<0.13	<0.077	1.4	1.4	180	<0.01	0.08	323	30	55	-276	7.30	13.1	1,132
	28-Aug-02	6.0	1.6 U	1.4 U	10	<0.01	2.0	<0.13	<0.077	1.2	1.3	170	0.01	0.06	340	40	50	-229	7.13	12.9	1,045
	11-Dec-02	2.0 U	0.014	0.069	18	0.12	1.2	<0.057	<0.018	1.7	1.1	210	<0.01	0.09	357	35	40	R	7.37	10.0	564
	9-Apr-03	4.2	0.007	0.030	1.0 J	1.52	1.6	<0.058	<0.018	1.7	1.8	190	0.01	0.09	323	35	45	-58	7.31	10.6	1,137
	20-Aug-03	18	0.010	0.046	<1.0	3.9	1.8	<0.058	<0.018	2.4	1.9	190	0.01	0.07	306	35	45	-95	7.18	16.3	1,094
	18-Apr-05	30	0.071	0.080	3.7	R	NM	NM	NM	1.1	2.0	210	<0.01	NM	NM	25	NM	-115	7.45	12.0	1,132
	17-Nov-05	NM	NM	NM	3.7J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	7.40	9.3	979
GWMS-47S	14-Nov-01	2.0 U	1.6 U	1.4 U	1.7	1.7	Na	1.3	<0.2	<0.01	1.8	70	0.13	<0.01	459	134	50	115	6.82	12.9	1,102
	12-Feb-02	2.0 U	1.6 U	1.4 U	1.6	8.8	Na	<0.13	<0.077	<0.01	<0.6	160	<0.01	<0.01	442	50	65	-14	7.21	10.7	1,092
	21-May-02	2.0 U	1.6 U	1.4 U	<1.1	6.1	2.6	0.59	<0.077	0.01	<0.6	140	<0.01	0.01	340	35	50	-31	7.10	12.0	1,078
	26-Aug-02	2.0 U	1.6 U	1.4 U	11	3.7	3.0	0.45	<0.077	0.04	<0.6	100	0.03	0.03	340	45	55	149	6.94	13.9	1,054
	10-Dec-02	2.0 U	0.007	0.013	38	2.4	3.1	2.5	<0.018	<0.01	<0.6	111	<0.01	<0.01	476	65	95	265	7.09	10.4	818
	8-Apr-03	0.32	0.005 U	0.010	1.1	1.0	1.8	1.1	<0.018	0.02	<0.6	170	<0.01	0.02	442	40	75	112	7.02	9.9	1,283
	19-Aug-03	0.46	0.006 U	0.001 U	1 J	2.3	3.2	1.1	<0.018	0.00	0.6	100	<0.01	<0.01	408	65	95	208	6.88	20.9	1,227
	11-Apr-05	NM	NM	NM	3.8	R	NM	NM	NM	0.04	<0.6	170	0.01	NM	NM	65	NM	16	7.11	11.6	1,405
MS-53PC	11-Apr-05	NM	NM	NM	110	NA	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NA	NA	NA	NA
PES-MW-1	16-Nov-01	2.0 U	1.6 U	1.4 U	1.0	1.3	Na	<0.2	<0.2	0.02	0.6	100	<0.01	0.03	255	15	55	-50	8.29	11.0	873
	15-Feb-02	2.0 U	1.6 U	1.4 U	30	1.1	Na	<0.13	<0.077	0.91	1.2	290	0.18	0.04	408	40	50	-324	7.25	10.5	1,032
	22-May-02	2.9	1.6 U	1.4 U	3	<0.01	2.3	<0.13	<0.077	0.37	0.6	200	0.02	0.05	374	40	45	-245	7.40	11.9	1,217
	28-Aug-02	170	1.6 U	1.4 U	14	<0.01	2.1	<0.13	<0.077	1.3	1.1	140	0.18	0.06	357	50	55	-299	7.06	12.8	1,084
	12-Dec-02	380	0.014	0.079	12	R	3.9	<0.057	<0.018	1.2	0.6	200	0.16	0.05	425	45	45	R	7.42	10.6	R
	10-Apr-03	2,000	0.002 J	0.050	< 1.0	1.23	1.7	<0.058	<0.018	3.0	1.6	180	<0.01	0.07	374	45	50	-241	7.30	11.7	1,154
	21-Aug-03	0.16	0.004 J	0.013	1.4 J	0.49	1.5	<0.058	<0.018	2.4	1.9	160	0.52	0.05	374	45	50	-164	7.28	14.3	1,098
	15-Apr-05	4,600	0.095	0.120	3.0	R	NM	NM	NM	3.1	7.6	220	0.09	NM	NM	35	NM	-132	7.23	11.6	1,158
PES-MW-2	15-Nov-01	2.0 U	1.6 U	1.4 U	1.7	0.39	Na	0.2	<0.2	0.17	<0.6	190	<0.01	0.09	1,700	50	60	-185	11.66	11.5	1,181
	14-Feb-02	2.0 U	1.6 U	1.4 U	3.2	0.74	Na	<0.13	<0.077	0.04	<0.6	340	<0.01	0.05	340	25	50	-188	7.82	10.3	1,005
	22-May-02	2.0 U	1.6 U	1.4 U	2.5	0.07	1.8	<0.13	<0.077	0.03	<0.6	230	0.02	0.06	323	30	45	-160	7.40	13.8	1,139
	28-Aug-02	2.5 J	1.6 U	1.4 U	12	0.19	2.9	<0.13	<0.077	0.11	1.2	220	0.08	0.06	340	45	45	-176	6.98	12.7	1,091
	11-Dec-02	150	0.008	0.054	6.5	0.03	1.4	<0.057	<0.018	0.02	0.6	200	0.01	0.07	374	30	40	R	7.45	10.3	589
	9-Apr-03	1,700	0.001 U	0.025	< 1.0	1.60	1.3	<0.058	<0.018	0.04	1.5	230	0.01	0.07	347	30	45	-26	7.37	10.8	1,180
	20-Aug-03	0.3	0.007	0.023	1.0 J	0.48	1.8	<0.058	<0.018	0.02	1.5	210	<0.01	0.03	340	30	55	-1	7.27	15.6	1,095
	14-Apr-05	11	0.022	0.070	1.9	R	NM	NM	NM	0.03	1.1	200	0.01	NM	NM	35	NM	-57	7.29	11.5	1,071
PES-MW-3	14-Nov-01	2.0 U	1.6 U	1.4 U	1.6	0.35	Na	<0.2	<0.2	0.48	0.9	150	<0.01	0.02	340	40	45	-76	7.05	12.1	1,078
	13-Feb-02	2.0 U	1.6 U	1.4 U	0.2	0.46	Na	<0.13	<0.077	1.3	1.4	200	<0.01	0.05	391	40	45	-288	7.09	10.3	1,092
	21-May-02	2.0 U	1.6 U	1.4 U	2.9	0.12	1.4	<0.13	<0.077	1.8	0.8	200	0.03	0.06	391	45	55	-311	7.30	12.8	1,151
	27-Aug-02	4.4	1.6 U	1.4 U	13	<0.01	2.0	<0.13	<0.077	2.1	1.5	150	0.04	0.08	374	65	55	-136	6.81	12.5	1,106
	10-Dec-02	210	0.020	0.081	24	R	1.5	<0.057	<0.018	2.1	0.8	220	0.14	0.09	425	35	50	-60	7.35	10.6	727
	8-Apr-03	1,700	0.005 U	0.007	2.0 J	4.91	1.9	<0.058	<0.018	2.7	0.8	190	0.04	0.09	408	35	55	-100	7.29	10.8	1,178
	20-Aug-03	1.3	0.012	0.026	2.6 J	1.2	3.4	<0.058	<0.018	2.0	1.9	200	0.12	0.04	357	50	55	-93	7.07	17.8	1,134
	14-Apr-05	88	0.038	0.065	1.6	R	NM	NM	NM	2.4	1.4	180	0.02	NM	NM	40	NM	-86	7.09	11.4	1,106

TABLE 11
SUMMARY OF GROUNDWATER GEOCHEMICAL DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Methane (µg/L)[a/]	Ethane (µg/L)	Ethene (µg/L)	TOC [b/] (mg/L) [c/]	Dissolved Oxygen (mg/L)	Dissolved Hydrogen (nM)[d/]	Nitrate (mg/L)	Nitrite (mg/L)	Ferrous Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Ammonia (mg/L)	Total Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Chloride (mg/L)	Redox Potential (mV)[e/]	pH (SU)[f/]	Temperature (°C) [g/]	Specific Conductivity (µs/cm) [h/]
PES-MW-4	14-Nov-01	2.0 U	1.6 U	1.4 U	Na	1.3	Na	<0.2	<0.2	<0.01	0.9	230	<0.01	0.02	374	55	70	-48	7.12	12.1	1,115
	12-Feb-02	2.0 U	1.6 U	1.4 U	1.3	3.0	Na	<0.13	<0.077	0.11	0.7	120	<0.01	0.03	408	35	65	-133	7.38	9.0	1,045
	21-May-02	2.0 U	1.6 U	1.4 U	2.0	1.2	2.9	0.18	<0.077	0.13	<0.6	180	<0.01	0.03	357	40	65	-129	7.10	13.1	1,123
	27-Aug-02	2.0 U	1.3 U	1.4 U	10	0.12	3.8	<0.13	<0.077	0.04	<0.6	200	0.08	0.05	340	60	70	6	6.62	12.2	1,083
	10-Dec-02	2.0 U	0.018	0.068	15	R	1.6	0.56	<0.018	0.31	<0.6	180	<0.01	0.07	408	35	65	20	7.30	10.7	740
	8-Apr-03	0.42	0.008	0.025	1.7 J	3.16	1.6	<0.058	<0.018	0.39	0.6	190	<0.01	0.05	340	30	60	4	7.28	10.6	1,133
	19-Aug-03	2.6	0.019	0.082	1.2 J	0.87	1.4	<0.058	<0.018	0.26	1.9	90	0.01	0.11	340	35	60	-47	7.07	20.5	1,087
	12-Apr-05	5.8	0.056	0.085	51	R	NM	NM	NM	0.46	1.4	180	0.20	NM	NM	50	NM	15	7.20	10.2	941
	14-Nov-05	NM	NM	NM	4.1J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	47	7.10	10.3	1,028
PES-MW-5	14-Nov-01	2.0 U	1.6 U	1.4 U	1.6	1.4	Na	0.58	<0.2	0.02	<0.6	120	<0.01	<0.01	422	85	105	104	6.80	11.7	1,279
	12-Feb-02	2.0 U	1.6 U	1.4 U	1.7	3.8	Na	<0.13	<0.077	0.04	<0.6	90	0.02	0.01	561	70	120	-64	7.04	10.1	1,241
	21-May-02	2.0 U	1.6 U	1.4 U	1.8	0.7	2.3	0.28	<0.077	0.01	<0.6	130	<0.01	<0.01	459	70	100	-65	6.90	13.1	1,266
	27-Aug-02	2.0 U	1.6 U	1.4 U	12	5.5	2.1	0.26	<0.077	<0.01	<0.6	120	<0.01	<0.01	202	50	80	197	6.17	11.9	1,011
	10-Dec-02	2.0 U	0.008	0.009	23	2.5	1.4	<0.057	<0.018	0.02	<0.6	111	<0.01	0.02	442	60	95	240	7.08	10.5	828
	8-Apr-03	0.04	0.005 U	0.009	< 1.0	3.3	1.9	0.87	< 0.018	0.06	<0.6	150	<0.01	<0.01	408	60	105	131	7.08	10.6	1,367
	19-Aug-03	0.1	0.015	0.026	<1.0	1.4	2.2	<0.058	<0.018	0.02	0.7	180	<0.01	0.01	306	40	85	218	7.10	21.9	1,081
	12-Apr-05	4.5	0.050	0.062	6.9	R	NM	NM	NM	0.02	<0.6	170	0.01	NM	NM	35	NM	13	6.99	9.4	1,403
PES-MW-6	15-Nov-01	2.0 U	1.6 U	1.4 U	1.4	0.22	Na	<0.2	<0.2	0.01	<0.6	160	0.20	0.04	306	40	55	-158	7.79	11.5	1,030
	15-Feb-02	2.0 U	1.6 U	1.4 U	12	0.35	Na	<0.13	<0.077	0.47	1.1	290	1.2	0.04	408	50	55	-408	7.29	11.0	1,107
	23-May-02	2.0 U	1.6 U	1.4 U	<0.83	0.03	1.9	<0.13	<0.077	0.28	<0.6	190	1.8	0.07	391	30	45	-160	7.30	11.1	1,256
	28-Aug-02	3.8	1.6 U	1.4 U	7	<0.01	2.6	<0.13	<0.077	0.52	1.0	170	0.80	0.07	357	70	55	-296	7.09	12.7	1,109
	12-Dec-02	70	0.019	0.082	16	0.90	3.5	<0.057	<0.018	0.55	<0.6	220	0.59	0.08	391	35	50	R	7.31	10.5	R
	10-Apr-03	12	0.012	0.051	<1.0	0.88	2.9	<0.058	<0.018	0.51	1.1	180	0.61	0.09	340	25	50	-292	7.30	11.0	1,163
	21-Aug-03	8.0	0.010	0.066	1.7 J	3.6	1.9	<0.058	<0.018	0.56	2.2	200	0.31	0.06	306	40	60	-98	7.19	14.3	1,075
	15-Apr-05	210	0.051	0.110	2.6	R	NM	NM	NM	0.38	1.5	200	0.02	NM	NM	30	NM	-89	7.37	12.3	1,104
PES-MW-7	16-Nov-01	2.0 U	1.6 U	1.4 U	1.4	2.3	Na	<0.2	<0.2	<0.01	<0.6	110	<0.01	0.03	238	50	60	-26	8.96	11.6	854
	14-Feb-02	2.0 U	1.6 U	1.4 U	26,000	0.50	Na	<0.13	<0.077	1.9	3.0	160	0.51	0.04	765	85	55	-314	6.93	10.9	1,552
	22-May-02	3.4	1.6 U	1.4 U	150	0.01	5.8	<0.65	2.2	7.8	18	80	0.35	0.23	663	200	60	-188	6.70	12.3	1,531
	28-Aug-02	7,400	1.6 U	1.4 U	150	0.06	3.2	<0.13	1.0	3.9	9.8	60	1.5	2.5	561	180	60	-395	6.58	12.5	1,351
	12-Dec-02	18,000	0.005 U	0.95	200	0.78	4.3	<0.057	0.69	6.3	29	100	0.36	0.70	629	190	60	R	6.74	10.6	R
	10-Apr-03	9,800	0.170	0.076	210	R	3.1	<0.058	<0.018	3.2	28	<7.0	0.25	0.50	629	200	60	-173	6.60	11.9	1,523
	21-Aug-03	8,500	0.006 U	0.001 U	53	0.29	2.5	<0.058	<0.018	4.7	33	<7.0	2.50	1.15	544	165	60	-161	6.71	13.0	1,285
	15-Apr-05	16,000	0.100	0.092	29	R	NM	NM	NM	5.2	33	140	0.07	NM	NM	70	NM	-110	6.80	11.4	1,123
	17-Nov-05	NM	NM	NM	110	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-43	6.88	9.9	1,827
PES-MW-8	15-Nov-01	2.0 U	1.6 U	1.4 U	2.4	0.43	Na	<0.2	<0.2	0.70	0.9	110	<0.01	0.04	408	55	65	-54	7.02	11.6	1,120
	14-Feb-02	2.0 U	1.6 U	1.4 U	6.8	0.55	Na	<0.13	<0.077	1.3	0.8	310	<0.01	0.05	442	40	50	-200	7.29	9.8	1,129
	22-May-02	2.0 U	1.6 U	1.4 U	1.9	0.07	1.2	<0.13	<0.077	1.1	0.7	220	<0.01	<0.01	408	40	60	-85	7.20	12.1	1,318
	28-Aug-02	2.6 J	1.6 U	1.4 U	14	<0.01	2.1	<0.13	<0.077	1.2	1.3	220	0.01	0.04	374	75	60	-69	6.83	12.7	1,160
	12-Dec-02	35	0.016	0.062	4.6	0.12	1.2	<0.057	<0.018	1.2	1.0	180	0.05	0.06	357	35	50	-80	7.15	10.2	R
	9-Apr-03	3.7	0.002 J	0.011	<1.0	2.55	1.7	<0.058	<0.018	1.2	1.4	160	<0.01	0.04	374	30	55	-128	7.25	11.2	1,201
	21-Aug-03	12	0.015	0.066	3.7	0.29	1.6	<0.058	<0.018	1.1	2.3	150	0.01	0.04	306	50	70	-82	7.08	13.3	1,087
	14-Apr-05	11	0.035	0.049	1.7	R	NM	NM	NM	1.0	1.5	180	0.03	NM	NM	50	NM	-87	7.22	11.9	1,097
PES-MW-9	15-Nov-01	2.0 U	1.6 U	1.4 U	1.4	1.1	Na	<0.2	<0.2	0.40	1.1	140	0.01	0.03	391	45	60	-123	7.09	10.9	1,051
	13-Feb-02	2.0 U	1.6 U	1.4 U	1.8	0.79	Na	<0.13	<0.077	0.55	0.9	220	0.01	0.05	340	25	50	-183	7.30	10.7	1,018
	22-May-02	2.0 U	1.6 U	1.4 U	58	0.15	1.5	<0.65	<0.39	4.7	2.1	30	0.04	<0.01	510	80	50	-460	7.10	11.2	1,346
	27-Aug-02	28	5.4 J	13	180	<0.01	8.2	<0.13	0.66	3.3	8.5	7.0	0.22	0.60	646	250	80	-180	6.58	12.5	1,445
	11-Dec-02	3,200	0.012	0.210	240	0.15	3.3	<0.057	0.37	NA	13	<7.0	0.06	1.1	646	600	60	R	7.03	10.4	1,650
	9-Apr-03	5,500	0.001 U	0.035	2.6	1.88	1.8	<0.058	<0.018	4.1	10	110	0.12	0.68	347	65	45	-192	7.52	11.1	1,182
	21-Aug-03	5,000	0.006 U	0.001 U	1.5 J	0.42	1.9	<0.058	<0.018	4.7	2.7	135	0.10	0.25	340	55	60	-180	7.30	15.9	1,141
	16-Apr-05	300	0.012	0.030	3.6	R	NM	NM	NM	2.5	1.6	190	0.02	NM	NM	35	NM	-93	7.41	10.7	991
	16-Nov-05	NM	NM	NM	2.8J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-207	6.27	10.5	1,023
PES-CW-1	13-Nov-01	2.0 U	1.6 U	1.4 U	1.0	0.25	Na	<0.2	<0.2	0.04	0.6	80	<0.01	<0.01	333	60	60	-25	7.08	11.9	1,064
	11-Feb-02	2.0 U	1.6 U	1.4 U	1.3	0.92	Na	0.49	<0.077	0.05	<0.6	130	<0.01	0.03	387	116	65	-195	7.23	11.3	1,079
	20-May-02	2.0 U	1.6 U	1.4 U	<1.3	2.3	2.3	0.20	<0.077	0.01	<0.6	160	<0.01	0.01	347	60	65	-28	7.04	11.2	1,079
	26-Aug-02	2.0 U	1.6 U	1.4 U	11	1.8	3.3	0.19	<0.077	0.04	<0.6	110	<0.01	0.04	408	70	110	45	6.47	13.1	1,258
	9-Dec-02	2.6 J	0.017	0.014	1.6	0.25	2.5	<0.057	<0.018	0.03	<0.6	120	<0.01	0.04	391	35	60	120	7.27	10.4	770
	7-Apr-03	0.23	0.005 U	0.013	< 1.0	0.65	3.1	0.73	<0.018	<0.01	<0.6	140	<0.01	0.02	408	50	125	72	6.89	10.4	1,354
	18-Aug-03	0.16	0.004 J	0.013	1.6 J	0.71	1.5	0.65	<0.018	0.03	2.0	160	<0.01	0.02	357	70	130	103	7.00	15.7	215

TABLE 11
SUMMARY OF GROUNDWATER GEOCHEMICAL DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Methane (µg/L)[a/]	Ethane (µg/L)	Ethene (µg/L)	TOC [b/] (mg/L) [c/]	Dissolved Oxygen (mg/L)	Dissolved Hydrogen (nM)[d/]	Nitrate (mg/L)	Nitrite (mg/L)	Ferrous Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Ammonia (mg/L)	Total Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Chloride (mg/L)	Redox Potential (mV)[e/]	pH (SU)[f/]	Temperature (°C) [g/]	Specific Conductivity (µs/cm) [h/]
PES-CW-2	13-Nov-01	2.0 U	1.6 U	1.4 U	0.97	0.28	Na	<0.2	<0.2	0.30	1.1	50	<0.01	0.05	323	74	65	-32	7.05	12.0	1,064
	11-Feb-02	2.0 U	1.6 U	1.4 U	0.97	2.3	Na	<0.13	<0.077	<0.01	<0.6	190	<0.01	0.01	340	45	55	-78	7.21	10.6	1,011
	20-May-02	2.0 U	1.6 U	1.4 U	<1.0	1.1	2.9	<0.13	<0.077	0.06	<0.6	140	<0.01	0.06	357	45	60	-44	7.10	11.9	1,020
	26-Aug-02	2.0 U	1.6 U	1.4 U	12	1.1	3.3	0.15	<0.077	0.02	<0.6	130	0.01	<0.01	357	55	80	82	6.59	13.2	1,134
	9-Dec-02	4.0	0.017	0.006	5.4	0.33	1.8	<0.057	<0.018	0.01	<0.6	170	<0.01	0.09	357	30	55	210	7.35	10.6	819
	7-Apr-03	0.12	0.005 U	0.011	< 1.0	0.85	3.8	0.84	<0.018	<0.01	0.6	140	<0.01	0.02	425	45	100	128	6.94	10.6	1,292
	19-Aug-03	0.3	0.007	0.023	1.7 J	1.79	1.8	1.10	<0.018	0.02	0.4	120	<0.01	0.01	391	50	125	87	6.50	15.8	140
	11-Apr-05	NM	NM	NM	3.6	R	NM	NM	NM	0.03	0.3	160	<0.01	NM	NM	60	NM	-3	7.14	11.9	1,164
	14-Nov-05	NM	NM	NM	30	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-9	7.22	11.2	1,273
PES-CW-3	13-Nov-01	2.0 U	1.6 U	1.4 U	0.75	0.60	Na	<0.2	<0.2	0.02	1.0	110	<0.01	0.04	357	70	63	32	7.07	12.8	1,014
	12-Feb-02	2.0 U	1.6 U	1.4 U	2.1	1.0	Na	<0.13	<0.077	<0.01	<0.6	150	<0.01	0.03	323	25	50	71	7.03	10.4	988
	20-May-02	2.0 U	1.6 U	1.4 U	<1.6	1.5	2.6	<0.13	<0.077	0.04	<0.6	130	<0.01	0.03	340	40	60	-60	7.10	14.0	920
	26-Aug-02	2.8	1.6 U	1.4 U	11	1.3	6.7	<0.13	<0.077	0.04	<0.6	150	0.01	0.08	238	35	50	81	6.74	13.4	962
	10-Dec-02	2.0 U	0.016	0.013	14	0.20	2.6	<0.057	<0.018	0.02	<0.6	140	<0.01	0.05	306	30	55	200	7.02	10.2	458
	7-Apr-03	1.2	0.007	0.011	< 1.0	0.80	3.0	<0.058	<0.018	0.03	<0.6	180	<0.01	0.01	289	30	55	103	7.29	7.4	1,056
	19-Aug-03	1.3	0.012	0.026	<1.0	0.98	3.4	0.360	<0.018	0.01	1.0	140	<0.01	<0.01	340	50	80	215	6.92	20.0	1,142
	11-Apr-05	NM	NM	NM	3.7	R	NM	NM	NM	0.03	0.4	170	<0.01	NM	NM	45	NM	29	7.50	11.5	1,153
	14-Nov-05	NM	NM	NM	3.5J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	38	7.11	10.7	1,029
PES-MW-10A	15-Apr-05	21,000	0.360	0.110	190	R	NM	NM	NM	5.1	17	87	0.10	NM	NM	120	NM	-111	6.61	11.4	1,365
	16-Nov-05	NM	NM	NM	51	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-202	5.54	10.0	1,037
PES-MW-10B	14-Apr-05	4.5	0.034	0.045	3.3	R	NM	NM	NM	0.04	0.8	180	0.04	NM	NM	40	NM	-52	7.15	13.0	1,064
	15-Nov-05	NM	NM	NM	<5.0	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	19	7.32	10.5	901
PES-MW-11A	13-Apr-05	3,900	0.090	0.066	8.9	R	NM	NM	NM	3.1	2.4	150	0.01	NM	NM	35	NM	-21	6.91	10.8	1,047
	15-Nov-05	NM	NM	NM	3.6J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	4	7.40	10.6	807
PES-MW-12A	12-Apr-05	2.1	0.042	0.080	6.0	R	NM	NM	NM	0.08	<0.6	150	0.03	NM	NM	35	NM	60	7.31	11.7	1,291
	15-Nov-05	NM	NM	NM	2.9J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	32	7.26	10.5	1,270
PES-MW-12B	20-Apr-05	7.8	0.140	0.180	5.5	R	NM	NM	NM	0.03	1.6	150	0.01	NM	NM	25	NM	18	7.08	10.6	1,348
	15-Nov-05	NM	NM	NM	3.5J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-6	7.39	10.7	827
PES-MW-13A	22-Apr-05	4.8	0.032	0.042	5.1	R	NM	NM	NM	0.19	1.3	190	0.01	NM	NM	25	NM	-34	7.57	13.5	1,102
	16-Nov-05	NM	NM	NM	3.0J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	210	6.00	10.3	942
PES-MW-14A	12-Apr-05	6,900	0.150	0.180	50	R	NM	NM	NM	3.19	2.3	130	0.12	NM	NM	65	NM	-44	6.88	12.0	901
	15-Nov-05	NM	NM	NM	7.1	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	-12	7.05	10.3	1,044
PES-MW-14B	20-Apr-05	7.7	0.120	0.140	4.2J	R	NM	NM	NM	0.01	0.7	220	0.01	NM	NM	20	NM	57	7.28	12.1	1,082
	16-Nov-05	NM	NM	NM	2.8J	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	195	6.03	10.7	984
INJECTION WELLS																					
PES-INJ-1	19-Nov-01	2.0 U	1.6 U	1.4 U	1.1	0.14	Na	<0.2	<0.2	0.01	0.6	140	<0.01	0.03	323	25	55	-1	7.62	10.7	1,015
	18-Feb-02	200 U	160 U	140 U	11,000	0.15	Na	19	<13	NA	NA	NA	36	6.3	8,500	8,500	85	-325	5.67	10.9	4,660
	23-May-02	140 U	280 U	250 U	2,500	0.10	4.4	0.9	9.7	280	3.3	<7.0	1.0	0.6	21,250	5,500	2,500	-89	5.50	11.3	1,702
	29-Aug-02	190	70	41	2,900	<0.01	16	<2.6	21	17	6.6	<7.0	0.11	0.1	2,975	2,500	125	-98	5.23	12.0	4,520
	13-Dec-02	630	35	24	2,600	R	5.2	<2.5	7.9	13	6.9	<7.0	0.14	1.3	4,675	2,800	125	-40	5.25	8.2	R
	10-Apr-03	73	3.1	7.6	2,300	1.58	4.4	<0.58	13	3.9	16	<7.0	0.04	0.7	4,250	2,500	250	-91	5.24	12.6	3,310
	22-Aug-03	660	21	25	2,100	0.65	32	<0.58	9.8 J	4.8	9.3	<7.0	0.03	0.5	2,040	2,000	100	-33	5.21	12.1	2,950
	19-Apr-05	14,000	6.3	4.6	2,500	R	NM	NM	NM	3.6	14	<7.0	6.9	NM	NM	2,500	NM	0 R	5.60	11.6	3,081
PES-INJ-2	19-Nov-01	2.0 U	1.6 U	1.4 U	0.8	<0.01	Na	<0.2	<0.2	0.01	<0.6	130	<0.01	0.04	289	25	55	74	7.77	10.5	971
	15-Feb-02	50 U	40 U	35 U	9,500	0.01	Na	34	110	NA	NA	NA	9	7.0	8,500	3,000	2,500	-323	5.44	10.6	4,200
	23-May-02	28 U	56 U	50 U	4,100	0.05	93	2.7	19	2.6	14	<7.0	1.9	3.1	29,750	7,500	2,500	-93	5.10	12.3	1,872
	29-Aug-02	13	5	2.8	4,130	<0.01	4.9	<2.6	28	NA	17	23	2.9	0.72	2,550	2,250	100	-55	5.10	12.4	4,870
	13-Dec-02	11	0.34	1.4	4,400	R	12	20	13	NA	5.4	61	0.8	0.68	4,250	2,900	100	-30	5.10	10.5	R
	11-Apr-03	99	0.35	1.4	2,300	0.63	39	<0.58	11 J	NA	78	<7.0	0.8	0.40	5,100	2,750	100	-33	5.09	11.1	3,160
	22-Aug-03	1,500	1.1	4.5	2,000	1.05	300	<0.58	6.7 J	2.4	69	<7.0	0.3	0.56	1,700	1,300	150	1	5.11	12.8	2,650
	19-Apr-05	5,800	1.1	3.8	2,400	R	NM	NM	NM	1.6	50	5	12	NM	NM	3,500	NM	5 R	5.35	11.0	2,434

TABLE 11
SUMMARY OF GROUNDWATER GEOCHEMICAL DATA
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Sample Date	Methane (µg/L)[a/]	Ethane (µg/L)	Ethene (µg/L)	TOC [b/] (mg/L) [c/]	Dissolved Oxygen (mg/L)	Dissolved Hydrogen (nM)[d/]	Nitrate (mg/L)	Nitrite (mg/L)	Ferrous Iron (mg/L)	Manganese (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Ammonia (mg/L)	Total Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Chloride (mg/L)	Redox Potential (mV)[e/]	pH (SU)[f/]	Temperature (°C) [g/]	Specific Conductivity (µs/cm) [h/]
PES-INJ-3	16-Nov-01	2.0 U	1.6 U	1.4 U	1.0	0.92	Na	<0.2	<0.2	0.01	0.6	110	<0.01	0.06	255	10	60	-79	8.47	12.1	881
	18-Feb-02	200 U	160 U	140 U	6,900	0.67	Na	15	<7.7	NA	NA	NA	23	3.3	11,900	4,500	60	-317	5.65	10.8	6,310
	23-May-02	140 U	280 U	250 U	4,100	0.12	30	1.9	23	NA	NA	66	1.8	2.2	25,500	7,500	2,500	-76	5.30	12.9	1,843
	29-Aug-02	7.5	5.6 J	1.4 U	3,650	<0.01	15	<2.6	32	5.6	31	<7.0	1.6	1.5	2,975	2,875	100	-98	5.23	12.0	4,520
	13-Dec-02	3.3	0.630	1.2	4,900	0.47	57	<2.5	13	NA	30	<7.0	2.8	2.0	5,525	3,875	100	-35	5.26	10.3	R
	11-Apr-03	58	0.35	1.4	4,600	0.04	39	<0.58	17 J	NA	20	<7.0	4.6	2.7	5,950	5,000	100	-88	5.14	11.3	4,010
	22-Aug-03	290	1.4	3.7	2,600	2.34	150	<0.58	15 J	5.7	22	<7.0	0.2	0.7	2,380	2,100	100	-54	5.19	15.0	3,710
	19-Apr-05	2,800	3.6	3.4	4,700	R	NM	NM	NM	4.5	74	<7.0	14	NM	NM	2,000	NM	9 R	5.33	11.6	3,328
	17-Nov-05	NM	NM	NM	13,000	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	3	5.86	10.5	5,081

a/ µg/L = micrograms per liter.

b/ TOC = total organic carbon.

c/ mg/L = milligrams per liter.

d/ nM = nano-Mol

e/ mV = millivolts.

f/ SU = pH standard units.

g/ °C = degrees Centigrade.

h/ µs/cm = microsiemens per centimeter.

i/ J indicates that the analyte was detected at a concentration above the method detection limit but below the reporting limit resulting in an estimated value.

j/ NM = Not measured.

k/ <20 indicates that the analyte was not detected above the referenced method detection limit.

l/ R = This data point is of suspect quality or was collected in the incorrect units (as percent saturation instead of mg/L). Therefore it is rejected and was not considered during data interpretation.

TABLE 12
BIOMASS AND VOLATILE FATTY ACIDS IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Distance Downgradient From Injection Wells (feet)	Sample Date	Total Organic Carbon (mg/L)[a/]	Bacterial Biomass (pmol/mL)[b/]	Starvation Ratio (unitless)	Total Volatile Fatty Acids (mg/L)	Metabolic Acids					
							Pyruvic (mg/L)	Lactic (mg/L)	Formic (mg/L)	Acetic (mg/L)	Proprionic (mg/L)	Butyric (mg/L)
MONITORING WELLS												
18S		4/18/2005	3.8	NM	0.00	< 4	< 4	< 1	< 1	< 1	< 1	< 1
26-S		4/15/2005	2.2	NM	0.09	NM	NM	NM	NM	NM	NM	NM
GWMS-27S	220	21-May-02	<1.7 [c/]	NM [d/]	NM	< 4 [b/]	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	9.9	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		9-Dec-02	16	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		7-Apr-03	2.8	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		18-Aug-03	1.2 J	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
GWMS-46S [e/]	-22	22-May-02	2.3	NM	NM	5.6	< 40	< 1	4.0	1.6	< 1	< 1
		28-Aug-02	10	NM	NM	6.2	< 4	0.8 J [f/]	1.9	2.6	0.9 J	< 1
		11-Dec-02	18	13.4	0.56	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	1.0 J	3	0.12	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		20-Aug-03	1.0 UJ	11	0.32	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		18-Apr-05	4	NM	1.22	< 4	< 4	< 1	< 1	< 1	< 1	< 1
GWMS-47S	224	21-May-02	<1.1	NM	NM	< 4	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	11	NM	NM	3.8	< 4	< 1	1.8	2.0	< 1	< 1
		10-Dec-02	38	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	1.1	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		19-Aug-03	1.0 J	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-1	16	22-May-02	3.0	NM	NM	6.5	< 40	< 1	3.7	1.8	0.97	< 1
		28-Aug-02	14	NM	NM	10.4	< 4	< 1	1.7	6.8	1.9	< 1
		12-Dec-02	12	31.3	1.13	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		10-Apr-03	<1.0	54	0.07	3.0	< 4	1.0	< 1	1.0	1.0	< 1
		21-Aug-03	1.4 J	14	0.25	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		15-Apr-05	3	NM	0.26	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-2	28	22-May-02	2.5	NM	NM	8.0	< 40	< 1	3.9	1.9	2.2	< 1
		28-Aug-02	12	NM	NM	3.6	< 4	< 1	1.7	1.9	< 1	< 1
		9-Dec-02	6.5	0.2	1.54	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		9-Apr-03	<1.0	7	0.11	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		20-Aug-03	1 J	19	0.07	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		14-Apr-05	1.9	NM	0.16	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-3	48	21-May-02	2.9	NM	NM	8.1	< 40	< 1	4.0	2.4	1.7	< 1
		27-Aug-02	13	NM	NM	6.7	< 4	< 1	1.7	3.8	1.2	< 1
		10-Dec-02	24	0.0	0.00	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	2.0 J	194	0.92	3.6	< 4	< 1	< 1	1.9	1.7	< 1
		20-Aug-03	2.6 J	44	0.27	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		14-Apr-05	2	NM	0.76	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-4	76	21-May-02	2.0	NM	NM	1.5	< 80	< 1	1.5	< 1	< 1	< 1
		27-Aug-02	10	NM	NM	3.7	< 4	< 1	1.8	1.9	< 1	< 1
		10-Dec-02	15	1.0	0.09	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	1.7 J	6.0	0.36	2.0	< 4	< 1	< 1	1.0	1.0	< 1
		19-Aug-03	1.2 J	119	0.62	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		12-Apr-05	51	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1

TABLE 12
BIOMASS AND VOLATILE FATTY ACIDS IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Distance Downgradient From Injection Wells (feet)	Sample Date	Total Organic Carbon (mg/L)[a/]	Bacterial Biomass (pmol/mL)[b/]	Starvation Ratio (unitless)	Total Volatile Fatty Acids (mg/L)	Metabolic Acids					
							Pyruvic (mg/L)	Lactic (mg/L)	Formic (mg/L)	Acetic (mg/L)	Proprionic (mg/L)	Butyric (mg/L)
PES-MW-5	142	21-May-02	1.8	NM	NM	1.4	< 80	< 0	1.4	< 1	< 1	< 1
		27-Aug-02	12	NM	NM	4.3	< 4	< 0.9	1.8	2.5	< 1	< 1
		10-Dec-02	23	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		8-Apr-03	<1.0	NM	NM	2.0	< 4	< 1	< 1	1.0	1.0	< 1
		19-Aug-03	<1.0	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-6	16	23-May-02	<0.83	NM	NM	19.1	< 40	< 1	4.1	12.3	2.7	< 1
		28-Aug-02	7	NM	NM	6.3	< 4	< 1	2.1	4.2	< 1	< 1
		12-Dec-02	16	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		10-Apr-03	<1.0	57	0.07	8.0	4.0	1.0	< 1	1.0	1.0	1.0
		21-Aug-03	1.7 J	18	0.02	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		15-Apr-05	3	NM	0.07	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-7	16	22-May-02	150	NM	NM	347	< 20	< 1	3.9	133	182	28
		28-Aug-02	150	NM	NM	212	< 4	< 1	1.9	57.8	122	30
		12-Dec-02	200	NM	NM	149	< 4	< 1	< 1	28.3	98	23
		10-Apr-03	210	87	0.50	202.2	< 4	< 1	< 1	43.4	153.5	5.3
		21-Aug-03	53	558	0.21	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		15-Apr-05	29	NM	0.10	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-8	40	22-May-02	1.9	NM	NM	5.6	< 40	< 1	4.0	1.6	< 1	< 1
		28-Aug-02	14	NM	NM	3.9	< 4	< 1	1.9	2.0	< 1	< 1
		12-Dec-02	4.6	NM	NM	< 1	< 4	< 1	< 1	< 1	< 1	< 1
		9-Apr-03	<1.0	62	2.35	8.0	4.0	1.0	< 1	1.0	1.0	1.0
		21-Aug-03	3.7	29	1.45	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		14-Apr-05	1.7	NM	0.67	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-9	36	22-May-02	58 J	NM	NM	140	< 40	< 1	4.2	53.8	82.4	< 1
		27-Aug-02	180	NM	NM	308	< 4	< 0.5	1.9	199	99.1	7.6
		11-Dec-02	240	NM	NM	295	< 4	< 1	0.6 J	229	47.5	18.1
		9-Apr-03	2.6	45	0.42	4.0	< 4	1.0	< 1	1.0	1.0	1.0
		20-Aug-03	1.5 J	121	0.19	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		16-Apr-05	4	NM	0.58	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-10A	16	15-Apr-05	190	NM	0.20	50.5	< 4	< 1	< 1	26.8	11.6	12.1
PES-MW-10B	13	14-Apr-05	3	NM	0.07	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-11A	38	13-Apr-05	9	NM	0.17	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-12A	155	12-Apr-05	6	NM	0.08	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-12B	155	20-Apr-05	6	NM	0.00	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-13A	NA	20-Apr-05	5	NM	0.08	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-14A	75	12-Apr-05	50	NM	0.37	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-MW-14B	75	20-Apr-05	4.2J	NM	0.05	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-CW-1	220	20-May-02	<1.3	NM	NM	<1	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	11	NM	NM	3.4	< 4	< 1	1.6	1.8	< 1	< 1
		9-Dec-02	1.5	NM	NM	< 1	< 4	< 1	< 1	< 1	< 1	< 1
		7-Apr-03	<1.0	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		18-Aug-03	1.6 J	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1

TABLE 12
BIOMASS AND VOLATILE FATTY ACIDS IN GROUNDWATER
NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT FRIDLEY
ANOKA COUNTY PARK
FRIDLEY, MINNESOTA

Sample Location	Distance Downgradient From Injection Wells (feet)	Sample Date	Total Organic Carbon (mg/L)[a/]	Bacterial Biomass (pmol/mL)[b/]	Starvation Ratio (unitless)	Total Volatile Fatty Acids (mg/L)	Metabolic Acids					
							Pyruvic (mg/L)	Lactic (mg/L)	Formic (mg/L)	Acetic (mg/L)	Proprionic (mg/L)	Butyric (mg/L)
PES-CW-2	212	20-May-02	<1.0	NM	NM	<1	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	12	NM	NM	3.4	< 4	< 1	1.7	1.7	< 1	< 1
		9-Dec-02	5.4	NM	NM	< 1	< 4	< 1	< 1	< 1	< 1	< 1
		7-Apr-03	<1.0	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
		19-Aug-03	1.7 J	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
PES-CW-3	220	20-May-02	<1.6	NM	NM	<1	< 80	< 1	< 1	< 1	< 1	< 1
		26-Aug-02	11	NM	NM	4.0	< 4	0.4 J	1.8	1.8	< 1	< 1
		10-Dec-02	14	NM	NM	< 1	< 4	< 1	< 1	< 1	< 1	< 1
		8-Jul-03	<1.0	NM	NM	3.0	< 4	< 1	< 1	1.0	1.0	1.0 J
		19-Aug-03	<1.0	NM	NM	< 4	< 4	< 1	< 1	< 1	< 1	< 1
INJECTION WELLS												
PES-INJ-1	NA [d/]	23-May-02	2,500	NM	NM	3,279	< 80	1.2	4.9	1,500	843	930
		29-Aug-02	2,900	NM	NM	2,910	< 4	1.2	3.0	1,468	458	980
		13-Dec-02	2,600	NM	NM	2,509	< 4	< 1	3.8	1,294	255	956
		10-Apr-03	2,300	3.0	2.47	2,321	< 4	< 1	1.5	1,276	179	865
		22-Aug-03	2,100	4.0	1.73	1,973	< 4	< 1	< 1	963	311	699
		19-Apr-05	2,500	NM	NM	1,954	< 4	< 1	< 1	1,222	167	565
PES-INJ-2	NA	23-May-02	4,100	NM	NM	5,777	< 80	< 20	32.7	1,471	2,835	1,438
		29-Aug-02	4,130	NM	NM	4,371	333	< 20	< 20	1,059	1,753	1,226
		13-Dec-02	4,400	7,698	0.05	3,176	177	< 10	< 10	917	1,047	1,035
		11-Apr-03	2,300	98	0.18	2,139	40	10	10	905	466	708
		22-Aug-03	2,000	350	0.00	1,879	< 4	< 1	< 1	893	379	607
		19-Apr-05	2,400	NM	0.25	1,334	< 4	< 1	< 1	794	174	366
PES-INJ-3	NA	23-May-02	4,100	NM	NM	5,410	< 80	< 20	33.4	1,303	2,355	1,719
		29-Aug-02	3,650	NM	NM	2,965	< 80	< 20	< 20	889	806	1,270
		13-Dec-02	4,900	NM	NM	3,202	< 4	< 10	< 10	1,265	652	1,285
		11-Apr-03	4,600	27	0.00	2,668	< 4	< 1	2.2	1,039	255	1,372
		22-Aug-03	3,600	59	0.79	2,787	243	< 1	20	963	231	1,330
		19-Apr-05	4,700	NM	NM	1,822	< 4	2.3	84	646	127	963
OTHER WELLS												
MS-53PC	NA	11-Apr-05	110	NM	NM	792	< 4	1.0	106	469	210	6

[a/] mg/L = milligrams per liter.
[b/] pmol/mL = picomoles per milliliter.
[c/] "<" indicates that anayte was below the limit of quantitation.
[d/] NM = not measured.
[e/] This well is located upgradient of the injection area.
f/ J indicates that the analyte was detectedat a concentration greater than the method detection limit and less than the reporting limit. Thus, the concentration is estimated.

FIGURES

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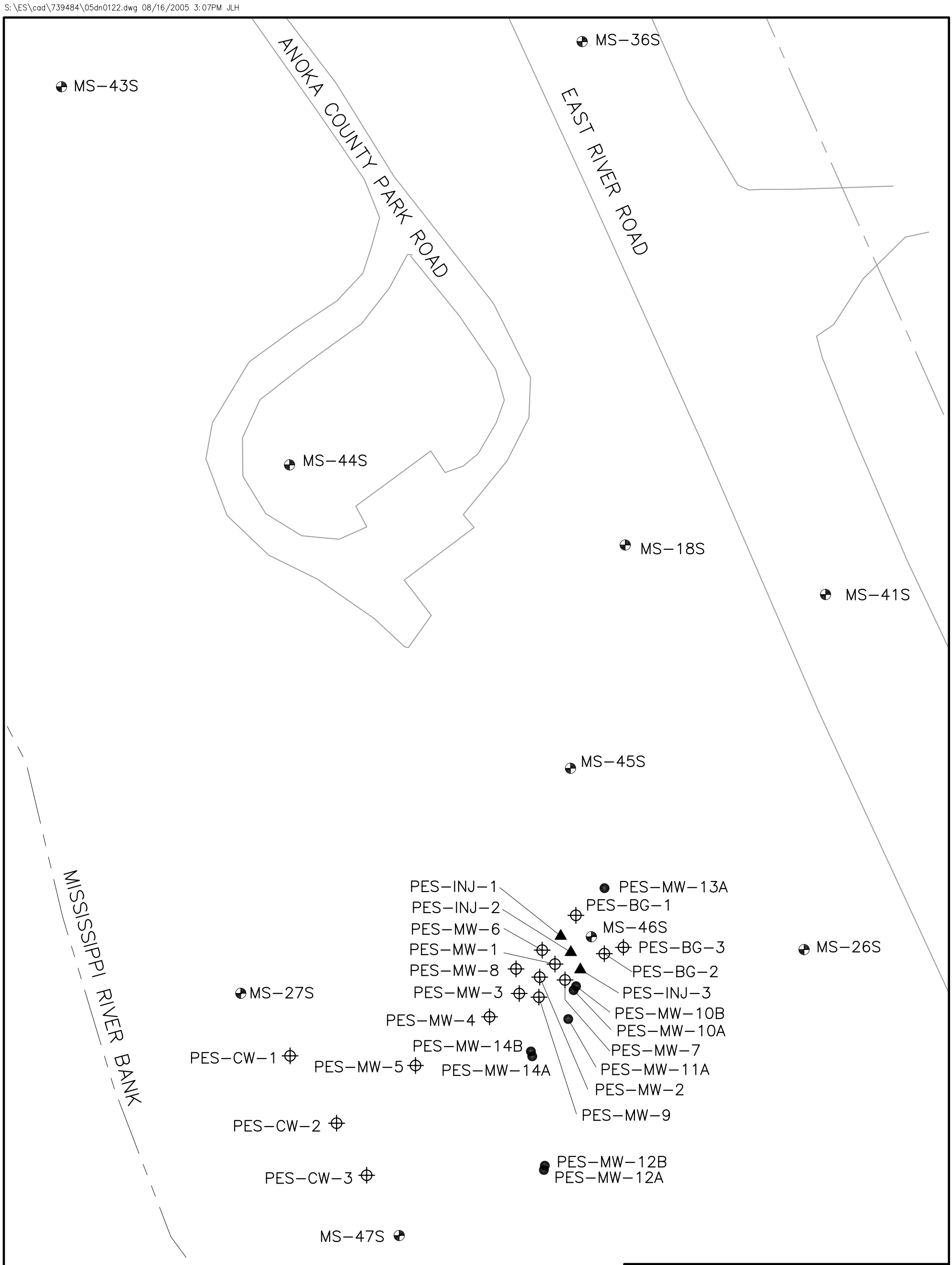

LEGEND

- NEWLY INSTALLED PILOT TEST MONITORING WELL
- EXISTING MONITORING WELL
- EXISTING PILOT TEST INSTALLED MONITORING WELL
- VEGETABLE OIL INJECTION WELL

N

0' 35' 70'

SCALE: 1"=70'

FIGURE 1

REGIONAL MAP OF THE PILOT TEST AREA

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

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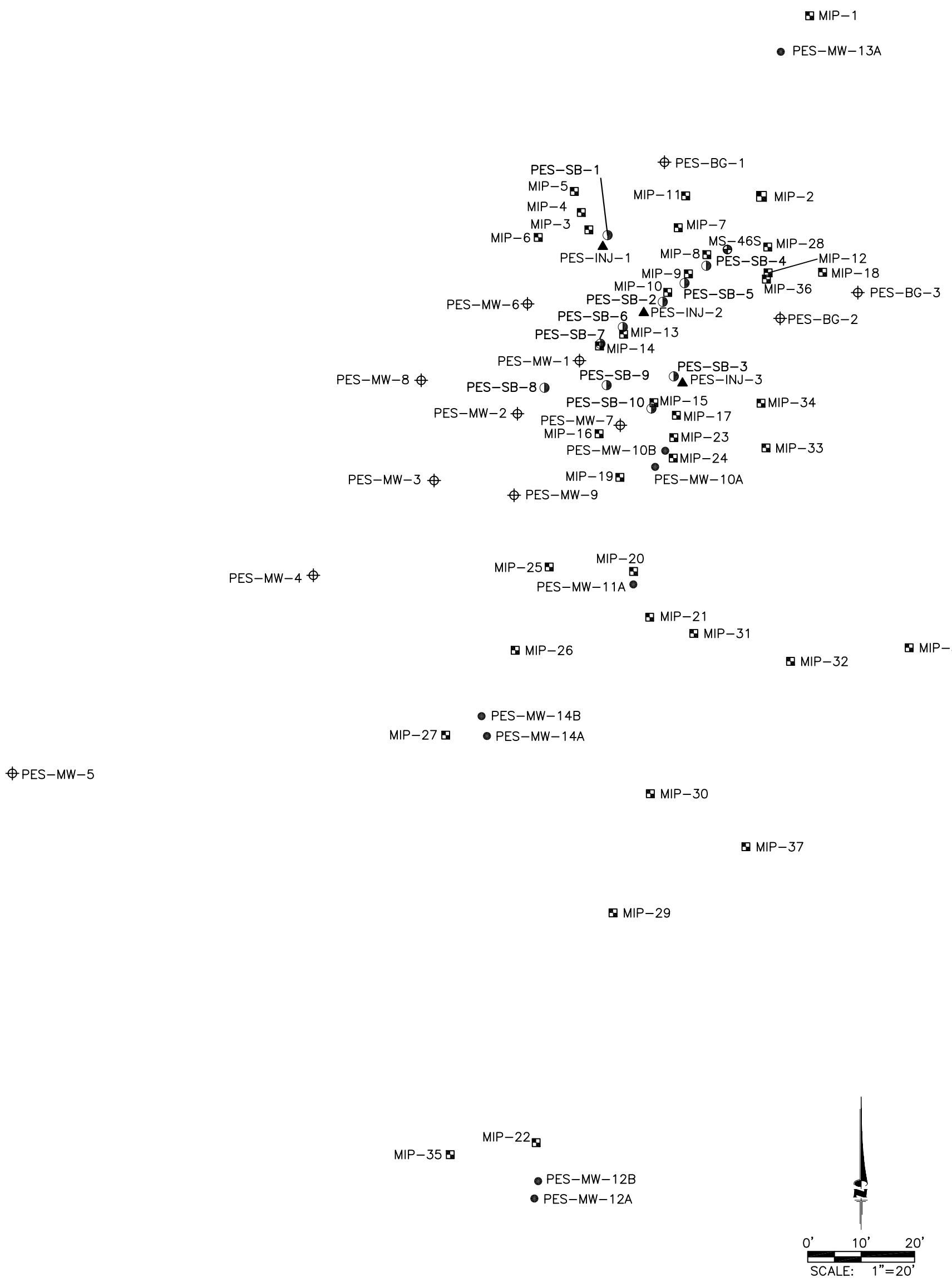

LEGEND

- EXISTING MONITORING WELL
- NEWLY INSTALLED MONITORING WELL
- VEGETABLE OIL INJECTION WELL
- MIP WELL LOCATION
- NEWLY INSTALLED SOIL BORING

FIGURE 2

LOCAL MAP OF THE PILOT TEST AREA

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

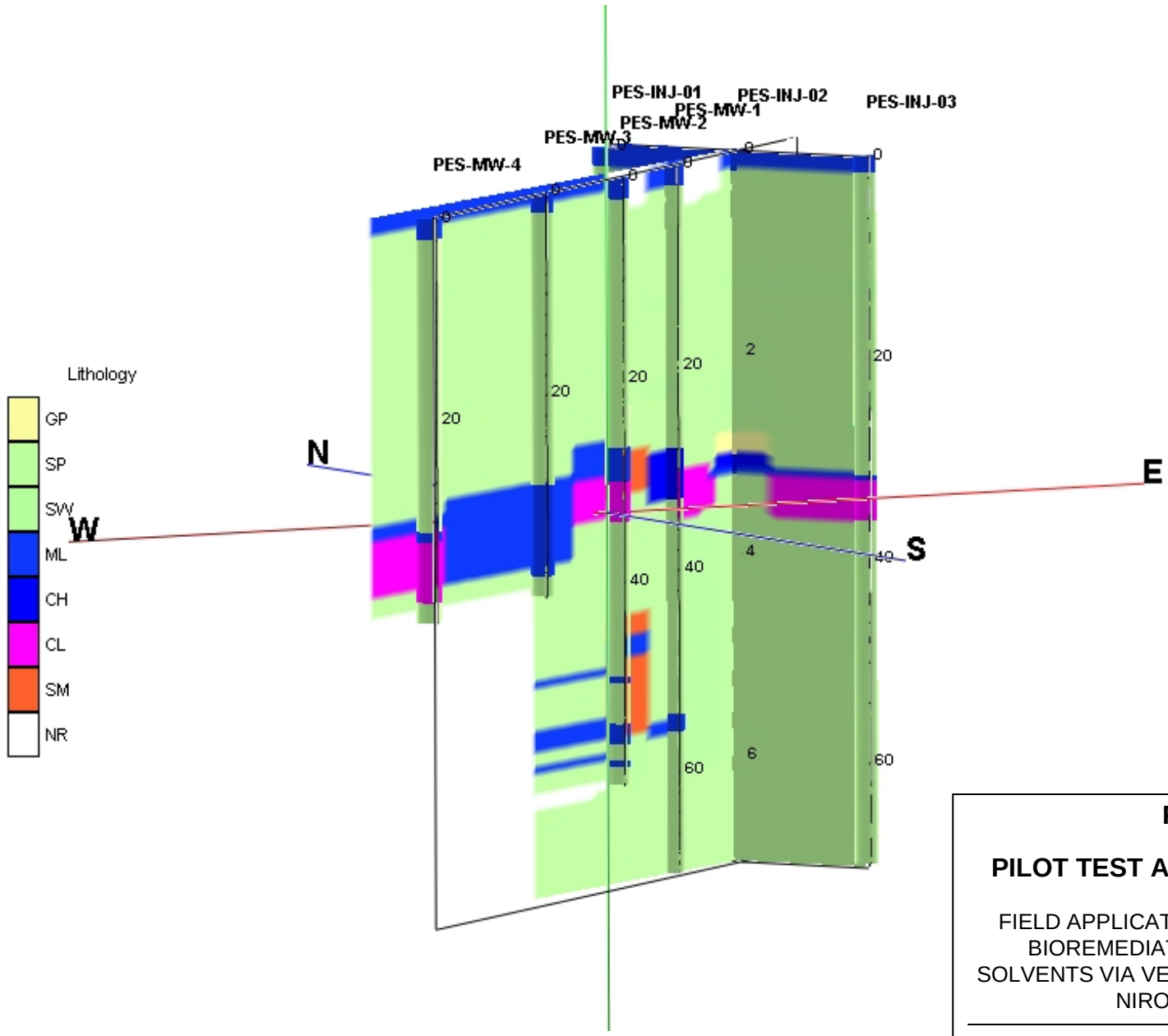

FIGURE 3

PILOT TEST AREA FENCE DIAGRAM

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

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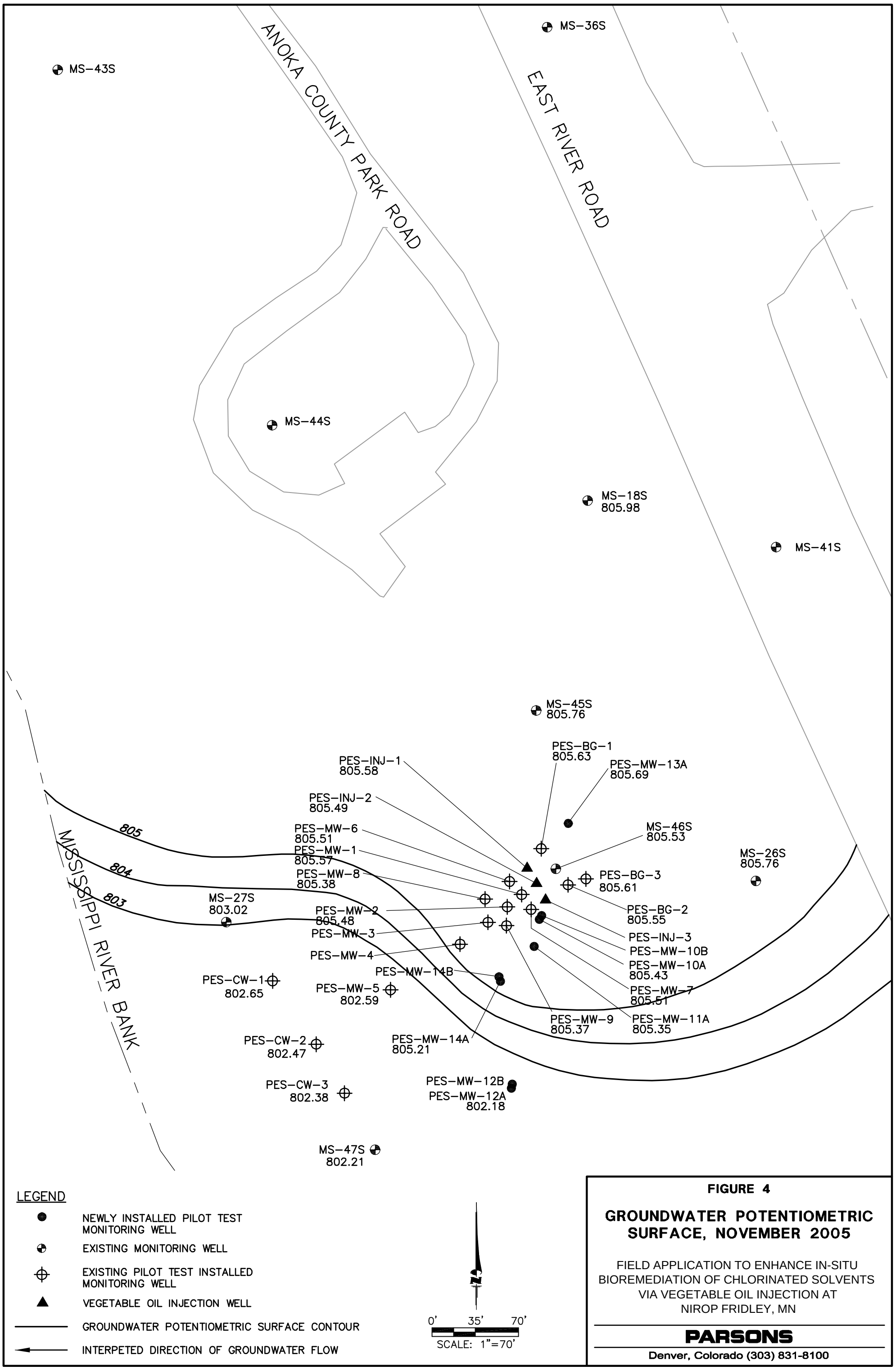

FIGURE 4

GROUNDWATER POTENTIOMETRIC SURFACE, NOVEMBER 2005

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

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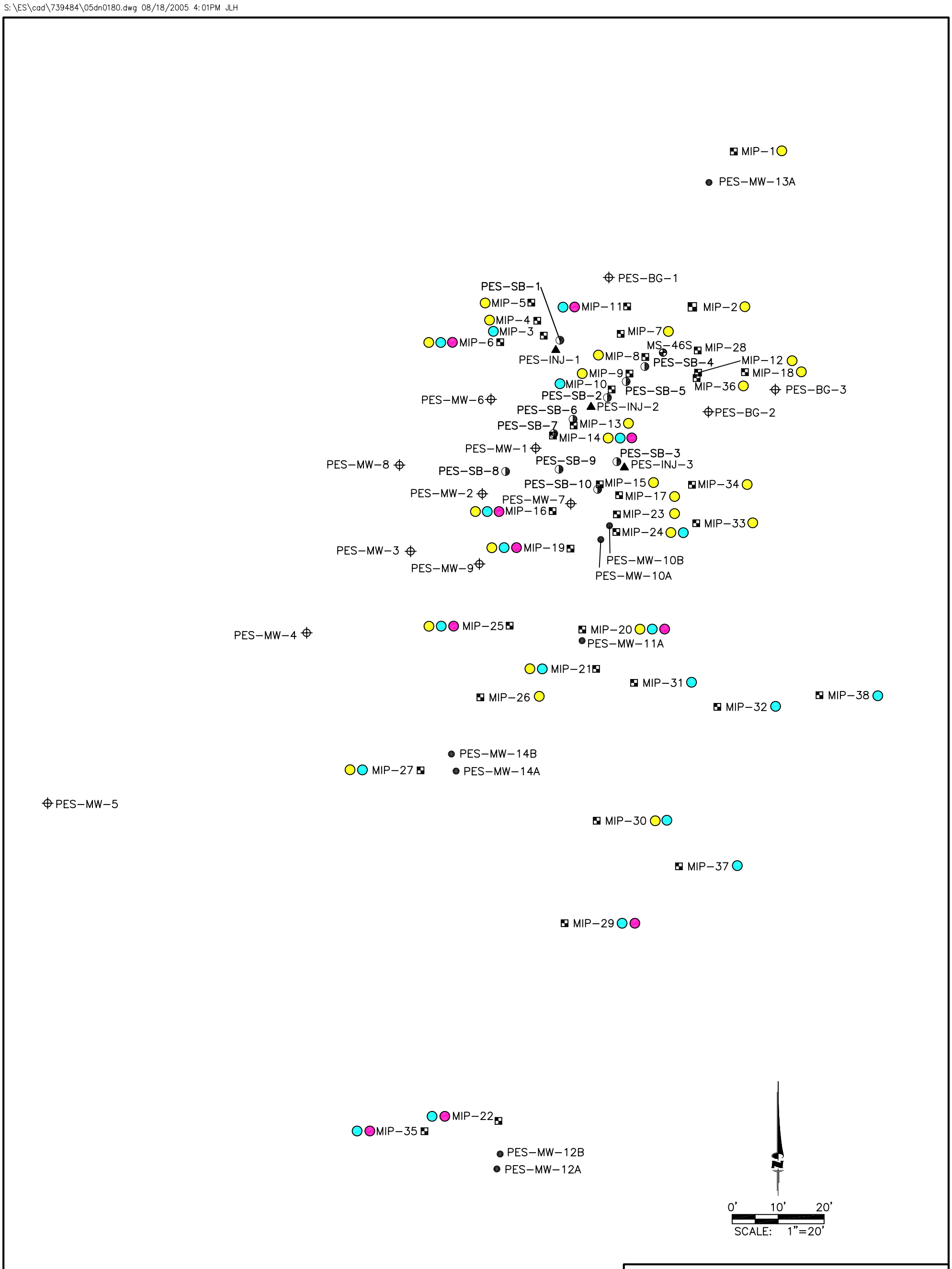

LEGEND

- EXISTING MONITORING WELL
- NEWLY INSTALLED MONITORING WELL
- VEGETABLE OIL INJECTION WELL
- MIP WELL LOCATION
- NEWLY INSTALLED SOIL BORING

PRESENCE AND DEPTH OF ELEVATED ECD RESPONSE

- 30 – 40 FEET BGS
- 40 – 50 FEET BGS
- 50 – 60 FEET BGS

FIGURE 5

SUMMARY OF ECD RESPONSE

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

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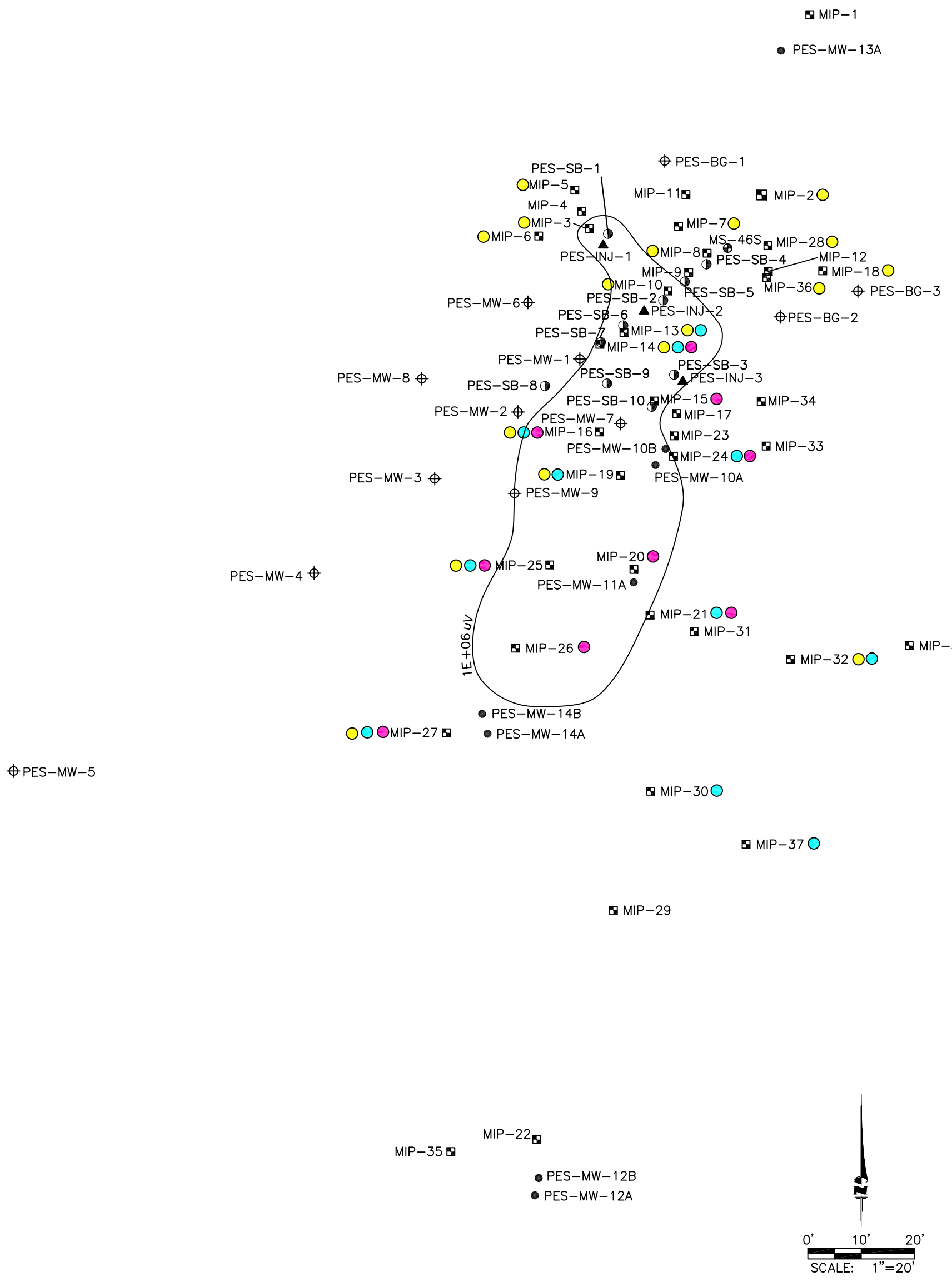

LEGEND

- EXISTING MONITORING WELL
- NEWLY INSTALLED MONITORING WELL
- VEGETABLE OIL INJECTION WELL
- MIP WELL LOCATION
- NEWLY INSTALLED SOIL BORING

PRESENCE AND DEPTH OF FID RESPONSE

- < 40 FEET BGS
- < 40 – 50 FEET BGS
- < 50 – 60 FEET BGS

FIGURE 6

SUMMARY OF FID RESPONSE

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado (303) 831-8100

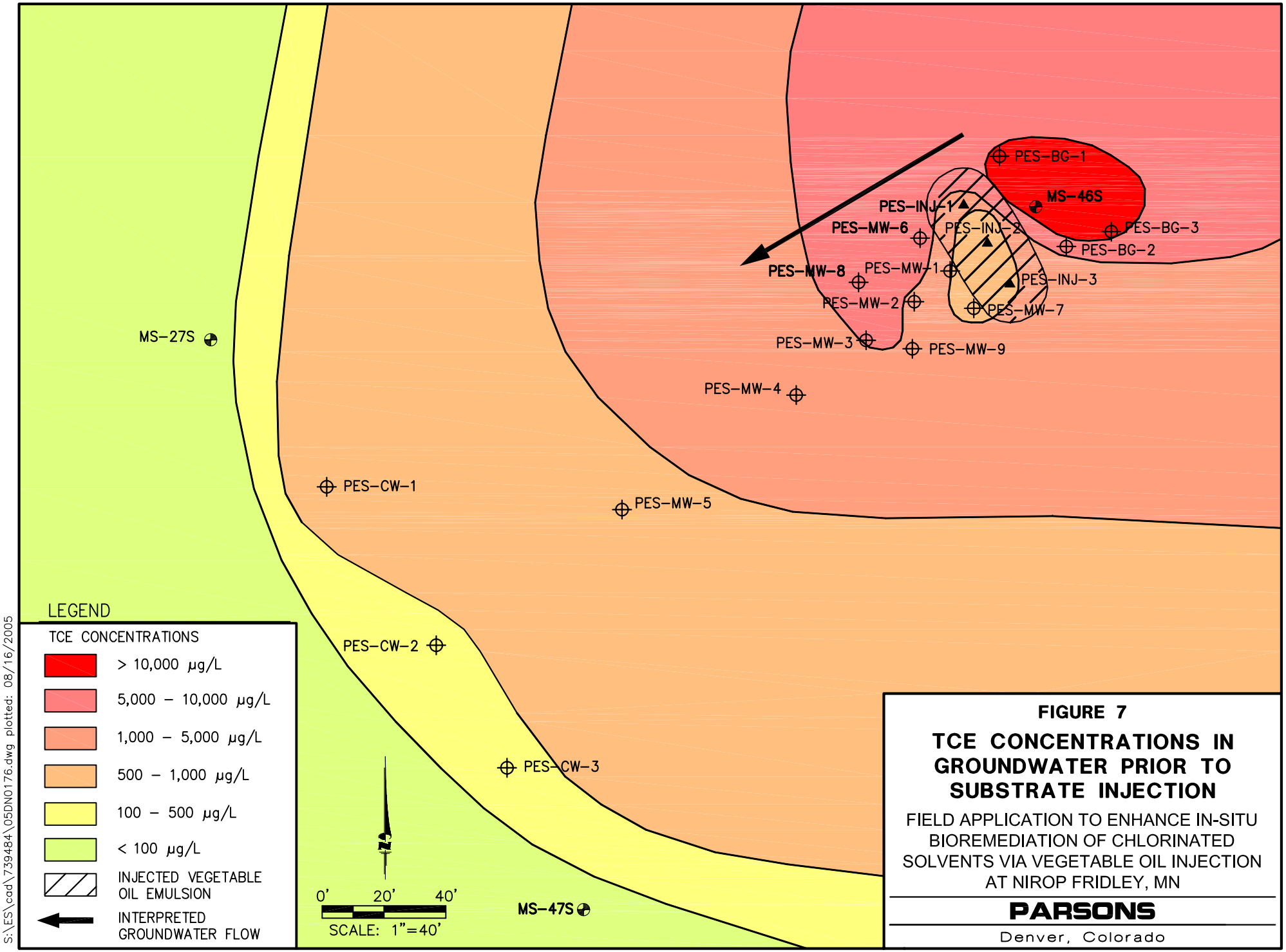

FIGURE 7

TCE CONCENTRATIONS IN GROUNDWATER PRIOR TO SUBSTRATE INJECTION

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado

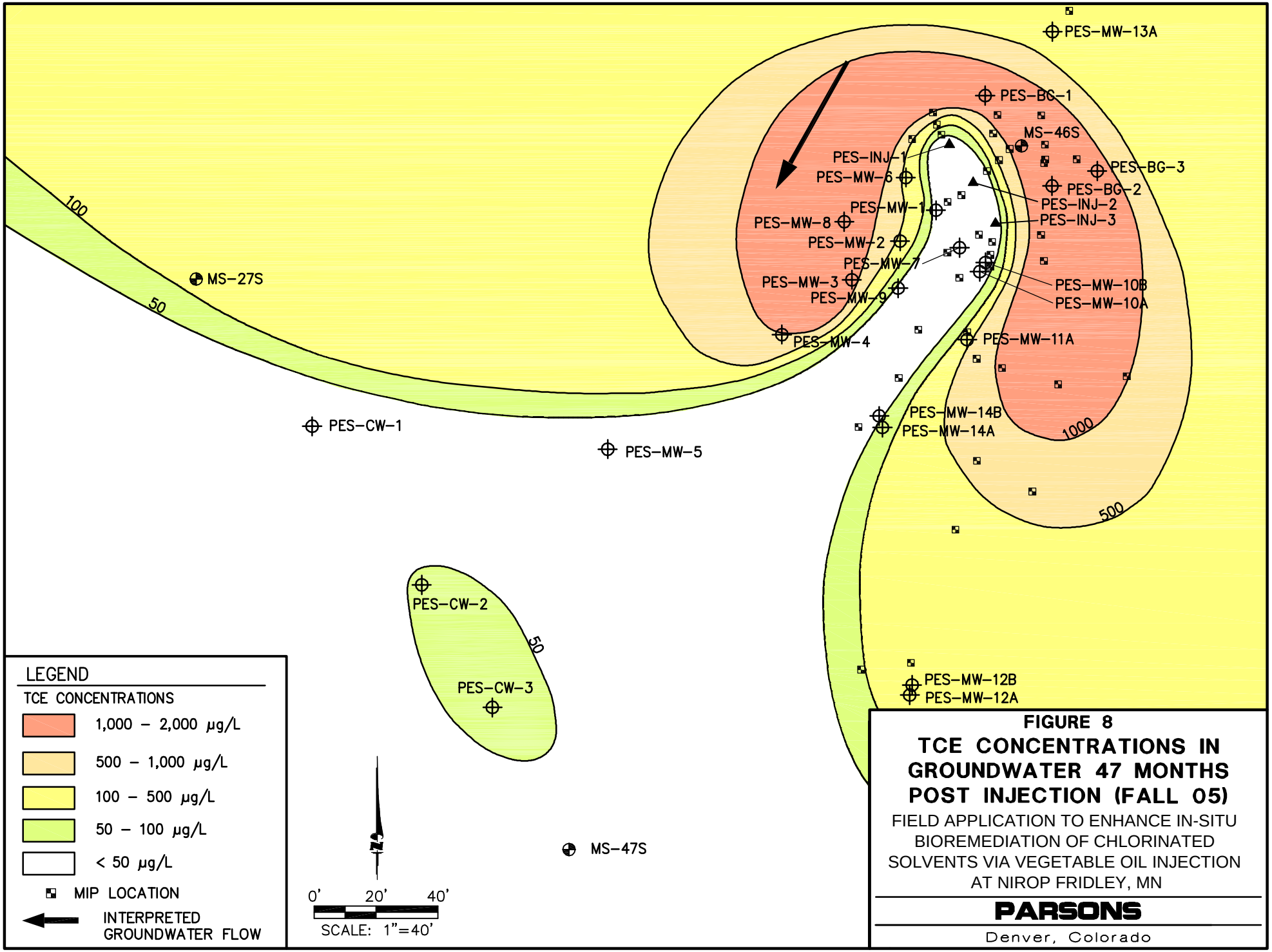

FIGURE 8

TCE CONCENTRATIONS IN GROUNDWATER 47 MONTHS POST INJECTION (FALL 05)

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado

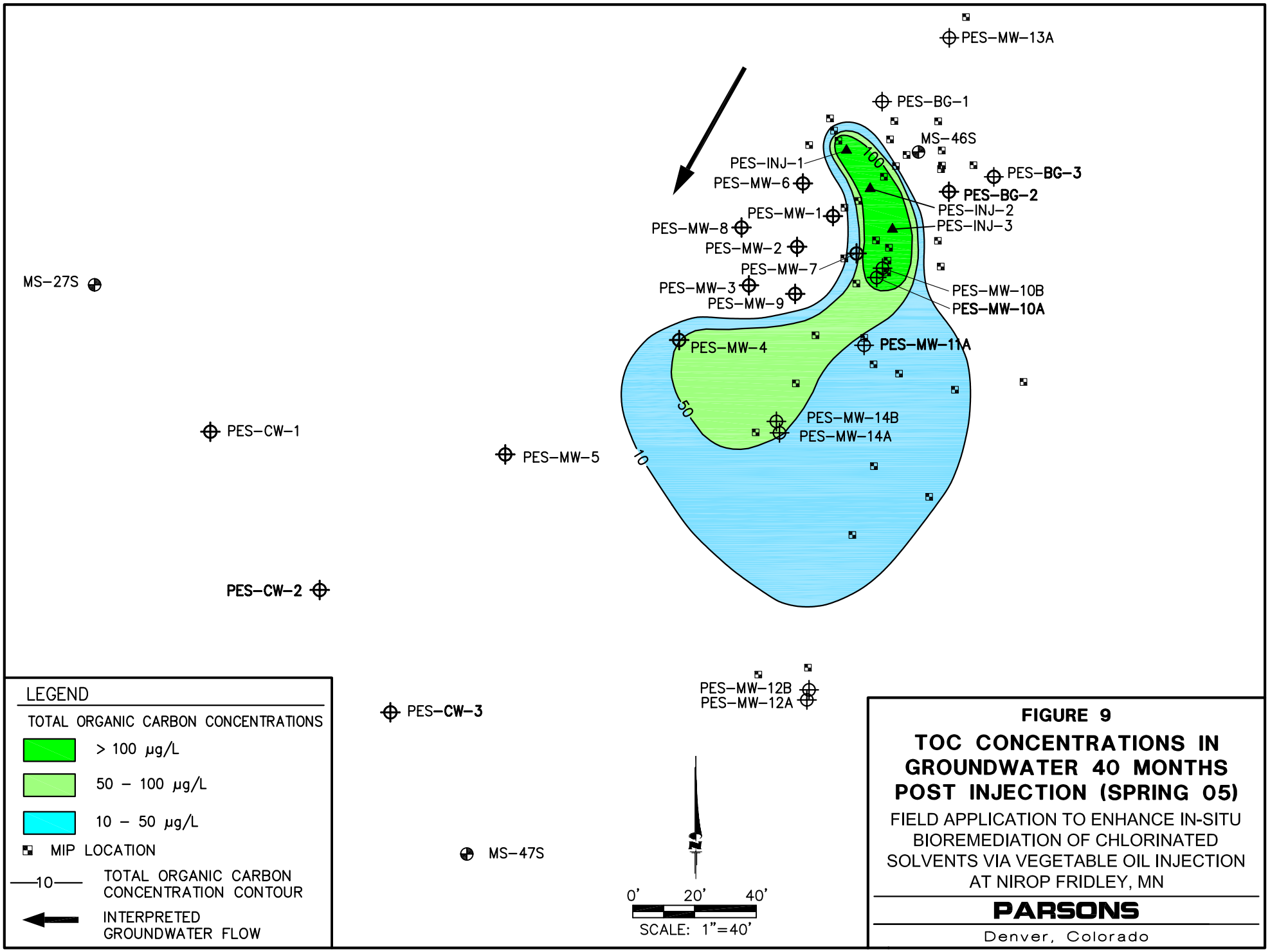

FIGURE 9

TOC CONCENTRATIONS IN GROUNDWATER 40 MONTHS POST INJECTION (SPRING 05)

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado

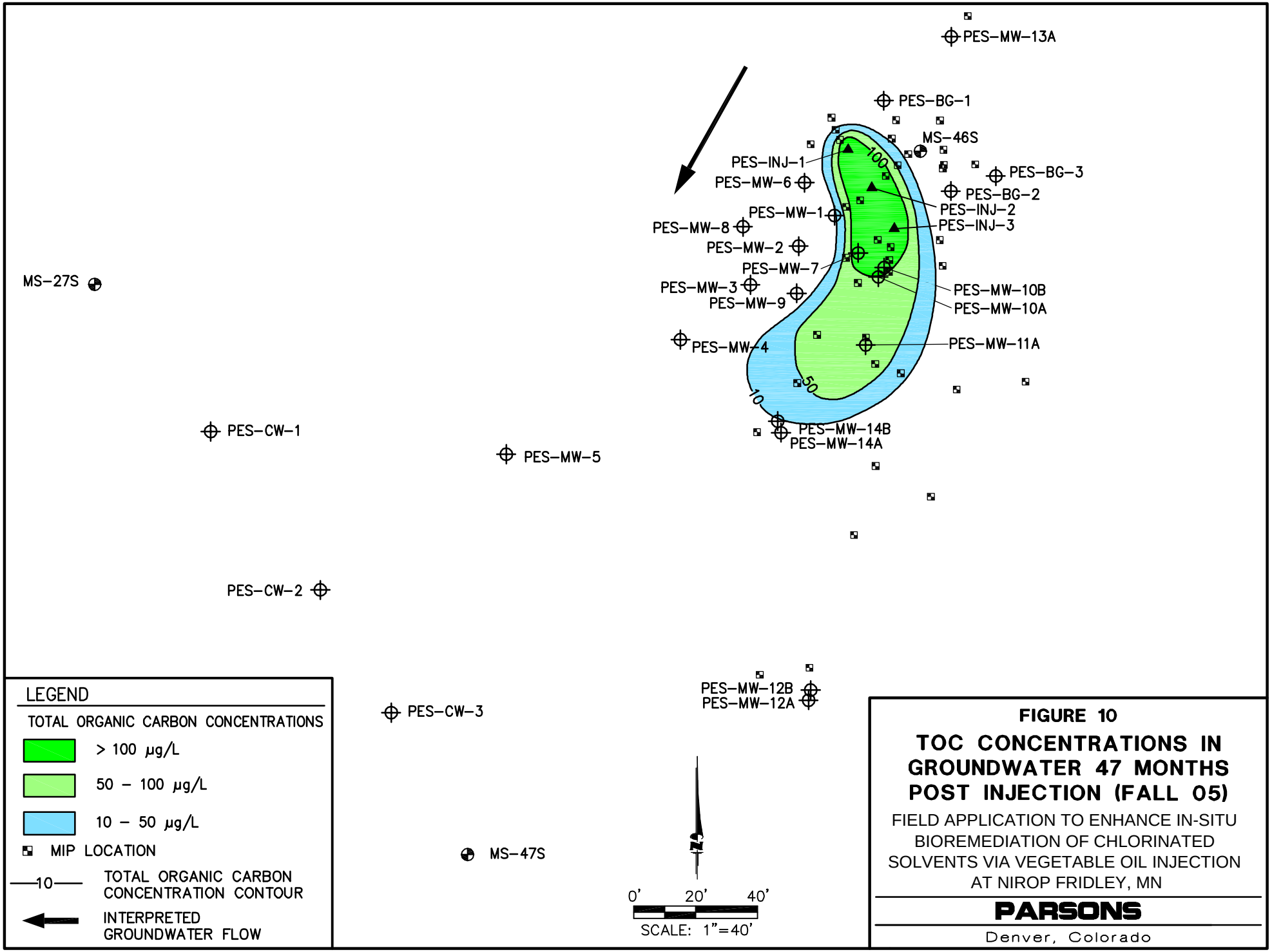

FIGURE 10

TOC CONCENTRATIONS IN GROUNDWATER 47 MONTHS POST INJECTION (FALL 05)

FIELD APPLICATION TO ENHANCE IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS VIA VEGETABLE OIL INJECTION AT NIROP FRIDLEY, MN

PARSONS

Denver, Colorado

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APPENDIX A

MEMBRANE INTERFACE PROBE LOGS

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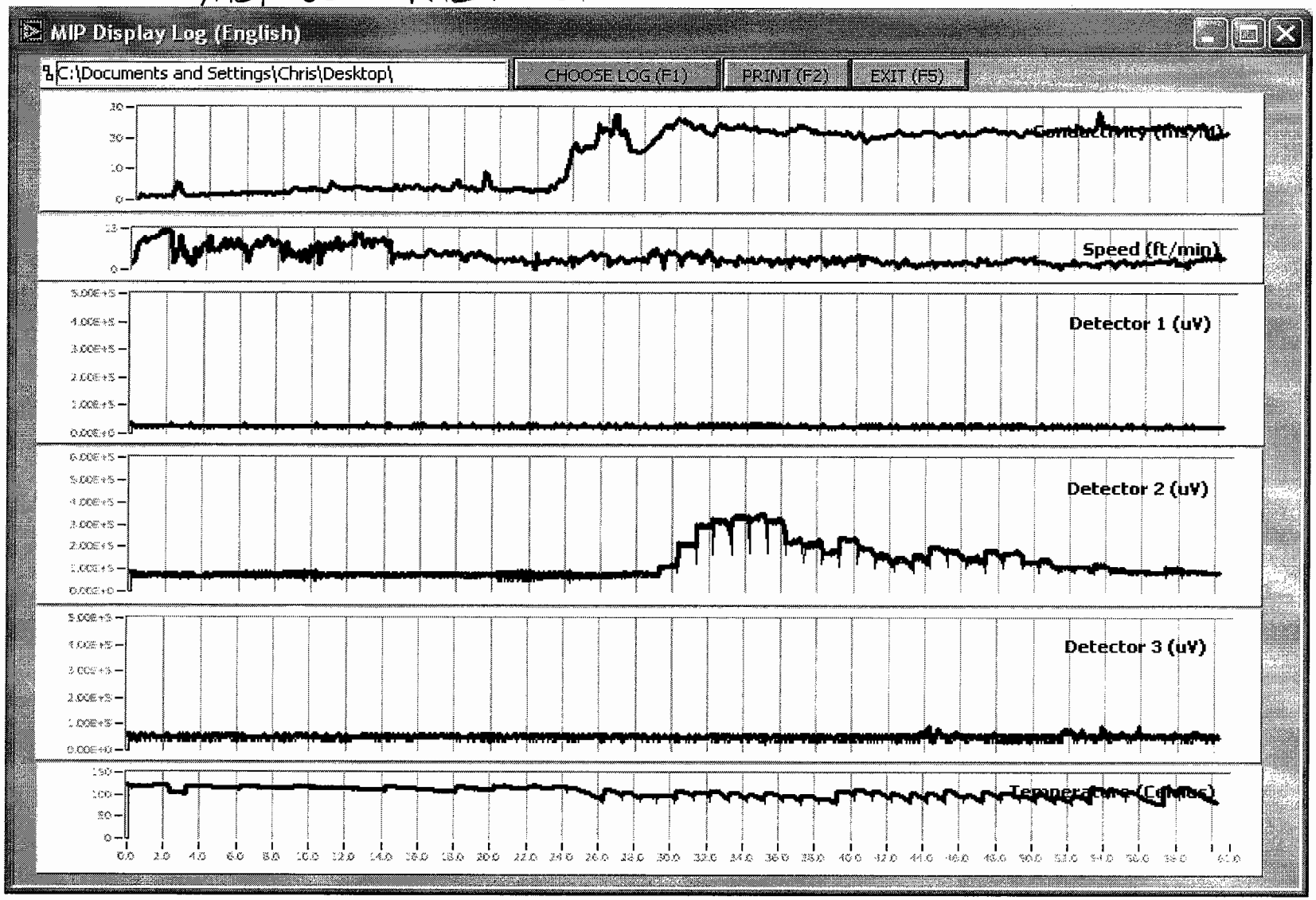

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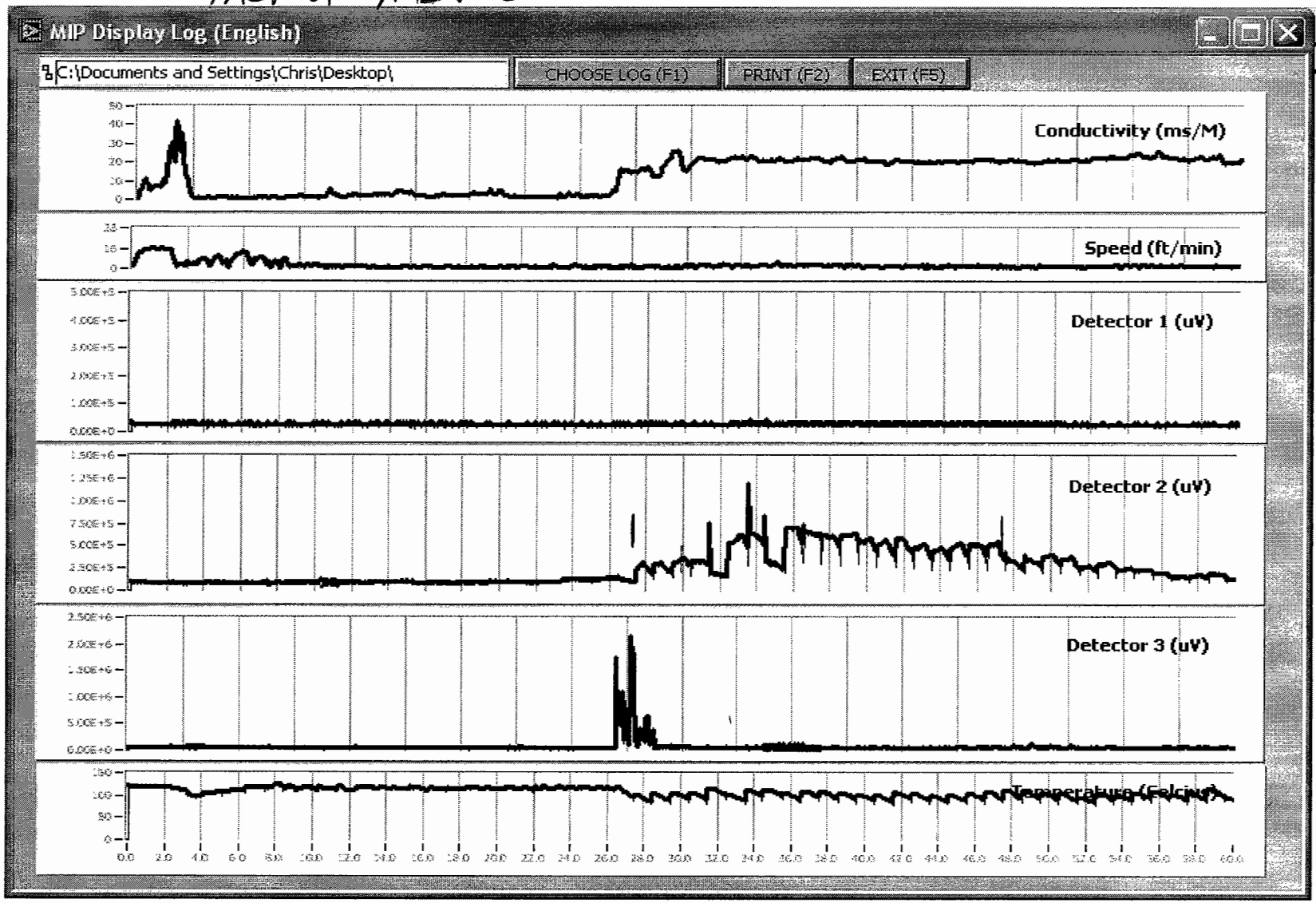

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MIP-03

Mottle 3
58-1

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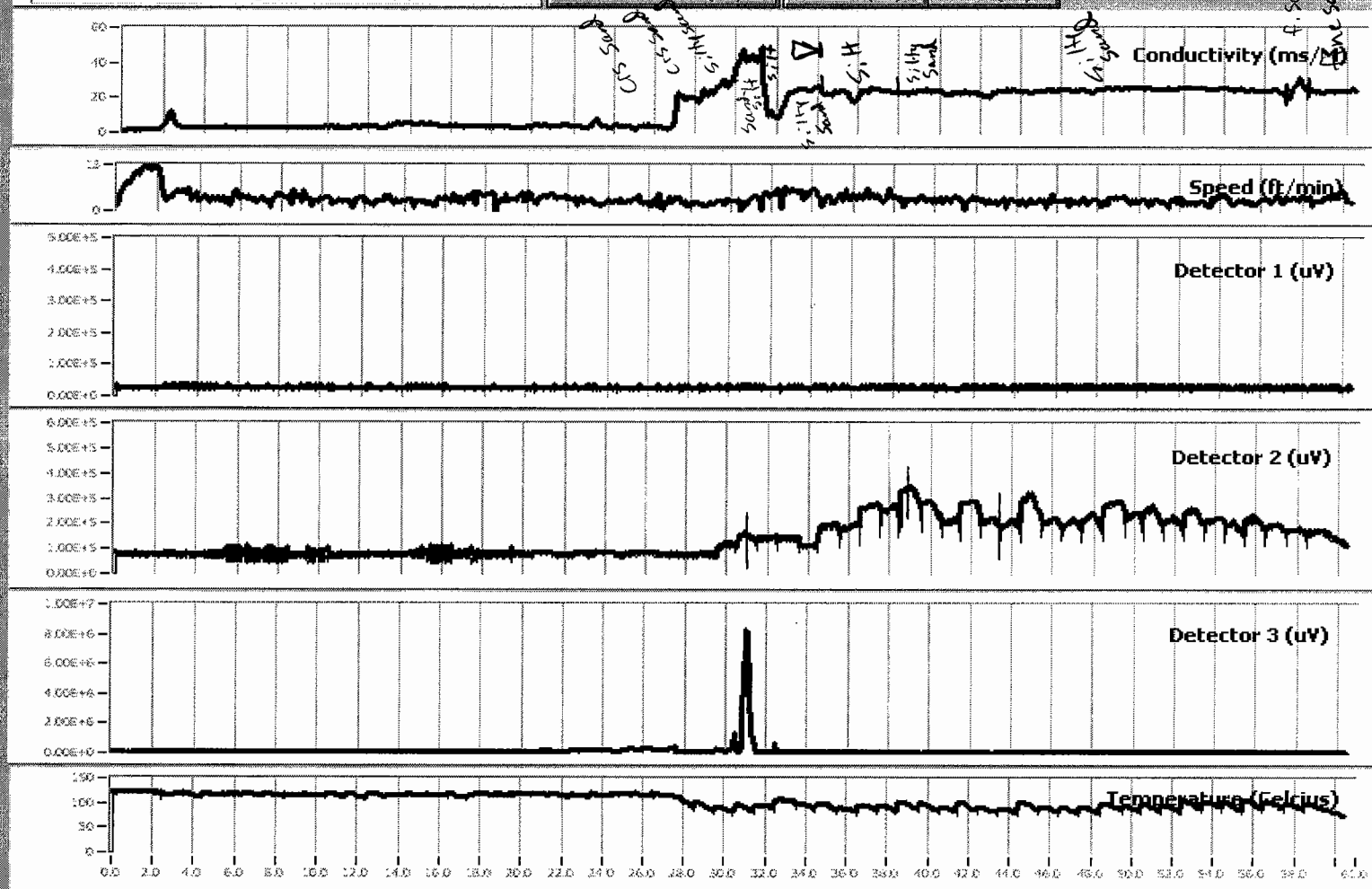
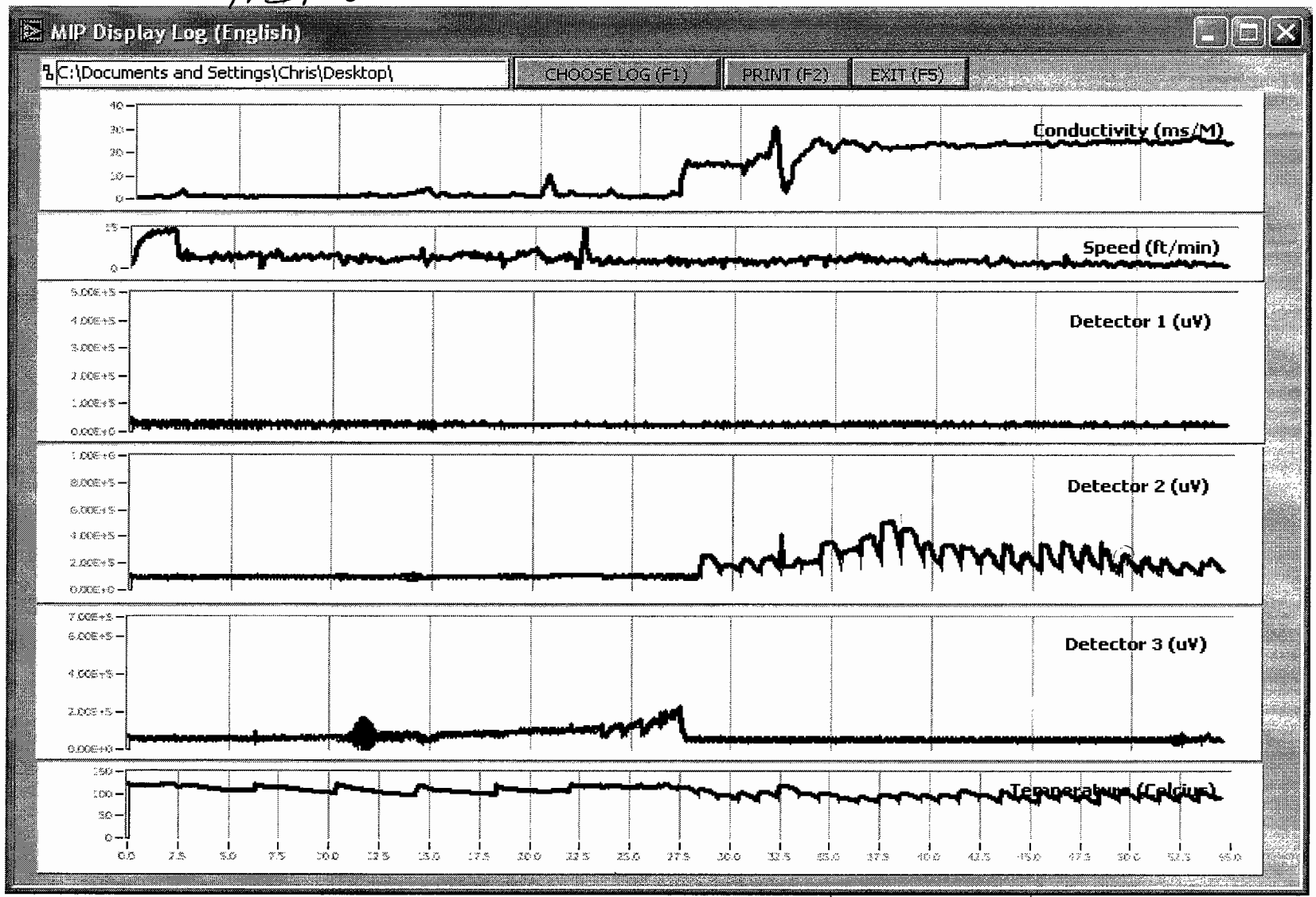


Inj 01

MIP-04



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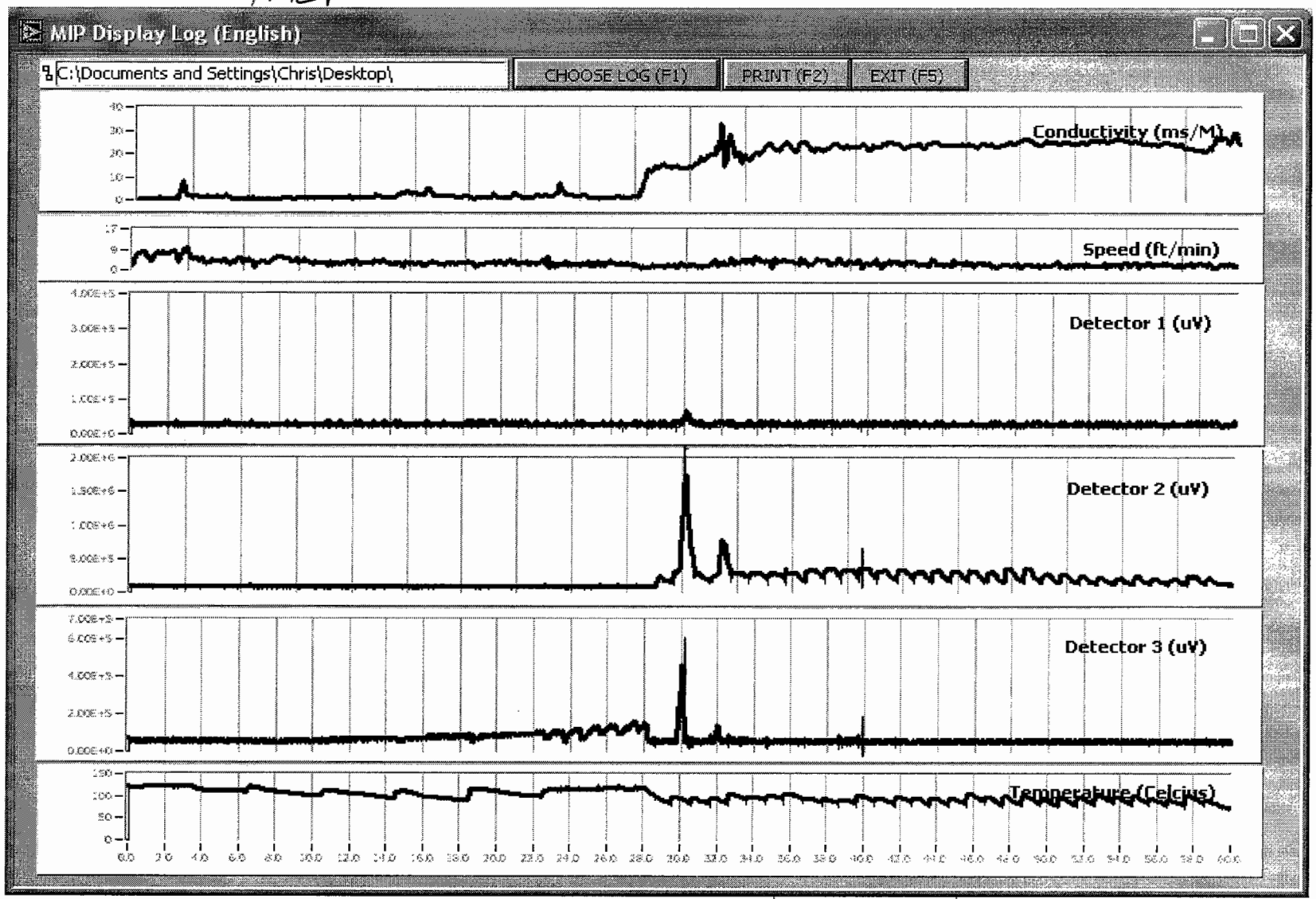

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INJ-01

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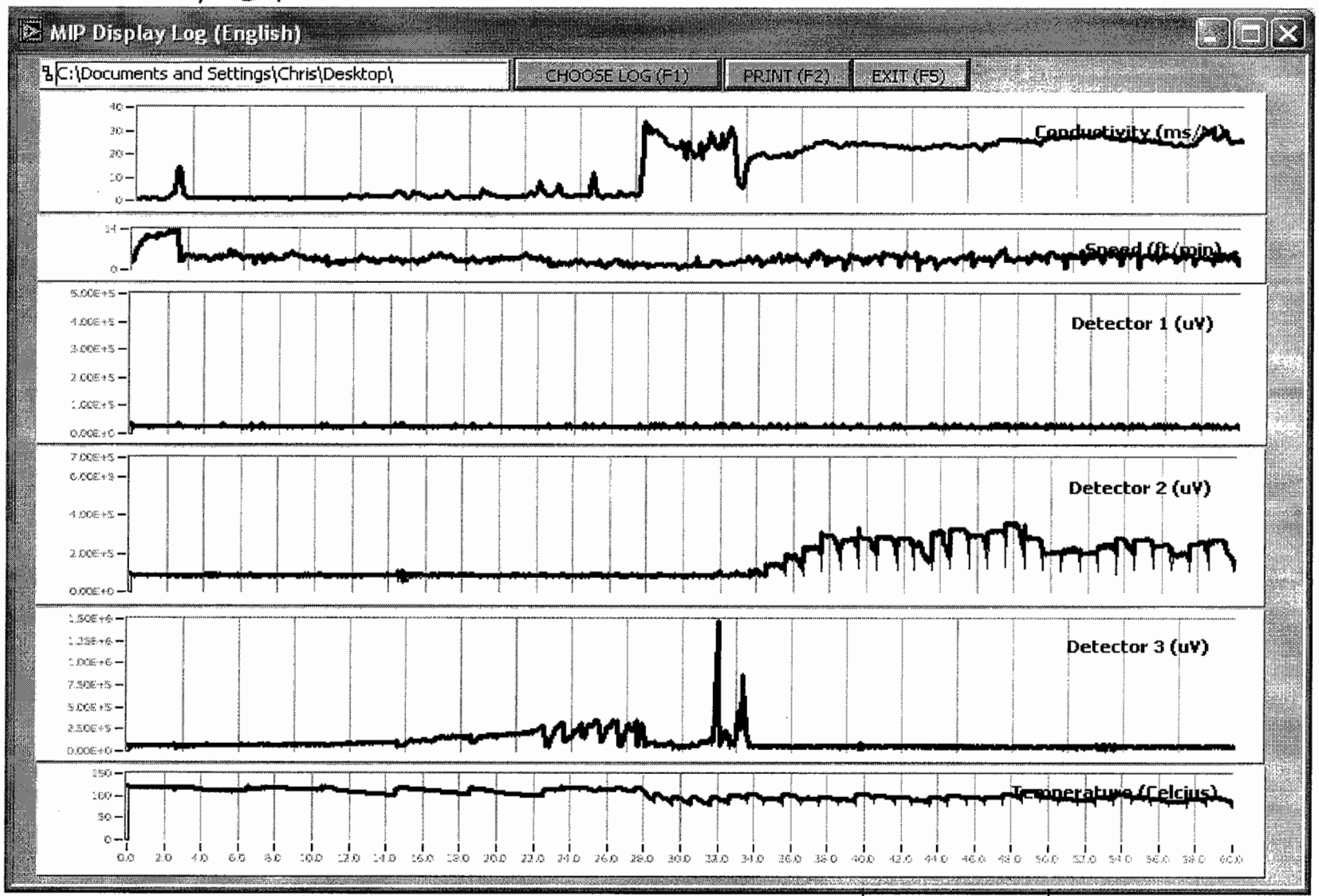

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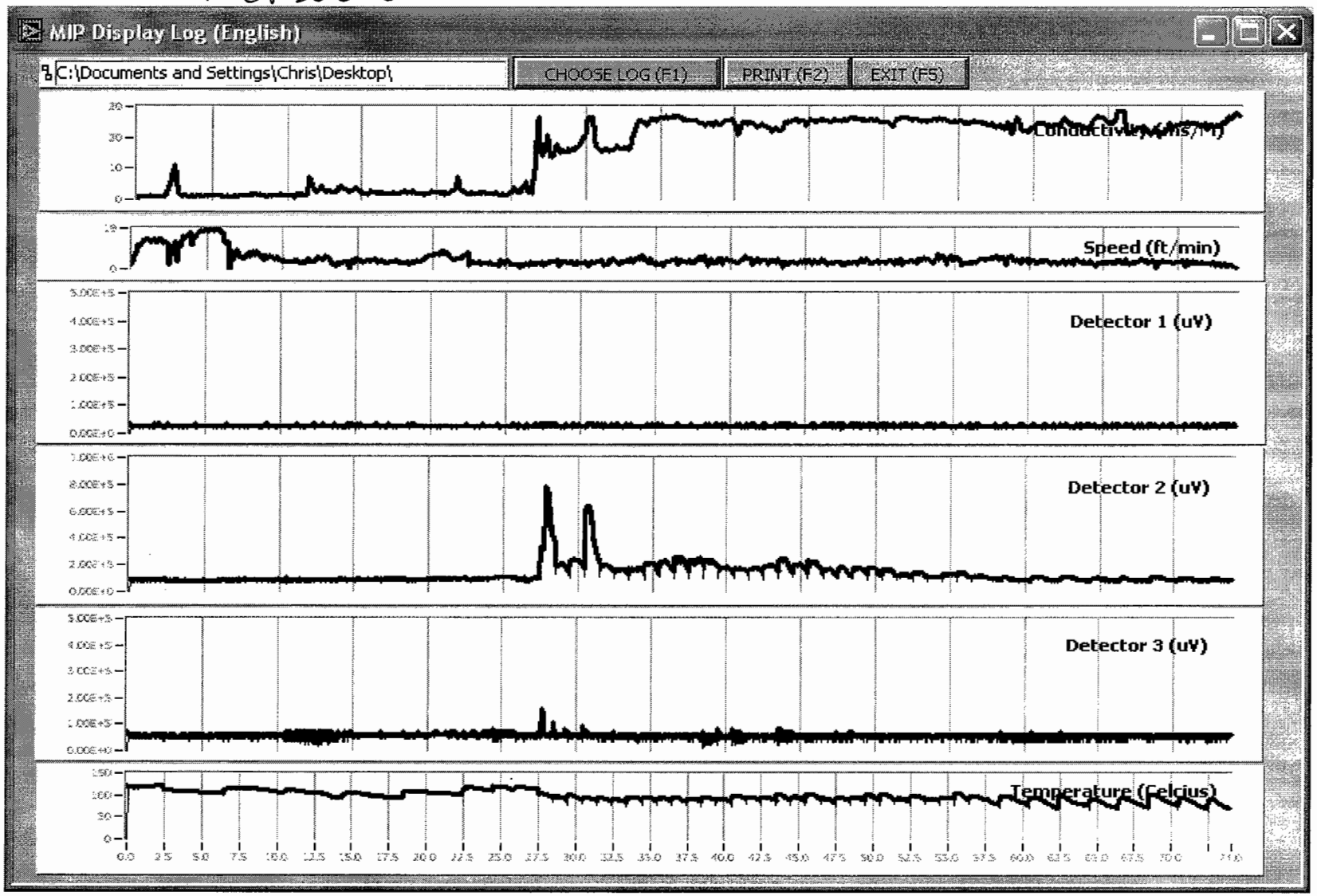
INJ-02

MIP ~~06~~ 07



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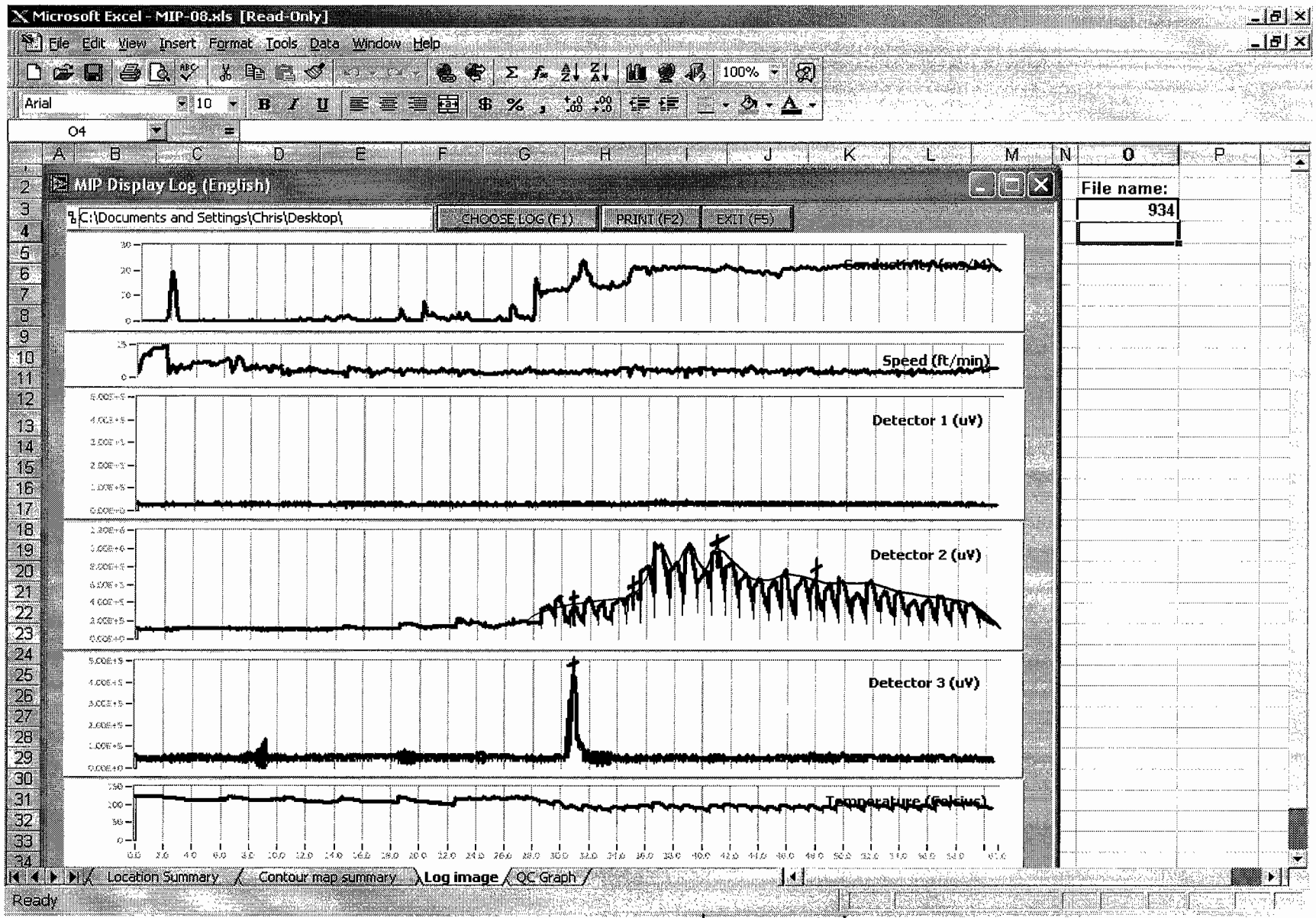
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Speed (ft/min)
Detector 1 (uV)
Detector 2 (uV)
Detector 3 (uV)
Temperature (Celsius)
Location Summary
Contour map summary
Log image
QC Graph
Ready

JNJ-02

MIP -09

Microsoft Excel - MIP-09.xls [Read-Only]

File Edit View Insert Format Tools Data Window Help

MIP Display Log (English)

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CHOOSE LOG (F1) PRINT (F2) EXIT (F5)

File name: 935

Speed (ft/min)

Detector 1 (uV)

Detector 2 (uV)

Detector 3 (uV)

Temperature (Celcius)

Location Summary / Contour map summary / Log image / QC Graph

Ready

INJ02

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MIP Display Log (English)

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CHOOSE LOG (F1) | PRINT (F2) | EXIT (F5)

File name: 936

Conductivity (mS/M)

Speed (ft/min)

Detector 1 (uV)

Detector 2 (uV)

Detector 3 (uV)

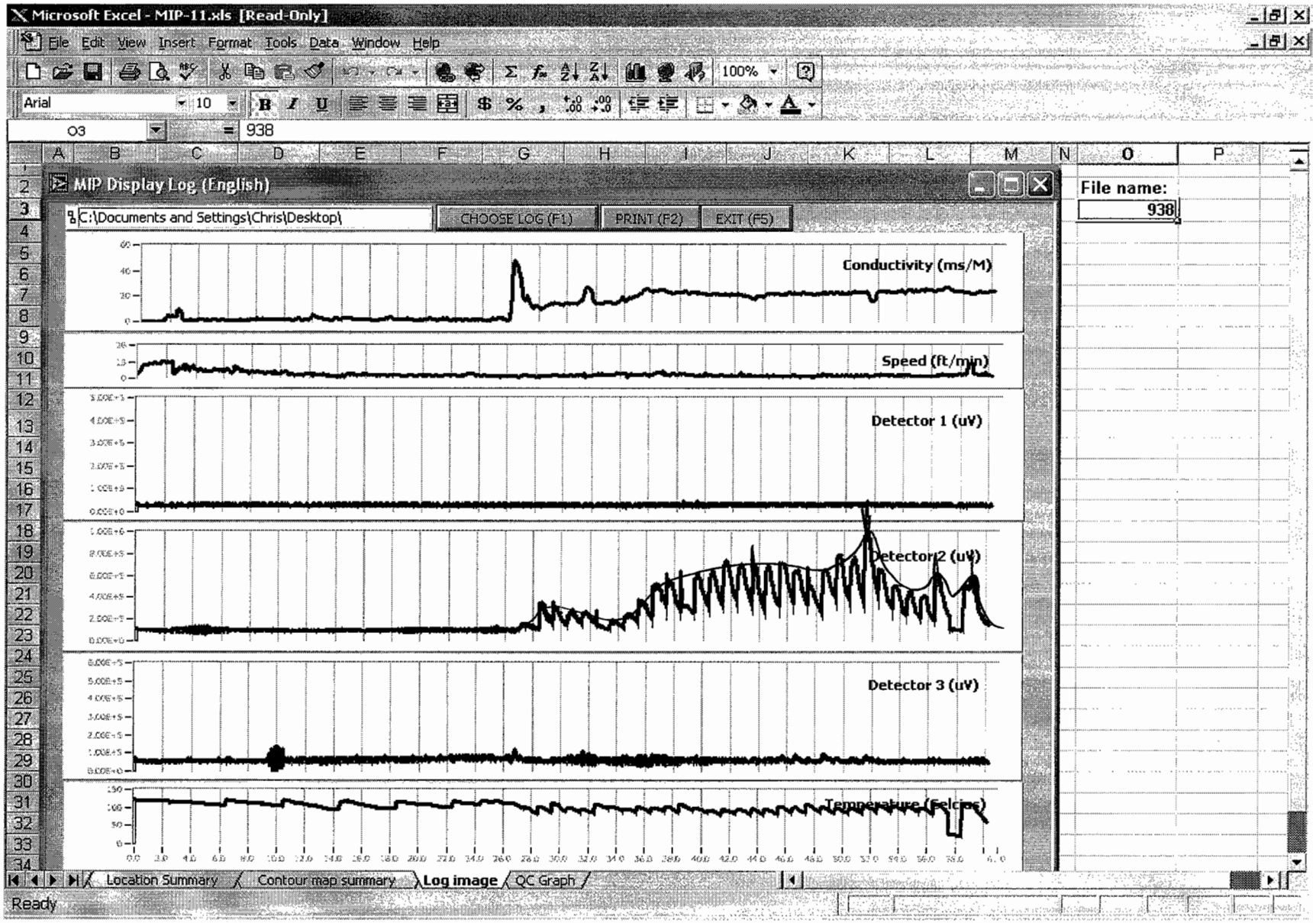
Temperature (Celcius)

Location Summary | Contour map summary | Log image | QC Graph

Ready

Model 2-83

INJ 02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Speed (ft/min)
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Detector 3 (uV)
Temperature (Celcius)
Location Summary
Contour map summary
Log image
QC Graph
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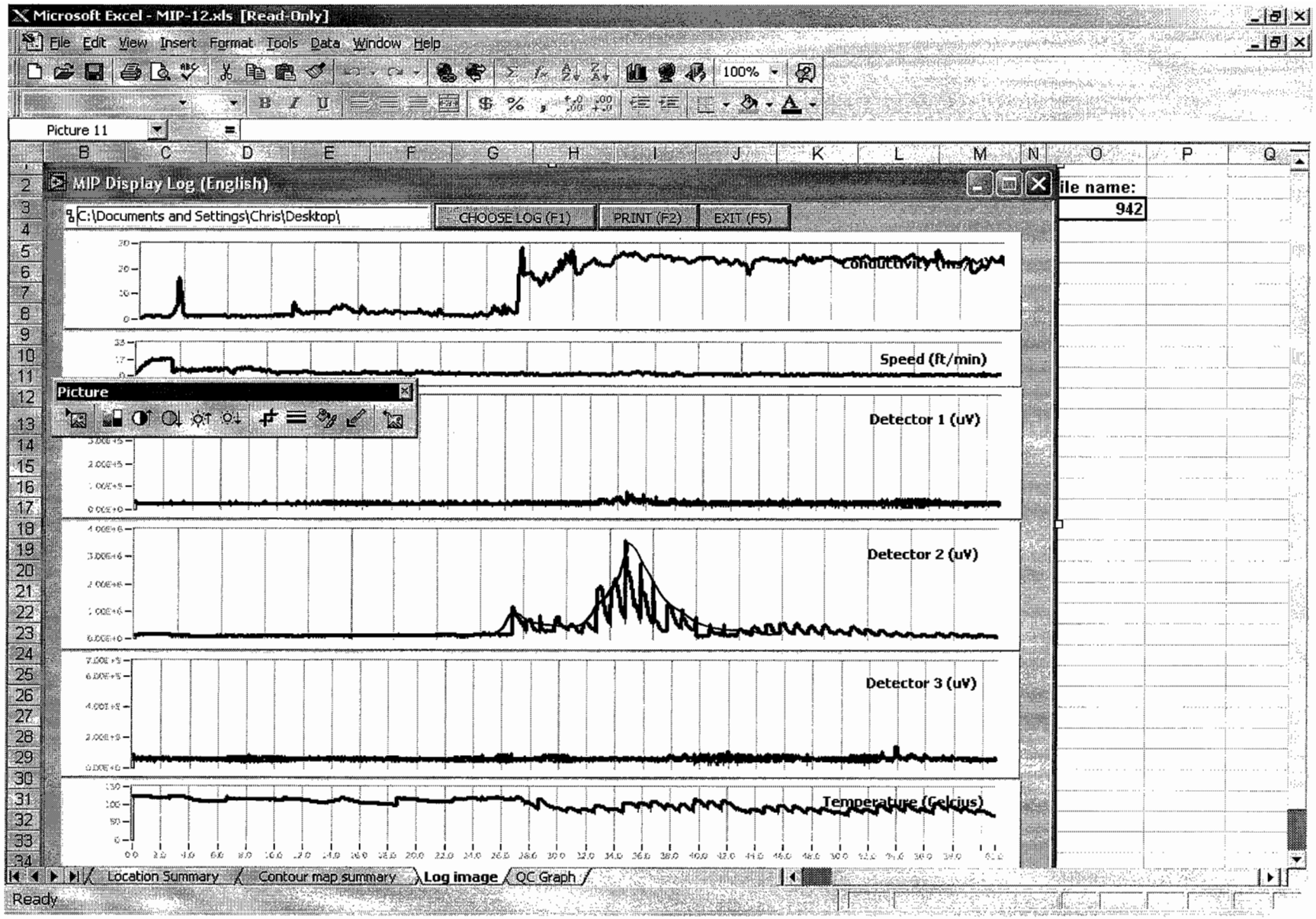
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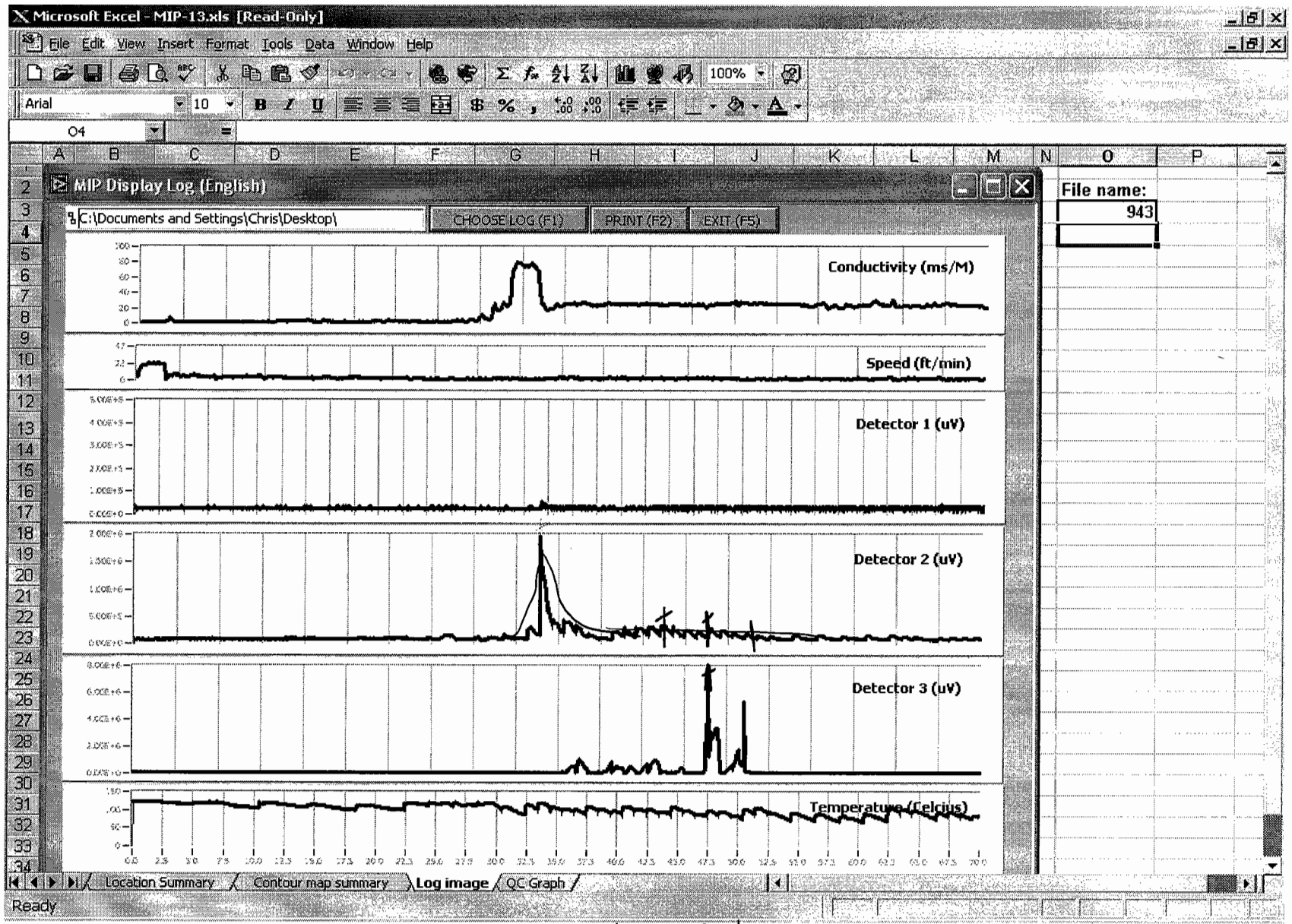
Conductivity (mS/cm)
Speed (ft/min)
Picture
Detector 1 (uV)
Detector 2 (uV)
Detector 3 (uV)
Temperature (Celcius)
ile name:
942
Location Summary
Contour map summary
Log image
QC Graph
Ready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Detector 3 (uV)
Temperature (Celcius)
Location Summary
Contour map summary
Log image
QC Graph
Ready

JN502

MIP-14

Methyl of SB-9

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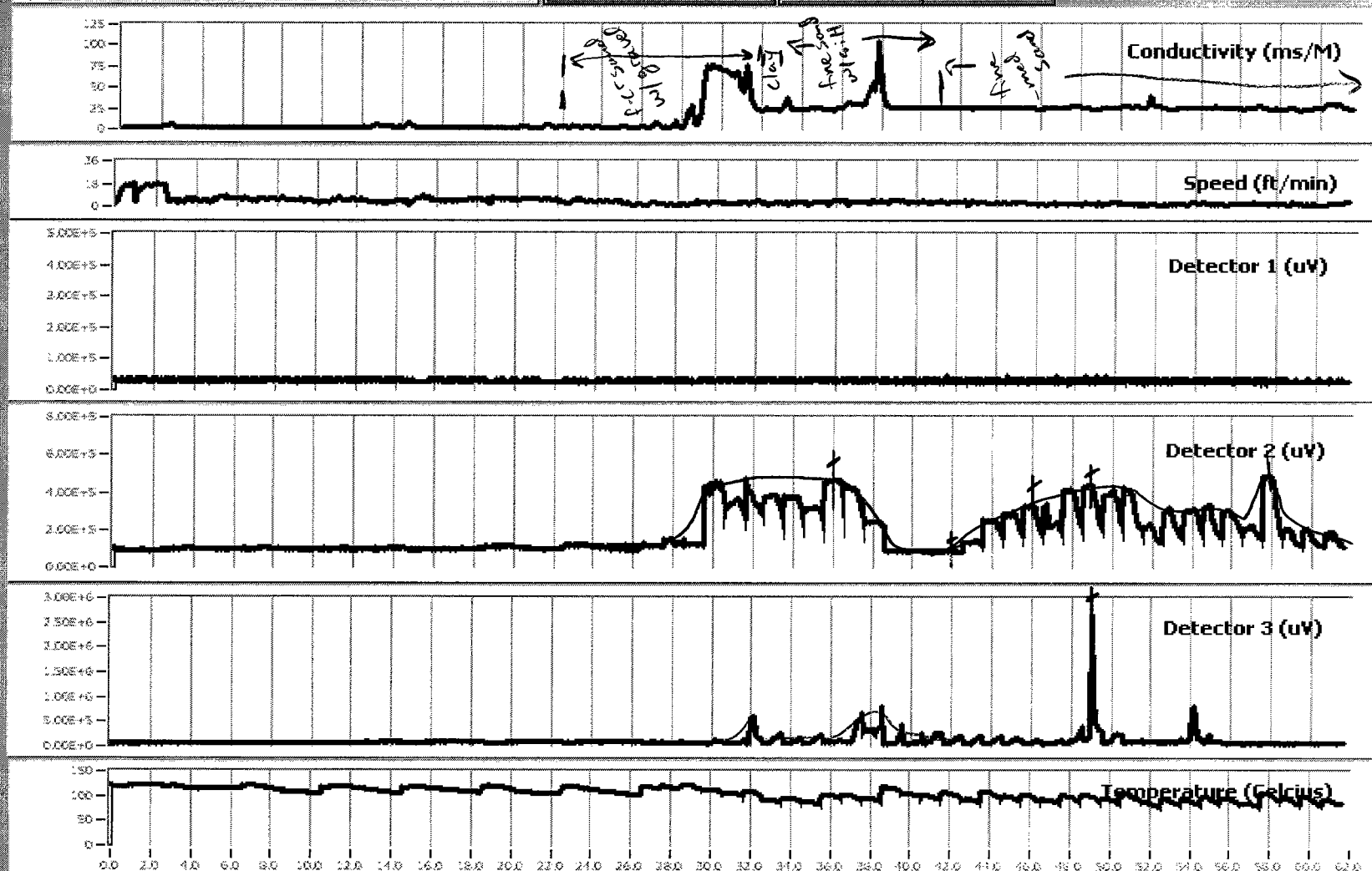

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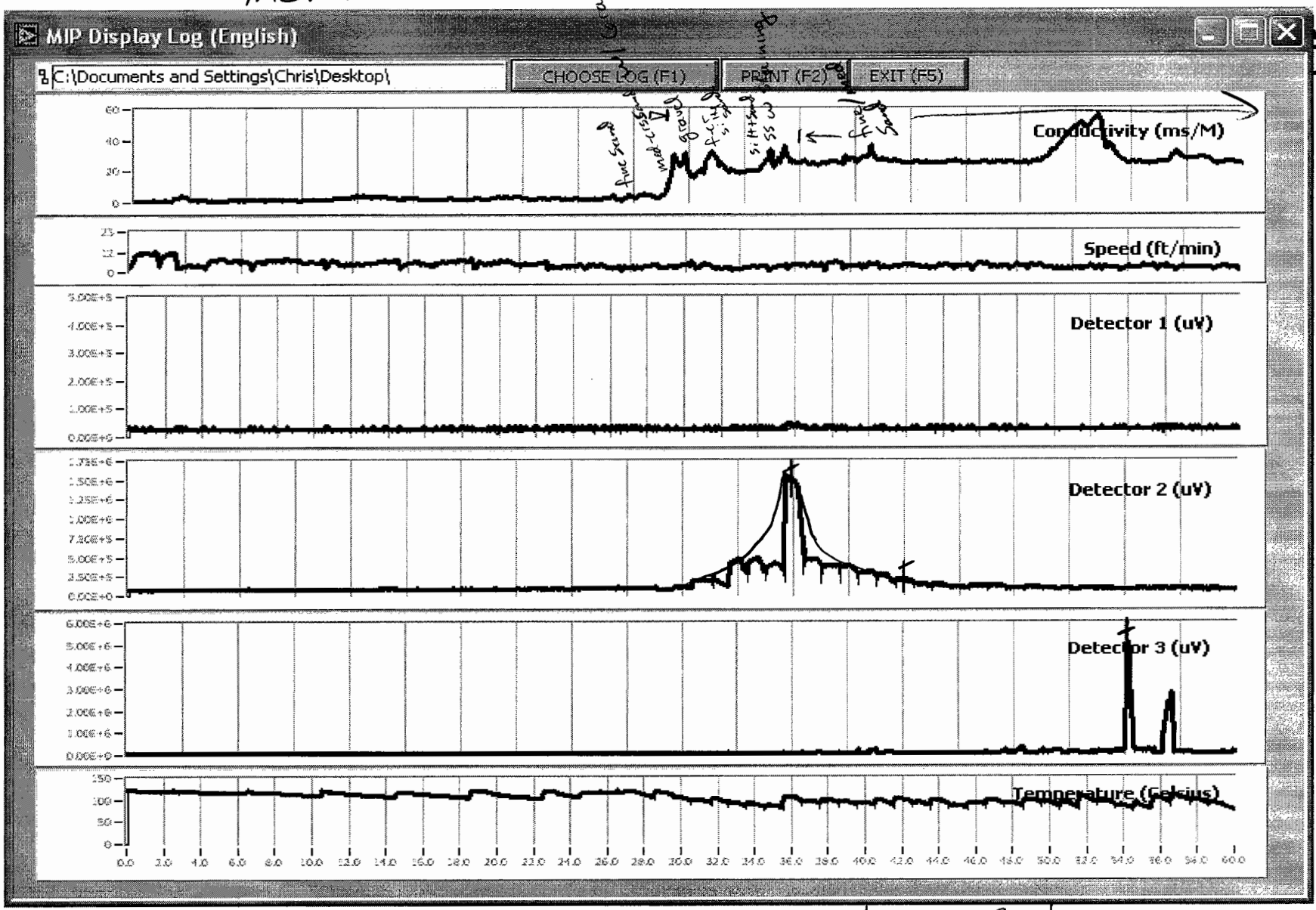

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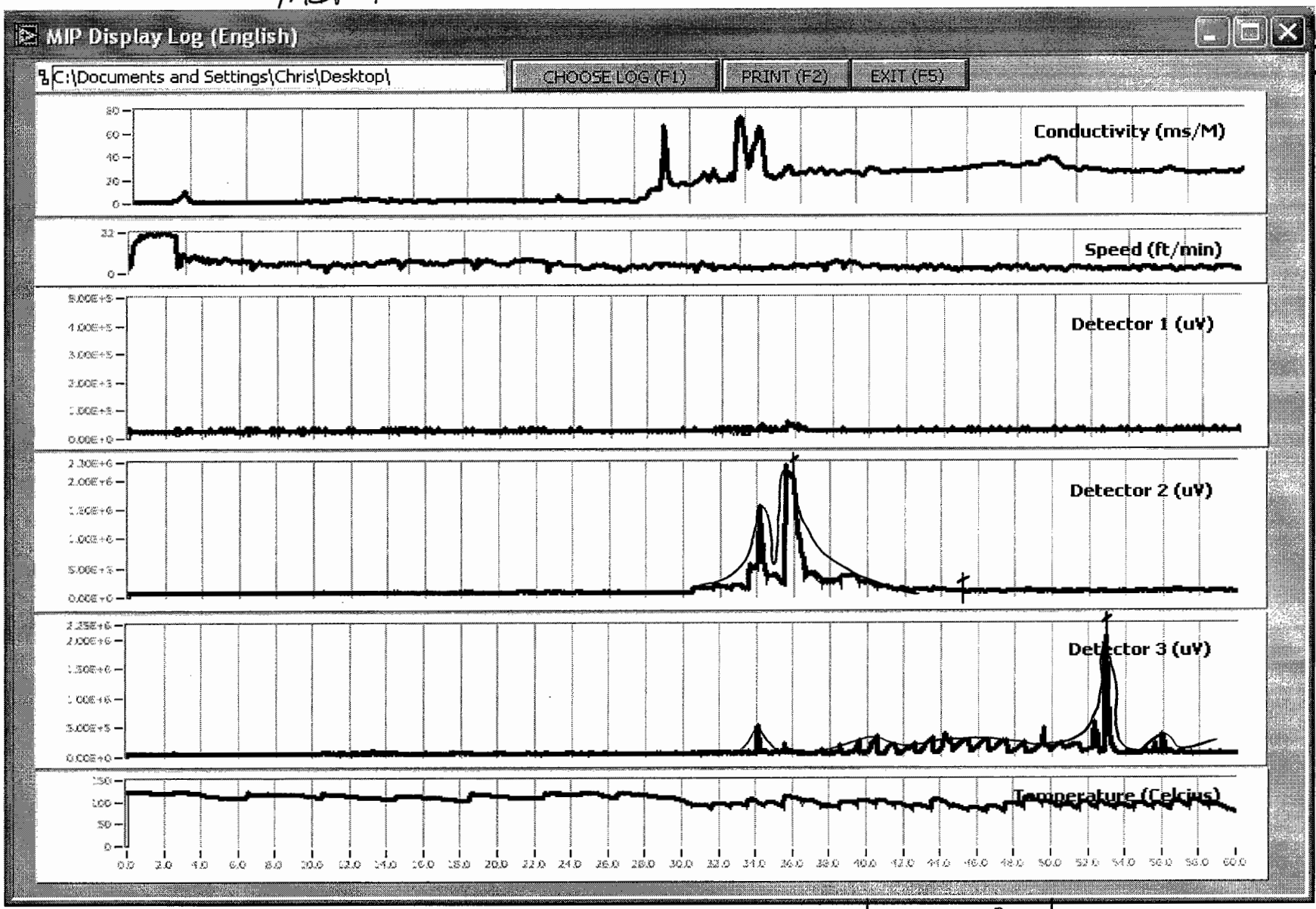

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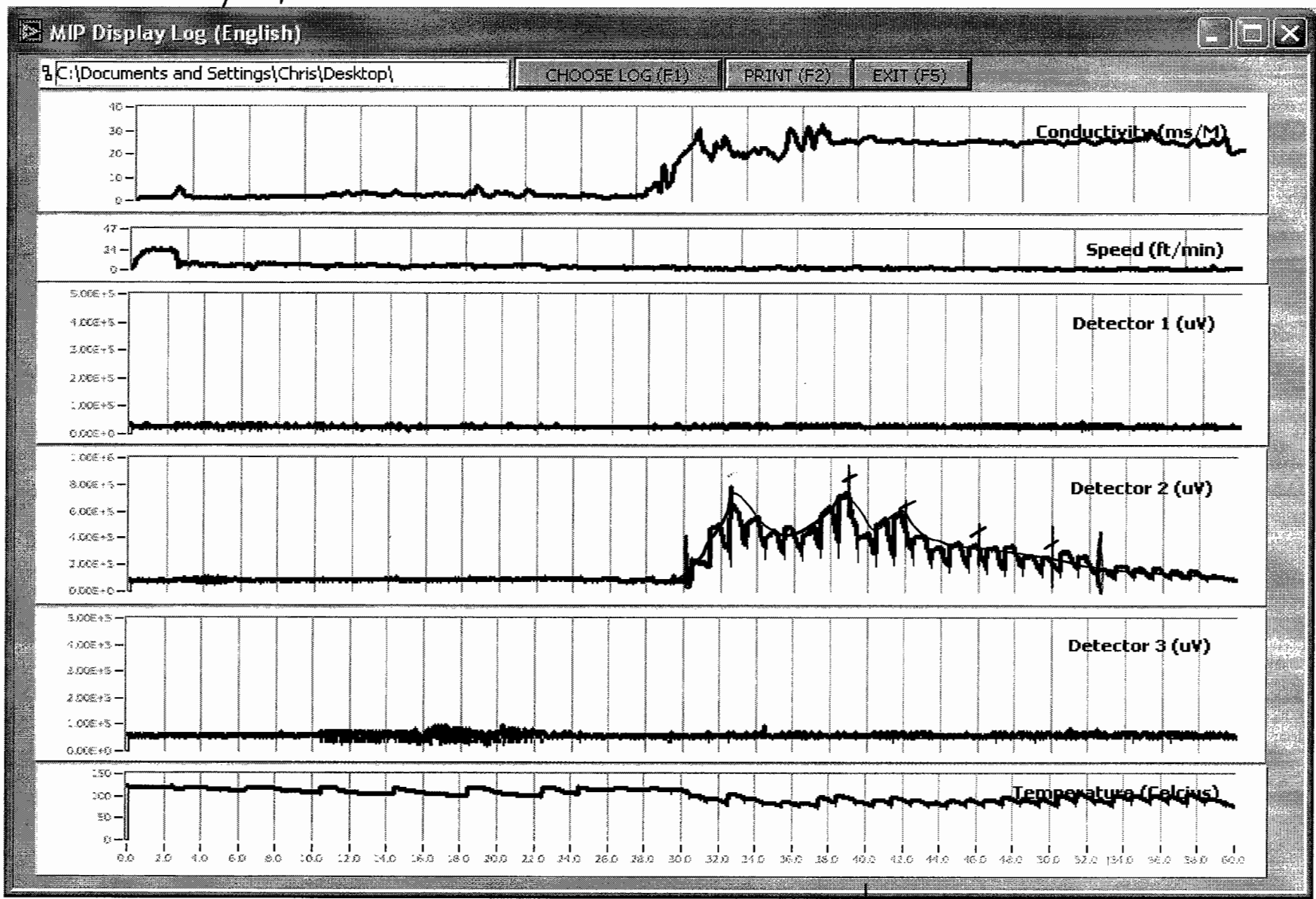

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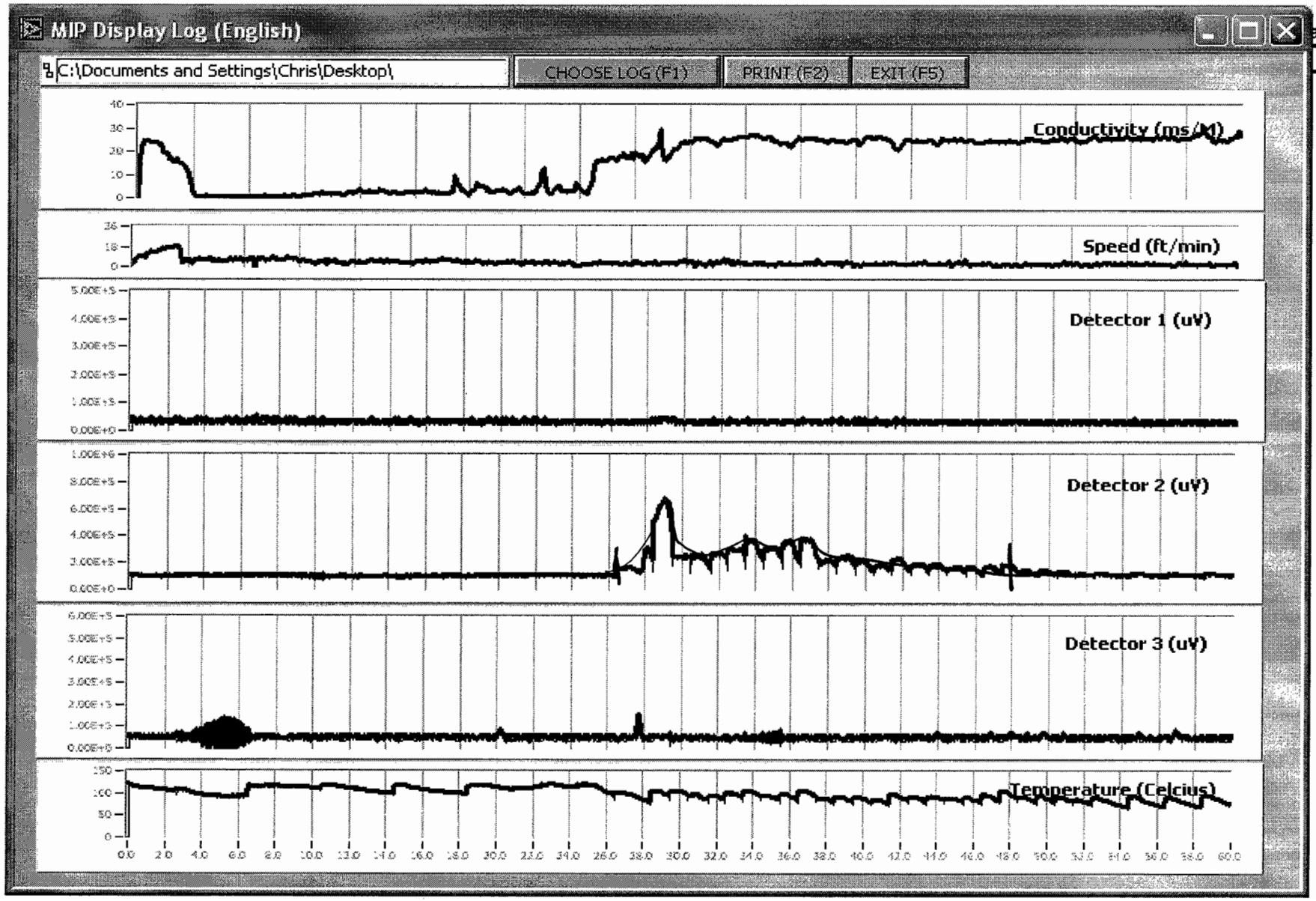

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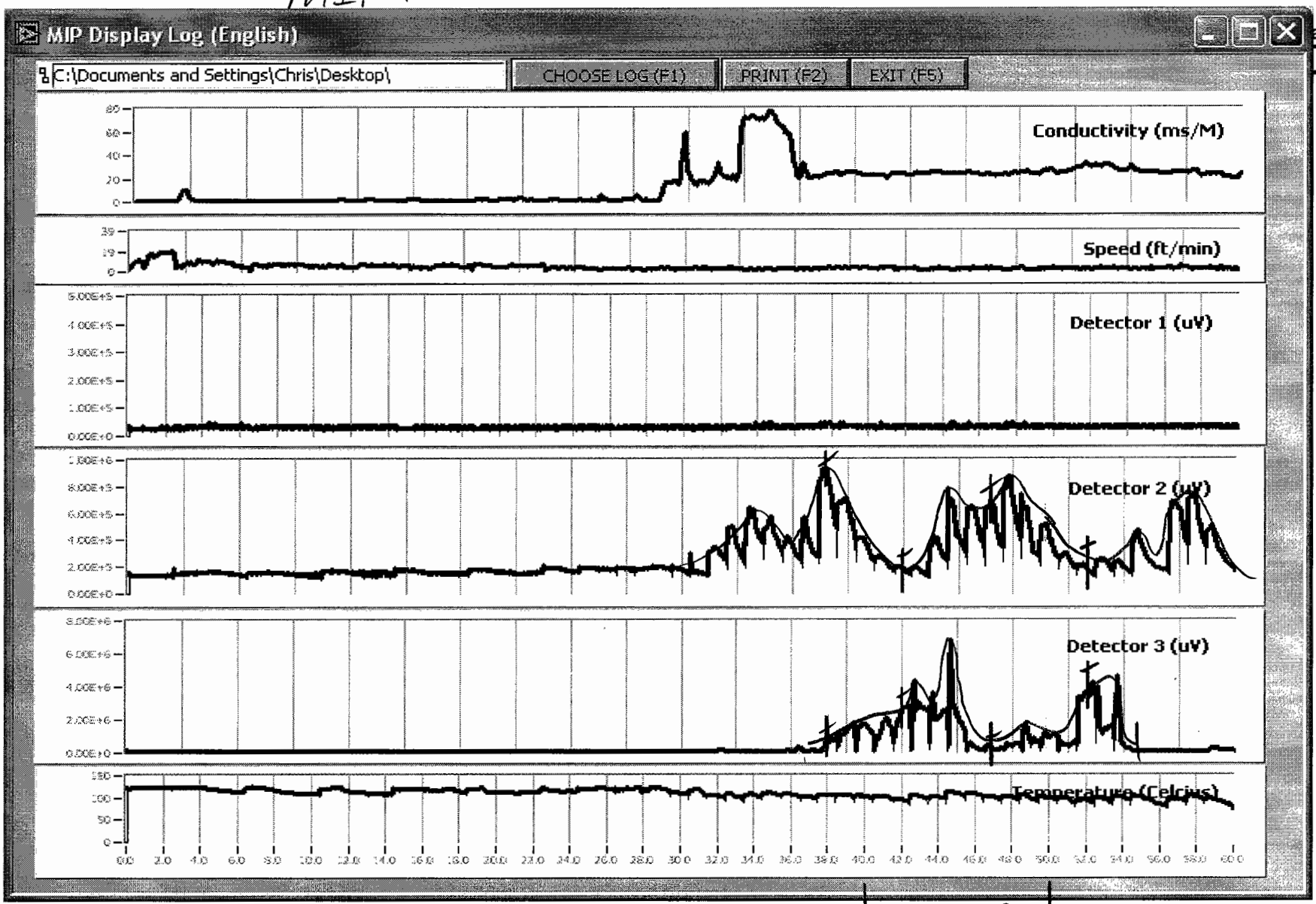

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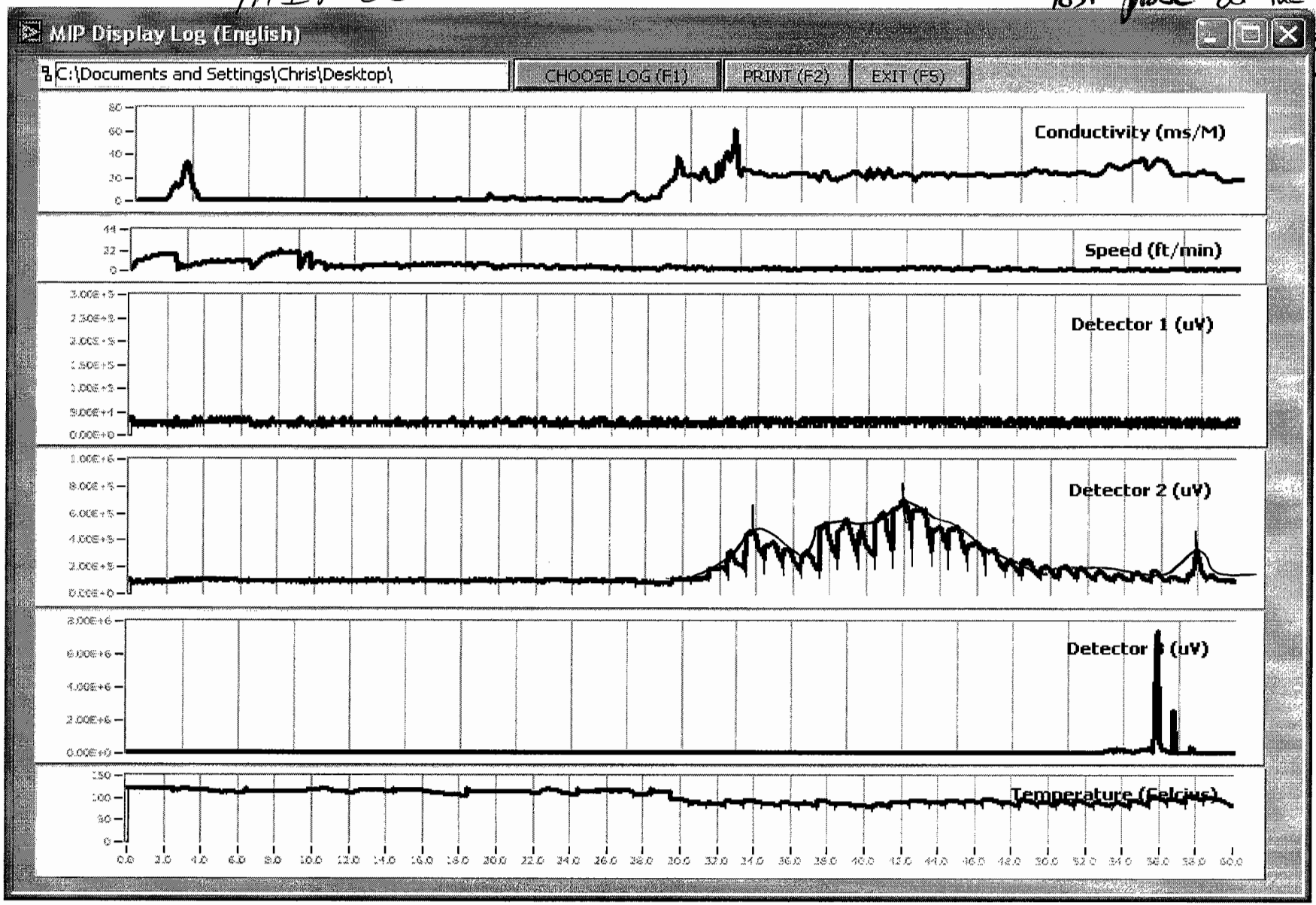
- lost probe at the bottom of Point



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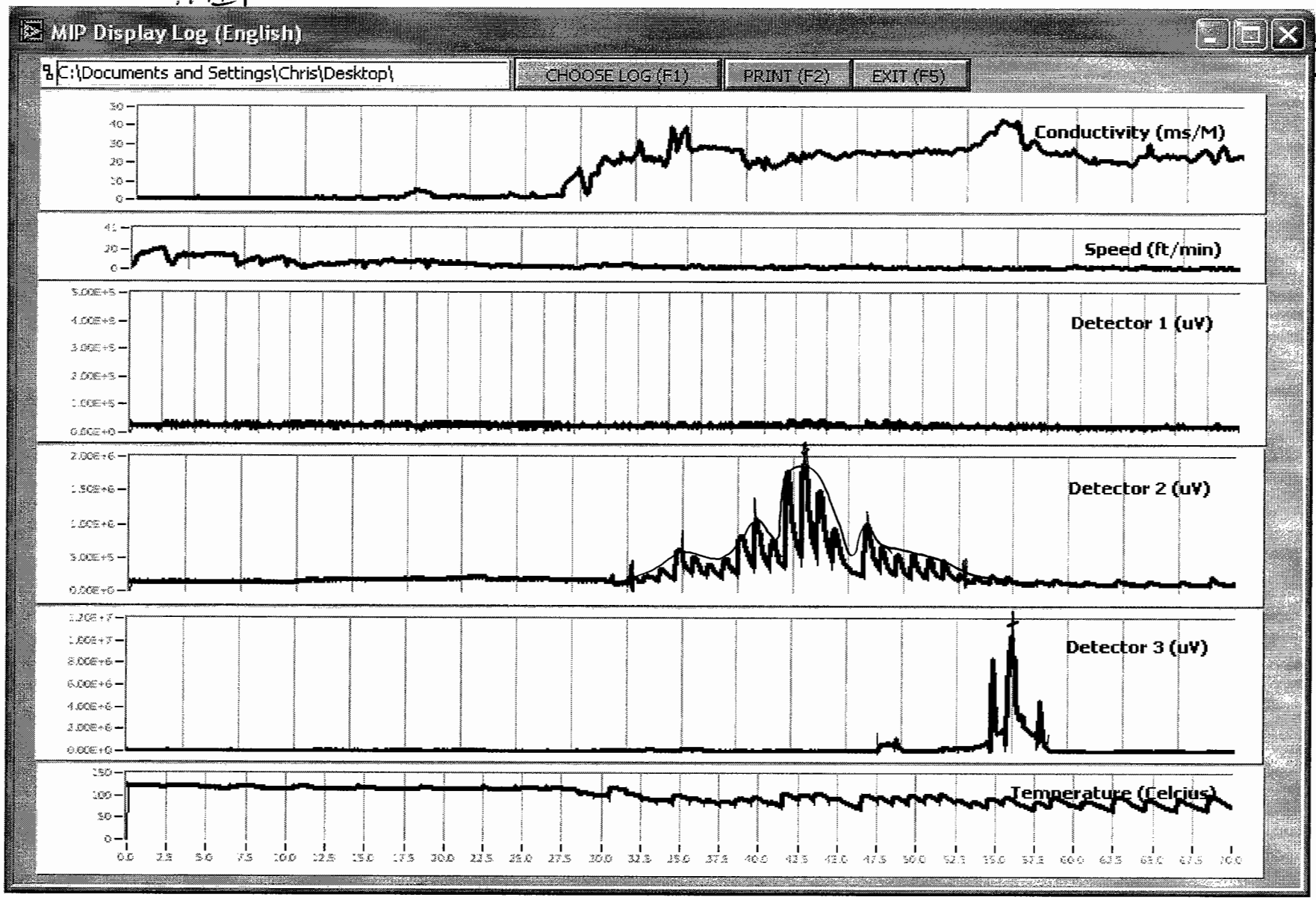
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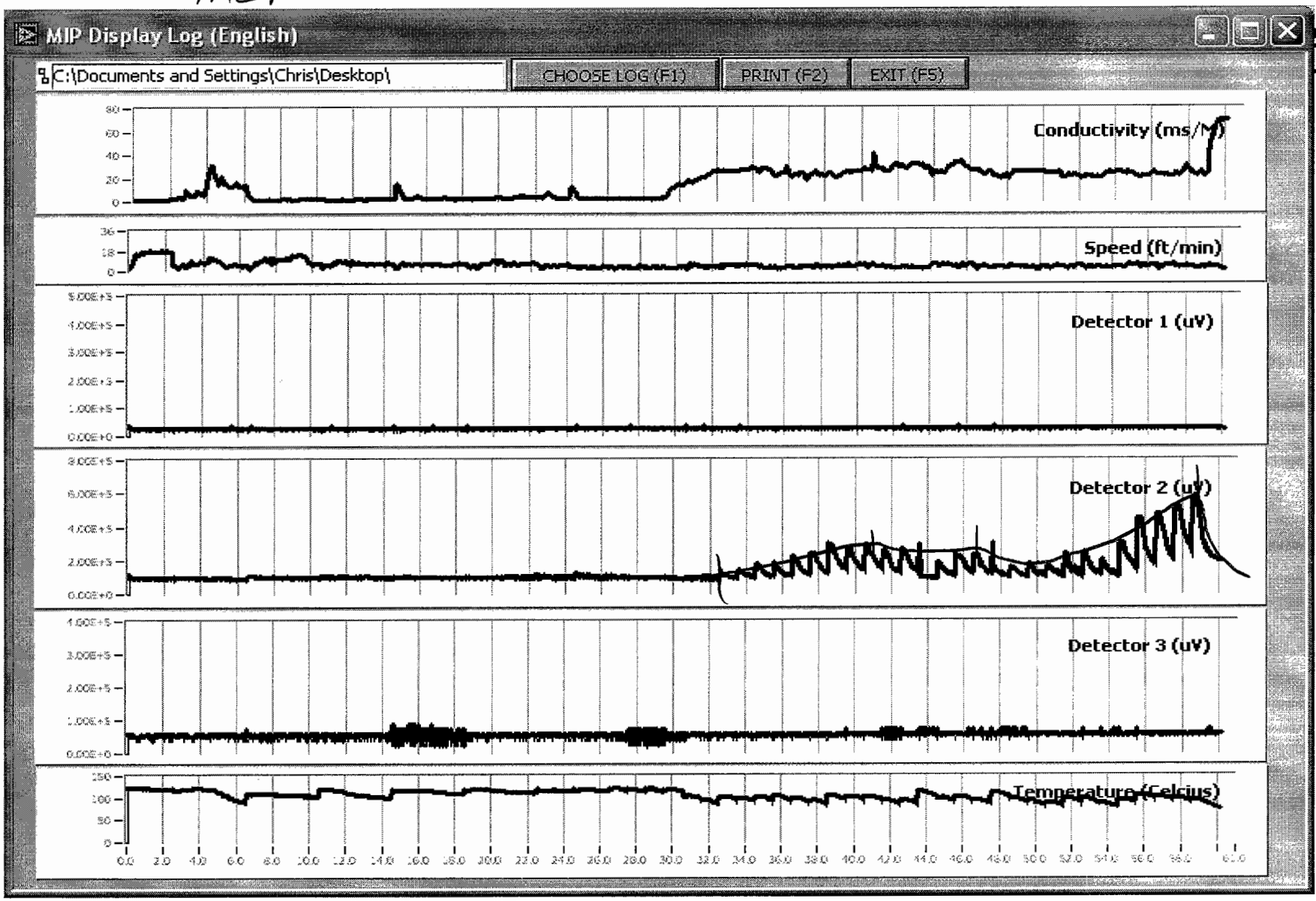
Detector 1 (uV)
Detector 2 (uV)
Detector 3 (uV)
Temperature (Celcius)

MIP-22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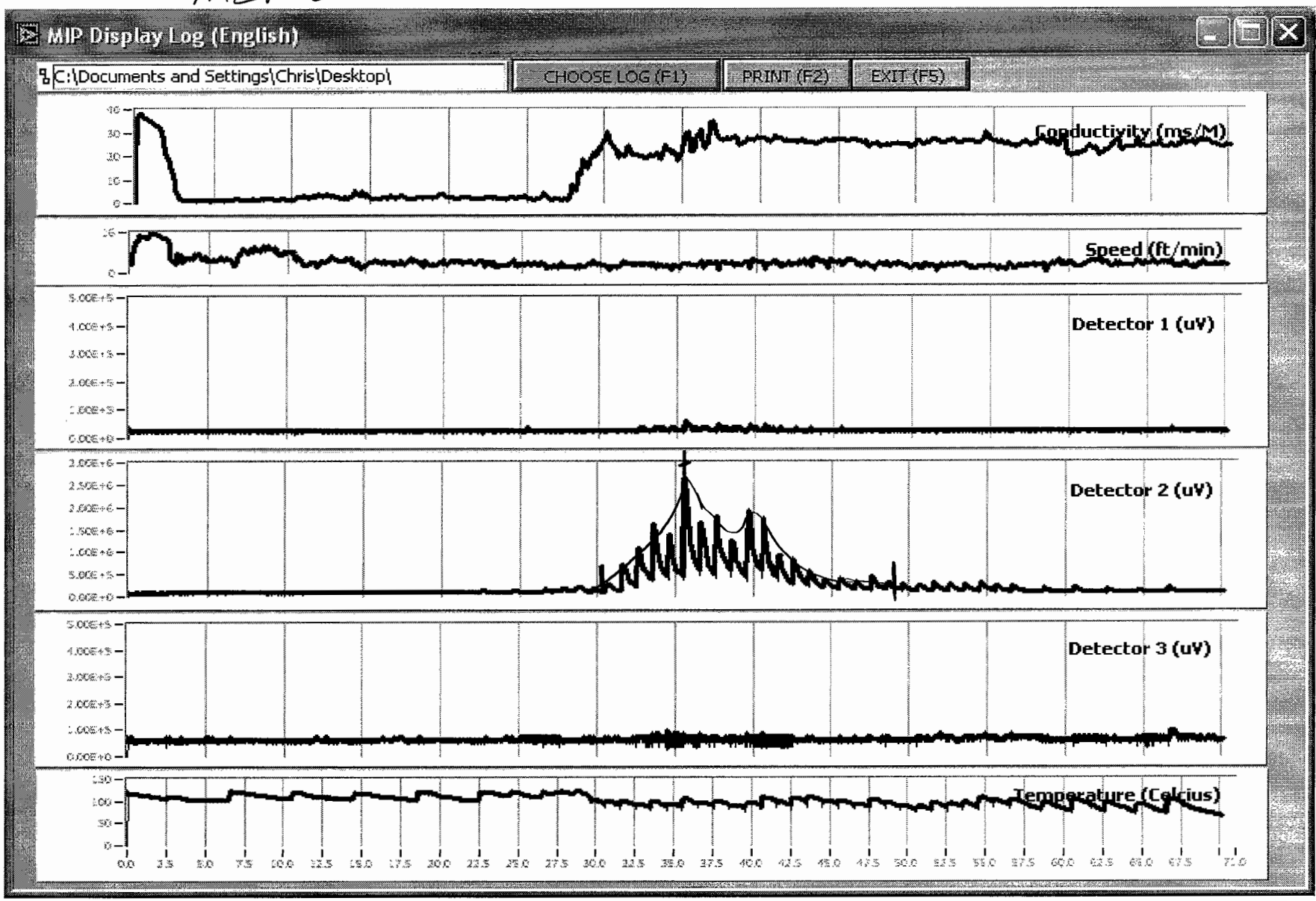
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Temperature (Celcius)

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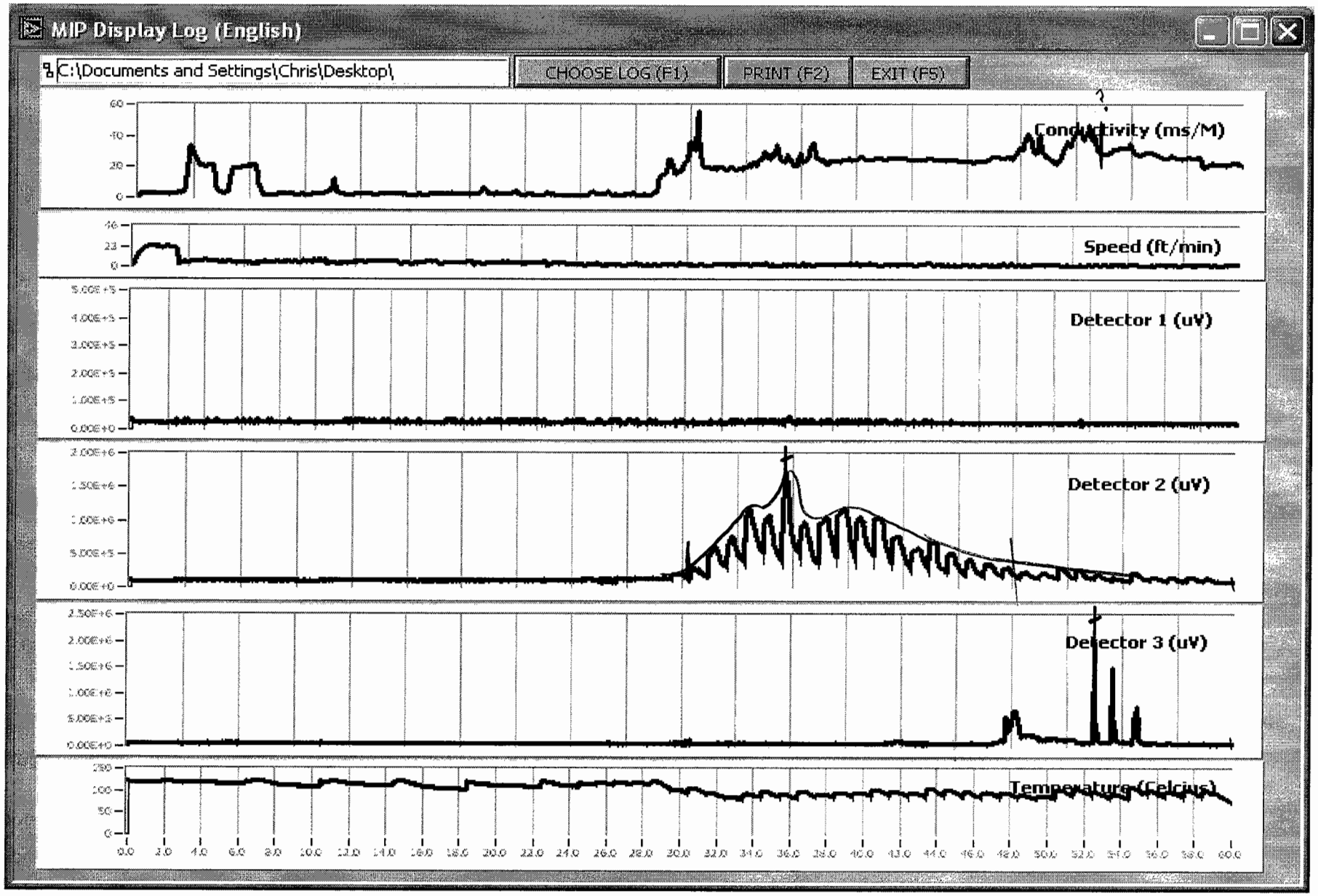
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Conductivity (ms/M)
Speed (ft/min)
Detector 1 (uV)
Detector 2 (uV)
Detector 3 (uV)
Temperature (Celcius)

MIP-25

me:
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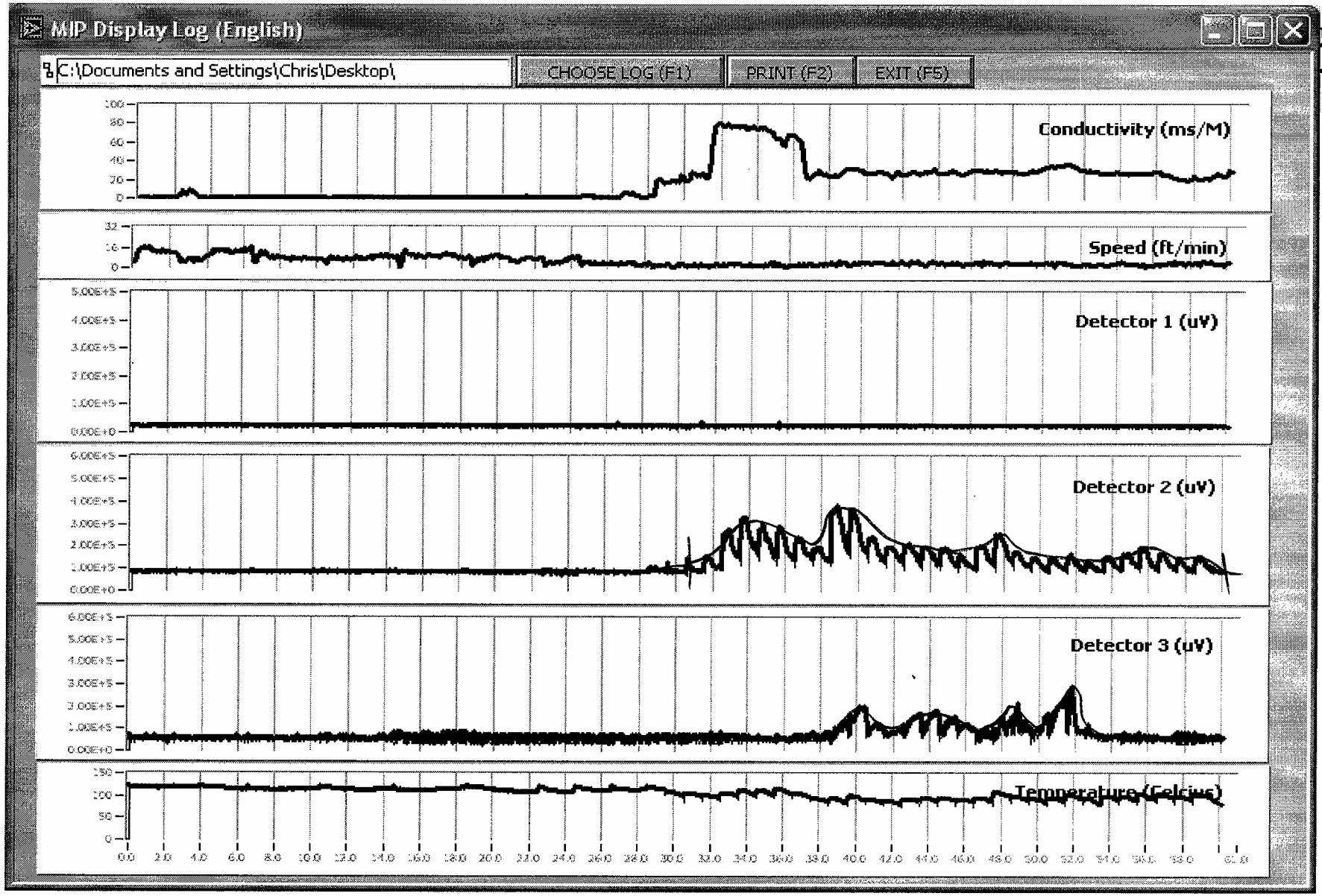
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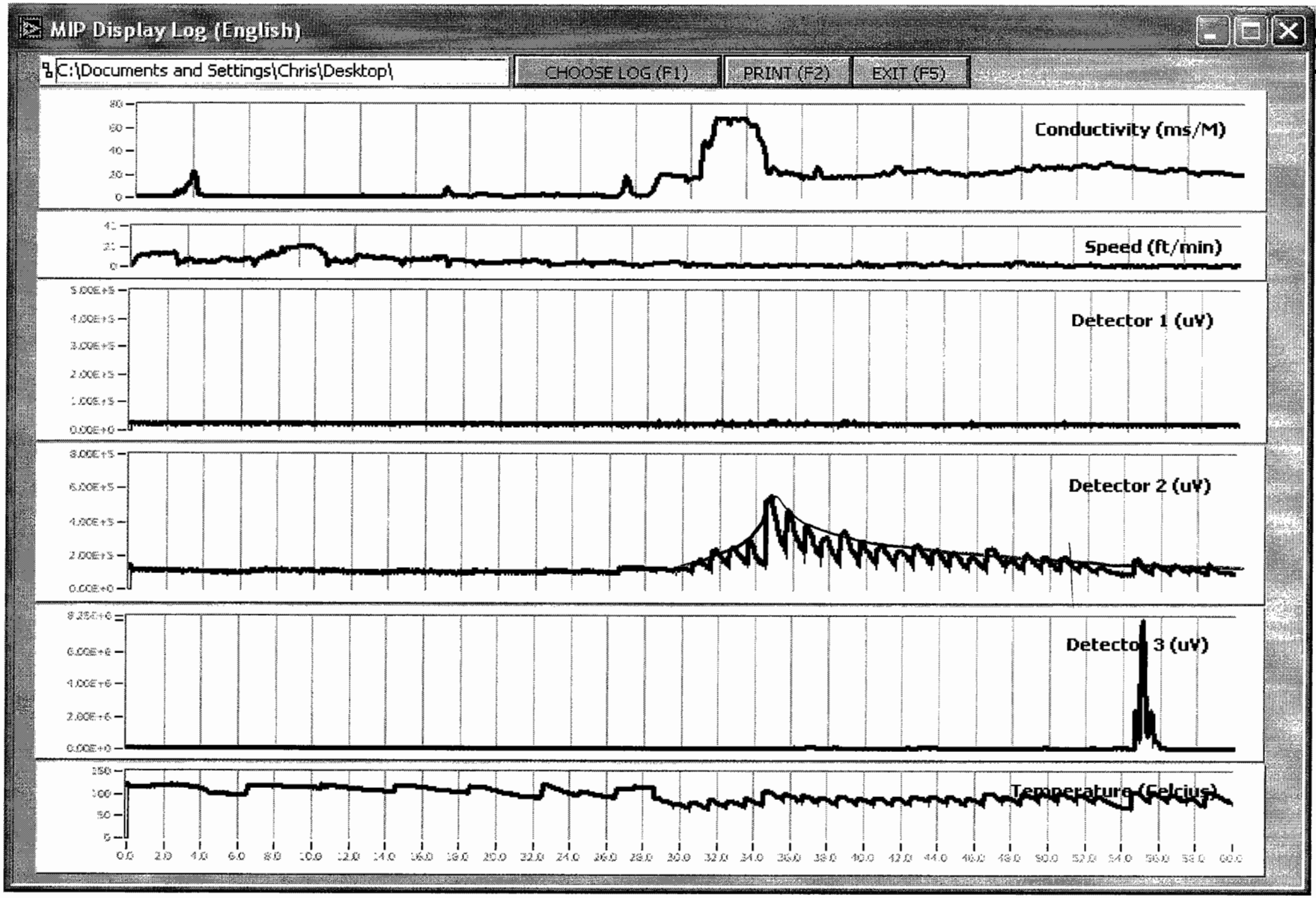
Detector 3 (uV)
Temperature (Celcius)

MIP-26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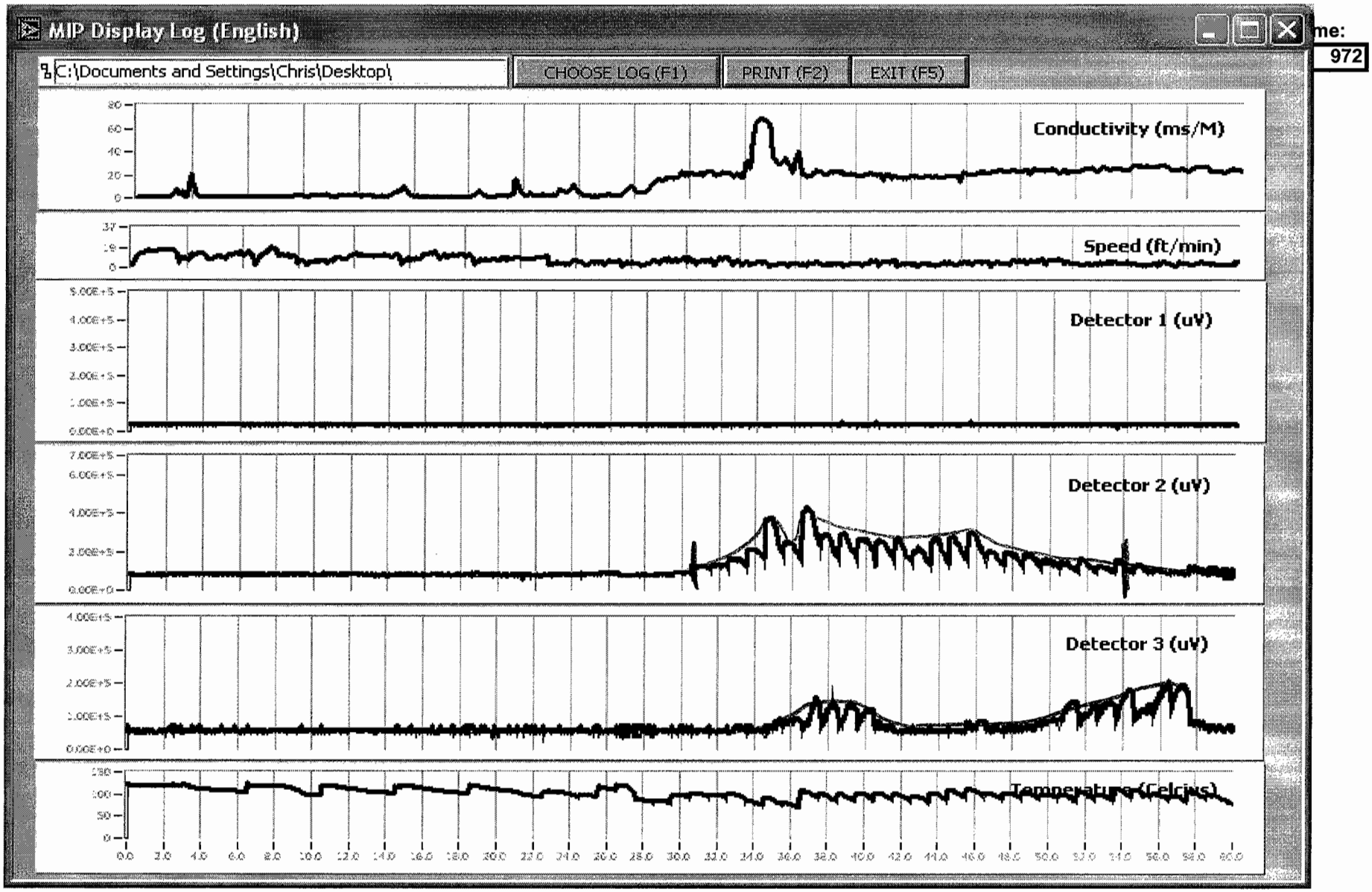
CHOOSE LOG (F1)
PRINT (F2)
EXIT (F5)
Conductivity (ms/M)
Speed (ft/min)
Detector 1 (uV)
Detector 2 (uV)
Detector 3 (uV)
Temperature (Celcius)

me:
970

MIP-27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PRINT (F2)
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Conductivity (ms/M)
Speed (ft/min)
Detector 1 (uV)
Detector 2 (uV)
Detector 3 (uV)
Temperature (Celcius)

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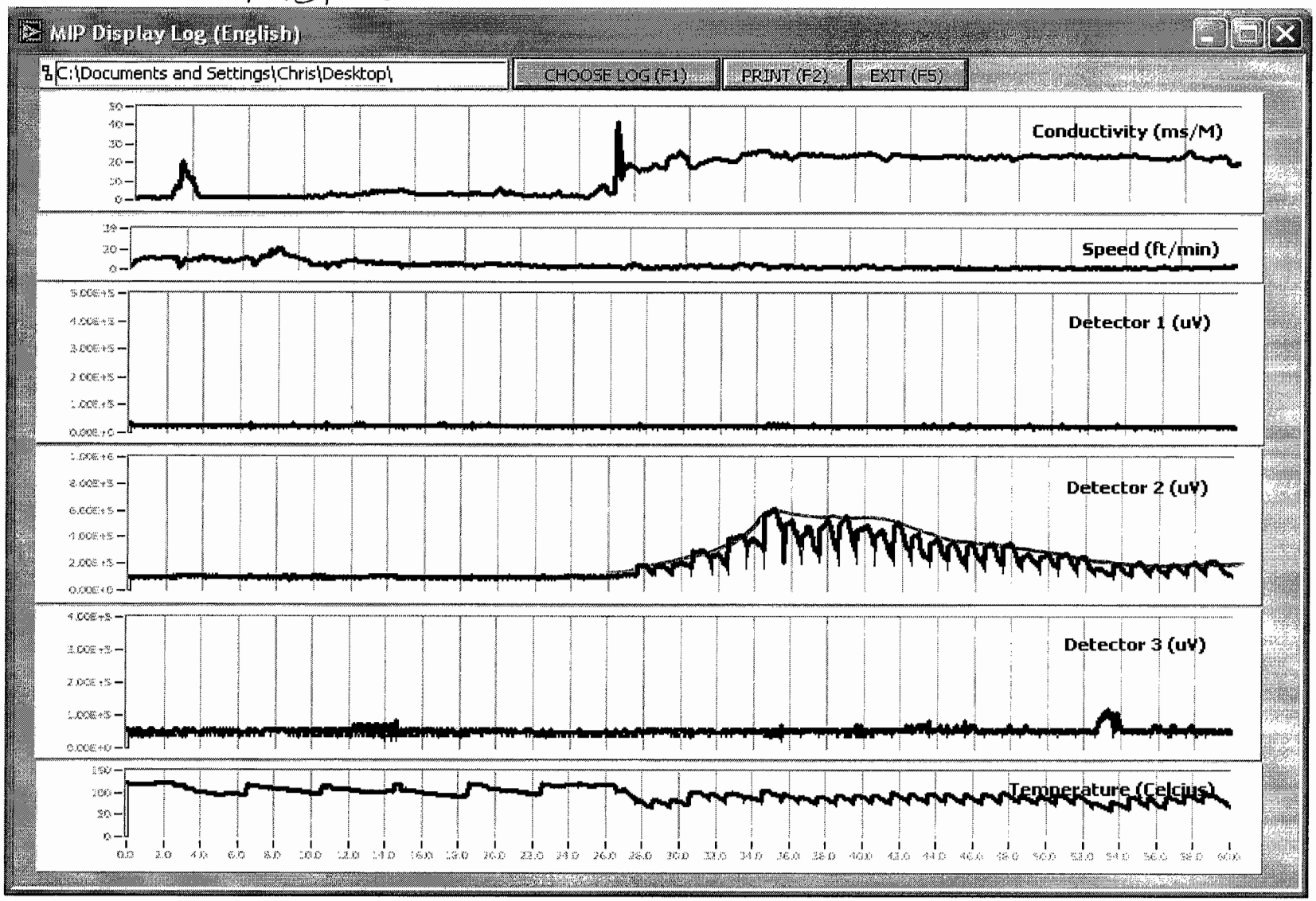
972

MIP-28



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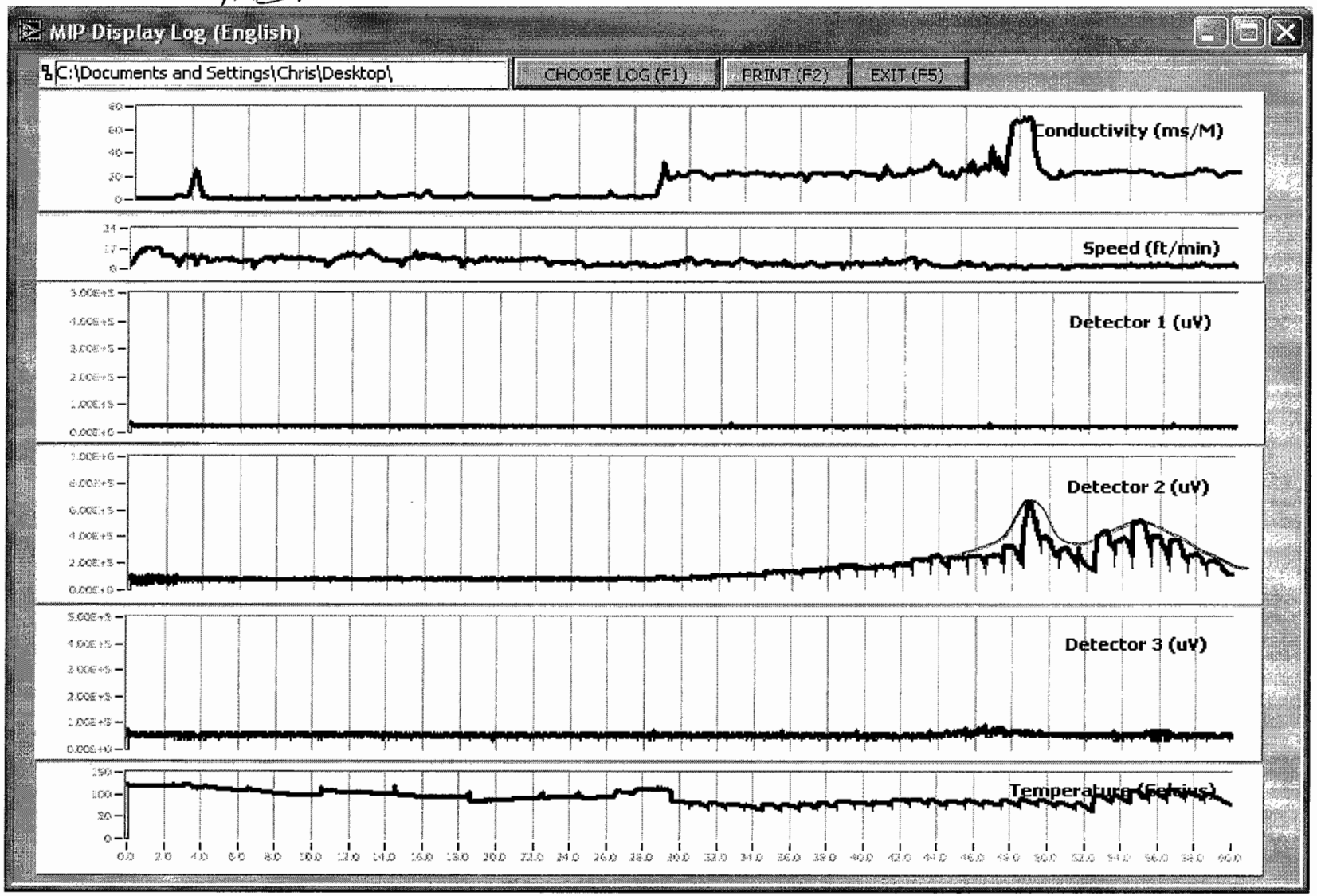

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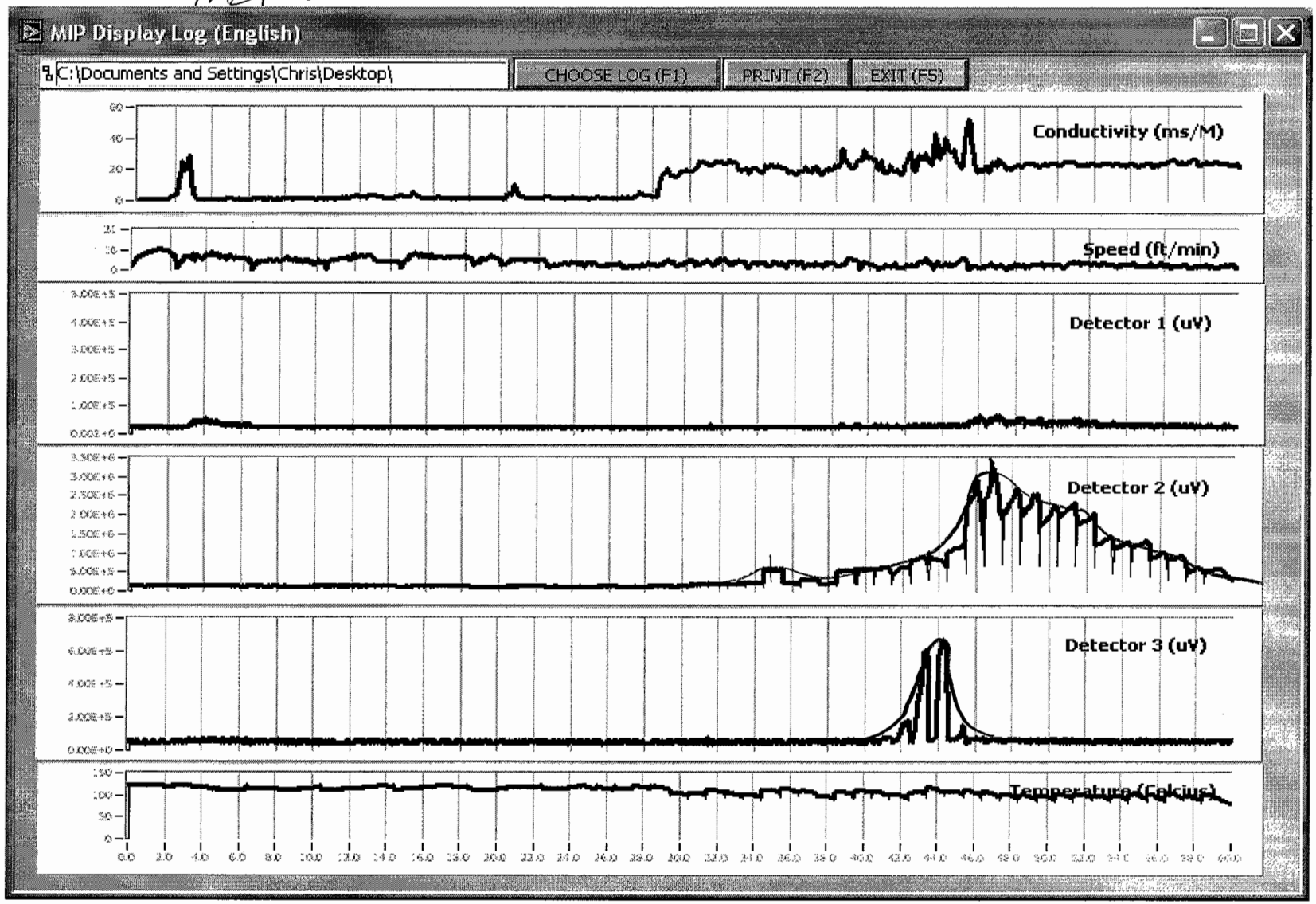

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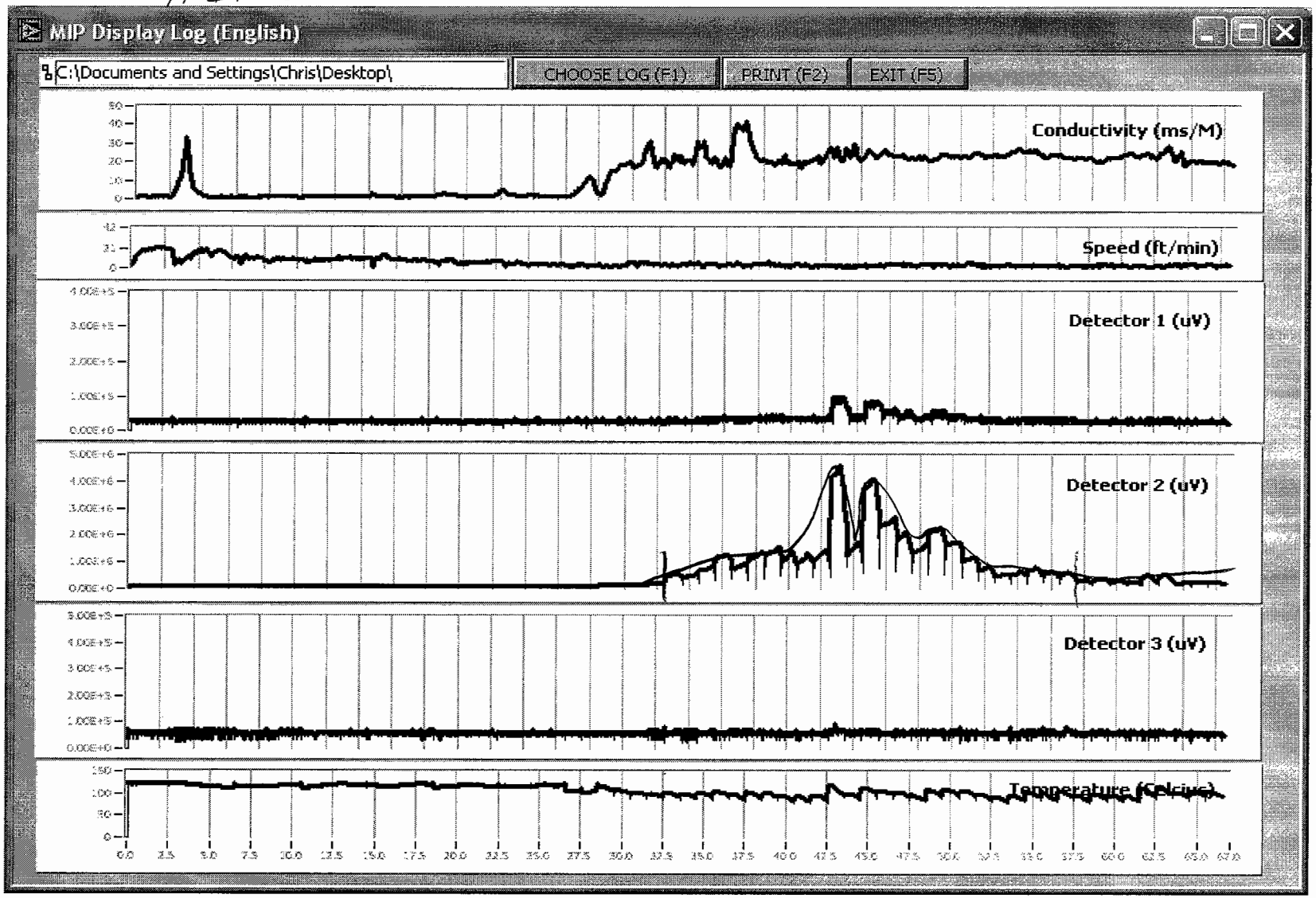

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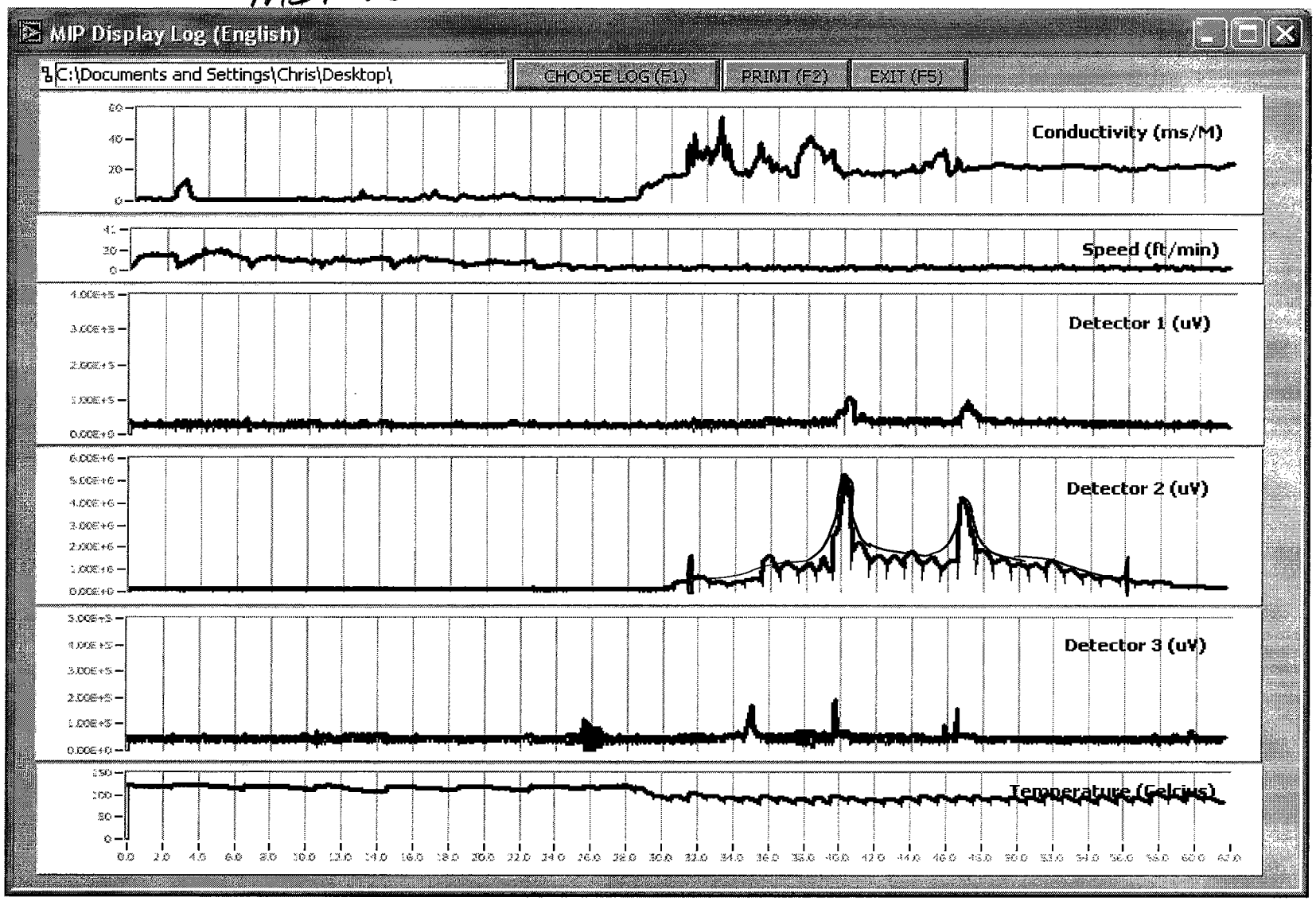

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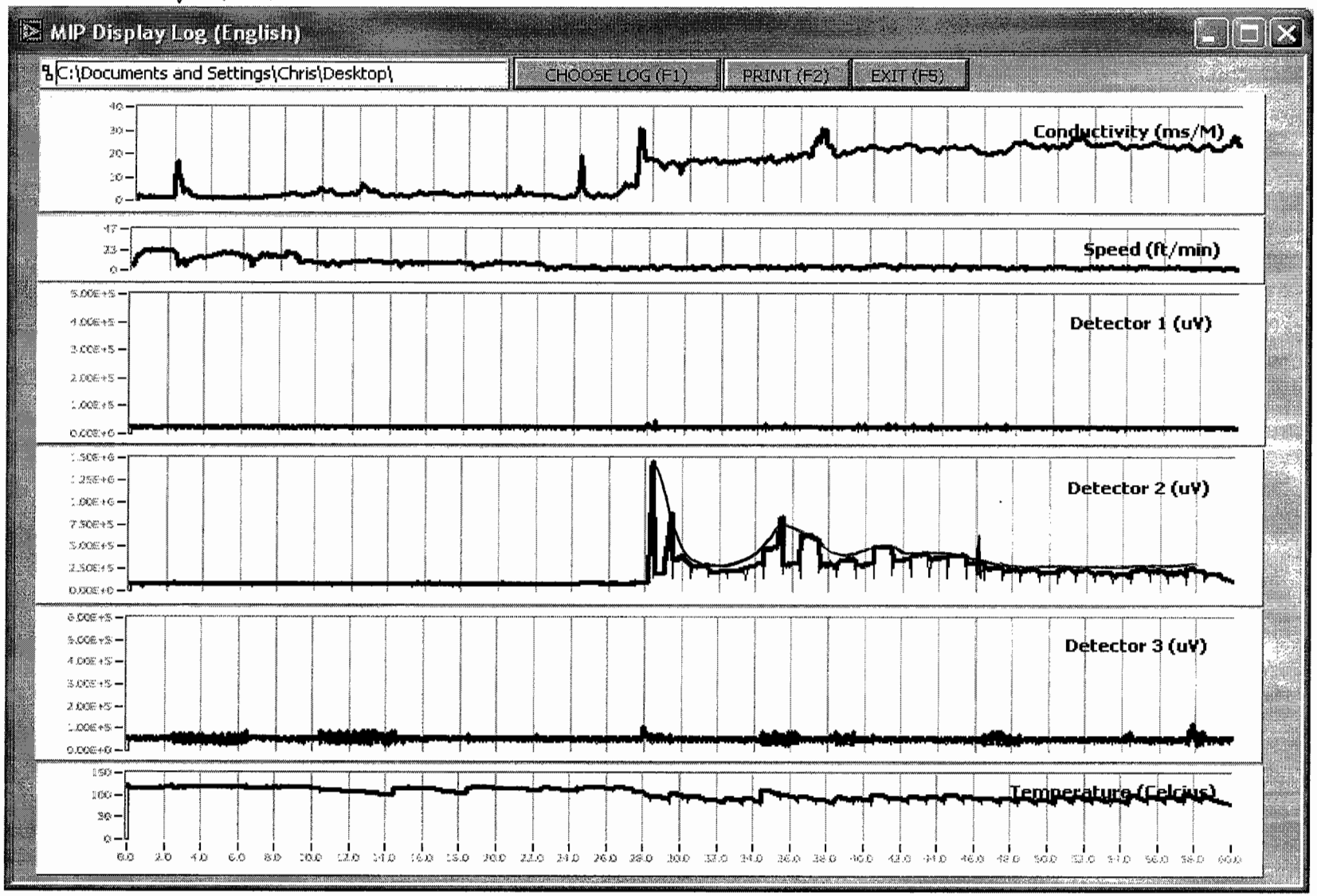

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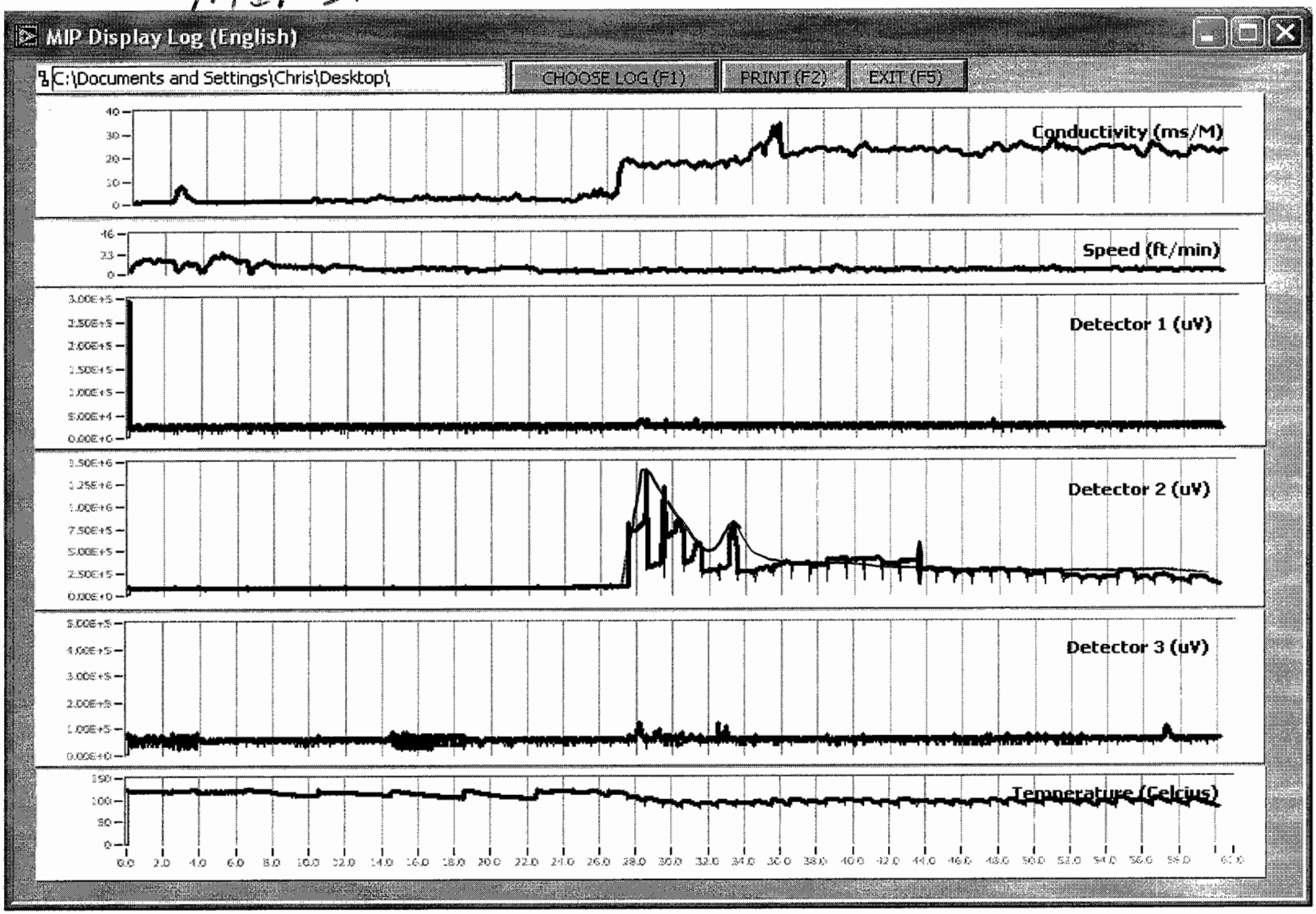

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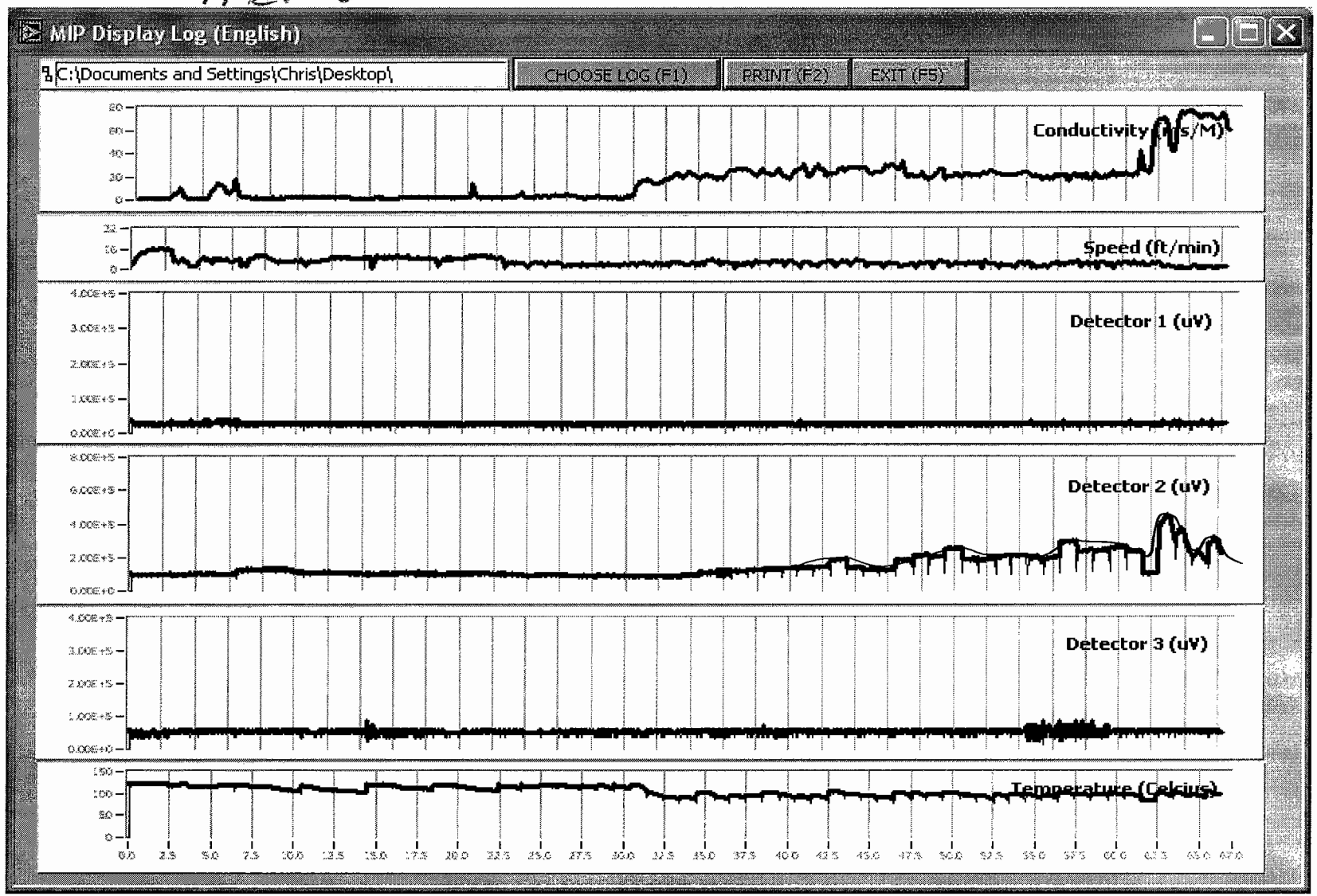
11 MP-35



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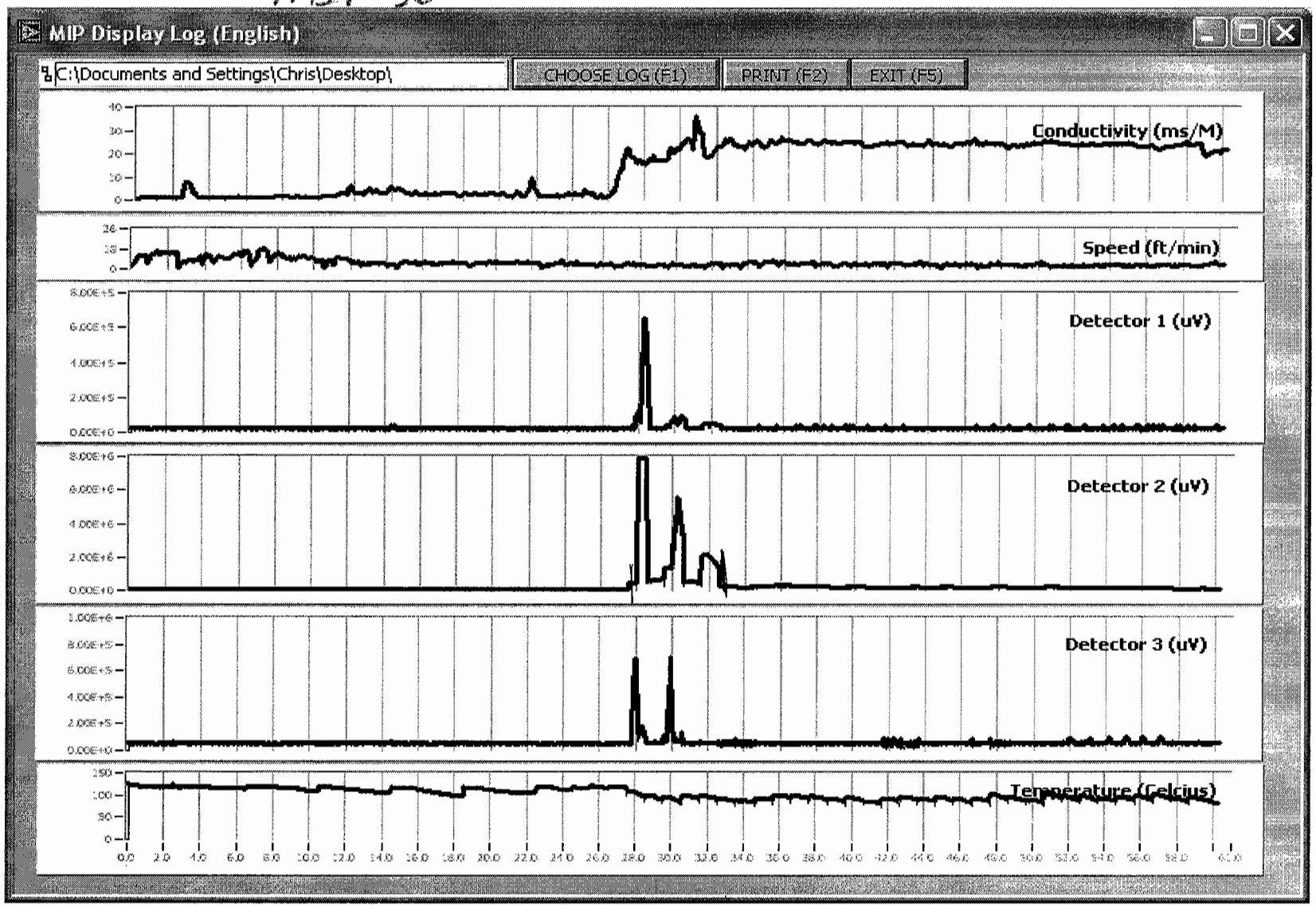

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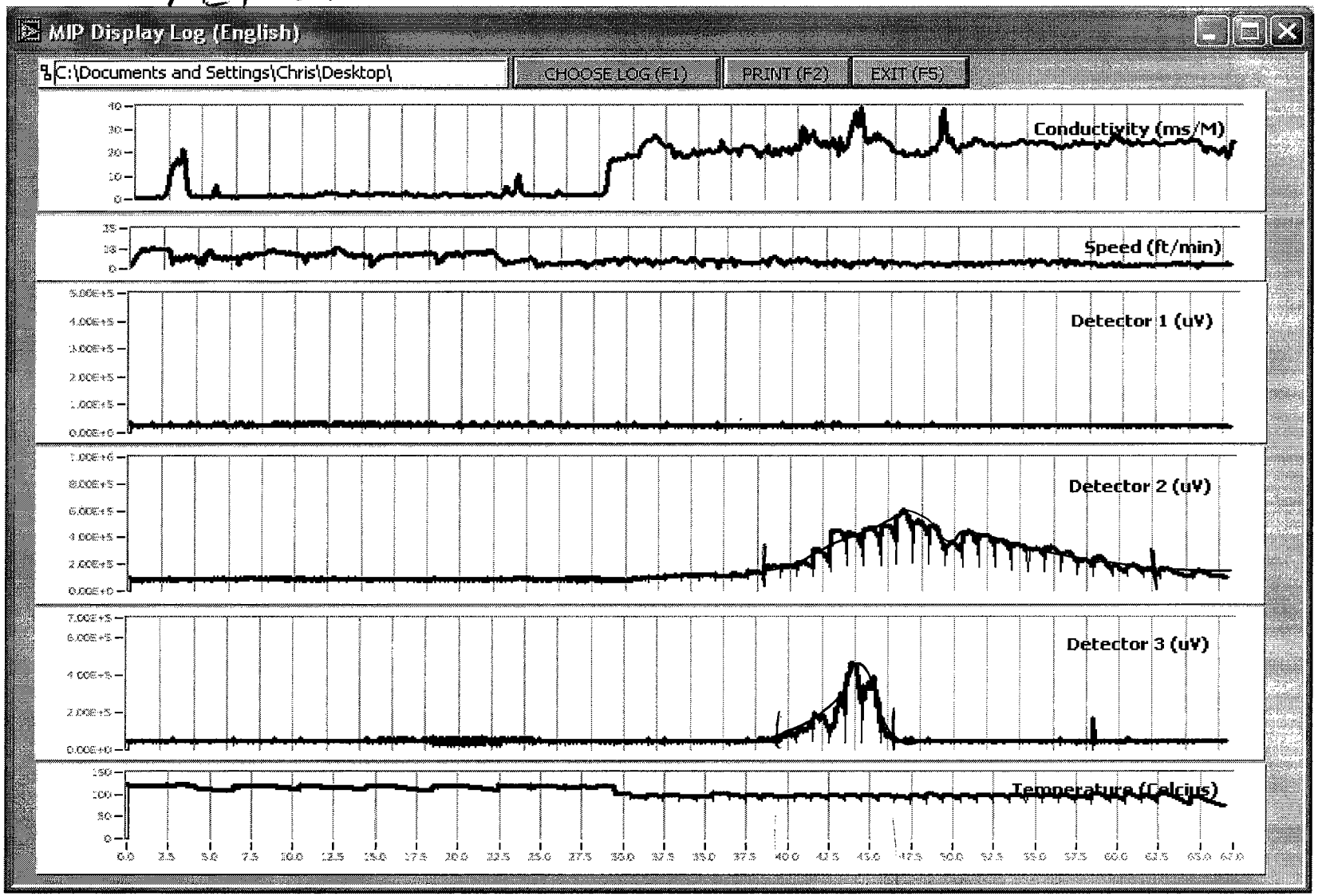

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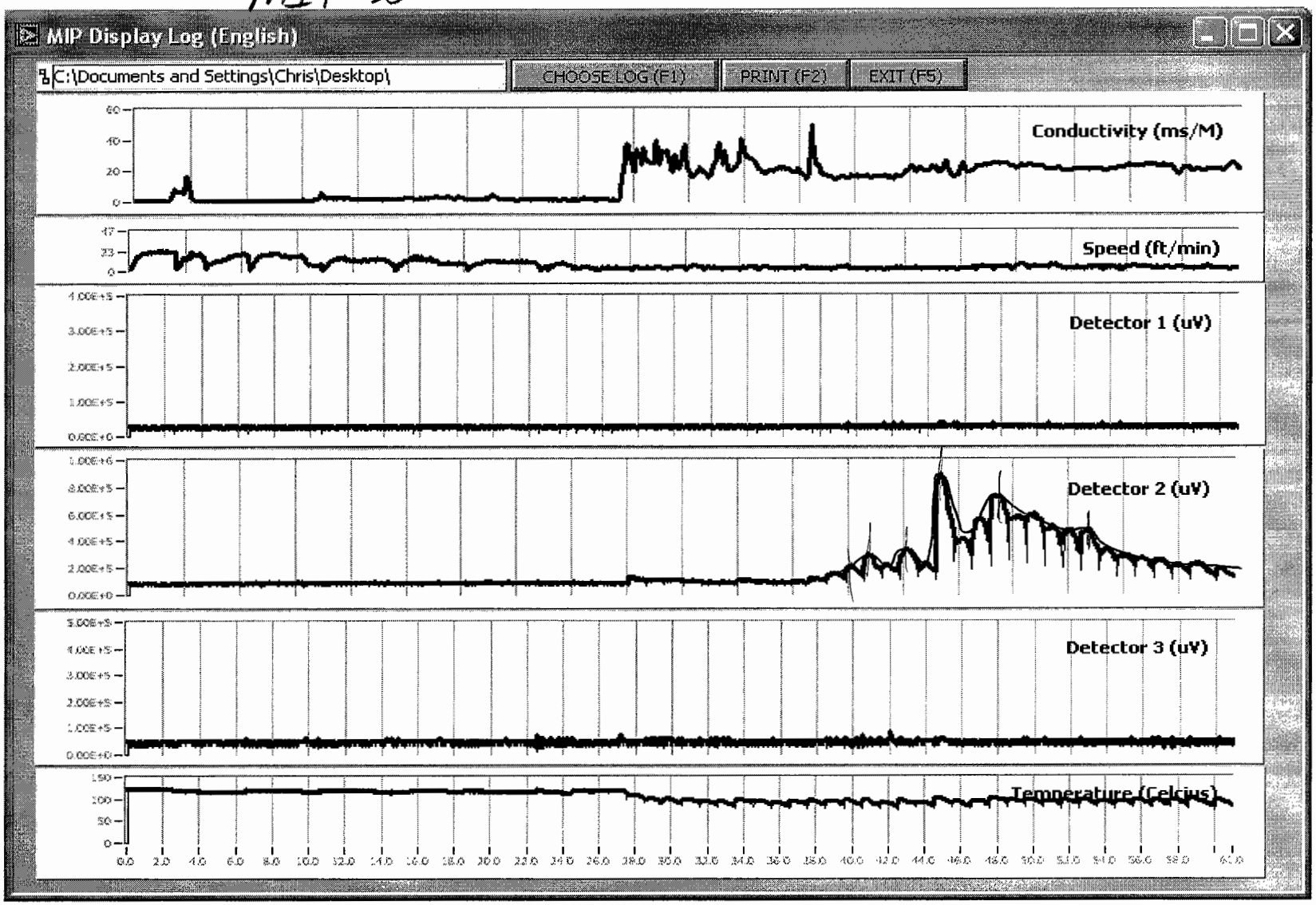

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APPENDIX B

BORING LOGS

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**10B**
Boring Depth:	75 feet	MW #:	MW-10B
GW Encountered	29 feet	Surface Elevation:	
Static GW Level:		Start time/date:	0727 3/31/05
Location:		End time/date:	1145 3/31/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
									10YR 2/2 (very dark brown) organic horizon
0	0-2	1.5'						ML	10YR 2/2 (very dark brown) moist cohesive silt and clay. Decomposed organic material present. No odor.
1					2.3			ML	10YR 4/2 (dark grayish brown) moist cohesive sandy silt. No odor.
2	2-4	1.2'							
3					2.3			SW-SM	10YR 4/3 (brown) moist, loose well-graded fine to medium sand with silt, very minor silt component. No odor.
4	4-6	1.5'						SW-SM	10YR 4/3 (brown) moist grading to dry, loose well-graded sand with silt with mottling. Very minor silt component. No odor.
5					2.3			SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand. No odor.
6	6-8	1.2'							
7					2.3			SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand with bedded layers of coarse sand. No odor.
8	8-10	1.5'							
9					4.7				
10	10-12	1.2'						SP	10YR 6/2 (light brownish gray) dry, loose poorly-graded fine sand. No odor.
11					4.7			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand with rocks up to 1.5 inch diameter. No odor.

Boring Number: 10B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12 13	12-14	1.2'			2.3			SW	10YR 4/3 (brown) dry, loose well-graded fine to coarse sand with gravel and rocks up to 2-inch diameter. No odor.
14 15	14-16	1.8			2.3			SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand with bedded bands of coarse sand. Mottled between 15 and 17 feet bgs. No odor.
16 17	16-18	1.5			4.7			SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand with bedded layers of coarse sand. No odor.
18 19	18-20	1.5			2.3			SW	10YR 5/2 (grayish brown) dry, loose well-graded fine to coarse sand with gravel. No odor.
20 21	20-22	1.5			2.3			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand with occasional pebbles. No odor.
22 23	22-24	1.8			2.3			SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand with gravel. No odor.
24 25	24-26	1.5			2.3				Same as above
26 27	26-28	0.5			2.3			SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand with gravel. Limited recovery due to rock lodged in sampler. No odor.
28	28-29	1.0						SW	10YR 3/2 (very dark grayish brown) moist grading to wet (at 29 feet bgs), loose well-graded medium to coarse sand with gravel. No odor.

Boring Number: 10B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	1.0		water	2.3			SW	Same as above. Wet at 29 feet below ground surface
30 31	30-32	1.0			2.3			GW	10YR 4/3 (brown) wet, loose well-graded gravel with coarse sand and silt component. Rocks up to 3-inches in diameter present. No odor.
32 33	32-34	0.5			2.3				Same as above
34 35	34-36	1.0			4.7			SM	10YR 4/3 (brown) wet, cohesive silty sand. Mottled bands to 36 feet bgs. No odor.
36 37	36-38	0.1			7.1			SM	10YR 4/3 (brown) wet, cohesive silty sand with occasional pebbles. No odor/sheen. Limited recovery.
38 39	38-40	0.0			--			--	No recovery 38-40 foot interval.
40 41	40-42	0.1			2.3			SM	10YR 4/3 (brown) wet, cohesive silty sand with occasional pebbles. No odor. Limited recovery.
42 43	42-44	1.8			2.3			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine and medium sand. No odor.
44	44-46	1.0						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor
45					2.3			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to medium sand. No odor.

Boring Number: 10B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46	46-48	1.0						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. Angular rocks up to 2-inches in diameter present. No odor.
47					2.3				
48	48-50	2.0							Same as above
49					2.3			SP	10YR 3/1 (very dark gray) wet, loose poorly-graded fine sand. Mild odor. Sampled 48-50 interval as "most impacted."
50	50-52	1.5						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
51					0.0				
52	52-54	1.0						SP	10YR 3/1 (very dark gray) wet, loose poorly-graded fine sand. Mild odor.
53					4.7				
54	54-56	1.5							
55					2.3			SP	10YR 4/3 (brown) wet, mildly cohesive very fine sand. No odor. No observed silt component.
56	56-58	1.0							
57					2.3				
58	58-60	1.0						SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine and medium sand. No odor.
59					2.3				
60	60-62	1.0						SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
61					4.7				
62	62-63	1.8						SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.

Boring Number: 10B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64	1.8			4.7			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
64	64-66	1.0						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
65					4.7				
66	66-68	1.0						SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
67					4.7				
68	68-70	1.5							Same as above
69					4.7				
70	70-72	2.0						SW	10YR 4/3 (brown) wet, loose well-graded fine and medium sand. No odor. Sampled 70-71 interval
71					4.7				
72	72-74	1.8							
73					4.7			SP	10YR 4/3 (brown) wet, mildly cohesive well-graded very fine sand. No silt component. No odor.
74	74-76	1.0							End of boring at 75 feet below ground surface.
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**11A**
Boring Depth:	57 feet	MW #:	PES-MW-11A
GW Encountered	29 feet	Surface Elevation:	
Static GW Level:		Start time/date:	0725 3/29/05
Location:		End time/date:	0950 3/29/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	0						--	No recovery 0 to 4 feet bgs due to augering through frost.
1					--				
2	2-4	0							
3					--				
4	4-6	1.5						SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand. No odor.
5					2.4			SW	10YR 5/4 (yellowish brown) dry, loose well-graded fine to medium sand with mottling at 5.75 feet bgs.
6	6-8	1.0							
7					4.9			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand with occasional pebbles. No odor
8	8-10	1.5						SP	10YR 6/3 (pale brown) dry, loose poorly-graded fine sand with bands of lamination. No odor
9					4.7			SW	10YR 6/6 (brownish yellow) dry, loose well-graded mottled fine and medium sand with occasional pebbles. No odor.
10	10-12	1.0						SP	10YR 6/2 (light brownish gray) dry, loose poorly-graded fine sand. No odor.
11					4.9			SW	10YR 5/2 (grayish brown) dry, loose well-graded fine to coarse sand with gravel. No odor.

Boring Number: 11A Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12	12-14	1.5						SW	10YR 5/2 (grayish brown) dry, loose well-graded fine to coarse sand with gravel. No odor.
								SP	10YR 6/3 (pale brown) dry, loose poorly-graded fine sand. No odor.
13					4.9			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand. No odor.
14	14-16	1.5							Same as above
15					4.9			SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand. No odor.
16	16-18	1.0						SP	10YR 6/4 (light yellowish brown) dry, loose poorly-graded mottled fine sand. No odor.
17					4.9			SP	10YR 6/2 (light brownish gray) dry, loose poorly-graded fine sand. No odor.
18	18-20	1.5						SW	10YR 6/2 (light brownish gray) dry, loose well-graded fine to coarse sand. No odor.
19					4.9			SP	10YR 6/2 (light brownish gray) dry, loose poorly-graded fine sand with bedded coarse sand. No odor.
20	20-22	1.5						SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand with occasional angular pebbles. No odor.
21					4.9			SW	10YR 5/3 (brown) dry grading to moist, loose well-graded fine to coarse sand with gravel. No odor.
22	22-24	1.5							Same as above
23					4.9			SP	10YR 5/2 (grayish brown) moist, loose poorly-graded fine sand. No odor.
24	24-26	1.2						SW	10YR 5/3 (brown) moist, loose well-graded fine to medium sand. No odor.
25					4.9			SW	10YR 4/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles. No odor.
26	26-28	1.5						SP	10YR 5/2 (grayish brown) moist, loose poorly-graded fine sand. No odor.
27					4.9				
28	28-29	0.5						GW	10YR 4/2 (dark grayish brown) moist grading to wet (at 29 feet bgs) well-graded rounded and angular gravel with fine to coarse sand. No odor.

Boring Number: 11A Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	0.5		water	4.9			GW	10YR 4/2 (dark grayish brown) moist grading to wet (at 29 feet bgs) well-graded rounded and angular gravel with fine to coarse sand. No odor.
30	30-32	1.2						GW	10YR 4/2 (dark grayish brown) wet, loose well-graded rounded and angular gravel with fine to coarse sand with rocks up to 2 inches in diameter. No odor.
31					4.9				
32	32-34	0.8							
33					4.9				Same as above
34	34-36	1.2						SM	10YR 3/3 (dark brown) wet, cohesive silty sand with <5% coarse sand component. No odor.
35					7.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
36	36-38	0.5						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor. Limited recovery.
37					9.8				
38	38-40	0.0						--	No recovery 38-40 feet bgs.
39					--				
40	40-42	0.5						SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to medium sand. No odor.
41					4.9			SW	10YR 4/2 (dark grayish brown) wet, cohesive well-graded fine to medium sand with silt. No odor.
42	42-44	1.2						SM	10YR 4/2 (dark grayish brown) wet, cohesive silty sand with occasional pebbles and fine sand component. No odor. Sampled at 42'-44' interval.
43					7.4				
44	44-46	--						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
45					9.8			SW	10YR 3/3 (dark brown) wet, loose well-graded fine to coarse sand. No odor.

Boring Number: 11A Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46 47	46-48	1.8			7.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand with mottled bands of 10YR 5/6 (yellowish brown) fine sand. No odor.
48 49	48-50	1.8			7.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor. Sample collected at 48'-50' interval FD-2
50 51	50-52	1.0			4.9			SP	10YR 4/3 (brown) wet, mildly cohesive very fine sand. No silt component. No odor.
52 53	52-54	1.0			2.4			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
54 55	54-56	0.5			4.9			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
56 57	56-58				4.9			SP	10YR 3/1 (very dark gray) wet, loose poorly-graded fine sand. No odor.
									End of boring at 57 feet below ground surface
58 59	58-60								
60 61	60-62								
62	62-63								

Boring Number: 11A Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**12B**
Boring Depth:	65 feet	MW #:	MW-12B
GW Encountered	29 feet	Surface Elevation:	
Static GW Level:		Start time/date:	0736 4/5/05
Location:		End time/date:	1045 4/5/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	1.5						SP-SC	10YR 3/3 (dark brown) cohesive, moist grading to frozen poorly-graded fine sand with clay and organic material. No odor.
1					0.0			SP	10YR 6/4 (light yellowish brown) frozen due to frost layer loose poorly-graded fine sand. No odor.
2	2-4	1.5						SP	GLEY 5/10G (greenish gray) frozen, loose poorly-graded fine sand. No odor.
3					1.3			CL	10YR 6/1 (gray) mottled to 10YR 6/8 (brownish yellow) moist, cohesive lean clay with sand and occasional pebbles. No odor.
4	4-6	1.8							
5					0.0			SP	10YR 4/2 (dark grayish brown) moist, loose poorly-graded fine sand. No odor.
6	6-8	1.5							
7					0.0			SW	10YR 4/4 (dark yellowish brown) moist, loose well-graded fine to coarse sand with gravel. No odor.
8	8-10	1.5						SW	10YR 4/4 (dark yellowish brown) moist, loose well-graded fine to medium sand mottled to 10YR 5/6 (yellowish brown). No odor.
9					1.3				
10	10-12	1.5						SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand with gravel. No odor.
11					0.0				

Boring Number: 12B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12 13	12-14	1.5			0.0			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand. No odor.
14 15	14-16	1.5			0.0			SW	Same as above.
16 17	16-18	0			--			--	No recovery 16 to 18 feet below ground surface.
18 19	18-20	1.8			1.3			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand with occasional pebbles. No odor.
20 21	20-22	1.8			1.3				Same as above
22 23	22-24	1.5			0.0			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand with gravel and rocks up to 2 inches in diameter. No odor.
24 25	24-26	1.2			1.3			SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand with bedded bands of coarse sand. No odor.
26 27	26-28	0.0			--			--	No recovery 26 to 28 feet below ground surface.
28	28-29	1.8'						SW	10YR 5/3 (brown) moist grading to wet, loose well-graded fine to medium sand. No odor or sheen.

Boring Number: 12B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	1.8		water	0.0			SW	10YR 5/3 (brown) wet at 29 feet bgs, loose well-graded fine to medium sand. No odor or sheen.
30	30-32	1.8						SW	10YR 5/2 (grayish brown) wet, loose well-graded fine to coarse sand. No odor.
31					0.0				
32	32-34	1.8						SW	10YR 5/3 (brown) wet, loose well-graded fine to coarse sand. No odor.
33					0.0				
34	34-36	1.8						SW	10YR 5/3 (brown) wet, loose well-graded fine to coarse sand. No odor.
35					0.0				
36	36-38	1.8						SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to coarse sand. No odor
37					1.3				
38	38-40	1.8							Same as above
39					1.3			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to coarse sand w/ gravel and rounded rocks up to 2.5 inches diameter. No odor.
40	40-42	1.5						SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to coarse sand. No odor.
41					0.0				
42	42-44	1.8							Same as above.
43					0.0			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to coarse sand with rounded gravel. No odor.
44	44-46	1.5							
45					0.0				Same as above.

Boring Number: 12B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46	46-48	1.0						SW	10YR 4/1 (dark gray) wet, loose well-graded fine to coarse sand. No odor.
47					1.3				
48	48-50	1.0						SW	10YR 4/1 (dark gray) wet, loose well-graded fine to coarse sand. No odor.
49					1.3				
50	50-52	1.5							Same as above
51					0.0			SP	10YR 5/1 (gray) wet, loose poorly-graded fine sand No odor
52	52-54	1.8							
53					0.0				Same as above
54	54-56	1.5						SP	10YR 5/1 (gray) wet, loose poorly-graded fine sand No odor.
55					0.0			GW	10YR 5/1 (gray) wet, loose well-graded rounded gravel with coarse to fine sand. No odor.
56	56-58	0.0						--	No recovery 56 to 58 feet below ground surface
57					--				
58	58-60	1.5						SW	10YR 4/1 (dark gray) wet, loose well-graded fine to coarse sand. No odor
59					0.0			GW	10YR 4/1 (dark gray) wet, loose well-graded rounded gravel with coarse sand and rocks up to 2 inches in diameter. No odor.
60	60-62	1.0						SW	10YR 4/1 (dark gray) wet, loose well-graded fine to coarse sand. No odor.
61					0.0				
62	62-63	1.0			0.0			SW	10YR 4/1 (dark gray) wet, loose well-graded fine to coarse sand with gravel and rocks up to 3 inch in diameter. No odor.

Boring Number: 12B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64	1.0			0.0			CL	10YR 4/2 (dark grayish brown) wet, friable tight lean clay with silt and occasional pebbles. No odor Sampled 62-63 interval for "screened interval" sample.
64	64-66	1.0			1.3				End of boring at 65 feet below ground surface
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**14B**
Boring Depth:	75 feet	MW #:	MW-14B
GW Encountered	29 feet	Surface Elevation:	
Static GW Level:		Start time/date:	1005 4/1/05
Location:		End time/date:	1018 4/4/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	2.0						SP	10YR 3/2 (very dark grayish brown) moist, cohesive well-graded fine sand with organic material and silt. No odor.
1					2.5				
2	2-4	1.8							Same as above
3					2.5			SP-SM	10YR 4/4 (dark yellowish brown) moist, cohesive poorly-graded fine sand with silt. No odor.
4	4-6	1.5						SP	10YR 5/4 (yellowish brown) moist, loose poorly-graded fine sand. No odor.
5					2.5				
6	6-8	1.5						SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand. No odor.
7					2.5			SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand. No odor.
8	8-10	1.0						SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand. No odor.
9					2.5				
10	10-12	1.2						SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand with rocks up to 2 inches diameter. No odor.
11					2.5				

Boring Number: 14B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12 13	12-14	0.5			2.5			SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand. No odor.
14 15	14-16	1.5			2.5			SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand with mottling to 10YR 5/8 (yellowish brown) and bedded layers of coarse sand.
16 17	16-18	1.5			2.5				Same as above
18 19	18-20	1.5			2.5			SP	10YR 6/3 (pale brown) dry, loose poorly-graded fine sand. No odor. Same as above
20 21	20-22	1.5			0.0			SW	10YR 4/2 (dark grayish brown) dry, loose well-graded fine to coarse sand. No odor.
22 23	22-24	1.5			5.1			SP	10YR 6/2 (light brownish gray) dry, loose poorly-graded fine sand. No odor.
24 25	24-26	1.5			2.5			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand with gravel. No odor.
26 27	26-28	1.2			2.5			SW	10YR 4/3 (brown) moist, loose well-graded fine to medium sand. No odor
28	28-29	1.5			5.1			SW	10YR 4/3 (brown) moist grading to wet at 29 feet bgs, loose well-graded fine to coarse sand. No odor.

Boring Number: 14B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	1.5		water	5.1			SW	10YR 4/3 (brown) wet, loose well-graded fine to coarse sand. No odor.
30	30-32	1.5						SP	10YR 5/3 (brown) wet, loose poorly-graded fine sand. No odor.
31					5.0			SW	10YR 5/3 (brown) wet, loose well-graded fine to coarse sand with gravel. No odor
32	32-34	1.8							
33					7.5			SM	10YR 4/3 (brown) wet, cohesive silty sand with occasional pebbles. No odor.
34	34-36	1.5						SW	10YR 4/3 (brown) wet, loose well-graded fine to coarse sand with gravel and very minor silt component. No odor.
35					7.5				
36	36-38	1.0						SW	10YR 3/2 (very dark grayish brown) wet, loose well-graded fine to coarse sand. Very minor silt component. No odor.
37					5.0				
38	38-40	1.5						SW	10YR 3/2 (very dark grayish brown) wet, loose well-graded fine to medium sand. Dark band of sand 10YR 3/1 (very dark gray) observed at 39 feet bgs. Mild odor in this dark band.
39					5.0			ML	10YR 4/3 (brown) 3-inch think layer of cohesive silt with sand. No odor
40	40-42	1.0						ML	10YR 4/3 (brown) wet, cohesive silt with sand with occasional pebbles. No odor. Sampled at 40'-42' interval as foot above bottom of silt layer.
41					5.0				
42	42-44	1.0						ML	10YR 4/3 (brown) wet, cohesive silt with sand with occasional pebbles. No odor. Sampled 42'.
43					5.0				
44	44-46	1.0						SW	10YR 3/3 (dark brown) wet, loose well-graded fine to coarse sand with gravel. No odor.
45					5.0				

Boring Number: 14B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46 47	46-48	1.5			7.5			SP	10YR 3/2 (very dark grayish brown) wet, loose poorly-graded fine sand. Dark band of 10YR 2/2 (very dark brown) fine sand with mild odor at 47.5 feet bgs. Otherwise no odor in recovered soil
48 49	48-50	1.0			7.5			SP	10YR 4/2 (drark grayish brown) wet, loose poorly-graded very fine sand. No odor.
50 51	50-52	1.0			5.0			SP	10YR 3/2 (very dark grayish brown) wet, loose poorly-graded fine sand. No odor.
52 53	52-54	1.0			5.0			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded very fine sand. No odor.
54 55	54-56	1.0			5.0				Same as above
56 57	56-58	1.0			5.0			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
58 59	58-60	1.5			5.0				Same as above
60 61	60-62	--			5.0			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded very fine sand. No odor.
62	62-63	1.2						SW	10YR 3/3 (dark brown) wet, loose well-graded fine to medium sand. No odor or staining.

Boring Number: 14B Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64	1.2			5.0			SW	10YR 3/3 (dark brown) wet, loose well-graded fine to medium sand. No odor or staining.
64	64-66	0.0			--				No recovery from 64 to 66 feet bgs.
65									
66	66-68	2.0			5.0			SW	10YR 4/3 (brown) wet, loose well-graded fine to medium sand. No odor.
67									
68	68-70	1.0			5.0			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
69									
70	70-72	1.5			2.5			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor. Sampled 70-72 interval as center of well screen.
71									
72	72-74	1.0			5.0			SW	10YR 4/3 (brown) wet, loose well-graded fine and medium sand. No odor.
73									
74	74-76	1.0						SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
75									End of boring at 75 feet below ground surface
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**13A**
Boring Depth:	45 feet	MW #:	MW-13A
GW Encountered	30 feet	Surface Elevation:	
Static GW Level:		Start time/date:	1053 3/28/05
Location:		End time/date:	1310 3/28/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	--							No recovery from 0 to 4 feet below ground surface due to augering through frost.
1					--				
2	2-4	--							
3					--				
4	4-6	1.5						SP	10YR 4/6 (dark yellowish brown) moist, loose poorly-graded fine sand. No odor.
5					2.5			SP	10YR 4/3 (brown) moist, loose poorly-graded fine sand. No odor.
6	6-8	1.8						SW	10YR 3/1 (very dark gray) dry, loose well-graded fine to medium sand with roots and decomposing organic material. This band 1-inch thick. No odor.
7					5.1			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand. No odor.
8	8-10	1.5						SP	10YR 5/2 (grayish brown) dry, loose poorly-graded fine sand. No odor.
9					5.1			SW	10YR 4/3 (brown) dry, loose well-graded fine to coarse sand mottled to 10YR 5/8 (yellowish brown). No odor.
10	10-12	1.2						SP	10YR 5/3 (brown) dry, loose poorly-graded fine mottled sand. No odor.
11					2.5				

Boring Number: 13A Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12	12-14	1.5						SW	10YR 4/3 (brown) moist, loose well-graded medium to coarse sand with gravel. No odor.
13					5.1			SW	10YR 5/3 (brown) moist grading to dry, loose well-graded fine to medium sand. No odor.
14	14-16	1.8						SP	10YR 5/3 (brown) wet, loose poorly-graded fine sand. No odor.
15					5.1			SW	10YR 5/3 (brown) wet, loose well-graded fine to coarse sand with gravel. No odor.
16	16-18	1.5						SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles. No odor.
17					2.5				
18	18-20	1.0						SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with gravel. No odor.
19					10.2				
20	20-22	1.0						SW	10YR 4/3 (brown) moist, loose well-graded fine to coarse sand with gravel. No odor.
21					2.5				
22	22-24	1.5						GW	10YR 3/3 (dark brown) moist, loose well-graded gravel with fine to coarse sand. No odor.
23					2.5				
24	24-26	1.5						SW	10YR 3/3 (dark brown) moist, well-graded fine to coarse sand bedded with GLEY 2.5/5B (bluish black) coarse and medium sand. No odor.
25					2.5			SM	10YR 3/3 (dark brown) wet, cohesive silty sand with occasional pebbles.
26	26-28	1.0						SM	10YR 3/3 moist, cohesive silty sand with occasional pebbles. No odor. Sampled at 26' bgs.
27					2.5				Sampled at 27' bgs Same as above
28	28-29	1.5			2.5			SP	10YR 3/4 (dark yellowish brown) wet, loose poorly-graded fine sand. No odor.

Boring Number: 13A Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	1.5			2.5			SP	10YR 3/4 (dark yellowish brown) moist grading to wet, poorly-graded fine sand. No odor.
30	30-32	1.5		water				SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine and medium sand with occasional pebbles. No odor. Wet at 30 feet bgs.
31					5.1				
32	32-34	1.0							Same as above
33					15.3			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
34	34-36	1.8						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. 1-inch thick band of 10YR 4/1 (dark gray) fine sand at 35.5 feet bgs. No odor.
35					10.2				
36	36-38	1.5						SP	10YR 3/3 (dark brown) wet, loose poorly-graded fine sand with laminated bands from 37 to 38 feet below ground surface. No odor.
37					5.1				
38	38-40	1.5							
39					5.1			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to coarse sand. No odor.
40	40-42	1.0						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
41					2.5				
42	42-44	2.0						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor. Sampled at 42 feet bgs.
43					5.1				
44	44-46	1.0			5.1			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine and medium sand. No odor.
45									End of boring at 45 feet below ground surface

Boring Number: 13A Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46	46-48								
47									
48	48-50								
49									
50	50-52								
51									
52	52-54								
53									
54	54-56								
55									
56	56-58								
57									
58	58-60								
59									
60	60-62								
61									
62	62-63								

Boring Number: 13A Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	DJW - EMR, Inc.	Boring #:	**SB-1**
Boring Depth:	60 feet	MW #:	
GW Encountered	34 feet	Surface Elevation:	
Static GW Level:		Start time/date:	March 16, 2005
Location:		End time/date:	March 16, 2005

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	0.0							No recovery 0'-4' below ground surface due to augering through frost layer.
1									
2	2-4	0.0							
3									
4	4-6	1.6						SP	10YR 4/6 (dark yellowish brown) dry, loose poorly-graded medium sand. No odor or stain.
5					4.2			SP	10YR 4/4 (dark yellowish brown) dry, loose poorly-graded medium sand. No odor or stain.
6	6-8	1.6							
7					4.2				Same as above
8	8-10	1.8							
9					4.2				Same as above
10	10-12	1.8						SP	10YR 5/4 (yellowish brown) dry, loose poorly-graded medium sand. No odor or stain.
11					8.5				

Boring Number: SB-1 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12 13	12-14	1.8			6.3			SP	10YR 7/3 (very pale brown) dry, loose poorly-graded fine sand. No odor or stain.
14 15	14-16	1.0			6.3			SP	10YR 7/3 (very pale brown) dry, loose poorly-graded fine sand. 2-inch diameter cobble recovered in sampler. No odor or stain.
16 17	16-18	1.8			8.5				Same as above
18 19	18-20	1.8			8.5			SW	10YR 6/3 (pale brown) dry, loose well-graded fine to medium sand. No odor or stain.
20 21	20-22	1.8			6.3			SW	10YR 6/3 (pale brown) dry, loose well-graded fine to medium sand. 4-inch thick layer of well-graded coarse to medium sand between 21.6' and 22' bgs. No odor or stain.
22 23	22-24	1.5			6.3			SW	Same. Alternates between 22-23 (SW fine to med sand) and 23-24 (med to coarse sand). Dry, no odor, no stain.
24 25	24-26	ND			4.2			SW	Same. Medium to coarse well-graded sand with some small cobbles and pebbles. No odor/stain.
26 27	26-28	ND			6.3			SP	10YR 4/4 (dark yellowish brown) loose coarse to very coarse poorly-graded sand with pebbles. No odor/stain.
28	28-29	1.6						SM	10YR 4/2 (dark grayish brown) moist, loose poorly-graded silty sand with occasional pebbles and rocks up to 2-inch diameter. No odor.

Boring Number: SB-1 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	1.6			19.1			SM	10YR 4/2 (dark grayish brown) moist, loose poorly-graded silty sand with occasional pebbles and rocks up to 2-inch diameter. No odor.
30 31	30-32	0.5			63.8			ML	10YR 4/2 (dark grayish brown) moist, cohesive blocky silt with sand and occasional pebbles and rocks up to 1-inch diameter. No odor.
32 33	32-34	1.8			8.5			ML	10YR 4/3 (brown) moist grading to wet at 34' bgs, cohesive silt with occasoinal pebbles and 10YR 3/1 (very dark gray) bands of staining. Mild odor. Sample collected at 32'-35' below ground surface Wet at 34 feet below ground surface
34	34-36	1.8		water				ML	10YR 4/2 (dark grayish brown) wet, silt with poorly-graded fine sand. Mild odor.
35					10.6			ML	10YR 4/1 (dark gray) wet silt with occasional pebbles. Mild odor. Sampled at 35'-36' bgs.
36 37	36-38	1.6			51.0			ML	10YR 2/1 (black) wet silt with poorly-graded fine sand. Stained with mild odor. Sample collected at 37'-38' bgs.
38 39	38-40	2.0			8.5			SP-SM	10YR 4/2 (dark grayish brown) wet, cohesive poorly-graded fine sand with silt. Mild odor.
40	40-42	1.5						ML	10YR 3/2 (very dark grayish brown) wet, cohesive silt with poorly-graded fine sand. No odor.
41					8.5			SM	10YR 4/2 (dark grayish brown) wet, cohesive poorly-graded fine silty sand. No odor.
42 43	42-44	1.8			8.5			SM	10YR 4/3 (brown) wet, cohesive poorly-graded fine silty sand. No odor
44 45	44-46	1.6			4.2			SM	10YR 4/3 (brown) wet, cohesive poorly-graded fine silty sand. No odor. Same as above.

Boring Number: SB-1 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46 47	46-48	1.5			6.3			SM	10YR 4/3 (brown) wet, cohesive poorly-graded fine silty sand. No odor. Same as above.
48 49	48-50	2.0			6.3			SM	10YR 4/4 (dark yellowish brown) wet, cohesive poorly-graded fine silty sand. No odor.
50 51	50-52	2.0			6.3			SM	10YR 4/4 (dark yellowish brown) wet, cohesive poorly-graded fine silty sand. No odor.
52 53	52-54	1.8			8.5			SM	10YR 4/4 (dark yellowish brown) wet, cohesive poorly-graded fine silty sand. No odor.
54 55	54-56	1.8			8.5			SM	10YR 4/4 (dark yellowish brown) wet, cohesive poorly-graded fine silty sand. No odor. Sample collected at 54'-56' bgs.
56 57	56-58	1.3			10.6			SM SP-SC	10YR 4/4 (dark yellowish brown) wet, cohesive poorly-graded fine silty sand. No odor. 10YR 4/4 (dark yellowish brown) wet, cohesive poorly-graded fine sand with clay. No odor.
58 59	58-60	1.5			8.5			SP-SC	10YR 4/4 (dark yellowish brown) wet, cohesive poorly-graded fine sand with clay. No odor. End of boring at 60 feet below ground surface.
60 61	60-62								
62	62-63								

Boring Number: SB-1 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:		**Drilling Information**	
NIROP Pilot-Scale 2005		Drilling Contractor:	Bergerson-Caswell
EMR Project Number:		Drilling Method:	Hollow Stem Auger
5427		Drillers Name:	Dave Lenzmeier
Note:		Borehole Diameter:	8-1/4 inch
adjacent to Inj-2		Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	DJW - EMR, Inc.	Boring #:	**SB-2**
Boring Depth:	60 feet	MW #:	
GW Encountered	28 feet	Surface Elevation:	
Static GW Level:		Start time/date:	03-15-05
Location:	2' NE of INJ #2	End time/date:	03-15-05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	--						--	No sampling 0-4 feet bgs. Augered through frost.
1					--				
2	2-4	--							
3					--				
4	4-6	2.0						SP	10YR 4/4 (dark yellowish brown) grading to 10YR 6/4 (light yellowish brown) homogeneous, loose poorly-graded coarse sand. No odor. Rootlets present. Color change occurs at 5 feet
5					2.1				
6	6-8	2.0						SP	Same as above. 10YR 6/4; dry; no odor.
7					2.1				
8	8-10	2.0						SP	Same as above. 10YR 6/4; dry; no odor.
9					2.1				
10	10-12	2.0						SP	Same as above. 10YR 6/4; dry; no odor.
11								SP	3.5-inch lens of cohesive, homogeneous poorly-graded fine sand with clay; moist; no odor.
					0.0			SP	Same as above. 10YR 6/4; dry; no odor.

Boring Number:	SB-2	Project :	NIROP Pilot-Scale 2005	Project #:	5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12 13	12-14	2.0			2.1			SP	10YR 8/3 (very pale brown) loose, homogeneous poorly-graded fine sand; dry; no odor.
14	14-16	1.75						SW	10YR 5/6 (yellowish brown) loose, homogeneous, well-graded coarse sand with gravel, moist, no fines, no odor (1.1 feet thick)
15					0.0			SP	10YR 8/3 (very pale brown) loose, homogeneous, poorly-graded fine sand, moist.
16	16-18	2.0						SP	6-inch lens of poorly-graded coarse sand. 10YR 5/6 (yellowish brown), moist, no odor.
17					0.0			SP	10YR 8/3 (very pale brown) loose, homogeneous, poorly-graded fine sand, moist.
18 19	18-20	2.0			0.0			SW	10YR 6/4 (light yellowish brown) loose, well-graded medium sand grading to a coarse sand at 19.8 feet bgs; dry; no odor, a two-inch diameter cobble in sampler.
20 21	20-22	1.2			0.0			SP	10YR 6/3 (pale brown) loose, poorly-graded medium sand, dry, no odor. (same as above); 3-inch clast of rock in top of sampler
22 23	22-24	1.5			4.2			SW	10YR 4/4 (dark yellowish brown) loose, well-graded coarse sand grading to very coarse; no odor or oil, a 2-inch feldspathic cobble present.
24 25	24-26	0.25			0.0			SP	10YR 5/6 (yellowish brown) loose, poorly-graded medium sand, moist, no odor. Rock at 24 feet prevented recovery.
26 27	26-28	0.25			0.0				Same as above; rock again hit at 26 feet preventing recovery.
28	28-29	0.25		water					Same as above; rock again hit at 28 feet preventing recovery. Very wet - spoon has water in it.

Boring Number: SB-2 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	0.25			0.0				Same as above; rock again hit at 28 feet preventing recovery. Very wet - spoon has water in it.
30 31	30-32	0.1			0.0				No recovery except 3 rock fragments measuring 2 to 3 inches in diameter.
32 33	32-34	1.6			0.0			ML	10YR 5/4 (yellowish brown) homogeneous, claey silt, wet, dense, no vegetable oil, no odor.
34 35	34-36	1.5			4.2			SM	10YR 5/4 (yellowish brown) homogeneous silty sand, fine and poorly-graded, wet, no odor or oil.
36 37	36-38	1.8			6.3			ML	10YR 5/4 (yellowish brown) sandy silt, wet, high silt content.
								ML	10YR 2/1 (black) sandy silt, sharp odor, color grades to 10YR 5/4 (yellowish brown) at 38 feet. Color contact more sand than overlying silt.
38 39	38-40	1.75			10.6			SP	10YR 5/3 (brown) loose, homogeneous poorly-graded fine to medium sand, moist to wet, faint odor, no oil or stain. Sample collected at 37'-38' bgs.
40 41	40-42	1.5			8.5			SP	10YR 6/3 (pale brown) loose, homogeneous poorly-graded fine sand, wet, no odor or stain.
42 43	42-44	1.5			8.5			SP	Same as above. Faint odor.
44 45	44-46	1.6			4.2			SP	10YR 6/3 (pale brown) loose, homogeneous poorly-graded fine sand, wet, increasing odor.

Boring Number: SB-2 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46 47	46-48	2.0			2.1			SP	10YR 4/3 (brown) loose, homogeneous poorly-graded fine to medium sand, wet, some black discoloration/staining, moderate odor.
48 49	48-50	2.0			4.2			SP	Same as above. Some light staining/discoloration Some odor.
50 51	50-52	1.7			12.7			SP	Same as above, fine sand, light odor.
52 53	52-54	2.0			24.7			SP	10YR 3/1 (very dark gray) homogeneous, silky-fine sand, wet, staining black and light odor, grading to silt but is not blocky.
54 55	54-56	2.0			36.1			SP	10YR 3/2 (very dark grayish brown) homogeneous fine sand, poorly-graded, light odor, black staining loose, wet.
56 57	56-58	--			46.8			SP	10YR 5/3 (brown) poorly-graded medium sand, loose, wet, no stain, light odor, graded to a fine sand by 58 feet bgs.
58 59	58-60	--			61.7			SP	Same as above. Poorly-graded fine sand, no stain, no impact all fine sand, moist, no odor. Sample collected at 60 feet bgs.
60 61	60-62								End of boring at 60 feet below ground surface.
62	62-63								

Boring Number: SB-2 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	SJC - EMR, Inc.	Boring #:	**SB-3**
Boring Depth:	60 feet	MW #:	
GW Encountered	approx 29 feet	Surface Elevation:	
Static GW Level:		Start time/date:	1055 3/14/05
Location:		End time/date:	1530 3/14/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	0.0							No recovery 0 to 4 feet below ground surface due to frost.
1					--				
2	2-4	0.0							
3					--				
4	4-6	80%						SW	NR 10YR 4/3 (brown) loose, homogenous, dry, well-graded sand with silt. Occasional pebbles.
5								SP	10YR 6/2 (light brownish gray) loose, homogenous dry poorly-graded sand with occasional pebbles, sands are weakly bedded with slight changes to define layers, clast size ranges from medium to coarse only very minor amounts of silt.
6	6-8	1.3							
7									Same as above.
8	8-10	1.5						SW	10YR 6/2 (light brownish gray) loose, bedded, dry, well-graded sand, fine to medium grained, rare small pebbles.
9								SW	Same as above only more coarse, contact with above is sharp, diameter becoming greater with depth to coarse sand at 10 feet.
10	10-12	1.0						SW-SM	10YR 6/2 (light brownish gray) loose, dry fine sand with silt, laminated. Laminations are 1/2-inch wide and defined by darker horizons, well graded
11									

Boring Number:	SB-3	Project :	NIROP Pilot-Scale 2005	Project #:	5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12	12-14	2.0							10YR 6/2, same as last unit.
13								SP	10YR 4/2 (dark grayish brown) loose, homogenous poorly-graded coarse sand with gravel. Mottled. Gravel clasts up to 1.5-inch diameter.
14	14-16	1.6						SW	10YR 5/4 (yellowish brown) loose, homogenous, well-graded coarse sand, one decomposed clase at 14.5 feet, dry, medium to coarse grained.
15									
16	16-18	1.0						SP	10YR 6/6 (brownish yellow) loose, weakly bedded poorly-graded medium to coarse sand with occasional pebbles, mottled orange to gray. Dry.
17								SW	10YR 6/2 (light brownish gray) loose, weakly laminated, well-graded fine sand with minor silt, occasional pebbles to 3/4-inch diameter.
18	18-20	1.8							10YR 6/2 (light brownish gray) loose, graded fine to coarse sand, coarsening with depth to coarse sand with clasts to 3/4-inch' dry.
19									
20	20-22	1.6						SP	10YR 6/2 (light brownish gray) loose, homogenous medium to coarse sand with occasional clasts up to 1.5-inches diameter; dry, poorly-graded.
21									
22	22-24	0.4						SP	10YR 5/2 (grayish brown) otherwise same as above Driller said that it felt like they were pushing a rock with the sampler.
23									
24	24-26	1.4						SP	10YR 5/4 (yellowish brown) loose, graded coarse to medium poorly-graded sand, fining with depth to 25.5 feet then corsening again, otherwise homogenous.
25									
26	26-28	0.0							No recovery, possibly due to rock.
27									
28	28-29	0.2		water					10YR 3/4 (dark yellowish brown) loose, fine gravel (average clast approx. 1/4-inch) saturated, no veg. oil; limited recovery; water in sampler.

Boring Number: SB-3 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	0.2							10YR 3/4 (dark yellowish brown) loose, fine gravel (average clast approx. 1/4-inch) saturated, no veg. oil; limited recovery; water in sampler.
30	30-32	0.2							No recovery - slough in sampler
31									10YR 4/2 (dark grayish brown) firm, homogenous, non-elastic silt with minor fine sand. Occasional clasts up to 3/4-inch diameter; slight vegetable oil odor in slough on top of silt; low plasticity, no/low dilatancy.
32	32-34	1.0							
33									Same as above except no visible clasts. Samples collected from 30'-32' and 32'-34'. No PID at 32' sample material.
34	34-36	0.8							10YR 4/2 (dark grayish brown) firm, homogenous, non-elastic silt with pebbles; wet; no dilatancy, low plasticity.
35									
36	36-38	1.8						SP	10YR 4/3 (brown) loose, homogenous, poorly-graded sand, fine to medium grained, saturated; minor amounts of pebbles, no veg oil odor. Minor silt content from 36'-37' with quick dilatancy.
37									
38	38-40	1.4						SP	10YR 4/2 (dark grayish brown) loose, homogenous poorly-graded fine sand with silt, only rare pebbles mild "fish-like" odor at 39' bgs. Quick dilatancy.
39									
40	40-42	1.4						SP	10YR 4/2 (dark grayish brown) loose, homogenous very poorly-graded fine sand with silt; very rare pebbles; mild veg oil odor; black staining from 41.5' to 42' (magnatite?); saturated. Sampling this interval as veg oil impacted - 42 feet bgs.
41									
42	42-44	1.2							10YR 2/1 (black) soft, homogenous non-elastic silt with minor fine sand; saturated; black from magnatite?; moderate veg oil odor.
43									
44	44-46	1.0							Same as above but black staining is lessening; odor still pronounced.
45									

Boring Number: SB-3 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46	46-48	1.8						SP	10YR 5/2 (grayish brown) loose, homogenous fine sand with silt; very poorly-graded; some black staining; saturated; mild veg. Oil odor. Maybe slough.
47									10YR 2/1 (black) to 10YR 5/2 (grayish brown) soft homogenous non-elastic silt with fine sand; moderate veg oil odor; 75% stained black; saturated; slightly clayey/cohesive at 47.74 feet.
48	48-50	1.6						SP	10YR 4/6 (dark yellowish brown) loose, homogenous, very poorly-graded fine sand with minor silt; saturated, quick dilatancy. Mild veg oil odor.
49									
50	50-52	2.0						SP	10YR 3/2 (very dark grayish brown) loose, homogenous very poorly-graded fine sand with silt; saturated; quick dilatancy; mild veg oil odor.
51									10YR 4/3 (brown) same as above except color change is gradational.
52	52-54	2.0						SP	10YR 3/2 (very dark grayish brown) loose, homogenous very poorly-graded fine sand with minor silt; saturated; quick dilatancy; mild veg oil odor.
53									
54	54-56	1.6						SP	Same as above.
55									
56	56-58	2.0						SP	Same as above.
57								ML	10YR 4/4 (dark yellowish brown) soft, homogenous non-elastic silt; saturated; quick dilatancy, mild veg oil odor.
58	58-60							SP	10YR 3/2 (very dark grayish brown) loose, homogenous very poorly-graded fine sand with minor silt; saturated; quick dilatancy; mild veg oil odor.
59									Sampled at 60 feet below ground surface.
60	60-62								End of boring at 60 feet below ground surface.
61									
62	62-63								

Boring Number: SB-3 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note: bentonite grount encountered
No impacted soil encountered

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**SB-4**
Boring Depth:	60 feet	MW #:	
GW Encountered	30 feet	Surface Elevation:	
Static GW Level:		Start time/date:	0803 3/24/05
Location:		End time/date:	1035 3/24/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	0.0							No recovery 0'-4' below ground surface due to frost layer.
1					--				
2	2-4	0.0							
3					--				
4	4-6	1.5						SW	10YR 6/3 (pale brown) dry, loose well-graded fine and medium sand. No odor.
5					2.4			SW	10YR 4/3 (brown) dry, loose well-graded fine and medium sand. No odor.
6	6-8	1.2						SW	10YR 5/3 (brown) dry, loose well-graded fine and medium sand, no odor.
7					2.4				
8	8-10	1.0						SW	10YR 5/3 (brown) dry, loose well-graded fine and medium sand. No odor.
9					2.4				
10	10-12	1.5						SW	Same as above
11					2.4			SP	10YR 6/2 (light brownish gray) dry, loose poorly-graded fine sand. No odor.

Boring Number: SB-4 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12	12-14	1.5						SP	10YR 6/2 (light brownish gray) dry, loose poorly-graded fine sand. No odor.
13					2.4			SW	10YR 4/1 (dark gray) moist, loose well-graded fine to coarse sand with gravel and rock up to 1.5-inch diameter. No odor.
14	14-16	1.8						SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand. No odor.
15					2.4			SW	10YR 5/2 (grayish brown) dry, loose well-graded fine to coarse sand with occasional pebbled. No odor
16	16-18	1.8						SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand. No odor.
								SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand with occasional pebbles. No odor.
17					2.4			SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand . No odor.
18	18-20	1.5						SP	10YR 5/4 (yellowish brown) moist, loose poorly-graded fine sand. No odor.
19					2.4			SW	10YR 5/2 (grayish brown) moist loose well-graded fine and medium sand with occasional rounded pebbles and rock up to 1-inch diameter. No odor.
20	20-22	1.5						SW	10YR 5/2 (grayish brown) moist, loose well-graded fine to coarse sand. No odor.
21					2.4				
22	22-24	0.8							
23					2.4			SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand. No odor.
24	24-26	0.0							No recovery 24'-26'
25					--				
26	26-28	0.5						SW	10YR 3/3 (dark brown) moist, loose well-graded medium to coarse sand with gravel and rock up to 1-inch diameter. Limited recovery.
27					2.4				
28	28-29	0.5						ML	10YR 4/4 (dark yellowish brown) moist grading to wet cohesive silt with sand. No odor. Limited recovery.

Boring Number: SB-4 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	0.5		water	2.4			ML	Same as above. Wet at 30 feet bgs.
30 31	30-32	1.0			2.4			ML	10YR 4/3 (brown) cohesive, wet silt with sand and occasional pebbles. No odor Sample collected at 30 feet bgs. Sample collected at 31 feet bgs.
32 33	32-34	1.8			2.4			SP	10YR 4/2 (dark grayish brown) mildly cohesive wet poorly-graded fine sand. No odor.
34 35	34-36	ND			2.4			SW	10YR 3/3 (dark brown) wet, loose well-graded fine and medium sand with occasional pebbles. Mostly fine sand components. No odor.
36 37	36-38	1.8			2.4			SP	10YR 4/2 (dark grayish brown) wet, mildly cohesive poorly-graded fine sand; no odor; 1/4-inch thick band of bentonite grout observed in sampler at 36.5 feet bgs. otherwise homogenous fine sand and color throughout sampler.
38 39	38-40	1.0			2.4			SP	10YR 4/2 (dark grayish brown) wet, mildly cohesive poorly-graded fine sand. No odor.
40 41	40-42	1.8			2.4			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand; no odor; homogenous throughout recovery.
42 43	42-44	1.5			2.4			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor. Sample collected at 42'-44' bgs.
44 45	44-46	1.8			2.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand; homogenous throughout recovery.

Boring Number: SB-4 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46 47	46-48	1.5			2.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand; laminated bands of 10YR 4/1 (dark gray) between 47 and 48 feet bgs. No odor.
48 49	48-50	1.5			2.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand; stained bands of 10YR 4/1 (dark gray) at 49 feet bgs. No odor.
50 51	50-52	1.8			2.4			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand; no staining or lamination, no odor.
52 53	52-54	1.8			2.4			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand; homogenous, no odor. Sample collected at 52'-54' bgs.
54 55	54-56	1.5			2.4			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
56 57	56-58	1.3			2.4			SP SW	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor. 10YR 4/3 (brown) wet, loose well-graded fine and medium sand. No odor.
58 59	58-60	1.8			2.4			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine and medium sand; 2-inch thick band or 10YR 5/8 (yellowish brown) mottled medium sand at 59 feet bgs. No odor.
60 61	60-62								End of boring at 60 feet bgs.
62	62-63								

Boring Number: SB-4 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**SB-5**
Boring Depth:	60 feet	MW #:	
GW Encountered	29.5 feet	Surface Elevation:	
Static GW Level:		Start time/date:	1245 3/24/05
Location:		End time/date:	0910 3/25/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	0.0							No recovery 0'-4' bgs due to augering through frost.
1					--				
2	2-4	0.0							
3					--				
4	4-6	1.5						SW	10YR 4/6 (dark yellowish brown) moist, loose well-graded fine to medium sand. No odor.
5					2.4			SW	10YR 4/3 (brown) moist, loose well-graded fine to coarse sand. No odor.
6	6-8	1.2							
7								SW	10YR 6/2 (light brownish gray) dry, loose well-graded fine to medium sand. No odor.
8	8-10	1.5						SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand with occasional pebbles. No odor.
9									
10	10-12	1.8						SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand. No odor.
								SW	10YR 4/3 (brown) dry, loose bedded band 3-inch thick of fine to coarse sand and gravel. No odor.
11								SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand. No odor.

Boring Number: SB-5 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12	12-14	1.8						SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand. No odor.
13					2.4			SW	10YR 5/2 (grayish brown) moist, loose well-graded fine to coarse sand with gravel and rocks up to 1.5-inch diameter. No odor.
14	14-16	1.5						SP	10YR 5/3 (brown) moist, loose poorly-graded fine sand with occasional rounded pebbles. No odor.
15					2.4				
16	16-18	1.5						SW	10YR 5/8 (yellowish brown) moist, loose well-graded medium and coarse sand. No odor.
17					2.4			SP	10YR 6/2 (light brownish gray) moist, loose poorly-graded fine sand with occasional pebbles. No odor. Mottled at 18.2 feet bgs.
18	18-20	1.8						SW	10YR 5/2 (grayish brown) moist, loose well-graded fine to coarse sand with occasional pebbles. No odor.
19					2.4			SP	10YR 5/2 (grayish brown) moist, loose poorly-graded fine sand with occasional pebbles. No odor.
20	20-22	1.2						SW	10YR 5/2 (grayish brown) moist, loose well-graded fine to coarse sand with occasional pebbles and rock up to 1-inch diameter. Mottled bands from 20.5 to 21.0 feet bgs; laminated bands from 21.0 to 22.0 feet bgs. No odor.
21					2.4				
22	22-24	1.5						SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand with rock up to 1.5-inch diameter. No odor.
23					2.4				
24	24-26	1.5						SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand with gravel and rocks up to 2-inch diameter. No odor.
25					2.4				
26	26-28	1.5						SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand with gravel. No odor.
27					4.9				
28	28-29	1.0						ML	10YR 4/2 (dark grayish brown) moist grading to wet, cohesive silt with occasional pebbles. No odor.

Boring Number: SB-5 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30			water	4.9				Same as above Wet at 29.5 feet bgs.
30 31	30-32	1.5			5.0			ML	10YR 4/3 (brown) wet, cohesive silt with sand and occasional pebbles. No odor.
32 33	32-34	1.0			7.5			SP	10YR 4/2 (dark grayish brown) wet, mildly cohesive poorly-graded fine sand. No odor.
34 35	34-36	1.2			5.0			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine and medium sand. No odor.
36 37	36-38	1.2			2.5			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
38 39	38-40	1.5			2.5			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor. Occasional pebbles in the 38'-39' interval.
40 41	40-42	1.0			2.5			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
42 43	42-44	1.5			5.0			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine and medium sand. No odor. Sample collected at 42'-44' bgs.
44 45	44-46	1.2			5.0			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded sand. No odor.
								SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.

Boring Number: SB-5 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46 47	46-48	1.0			2.5			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand with bands of lamination 10YR 4/1 (dark gray) throughout recovered soil. No odor.
48 49	48-50	1.2			5.0			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand with a single band of lamination 10YR 4/1 (dark gray) at 49.0 feet bgs. No odor. Sample collected at 48'-50' bgs.
50 51	50-52	1.0			2.5			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor. No lamination observed.
52 53	52-54	1.0			5.0			SP	10YR 4/4 (dark yellowish brown) wet, loose poorly-graded fine sand. No odor.
54 55	54-56	1.2			5.0			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
56 57	56-58	1.0			5.0			SW	10YR 4/3 (brown) wet, loose well-graded fine to medium sand. No odor.
58 59	58-60	1.0			7.5			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to medium sand. No odor.
60 61	60-62								End of boring at 60 feet below ground surface
62	62-63								

Boring Number: SB-5 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**SB-6**
Boring Depth:	60 feet	MW #:	
GW Encountered	30 feet	Surface Elevation:	
Static GW Level:		Start time/date:	1050 3/23/05
Location:		End time/date:	1400 3/23/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	--							No recovery 0'-4' bgs due to to augering through frost.
1					--				
2	2-4	--							
3					--				
4	4-6	1.5						SW	10YR 5/6 (yellowish brown) moist, loose well-graded fine and medium sand. No odor.
5					2.4			SW	10YR 5/4 (yellowish brown) moist, loose well-graded fine and medium sand. No odor.
6	6-8	1.5						SW	10YR 5/3 (brown) moist grading to dry, loose well-graded fine to coarse sand. No odor.
7					0.0			SP	10YR 5/2 (grayish brown) dry, loose poorly-graded fine sand. No odor.
8	8-10	1.0							
9					2.4			SW	10YR 5/3 (brown) dry, loose well-graded fine and medium sand. No odor.
10	10-12	1.8						SW	10YR 5/8 (yellowish brown) 3-inch mottled band of fine to medium sand. No odor.
11					2.4			SP	10YR 6/2 (light brownish gray) dry, loose poorly-graded fine sand. No odor.

Boring Number:	SB-6	Project :	NIROP Pilot-Scale 2005	Project #:	5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12	12-14	1.5						SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand. No odor.
13					2.4			SW	10YR 5/2 (grayish brown) dry, loose well-graded fine to coarse sand with gravel. No odor.
14	14-16	1.8						SW	10YR 5/2 (grayish brown) dry, loose well-graded fine to coarse sand. No odor.
15					0.0			SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand, 1/4-inch thick band of 10YR 2/1 (black) stained soil at 15.5 feet bgs. No odor.
16	16-18	1.0						SW	10YR 5/4 (yellowish brown) moist, loose well-graded fine to coarse sand. No odor.
17					0.0			SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles. No odor.
18	18-20	1.2						SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand. No odor.
19					2.4				
20	20-22	1.5						SW	10Yr 5/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles and rocks up to 1/2-inch dia.
21					0.0			SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles.
22	22-24	1.5							
23					0.0			SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand with gravel with rounded rocks up to 1-inch dia. No odor; laminated bands throughout sample down to 26 feet bgs.
24	24-26	1.8							
25					2.4			SW	10YR 3/3 (dark brown) moist, loose well-graded fine to coarse sand with gravel. Laminated bands of 10YR 3/1 (very dark gray) coarse and fine sand. No odor
26	26-28	0.0							No recovery 26'-28' bgs due to rock layer.
27					--				
28	28-29	1.0						GW	10YR 3/4 (dark yellowish brown) wet, loose well-graded blocky gravel and rock with fine to coarse poorly graded sand. No odor.

Boring Number: SB-6 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	1.0		water	0.0			GW	10YR 3/4 (dark yellowish brown) wet, loose well-graded blocky gravel and rock with fine to coarse poorly graded sand. No odor. Wet at 30' bgs
30 31	30-32	0.0			--				No recovery 30'-32' bgs.
32 33	32-34	1.0			4.9			GW	10YR 4/3 (brown) wet, cohesive well-graded gravel with sand and silt. No odor.
34	34-36	1.5							Same as above
35					4.9			SP	10YR 4/1 (dark gray) wet, loose poorly-graded fine sand. Mild odor. 1.5-inch thick stained band of fine sand 10YR 3/1 (very dark gray) at 35.5 feet bgs.
36 37	36-38	1.8			2.4			SP	10YR 2/1 (black) wet, loose poorly-graded fine sand. Strong odor, no sheen. Sample collected at 36'-38' bgs.
38 39	38-40	1.0			4.9			SP	10YR 2/1 (black) wet, loose poorly-graded fine sand. Strong odor.
40 41	40-42	1.5			0.0			SW	10YR 4/1 (dark gray) wet, loose well-graded fine and medium sand with very minor silt component. Moderate odor.
42 43	42-44	1.8			2.4			SP	10YR 4/1 (dark gray) wet, loose poorly-graded fine sand. Strong odor.
44 45	44-46	1.5			2.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand with minor silt component. Moderate odor.

Boring Number: SB-6 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46 47	46-48	1.5			2.4			SP	10YR 5/2 (grayish brown) wet, loose poorly-graded fine sand with laminated bands of fine sand 10YR 3/1 (very dark gray). Strong odor. No sheen.
48 49	48-50	2.0			2.4			SP	10YR 4/2 (dark grayish brown) wet, mildly-cohesive poorly-graded fine sand. Strong odor, no sheen. Homogenous throughout recovery.
50 51	50-52	1.5			2.4			SP SP	1/2-inch band of stained 10YR 2/1 (black) fine sand at 51.3 feet bgs. 10YR 4/1 (dark gray) wet, mildly cohesive fine sand Moderate odor.
52 53	52-54	1.0			2.4			SP	10YR 3/2 (very dark grayish brown) wet, mildly cohesive, poorly-graded fine sand. Mild odor.
54 55	54-56	--			4.9			SW	10YR 3/2 (very dark grayish brown) wet, mildly cohesive well-graded fine and medium sand with occasional pebbles. Laminated bands throughout sample core colored 10YR 2/1 (black). Mild odor.
56 57	56-58	--			2.4			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine and medium sand. No odor. Sample collected at 56'-58' bgs.
58 59	58-60	--			4.9			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
60 61	60-62								End of boring at 60 feet below ground surface.
62	62-63								

Boring Number: SB-6 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**SB-7**
Boring Depth:	60 feet	MW #:	
GW Encountered	30 feet	Surface Elevation:	
Static GW Level:		Start time/date:	1500 3/22/05
Location:		End time/date:	0928 3/23/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	--							No recovery 0'-4' bgs due to augering through frost.
1					--				
2	2-4	--							
3					--				
4	4-6	1.5						SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand. No odor.
5					2.4				
6	6-8	1.5						SW	10YR 5/3 (brown) dry, loose well-graded fine to coarse sand. No odor.
7					2.4			SW	10YR 4/3 (brown) dry grading to moist, loose well-graded fine to coarse sand. No odor.
8	8-10	1.8							
9					2.4			SP	10YR 5/4 (yellowish brown) moist, loose poorly-graded fine sand. No odor.
10	10-12	1.6						GW	10YR 5/4 (yellowish brown) moist, loose well-graded fine to coarse gravel. No odor
								GW	10YR 6/6 (brownish yellow) well-graded gravel and rock
11					2.4			SP	10YR 5/3 (brown) moist, loose poorly-graded fine sand. No odor.

Boring Number: SB-7 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12	12-14	1.8						SP	10YR 5/3 (brown) moist, loose poorly-graded fine sand. No odor.
13					4.8			SW	10YR 3/2 (very dark grayish brown) moist, loose well-graded fine to coarse sand with gravel. No odor.
14	14-16	1.5						SW	10YR 4/3 (brown) moist, loose well-graded fine to coarse sand. No odor.
15					4.8			SP	10YR 5/3 (brown) moist, loose poorly-graded fine sand. No odor.
16	16-18	1.5						SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles. No odor.
17					2.4			SP	10YR 6/2 (light browish gray) moist, loose poorly-graded fine sand. No odor.
18	18-20	1.6						SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles. Sand consists of mostly fine sand. No odor.
19					4.8				
20	20-22	0.3						SP	Limited recovery due to rock in sampler 10YR 5/3 (brown) moist, loose poorly-graded fine sand with occasional pebbles. No odor.
21					4.8				
22	22-24	1.5						SW	10YR 5/3 (brown) moist, loose well-graded medium to coarse sand with gravel. No odor.
23					4.8			SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles. No odor.
24	24-26	1.2						SW	10YR 4/3 (brown) moist, loose well-graded medium and coarse sand with angular gravel. Stained band 10YR 3/2 (very dark grayish brown) 2-inches thick at 25.5 feet bgs coarse sand and gravel.
25					4.8				
26	26-28	1.8						SW	10YR 5/3 (brown) moist, loose well-graded medium and coarse sand with gravel. No odor. Mottled at 26.25' bgs.
								SP	10YR 5/2 (grayish brown) moist, loose poorly-graded fine sand. No odor.
27					4.8			SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with gravel. Laminated bands at 27.5' bgs. No odor.
28	28-29	0.1						SW	10YR 3/3 (dark brown) moist grading to wet at 30' bgs, loose well-graded fine to coarse sand with angular gravel. No odor.

Boring Number: SB-7 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	0.1			4.8			SW	10YR 3/3 (dark brown) moist grading to wet at 30' bgs, loose well-graded fine to coarse sand with angular gravel. No odor.
30	30-32	11.6		water				CL	10YR 4/3 (brown) wet, cohesive tight lean clay with silt and occasional pebbles. No odor.
31					2.4			CL	10YR 4/3 (brown) wet, cohesive tight lean clay with medium to coarse sand and occasional pebble No odor. Very minor silt component. Sample collected at 32'-34' bgs.
32	32-34	1.5							
33					2.4				
34	34-36	1.4							Same as above Sample collected at 34'-36 bgs.
35					4.9			SP	10YR 3/3 (dark brown) wet, loose poorly-graded fine sand. No odor.
36	36-38	1.6						SM	10YR 4/2 (dark grayish brown) wet, cohesive silty sand. No odor.
37					4.9				
38	38-40	1.5						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor.
39					4.9			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine and medium sand. No odor.
40	40-42	1.6						SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to coarse sand bedded with layers of fine sand. No odor.
41					4.9			SW	10YR 4/2 (dark grayish brown) wet, loose well-graded fine to medium sand. No odor.
42	42-44	1.8							
43					4.9			SP	10YR 3/1 (very dark gray) wet, loose poorly-graded fine sand. Mild odor, progressively more stained with depth.
44	44-46	1.6							
45					2.4			SP	10YR 3/1 (very dark gray) wet, loose poorly-graded fine sand. Mild odor.

Boring Number: SB-7 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46 47	46-48	1.8			4.9			SP	10YR 2/1 (black) wet, loose poorly-graded fine sand. Strong odor, no sheen. Sample collected at 46'-48' bgs. FD-1 sampled at 46'-48' bgs.
48 49	48-50	1.5			4.9			SP	10YR 3/2 (very dark grayish brown) wet, cohesive poorly-graded fine sand with very minor silt component. Mild odor. Stained with bands of 10YR 2/1 (black) fine sand.
50 51	50-52	1.8			2.4			SP	10YR 3/2 (very dark grayish brown) grading to 10YR 3/3 (dark brown) wet, loose poorly-graded fine sand. Moderate odor.
								SP	10YR 4/4 (dark yellowish brown) wet, loose poorly-graded fine sand. Mild to no odor.
52 53	52-54	0.5			2.4			SP	10YR 4/3 (brown) wet, loose poorly-graded sand. Mild odor. Limited sample recovery.
54 55	54-56	1.8			2.4			SW	10YR 4/3 (brown) wet, loose well-graded fine and medium sand. No odor, no staining.
56 57	56-58	1.8			4.9			SW	10YR 4/3 (brown) wet, loose well-graded fine and medium sand. No odor.
								SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
58 59	58-60	2.0			4.9			SP	10YR 4/3 (brown) wet, loose poorly-graded fine sand. No odor.
60 61	60-62								End of boring at 60 feet below ground surface.
62	62-63								

Boring Number: SB-7 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**SB-8**
Boring Depth:	60 feet	MW #:	
GW Encountered	30 feet	Surface Elevation:	
Static GW Level:		Start time/date:	1420 3/16/05
Location:		End time/date:	1030 3/17/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	0.0							No recovery 0'-4' due to augering through frost.
1					--				
2	2-4	0.0							
3					--				
4	4-6	1.7						SW	10YR 4/4 (dark yellowish brown) dry, loose well-graded fine to medium sand. No odor.
5					4.2				
6	6-8	1.5						SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand. No odor.
7					4.2				
8	8-10	1.5						SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand. No odor.
9					2.1				
10	10-12	1.7						SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand. No odor.
11					2.1				

Boring Number:	SB-8	Project :	NIROP Pilot-Scale 2005	Project #:	5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12	12-14	1.5						SW	10YR 5/3 (brown) dry, loose well-graded fine to medium sand. No odor.
									10YR 6/4 (light yellowish brown) 6-inch thick rock layer
13					4.2			SW	10YR 5/4 (yellowish brown) moist, loose well-graded fine to coarse sand. No odor.
14	14-16	1.7							
15					2.1			SP	10YR 6/2 (light brownish gray) moist, loose poorly-graded fine sand. No odor.
16	16-18	1.6							
17					4.2				
18	18-20	1.5						SP	10YR 6/2 (light brownish gray) moist, loose poorly-graded fine sand. No odor.
19					4.2				
20	20-22	1.4							
21					2.1			SW	10YR 5/2 (grayish brown) moist, loose well-graded fine to medium sand with pebbles and rock up to 1/2-inch diameter. No odor.
22	22-24	1.5						SW	10YR 6/2 (light brownish gray) moist, loose well-graded fine to medium sand. Lamination visible at 23.5 feet bgs. No odor.
23					4.2				
24	24-26	1.6						SW	10YR 4/3 (brown) moist, loose well-graded fine to coarse sand with gravel. Mild odor, no stains.
25					4.2				
26	26-28	1.5						SW	10YR 4/3 (brown) moist, loose well-graded fine to coarse sand with gravel. No odor. No staining.
27					4.2				
28	28-29	0.2						SM	10YR 3/1 (very dark gray) wet, loose poorly-graded fine to coarse silty sand. No odor. Minimal recovery

Boring Number: SB-8 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	0.2		water	4.4			SM	10YR 3/1 (very dark gray) wet, loose poorly-graded fine to coarse silty sand. No odor. Minimal recovery
30	30-32	0.1						SW-SM	10YR 4/3 (brown) wet, loose well-graded sand with silt. No odor.
31					2.2				
32	32-34	0.2						SP	10YR 4/3 (brown) wet, cohesive poorly-graded fine sand with silt. No odor.
33					2.2				
34	34-36	1.2						SW	10YR 3/1 (very dark gray) wet, cohesive well-graded fine to coarse sand with clay and gravel. No odor.
35					2.2			SP	10YR 3/1 (very dark gray) wet, cohesive poorly-graded sand with silt. No odor.
36	36-38	0.3							
37					4.4			SP	10YR 3/1 (very dark gray) wet, cohesive poorly-graded sand with silt. No odor.
38	38-40	1.0						ML	10YR 4/1 (dark gray) wet, cohesive poorly-graded fine silt with sand. No odor.
39					2.2				
40	40-42	1.4						ML	10YR 4/1 (dark gray) wet, cohesive poorly-graded fine silt with sand. No odor.
41					2.2				
42	42-44	1.3						ML	10YR 4/2 (dark grayish brown) wet, cohesive poorly-graded fine sandy silt. No odor.
43					4.4				
44	44-46	0.2						SP-SM	10YR 4/2 (dark grayish brown) wet, cohesive poorly-graded fine sand with silt. No odor.
45					4.4				Sample collected at 46' bgs.

Boring Number: SB-8 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46 47	46-48	ND			4.4			ML	10YR 4/2 (dark grayish brown) wet, cohesive silt with fine poorly-graded sand. Some 10YR 3/1 (very dark gray) staining at 46'-47' bgs. No odor.
48 49	48-50	ND			6.6			SP-SM	10YR 3/2 (very dark grayish brown) wet, cohesive poorly-graded fine sand with silt. Mild odor. Sampled "most impacted" at 48'-50' bgs.
50 51	50-52	ND			4.4			SP-SM	10YR 4/2 (dark grayish brown) wet, cohesive poorly-graded fine sand with silt. No odor Sample collected at 51' bgs.
52 53	52-54	ND			4.4			SP-SM	10YR 3/2 (very dark grayish brown) wet, cohesive poorly-graded fine sand with silt. No odor. Dark stained band of 10YR 3/1 at 53.5' bgs.
54 55	54-56	ND			4.4			SP-SM	10YR 4/2 (dark grayish brown) wet, cohesive poorly-graded fine sand with silt. No odor.
56 57	56-58	ND			4.4			SW	10YR 4/3 (brown) wet, cohesive well-graded fine to coarse sand. No odor. Sample collected at 56' bgs.
58 59	58-60	ND			4.4			SW	10YR 4/3 (brown) wet, cohesive well-graded fine to coarse sand. No odor.
60 61	60-62								
62	62-63								

Boring Number: SB-8 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**SB-9**
Boring Depth:	60 feet	MW #:	
GW Encountered	28 feet	Surface Elevation:	
Static GW Level:		Start time/date:	0910 3/21/05
Location:		End time/date:	1220 3/21/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	0.0							No recovery 0'-4' bgs due to augering through frost.
1					--				
2	2-4	0.0							
3					--				
4	4-6	1.8						SW	10YR 4/4 (dark yellowish brown) dry, loose well-graded fine to medium sand with occasional pebbles.
5					2.4			SP	10YR 4/2 (dark grayish brown) dry, loose poorly-graded fine sand. No odor. Bedded 10YR 4/3 (brown) poorly-graded fine sand at 5.8' bgs.
6	6-8	1.2						SP	10YR 5/2 (grayish brown) dry, loose poorly-graded fine sand; homogenous throughout recovery. No odor.
7					0.0				
8	8-10	1.4						SP	10YR 5/2 (grayish brown) dry, loose poorly-graded fine sand with bedded 1-inch thick bands of 10YR 5/6 (yellowish brown) poorly-graded fine sand after 9' bgs. No odor.
9					0.0				
10	10-12	1.4						SP	10YR 5/3 (brown) dry, loose poorly-graded medium sand. No odor.
11					2.4			SP	10YR 5/3 (brown) dry, loose poorly-graded medium sand with gravel. No odor.

Boring Number:	SB-9	Project :	NIROP Pilot-Scale 2005	Project #:	5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12	12-14	1.5						SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand. No odor.
13					4.9			SW	10YR 4/2 (dark grayish brown) well-graded fine to coarse sand with blocky gravel and rocks up to 2-inch diameter. No odor.
14	14-16	1.2							
15					2.4			SP	10YR 5/3 (brown) moist, loose poorly-graded fine sand. No odor.
16	16-18	1.4						SP	10YR 5/2 (grayish brown) moist, loose poorly-graded medium sand. No odor.
17					2.4			SP	10YR 5/2 (grayish brown) moist loose poorly-graded fine sand bedded with 2"-4" thick bands of 10YR 5/3 (brown) well-graded medium to coarse moist, loose sands at 18.5 feet bgs. No odor.
18	18-20	1.5							
19					0.0			SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles. No odor.
20	20-22	1.6						SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to medium sand. No odor. Dark colored 10YR 3/1 (very dark gray) 2-inch thick band of coarse sand at 21' bgs.
21					0.0			SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand. No odor.
22	22-24	1.8						SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with occasional pebbles. No odor.
23					2.4				
24	24-26	1.5						SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand with angular gravel. No odor.
								SP	10YR 5/2 (grayish brown) moist, loose band of fine sand 3-inch thick at 25 feet bgs.
25					0.0			SW	10YR 4/2 (dark grayish brown) moist, loose well-graded fine to coarse sand with angular gravel. No odor.
26	26-28	1.4						SP	10YR 5/2 (grayish brown) moist, loose poorly-graded fine sand. No odor. This horizon approx. 5-inch thick.
27					0.0			SW	10YR 5/3 (brown) moist, loose well-graded fine to coarse sand with gravel. No odor.
28	28-29	0.2		water				SW	10YR 4/4 (dark yellowish brown) wet, loose well-graded fine to coarse sand. No odor or sheen.

Boring Number: SB-9 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30	0.2			0.0			SW	10YR 4/4 (dark yellowish brown) wet, loose well-graded fine to coarse sand. No odor or sheen.
30	30-32	0.3						SW	10YR 4/4 (dark yellowish brown) wet, cohesive well-graded medium to coarse sand with gravel and silt. No odor. Minimal recovery.
31					0.0				
32	32-34	0.4							Same as above.
33					0.0			CL	10YR 4/4 (dark yellowish brown) wet, cohesive tight lean clay with fine sand. No odor.
34	34-36	1.0						SP-SM	10YR 4/4 (dark yellowish brown) wet, cohesive poorly-graded fine sand with silt. Mild odor.
35					4.9			SP-SM	10YR 3/1 (very dark gray) wet, cohesive poorly-graded fine sand with silt. Strong odor, no sheen. Sample collected at 34'-36' bgs
36	36-38	1.0						SP-SM	10YR 3/2 (very dark grayish brown) wet, cohesive poorly-graded fine sand with silt. Moderate odor.
37					2.4			SP-SM	10YR 3/1 (very dark gray) wet, cohesive poorly-graded fine sand with silt. Moderate odor.
38	38-40	1.9						SP-SM	10YR 3/2 (very dark grayish brown) wet, cohesive poorly-graded fine sand with silt. Moderate odor.
39					0.0				
40	40-42	0.3						SW-SM	10YR 3/2 (very dark grayish brown) wet, cohesive well-graded fine to medium sand. Mild odor. Minimal recovery. Very minor silt component.
41					4.9				
42	42-44	1.6						SW-SM	10YR 3/1 (very dark gray) wet, cohesive well-graded fine to medium sand. Mild odor. Very minor silt component.
43					0.0				
44	44-46	0.4						SW-SM	10YR 3/2 (very dark grayish brown) wet, cohesive well-graded fine to medium sand with minor silt component. Mild odor.
45					0.0				

Boring Number: SB-9 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46	46-48	1.0						SW-SM	10YR 4/2 (dark grayish brown) wet, cohesive well-graded fine to medium sand with silt. Laminated bands throughout recovery. Mild odor. Sample collected at 46' bgs.
47					0.0				
48	48-50	1.0						SP-SM	10YR 4/2 (dark grayish brown) wet, cohesive poorly-graded fine sand with silt. Mild odor. Occastional pebbles.
49					4.9			SP-SM	10YR 3/2 (very dark grayish brown) wet, cohesive poorly-graded fine sand with silt. Mild odor.
50	50-52	1.4						SP-SM	10YR 3/1 (very dark gray) wet, cohesive poorly-graded fine sand with silt. Mild odor.
51					0.0			SP-SM	10YR 2/1 (black) wet, cohesive poorly-graded fine sand with silt with laminated dark bands. Mild odor. Sample collected at 51' bgs.
52	52-54	1.6						SP-SM	10YR 3/2 (very dark grayish brown) wet, cohesive poorly-graded fine sand with silt and occasional rounded pebbles. Consistant color throughout recovery. Mild odor.
53					4.9				
54	54-56	ND							Same as above.
55					4.9			SW-SM	10YR 4/2 (dark grayish brown) wet, cohesive well-graded fine to medium sand with silt. No odor.
56	56-58	ND						SW-SM	10YR 4/2 (dark grayish brown) wet, cohesive well-graded fine to coarse sand with silt. Mild odor. Sample collected at 56' bgs.
57					4.9			SP-SM	10YR 4/3 (brown) wet, cohesive poorly-graded fine sand with silt. No odor.
58	58-60	ND						--	No recovery from 58' to 60' bgs due to recovery sliding out of sampler.
59					--				
60	60-62								End of boring at 60 feet below ground surface.
61									
62	62-63								

Boring Number: SB-9 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

VISUAL CLASSIFICATION OF SOILS

EMR INCORPORATED

EMR Project Name:
NIROP Pilot-Scale 2005
EMR Project Number:
5427
Note:

Drilling Information

Drilling Contractor:	Bergerson-Caswell
Drilling Method:	Hollow Stem Auger
Drillers Name:	Glen Holmen
Borehole Diameter:	8-1/4 inch
Sampler Type:	Stainless Split Spoon

Event Information

Logged by:	CAD - EMR, Inc.	Boring #:	**SB-10**
Boring Depth:	60 feet	MW #:	
GW Encountered	29.5 feet	Surface Elevation:	
Static GW Level:		Start time/date:	0936 3/22/05
Location:		End time/date:	1204 3/22/05

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Groundwater	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
0	0-2	0.0							No recovery 0'-4' bgs due to augering through frost.
1					--				
2	2-4	0.0							
3					--				
4	4-6	1.4						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded medium sand. No odor.
5					0.0			SP	10YR 4/3 (brown) moist, loose poorly-graded medium sand. No odor.
6	6-8	1.8						SP	10YR 5/3 (brown) moist, loose poorly-graded medium sand. No odor. Homogenous.
7					2.8				
8	8-10	1.6						SW	10YR 5/2 (grayish brown) moist grading to dry, loose, well-graded fine and medium sand. No odor.
9					2.4			SW	10YR 5/3 (brown) dry, loose well-graded fine and medium sand. No odor.
10	10-12	1.0						GW	10YR 4/3 (brown) dry, loose well-graded gravel with fine and medium sand. No odor.
11					0.0			SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand. No odor.

Boring Number:	SB-10	Project :	NIROP Pilot-Scale 2005	Project #:	5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
12 13	12-14	0.6			4.8			SW	10YR 4/3 (brown) dry, loose well-graded medium and coarse sand with gravel. No odor
14	14-16	1.4						SW	10YR 5/2 (grayish brown) dry, loose well-graded fine to coarse sand. No odor.
								SP	10YR 5/2 (grayish brown) dry, loose poorly-graded fine sand. No odor.
15					4.8			SW	10YR 5/2 (grayish brown) dry, loose well-graded medium and coarse sand. No odor.
16	16-18	1.8						SW	10YR 5/3 (brown) dry, loose well-graded fine and medium sand with occasional pebbles. No odor.
17					2.4			SP	10YR 5/2 (grayish brown) dry, loose poorly-graded fine sand. No odor.
18	18-20	0.8						SP	10YR 5/3 (brown) dry, loose poorly-graded fine sand with occasional pebbles. No odor.
19					2.4			SW	10YR 5/3 (brown) dry, loose well-graded fine and medium sand with occasional pebbles. No odor.
20 21	20-22	0.5			2.4			SW	10YR 5/2 (grayish brown) dry, loose well-graded fine to coarse sand with occasional pebbles. No odor. Homogenous throughout sample recovery.
22 23	22-24	1.2			2.4			SW	10YR 4/2 (dark grayish brown) dry, loose fine to coarse well-graded sand with occasional pebbles. No odor. Homogenous throughout recovery.
24	24-26	1.6						SP	10YR 4/2 (dark grayish brown) dry, loose poorly-graded fine sand with occasional pebbles. No odor
25					4.8			SW	10YR 4/2 (dark grayish brown) dry, loose well-graded fine to coarse sand with gravel. Rocks up to 3/4-inch diameter. No odor.
26 27	26-28	1.2			2.4			SP	10YR 5/2 (grayish brown) moist, loose poorly-graded fine sand. No odor.
28	28-29							SW	10YR 3/3 (very dark grayish brown) moist grading to wet at 29.5' bgs, loose medium to coarse sand with gravel. Mild odor.

Boring Number: SB-10 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
29	29-30			water	2.4			SW	10YR 3/3 (very dark grayish brown) moist grading to wet at 29.5' bgs, loose medium to coarse sand with gravel. Mild odor.
30 31	30-32	1.0			4.8			GW	10YR 4/3 (brown) wet, loose well-graded gravel with coarse sand. No odor. Very minor silt component.
32 33	32-34	0.4			2.4			SW-SM	10YR 3/3 (dark brown) wet, loose well-graded fine to coarse sand with silt. No odor.
34	34-36	0.6						ML	10YR 3/4 (dark yellowish brown) wet, cohesive silt with fine sand. No odor.
35					4.8			SM	10YR 3/4 (dark yellowish brown) wet, cohesive silty fine sand. No odor. Some staining to 10YR 3/2 (very dark grayish brown) at 35.5' bgs.
36 37	36-38	1.0			2.4			SM	10YR 3/2 (very dark grayish brown) wet, cohesive silty fine sand with stained bands of 10YR 3/1 (very dark gray) throughout recovery.
38 39	38-40	1.9			2.4			SP-SM	10YR 4/2 (dark grayish brown) wet, mildly cohesive fine sand with very minor silt component. No odor. Homogenous throughout sample recovery.
40 41	40-42	1.2			2.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor. Homogenous throughout sample recovery.
42 43	42-44	1.6			2.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor. Homogenous throughout sample recovery.
44	44-46	1.8						SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor. Homogenous throughout sample recovery.
45					2.4			SP	10YR 2/1 (black) wet, loose poorly-graded fine sand. Moderate odor, no sheen.

Boring Number: SB-10 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
46	46-48	1.8						SP	10YR 2/1 (black) wet, loose poorly-graded fine sand. Strong odor. No sheen. Homogenous through sample recovery. Sample collected at 46' bgs.
47					2.4				
48	48-50	1.6						SP	10YR 2/1 (black) wet, loose poorly-graded fine sand. Moderate odor, no sheen. Same as above.
49					4.8				
50	50-52	1.6							Same as above.
51					2.4			SP	10YR 4/2 (dark grayish brown) wet, loose poorly-graded fine sand. No odor. Sample collected at 51' bgs.
52	52-54	1.5						SP	10YR 3/2 (very dark grayish brown) wet, loose poorly-graded fine sand. No odor.
53					2.4			SP	10YR 3/3 (dark brown) wet, loose poorly-graded fine sand. No odor.
54	54-56	1.8						SM	10YR 4/3 (brown) wet, cohesive poorly-graded fine silty sand. No odor.
55					2.4				
56	56-58	ND						SW	10YR 4/3 (brown) wet, cohesive well-graded fine to medium sand. No odor. Sample collected at 56' bgs.
57					2.4				
58	58-60	ND						SW	10YR 4/3 (brown) wet, cohesive well-graded fine to medium sand. Occasional pebbles. No odor.
59					4.8			SW	10YR 4/3 (brown) wet, cohesive well-graded fine to medium sand. No odor.
60	60-62								End of boring at 60 feet below ground surface
61									
62	62-63								

Boring Number: SB-10 Project : NIROP Pilot-Scale 2005 Project #: 5427

Depth (ft)	Sample Interval	Sample Recovery	Evacuation Rate	Ground water	PID/FID Readings	GC Reading	Graphic Log	USCS Classification	Soil Classification/ Description
63	63-64								
64	64-66								
65									
66	66-68								
67									
68	68-70								
69									
70	70-72								
71									
72	72-74								
73									
74	74-76								
75									
76	76-78								
77									
78	78-80								
79									

APPENDIX C

RESPONSE TO COMMENTS MATRICES

RESPONSE TO WRITTEN COMMENTS ON
THE TECHNICAL MEMORANDUM DATED NOVEMBER 2005
VEGETABLE OIL INJECTION PILOT TEST
NAVAL INDUSTRIAL ORDNANCE PLANT FRIDLEY, MINNESOTA

Item	Section	Page	Comments	Responses
General Response to Comments:				
Minnesota Pollution Control Agency Comments Note: MPCA states in their letter dated November 30th 2005 that it is unnecessary for the Navy to respond to comments provided in the subject letter. However, for completeness the comments provided by the MPCA are included in this response to comments document.				
1.	General	NA	The technical memorandum contains conclusions and recommendations that the MPCA may or may not agree with.	None necessary.
2.	General	NA	Revisions to the pilot test, including the new monitoring well network, have resulted in much more quantifiable and definitive assessments about the pilot study area and the magnitude of the impacts of vegetable oil injection.	None necessary.
3.	General	NA	The technical memorandum shows that the vegetable oil injection has resulted in the distribution of organic carbon within the impacted aquifer that has delivered a carbon source to a well-defined area of the aquifer down gradient of the injection area.	None necessary.
4.	General	NA	Within the area of carbon distribution, there have been reductions in TCE levels that have been shown. in part, to be a result of reductive dechlorination due to the vegetable oil injection.	None necessary.
5.	General	NA	The pilot test data quality objectives for the reduction of TCE levels continue to be met.	None necessary.
6.	General	NA	The production of VC from vegetable oil injection has not been observed to be an issue in the pilot test area.	None necessary.
7.	General	NA	After the pilot test report has been reviewed by the USEPA and MPCA, the NIROP partnering team will meet to discuss the conclusions and recommendations of the report and the potential applicability of the vegetable oil injection technology to the Anoka County Riverside Regional Park	None necessary.

Item	Section	Page	Comments	Responses
			groundwater contamination problem.	
8.	General	NA	Upon completion of the USGS capture evaluation report, the results of the capture evaluation as well as the results of the final pilot test will need to be taken into account when making remedy decisions for the parks groundwater contamination problem.	None necessary.
9.	General	NA	Any discussion in the technical memorandum beyond the objectives of the pilot test as cited in the Quality Assurance Project Plan should be considered the subject of subsequent meetings by the NIROP partnering team.	None necessary.
10.	General	NA	The NIROP contaminant plume in the park is currently exceeding MPCA surface water quality standards for this stretch of the Mississippi River. Meeting the MPCA water quality standards for the site contaminants of concern in the park compliance wells prior to plume discharge to the Mississippi River remains a remediation goal for NIROP and the primary reason that the NIROP partnering team is evaluating the vegetable oil technology in the park.	None necessary.
11	General	NA	Eventually the NIROP partnering team needs to discuss the potential application of the vegetable oil injection technology (and other appropriate remedies) to source area beneath the main NIROP building.	None necessary.
United States Environmental Protection Agency Comments				
1	General Comment: Generally, the recommendations provided in the last section of the Tech Memo appear vague. The second paragraph on Page 21 recommends "organic substrate addition in general and vegetable oil injection specifically be considered as a future remedial option at the site." However, the Tech Memo goes on to identify permeable reactive barriers or injectable zero valent [sic] iron as possible remedial technologies. In addition, the Tech Memo indicates "it is unlikely that any remedial technology will be successful in significantly accelerating the time it will take to clean up the site." These recommendations appear to be contradictory. The Final Vegetable Oil Pilot Test Report should include detailed discussions of specific recommendations. These recommendations should be			

RESPONSE TO WRITTEN COMMENTS ON
THE TECHNICAL MEMORANDUM DATED NOVEMBER 2005
VEGETABLE OIL INJECTION PILOT TEST
NAVAL INDUSTRIAL ORDNANCE PLANT FRIDLEY, MINNESOTA
(Continued)

Item	Section	Page	Comments	Responses
	developed only after addressing the concerns identified in the following Specific Comments regarding the analysis of potential applicability of the vegetable oil injection technology at the NIROP site and the impact of the diffusion of contaminants out of the fine grained sediments identified on site. General Response: The conclusions section in the technical memorandum will be revised and clarified such that recommendations regarding the future use to organic substrate addition at Anoka County Park are clear and well supported by the data collected to date.			
Specific EPA Comments				
1	Site Hydrology	13	The Tech Memo states that "hydraulic conductivity measurements conducted in wells PES-MW-3, PES-MW-8, and PES-MW-9 indicate that a zone of low hydraulic conductivity is present down gradient of the immediate injection area." The geometric mean for the hydraulic conductivity values measured in these wells was reported to be 0.010 cm/sec. Such values of hydraulic conductivity represent relatively permeable materials. It does not appear appropriate to characterize the area surrounding these wells as "a zone of low hydraulic conductivity." Although unclear, the discussion appears to suggest that this is an area of reduced hydraulic conductivity relative to other nearby areas. Revise this statement to provide a more detailed discussion of the areas being compared and the nature of the comparison.	The site hydrogeology section of the tech memo compares calculated hydraulic conductivities from three areas over time. The three areas are the injection area, the area surrounding wells PES-MW-3, PES-MW-8, and PES-MW-9, and the area around the contingency wells. The geometric mean of hydraulic conductivities calculated in the injection area and in the area surrounding the contingency wells was approximately 0.062 cm/sec and 0.069 cm/sec while the geometric mean of hydraulic conductivities in the area of PES-MW-3, PES-MW-8, and PES-MW-9 was 0.010 cm/sec. Thus, the calculated hydraulic conductivity in area surrounding wells PES-MW-3, PES-MW-8, and PES-MW-9 is low in relation to the injection area and the contingency well area as stated in the tech memo. The third sentence in the 5th paragraph of the hydrogeology section will be revised to read as follows: "Hydraulic conductivity measurements conducted in wells PES-MW-3, PES-MW-8, and PES-MW-9 indicate that a zone of low hydraulic conductivity, relative to the injection area and the area around the contingency wells, is present in the vicinity of these well locations."
2	VOCs in Ground	15	The Tech Memo utilizes the data presented in Tables 11A and 11B to support a conclusion that 'TCE concentrations within the pilot test area decreased much more rapidly than	Concur, the comparison of TCE reduction rates within the pilot test area to reduction rates observed outside of the pilot test area will be removed.

Item	Section	Page	Comments	Responses
	water		TCE concentrations outside of the pilot test area as indicated by the average slope within the pilot test area." However, Table 11A, which presents data outside of the pilot test area, includes data from monitoring wells located outside of the core area of the plume that likely do not represent the portions of the plume directly impacted by the recent upgrades in the groundwater extraction system (i.e., monitoring wells 17-S, 19-S, 27-S, 41-S, 43-S, and 44-S). If the data from the low concentration portions of the core areas of the plume (e.g., concentrations lower than 790 ugh TCE) are excluded from this assessment, the reductions in TCE concentrations outside the pilot test area appear similar to those within the pilot test area. In fact, the average percent reduction in TCE concentrations appears to be higher than in the pilot test area. The analysis of the data from within the pilot test area clearly indicates that injection of vegetable oil has resulted in significant reductions in chlorinated solvent concentrations in groundwater. Figure 8 clearly illustrates these decreases. Because of underlying background trends in contaminant concentrations, the comparison of reductions in contaminant concentrations within and outside of the pilot test area does not appear useful in demonstrating the effectiveness of the injection of vegetable oil in reducing contaminant concentrations in groundwater. It is recommended that analysis of data from within the pilot test area be used primarily for this purpose.	
3	Summa ry	18	The Tech *Memo* concludes that "any remedial strategies implemented in this (study) area should be targeted to the finer grained units present between approximately 30 and 40 feet bgs where the majority of the contaminant mass	The reviewer is correct. The referenced conclusion does assume that the referenced remedial option will be designed primarily to remove contaminant mass.

Item	Section	Page	Comments	Responses
			resides." However, this conclusion presumes that the object of any remedial strategy is to remove maximum amounts of contaminants from the subsurface. However, as indicated in the recommendations presented in the Tech Memo, other remedial objectives have been evaluated, including the objective of reducing the potential impact to receptors and therefore reducing the environmental risk associated with contaminants remaining in the subsurface or migrating via groundwater from up gradient areas. These other remedial objectives may not necessarily target the removal of contaminant mass from the finer grained units. The Final Vegetable Oil Pilot Test Report should fully acknowledge these other potential remedial strategies.	Concur, The conclusions section will be revised to discuss different remedial goals (e.g., contaminant mass removal verses reduction of contaminant mass flux toward the river, etc.) and the viability of organic substrate addition to meet each goal based upon the results of the pilot test.
4	Recommendations	21	The Tech Memo states that "vegetable oil has also been shown to be effective at stripping contaminant mass from the soil matrix through its surfactant properties and immobilizing contaminant mass through its preferential partitioning properties." The Tech Memo does not appear to directly discuss these properties of vegetable oil or discuss how the data reported in the Tech Memo support such a conclusion. Consequently, the basis for this statement is not clear. In addition, it is not clear if this statement is intended to indicate that the injection of vegetable oil might provide a means of addressing the contaminant mass shown to be concentrated in the fine grained deposits in the study area. Any such statements included in the Final Vegetable Oil Pilot Test Report should be fully supported and their implications for the remediation of subsurface contaminant mass at the NIROP facility should be clarified.	The basis for these conclusions are drawn from Section 4.4.3 of the draft NIROP pilot test report (Parsons, 2004) and will be properly referenced in the technical memorandum. This discussion is presented in order to support the conclusion that vegetable oil injection may be an effective means to sequester and immobilize contaminant mass and therefore meet the remedial goal of reducing contaminant flux to receptors. The conclusion that vegetable oil also effectively strips contaminant mass from the soil matrix could also indicate that vegetable oil injection might be an effective means of accelerating the removal of contaminant mass from the fine grained units. However, the effectiveness of vegetable oil to strip contaminant mass from the fine grained units would be limited by the degree of contact between the impacted soils and the vegetable oil. Thus, it would be very difficult to strip a significant amount of the contaminant mass that is sorbed to the fine grained units because it would be difficult to bring vegetable oil into direct contact with a significant percentage

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				of the fine grained sediments.
5	Recommendations	22	The Tech Memo states that "the rate at which contaminant mass diffuses out of the finer grained units could be increased slightly by removing the contaminant mass from the more transmissive units and thereby increasing the steepness of the contaminant concentration gradient." This statement is supported by citing the example of TCE concentrations measured in soil from the silt unit and underlying sand unit at Soil Boring SB-4. The significant differences in soil concentrations of TCE at this location are used to demonstrate that the soil data collected during the study "indicate that the contaminant concentration gradients from the finer grained units to the coarser grained units are already relatively steep." Based on this analysis, the Tech Memo concludes that "it is unlikely that any remedial technology will be successful in significantly accelerating the time it will take to clear up the site because contaminant mass will continue to diffuse out of the fine grained units for some time to come." However, it is important to note. that TCE diffuses out of the finer grained materials into the coarser grained materials according to the contaminant concentration gradient in groundwater and not in soils. As the data collected during this study have clearly indicated, the finer grained materials contain significantly greater amounts of organic carbon than coarser grained materials found on site. Since the degree of adsorption of TCE is largely controlled by the organic carbon content of subsurface materials, a much greater amount of TCE will adsorb onto the finer grained soils than the coarser grained soils for an	The reviewer is correct that contaminant gradients are typically calculated using groundwater data. However, in this case groundwater data from the silt unit is not available. Samples were collected using a groundwater profiler during the Spring 2005 field event as part of the MIP survey activities. However, the soil stratigraphy data collected by the MIP system is not representative of soil conditions as reflected by boring logs collected during soil boring and well installation activities. As a result the soil stratigraphy within each profiler sampling interval can not be accurately determined. The comparison of soil VOC data from the silt unit and the sand unit allows us to draw the qualitative conclusion that more contaminant mass is present in the silt unit than in the sand unit. The reviewer is correct that comparison of soil data does not however allow us to draw conclusions regarding the VOC concentration gradient from the silt unit to the sand unit because soil data represents both dissolved phase contaminant mass (pore water) and sorbed contaminant mass. The following statement: "However, the soil data collected during the Spring of 2005 indicates that the contaminant concentration gradient from the finer grained units to the coarser grained units is already relatively steep" will be removed from the conclusions section. Regardless, the observation that the contaminant mass diffusion rates out of the fine grained units could be improved slightly by removing contaminant mass from the coarse grained units (thus increasing the concentration gradient from the silt to the sand) is correct. The observation: "However, it is unlikely that any remedial technology will be successful in significantly accelerating the time it will take to clean up the

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			equivalent dissolved concentration of TCE. Consequently, it is not clear that the differences in soil concentrations of TCE observed between fine and coarse grained materials actually indicate significant gradients in the dissolved TCE concentrations in groundwater between the fine and coarse grained materials. Thus, it is not clear that TCE concentration gradients between the fine and coarse grained materials could not be significantly improved through the application of vegetable oil injection in Anoka County Park. There appears to be little basis provided in the Tech Memo for the above cited statement regarding the potential for increasing the rate of diffusion out of the fine grained materials through the injection of vegetable oil. Greater analysis of the factors that control diffusion out of the fined grained deposits found on site is required before such a statement can be fully evaluated.	site because contaminant mass will continue to diffuse out of the fine grained units for some time to come" is also correct as supported by the following calculations following Freeze and Cherry 1979 and using a modification of Ficks Law. Ficks Law States that a concentration at time T and position x can be calculated assuming linear diffusion using the following parameters: C(x,t) is the concentration at point x Co is the initial concentration D* is the diffusion coefficient x is the diffusion distance Through the following formula: C(x,t) =Co erfc{x/2*sqrt(D*t)} The calculation assumes that there is no advection, no dispersion, no retardation, no decay, and that diffusion is in one direction and so the calculation provides only an estimate of diffusion time. The calculation also assumes that the concentration at point x is zero so that the concentration gradient is maximized. However, the results are useful in that they provide a semi-quantitative estimate of diffusion time. Assuming x = 1 foot, Co is 710 ppb (TCE concentration in the silt unit), D is 1e-4 cm^2/sec (Evans, 1995) and C(x,t) is 5 ppb (the TCE USEPA MCL) the diffusion time as iteratively calculated is approximately 400 to 700 years. If one were to consider retardation as well than the diffusion time would be longer. These calculations indicate that even in the case where the concentration gradient is maximized (i.e., contaminant mass is removed from the sand unit at point x as fast as it diffuses out of the silt unit) the time it will take to

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				diffuse out the contaminant mass in the silt unit is on the order of hundreds of years. Thus, the application of a remedial option will not accelerate site cleanup time significantly (regardless of how effective the option is). The observation that the cleanup time for this site will be defined by diffusion based mechanics (i.e., the rate at which contaminant mass diffuses out of the silt units) leads to the conclusion that the primary remedial goal at this site should not be to simply remove/destroy contaminant mass but to protect receptors as stated in the conclusions section of the October 2005 technical memorandum. These calculations and discussion will be incorporated into the technical memorandum.
6	Recommendations	22	As indicated above in Specific Comment No. *5*, the Tech Memo indicates that soil sampling results have shown that the majority of the contaminant mass observed in soils is retained in the finer grained materials. The Tech Memo also appropriately indicates that this contaminant mass may provide an ongoing source of groundwater contamination. However, it is not clear that such slow diffusion of contaminants out of fine grained deposits into the relatively fast moving groundwater in the more permeable strata in the study area could result in the contaminant concentrations currently observed in groundwater in the study area. Preliminary analysis of contaminant concentrations in groundwater in coarse grained materials underlying highly contaminated finer grained sediments was provided during the October 5, 2005 Technical Meeting on the Tech Memo. This analysis appeared to indicate that the diffusion of contaminants out of the fine	Concur, it is unlikely that back diffusion of contaminant mass from the fine grained units alone could account for VOC concentrations measured in the more permeable units. The diffusion rate calculations presented above will be incorporated into the technical memorandum. Unfortunately analysis beyond the semi-quantative calculations presented above would require a significant effort involving an attempt to estimate the volume of silt and sand beneath the park, an estimate of contaminant mass in each unit, and an improved estimate of back diffusion rates and resultant mass released by back diffusion per unit time. The compilation of all of these estimates would produce theoretical masses in the silt and sand units and the relative contributions of each. This analysis is beyond Parsons current scope, budget, and schedule.

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			grained materials into the more permeable strata did not necessarily result in significantly elevated contaminated concentrations in groundwater. The Final Vegetable Oil Pilot Test Report should provide full analysis of the available data to help determine the relative impact of the diffusion of contaminants out of fine grained on the quality of groundwater migrating away from the study area.	

RESPONSE TO WRITTEN COMMENTS ON THE TECHNICAL MEMORANDUM DATED MARCH 2006 VEGETABLE OIL INJECTION PILOT TEST NAVAL INDUSTRIAL ORDNANCE PLANT FRIDLEY, MINNESOTA

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Minnesota Pollution Control Agency Comments				
1.	5	NA	It is MPCA staff's understanding that the conclusions and recommendations of the Report will be the subject of a forthcoming NIROP partnering and/or technical subcommittee meeting and that at this meeting, the future direction of the application of this technology for the NIROP site will be determined. The MPCA staff recommends that this meeting be scheduled as soon as possible.	The Navy concurs with this recommendation and will schedule the referenced NIROP partnering meeting to discuss the future of this technology at the NIROP site.
2.	5	NA	The MPCA staff requests that the Navy explain how and when Mr. Hal Davis final United States Geological Survey capture evaluation report will be factored into the Report, including final conclusions and recommendations for the application of this technology at the NIROP site.	Future analytical data collected from the vegetable oil pilot test monitoring well network as well as conclusions and recommendations for future work drawn from future data and from studies that have not been published yet (e.g., the Final Capture Report) will be presented in the Annual Monitoring Report.
3.	5	NA	The MPCA staff requests that the Navy identify any findings contained in the report entitled "2005 Annual Monitoring Report Naval Industrial Ordnance Plant Fridley, Minnesota" dated April 2006, that impact the conclusions and recommendations of the Report and identify how any such findings will be incorporated in the report.	The 2005 AMR finding that TCE concentrations continued to decrease between September 2004 and November 2005 at the majority of wells installed in Anoka County Park will be referenced to support conclusions presented in the conclusion section of the technical memorandum and the revised conclusions section of the 2004 report. The finding that current extraction system "appears to be adequate to provide containment of most of the contamination migrating from the NIROP source areas, especially at shallow and intermediate depths" will be incorporated by reference to support conclusions presented in the conclusion section of the technical memorandum and the revised conclusions section of the 2004 report.
4.	Tech Memo VOCs	11, paragraph 2	This paragraph discusses contaminant mass. The last sentence states that "…the fine grained silt/clay units contain more contaminant mass than the more transmissive sand units and will likely serve as secondary sources of	The referenced statement in the text ("…the fine grained silt/clay units contain more contaminant mass than the more transmissive sand units and will likely serve as secondary

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	in Soil Section		contaminant mass for some time" The MPCA staff requests that the Navy explain whether or not this contaminant mass accounts for the TCE mass transported in groundwater. Was the mass of TCE in the groundwater estimated in the calculation cited in this section?	sources of contaminant mass for some time") is partially inaccurate. VOC concentrations are higher in the fine grained units than in the coarser grained units, indicating that the fine units may contain more VOC mass than the coarse units. However, this is not necessarily the case because the total VOC mass in each unit is dependant on the VOC concentrations as well as the total volume of each unit. If the volume of the fine grained units is considerably smaller than the volume of the coarse grained units than the total VOC mass present in the fine grained unit may be smaller. The text will be revised to clarify this distinction. It is currently unknown whether the VOC concentrations in the coarse grained units are present entirely as a result of back diffusion from the fine grained units. The total volume of the fine and coarse grained units would have to be accurately known to make this determination with any confidence. However, it is the authors opinion that it is unlikely that all of the VOC mass present in the coarse grained unit (s) is solely due to back diffusion. It seems more likely that the VOC mass present in the coarser grained units is sourced from back diffusion (from the fine grained units) and from contaminant mass being transported from upgradient areas.
5.	Tech Memo Site Hydro Section	14, paragraph 4.	This paragraph discusses viscosity. If the vegetable oil is completely hydrophobic, then it "lowers the relative permeability of the aquifer matrix" as stated. However, if it decreases the viscosity of the interstitial groundwater, then it inherently lowers the hydraulic conductivity as the dynamic viscosity is proportional to the intrinsic permeability if the porous media. The MPCA staff requests that the Navy identify whether or not the phase of the vegetable oil has been established in the aquifer matrix.	Vegetable oil is completely hydrophobic and as a result does not form a water-oil-mixture. Thus, the viscosity of the interstitial groundwater remains unchanged. Instead the vegetable oil LNAPL decreases soil hydraulic conductivity by physically constricting or blocking soil pore throats with vegetable oil ganglia. Vegetable oil will be present as LNAPL blobs and stringers, as a coating on soil particles, and sorbed on the subsurface soil matrix. The phase of the vegetable oil present in the NIROP subsurface soils has not been directly

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				determined (through for example microscope analysis).
6.	Tech Memo. VOCs in ground water section.	16, paragraph 4	This paragraph states that "VC [vinyl chloride] has not (sic) [been] detected at concentrations above the MDL [method detection limit] in any of the contingency wells….or the new downgradient monitoring well cluster PES-MW-12A/B, during the course of the pilot test." The concentration of TCE in PES-MW-12A increased from 80 to 350 micrograms per liter (µg/L) from April to November 2005. Over the same time period, the concentration of TCE at PES-MW-12B went from 330 to 290 µg/L. The latter is essentially stable. If TCE is not trending downward at these wells, the MPCA staff requests that the Navy explain how the Navy knows that the pilot remedy has effected groundwater at the new downgradient monitoring well cluster PES-MW-12A/B at all. The MPCA staff requests that the Navy continue to monitor for declines in TCE concentration and vinyl chloride at this well cluster.	The editorial comment (addition of the word "been") will be incorporated. There is no evidence to indicate that either PES-MW-12A or PES-MW-12B have been directly impacted by the injected vegetable oil. MW-12A and B are listed as unimpacted monitoring wells on Table 6 of the March 2006 technical memorandum and are shown as being unimpacted on Figures 9 and 10 (depictions of elevated TOC in groundwater). In addition, TOC in soil data collected from the screen interval of PES-MW-12B is used as an example of unimpacted, naturally occurring TOC in soil (Page 8, paragraph 4 of the March 2006 technical memorandum). The Navy concurs with MPCA's recommendation to continue to monitor monitoring well PES-MW-12A as this well is installed downgradient of the injection area and the well screen was installed in the same vertical interval than contains the injected vegetable oil. The March 2006 technical memorandum recommended that this well location continue to be sampled as part of the long term monitoring program for the vegetable oil pilot project. The Navy disagrees with the recommendation to collect samples from PES-MW-12B annually because there is no evidence of vegoil impact at this well location or in the "B" installation depth at any of the newly installed well clusters. A recommendation to collect a groundwater sample from PES-MW-12B during the sampling round conducted immediately prior to a 5-year ROD review will be added per response to comment EPA-2.
United States Environmental Protection Agency Comments				

Response to Written Comments on
the Technical Memorandum Dated March 2006
Vegetable Oil Injection Pilot Test
Naval Industrial Ordnance Plant Fridley, Minnesota
(Continued)

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1	General Comment: *(Responders note: The following text has been excerpted from the USEPA letter dated April 14th 2006)* Several EPA comments on the previous Tech Memo (dated August 2005, revised October 2005) requested that changes be made in the Final Vegetable Oil Pilot Test Report. The Navy has addressed those comments by revising the Tech Memo and Sections 5 and 6 of the Report for a Field Application to Enhanced In-Situ Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota, dated March 2004 (Vegetable Oil Pilot Test Report). The revisions appear to be appropriate. However, the revisions made to Sections 5 and 6 of the Vegetable Oil Pilot Test Report create inconsistencies with the remainder of that document. For example, the recommendations in the executive summary of the Vegetable Oil Pilot Test Report (including a recommendation for full-scale application of vegetable oil injection) are not consistent with the conclusions and recommendations in the revised version of Section 5. In addition, the Navy previously responded to two sets of comments generated by EPA and Minnesota Pollution Control Agency (MPCA) (responses received August 6, 2004 and October 4, 2004). In these responses the Navy agreed to make numerous revisions in the Final Vegetable Oil Pilot Test Report. While the Tech Memo addresses some of the comments, numerous other comments relating to other sections of the Vegetable Oil Pilot Test Report have not been addressed. There is no comprehensive document that presents and evaluates the data collected during and since implementation of the pilot test. It is recommended that a Final Vegetable Oil Test Report should be produced. This Final Report should incorporate all previously agreed-upon revisions and all data and additional evaluations performed since the pilot test. General Response: The Navy feels that the combination of the draft 2004 report and the final technical memorandum adequately presents all of the data collected during the course of the pilot test and the conclusions and recommendations that were drawn from this data set. Therefore, the Navy will revise the final technical memorandum, update section 5 of the draft report, and release both as the final deliverable for this project. Future monitoring results collected from the vegetable oil pilot test monitoring well network will be presented in the Annual Monitoring Report.			
Specific EPA Comments				
1	VOCs in soil	11	A discussion of the diffusion of trichloroethene (TCE) out of low permeability units has been included in the March 2006 version of the Tech Memo. An analytical solution to Fick's Second Law of Diffusion is used to estimate the time required for TCE to diffuse out of low permeability deposits in Anoka County Park (ACP). The analytical solution is derived based on imposing a constant concentration boundary condition at x equals zero and a zero concentration at infinity. The initial condition assumes that no contaminant is initially present in the	The Fick's second law analysis was intended to provide a semi-quantitative estimate of the time required for the low-permeability silts and clays to be "flushed" free of contaminants by diffusion. Fick's second law is more accurately used to describe diffusion across a low-permeability layer with a constant, high-concentration source on one side. Parsons made the assumption that the rate of diffusion out of the low-permeability unit would be the same as the rate of diffusion into the unit. Therefore, the starting boundary conditions for the calculation were zero

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			solution domain. The analytical solution predicts the concentration profile throughout the solution domain in time in response to the diffusion of the contaminant from the constant source at x equals 0. It does not appear that this equation provides a useful analysis of the diffusion time out of the low permeability sediments in ACP. The Tech Memo states that "the calculation assumes that the concentration at point x is 0 so that the concentration gradient is maximized." However, this solution does not allow the concentration at x equals one foot, where the high permeability sediments are postulated to begin, to remain at zero or at some arbitrarily low contaminant concentration reflecting the dilution of diffusing contaminant into the high permeability deposits. If the analytical solution is run to develop a concentration profile from x equals 0 to x equals two feet (well into the high permeability deposits) for a series of times, it can be seen that the concentration profile extends well into the high permeability deposits. These computations will also show that the concentration gradient at the interface between the low and high permeability deposit (X = 1 ft.) steadily decreases with time. Thus, concentration gradients are clearly not maximized. Rather, this solution significantly underestimates the gradients at the interface between the low and high permeability deposits. The text indicates that using the analytical solution, the diffusion time is computed to be approximately 400 to 700 years. It is not clear how these times have been obtained or what exactly is meant by the "diffusion time." However, computations using the analytical solution indicate that the	concentration within the silty clay and 2,100 ug/L at the edge of the silty clay. Parsons calculated the time for the concentration at a distance of one foot (into the silty clay) to reach the approximate boundary concentration (i.e. the present-day concentration in the silty-clay) and than reversed the results per our first assumption. For several reasons, including those cited by both Parsons and EPA, we believe that this was a conservative approach. Parsons intent in including this discussion was to illustrate how slow diffusion based mechanics are. Parsons agrees with the EPA that the audience of this technical memorandum understands this point. Therefore, Parsons agrees with the EPA that this discussion is not necessary and will remove the Fick's second law presentation as suggested. The following text will be substitute in its place: "The removal of TCE mass from the silty clay units beneath the NIROP site will be an extremely slow process because removal rate will be limited by the rate of diffusion, which is typically several orders of magnitude slower than advective-dispersive processes. Thus, the application of a remedial option in the more permeable unit(s) will not accelerate site cleanup time significantly because the time to achieve MCLs on this site is dependant on the rate at which contaminant mass diffuses out of the fine grained units, not on the rate at which the remedial option of choice destroys contaminant mass."

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			ratio of the concentration at x equal 1 to the constant concentration at x equal zero (C/Co) reaches 0.86 in only 5 years and reaches 0.90 in 10 years. More importantly, if one examines the contaminant mass that has diffused out of the low permeability deposits as represented by the contaminant profile extending beyond x equals 1 foot, it is clear that in 10 years many times more contaminant mass has diffused from low permeability deposits than originally could have existed in these deposits if the entire thickness of the deposit was contaminated to a level equivalent to Co. Parsons should strongly consider removing this analysis from the Tech Memo. It is not considered essential to the conclusions of the document. It is acknowledged that the diffusion is a slow process and rapid removal of the contaminants from the low permeability deposits may not be a realistic remedial objective in ACP.	
2	Summary	22	This section recommends specific wells to include in future annual monitoring events. The list appears to be appropriate. However, it may be useful to have a more comprehensive set of water level and analytical data available for years when a five-year report is to be prepared. It is recommended that additional wells associated with the vegetable oil pilot test be monitored for the purposes of five-year reviews.	Concur, A second recommendations table (Table 14) will be added to present recommendations for additional sampling to be conducted prior to a 5-year CERCLA 121c review.
3	Summary	23	Second to last sentence, last full paragraph, shouldn't "than the tenants..." be changed to "then the tenants…"?	Concur, correction will be made as requested.
4	Appendix C	All	The title above the response table indicates the comments were generated based on a review of the "Draft Report for a Field Application to Enhanced in-Situ	Concur, correction will be made as requested.

Response to Written Comments on
the Technical Memorandum Dated March 2006
Vegetable Oil Injection Pilot Test
Naval Industrial Ordnance Plant Fridley, Minnesota
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			Bioremediation of Chlorinated Solvents via Vegetable Oil Injection at Naval Industrial Reserve Ordnance Plant." In fact, the comments were generated based on review of the Technical Memorandum on Preliminary Results for the Anoka County Park Organic Substrate Addition Pilot Test at the Naval Industrial Reserve Ordnance Plant, Fridley, Minnesota dated August 2005 and revised October 2005. The title in Appendix C should be revised to identify and correct review document.	