

FINAL
TECHNICAL MEMORANDUM
In Situ Anaerobic Biotic/Abiotic Treatability Study
Installation Restoration Site 28
Former Naval Air Station Moffett Field
Moffett Field, California

EMAC
Contract Number: N62473-08-D-8822
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Submitted to:



Base Realignment and Closure
Program Management Office West Naval Facilities Engineering Command
1455 Frazee Road, Suite 900
San Diego, California 92108

Submitted by:



4005 Port Chicago Highway
Concord, California 94520-1120

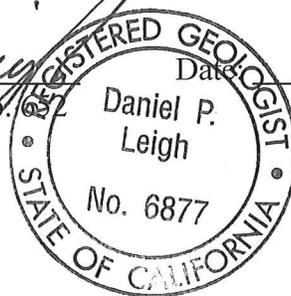
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Dan Leigh, California CHG No. 6877
Technical Lead



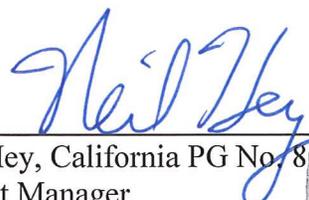
Approved by:  _____ Date: March 26, 2012
Neil Hey, California PG No. 8006
Project Manager



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Acronyms and Abbreviations

µg/L	microgram per liter
<	less than
>	greater than
°C	degree Celsius
ARC	Ames Research Center
β-elimination	beta-elimination
bgs	below ground surface
CE	chlorinated ethene
COC	chemical of concern
DCE	dichloroethene
DHC	<i>Dehalococcoides sp</i>
DNA	deoxyribonucleic acid
DNAPL	dense nonaqueous phase liquid
DO	dissolved oxygen
DPT	direct push technology
ECD	electron capture detector
Eh	reduction potential
EPA	U.S. Environmental Protection Agency
EVO	emulsified vegetable oil
Final Progress Report	<i>Final Progress Report, In Situ Anaerobic Biotic/Abiotic Treatability Study, IR Site 28, Former Naval Air Station Moffett Field, Moffett Field, California</i>
Final Work Plan	<i>Final Work Plan, In Situ Anaerobic Biotic/Abiotic Treatability Study, IR Site 28, Former Naval Air Station Moffett Field, Moffett Field, California</i>
FNU	formazin nephelometric unit
gpm	gallon per minute
IR	Installation Restoration
MCL	maximum contaminant level
mg/L	milligram per liter
MIP	membrane interface probe
Moffett Field	former Naval Air Station Moffett Field
mV	millivolt
NAPL	nonaqueous phase liquid
NASA	National Aeronautics and Space Administration
Navy	U.S. Department of the Navy
ORP	oxidation-reduction potential
PCE	tetrachloroethene
PQO	project quality objective
RL	reporting limit
ROD	<i>Record of Decision for the Farichild, Intel, and Raytheon Sites, Middlefield/Ellis/Whisman (MEW) Study Area, Mountain View, California</i>

Acronyms and Abbreviations (continued)

SAP	Sampling and Analysis Plan
SC	specific conductance
SCVWD	Santa Clara Valley Water District
SU	standard unit
TCE	trichloroethene
TOC	total organic carbon
TS	treatability study
TtECI	Tetra Tech EC, Inc.
VC	vinyl chloride
VFA	volatile fatty acid
VOC	volatile organic compound
WATS	West-Side Aquifers Treatment System
WS	worksheet
ZVI	zero-valent iron

1.0 Introduction

This technical memorandum describes the activities performed and results of a treatability study (TS) for in situ anaerobic biotic and combined abiotic/biotic treatment of chlorinated ethenes (CEs) in the A-aquifer at Installation Restoration (IR) Site 28, former Naval Air Station Moffett Field (Moffett Field), California (Figure 1). This technical memorandum has been prepared by Shaw Environmental, Inc. (herein referred to as Shaw) on behalf of the U.S. Department of the Navy (Navy) under Environmental Multiple Award Contract No. N62473-08-D-8822, Contract Task Order 0004. The activities described in this technical memorandum were performed in accordance with the *Final Work Plan, In Situ Anaerobic Biotic/Abiotic Treatability Study, IR Site 28, Former Naval Air Station Moffett Field, Moffett Field, California* (Final Work Plan; Shaw, 2010a) and the *Final Progress Report, In Situ Anaerobic Biotic/Abiotic Treatability Study, IR Site 28, Former Naval Air Station Moffett Field, Moffett Field, California* (Final Progress Report; Shaw, 2010b).

1.1 Background

IR Site 28 is the aquifers below the area generally bounded by Hangar 1 to the east, McCord Avenue to the west, King Road to the north, and a line approximately 300 feet south of Wescoat Road to the south, as shown on Figure 1. The A-aquifer, the focus of this TS, is impacted by volatile organic compounds (VOCs), primarily CEs including tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (DCE), and vinyl chloride (VC). The contamination at IR Site 28 resulted from on-flow of contamination from upgradient TCE sources at the Fairchild, Intel, and Raytheon sites collectively known as the Middlefield-Ellis-Whisman Superfund Site and on-site Navy PCE sources. Historical dry cleaning activities conducted at former Building 88 were determined to be the source of PCE along with the associated sanitary sewer line (Tetra Tech EC, Inc. [TtECI], 2008).

In 1993, the Navy agreed to adopt the *Record of Decision for the Fairchild, Intel, and Raytheon Sites, Middlefield/Ellis/Whisman Study Area, Mountain View, California* (ROD; U.S. Environmental Protection Agency [EPA], 1989) and to remediate contamination attributable to Navy sources (Navy, 1993). To comply with the ROD requirements, in 1994 the Navy removed Building 88, excavated contaminated soil, and installed a groundwater source control measure referred to as the Building 6 Treatment System. The Building 6 Treatment System was operated until 1997 when it was replaced with a plume-wide groundwater control system referred to as the West-Side Aquifers Treatment System (WATS). Operation of the WATS has been ongoing since November 1998 (SES-TECH, 2008).

In 2005, the Navy implemented an investigation to evaluate whether the residual PCE in the vadose zone at the former Building 88 location is a continuing source of contamination for groundwater, the extent of saturated soil with PCE concentrations that could be a source of groundwater contamination, and PCE source area treatability. It was concluded in the *Final Former Building 88 Investigation Report, Former Naval Air Station Moffett Field, Moffett Field, California* (TtECI, 2008) that residual contamination in two areas, the “Former Building 88 Area” and “Traffic Island Area,” act as ongoing PCE sources to groundwater contamination in the upper and lower portions of the A-aquifer (ranging from approximately 0 to 35 feet below ground surface [bgs] and 35 to 65 feet bgs, respectively). The investigation report recommended further source removal to meet the requirements of the ROD (EPA, 1989) and to expedite the cleanup of contaminated groundwater. Further characterization of the PCE soil and/or groundwater contamination was also recommended. Consequently, in August 2009, the Navy contracted Shaw to further characterize these areas of interest, including the area surrounding well W9-18, and to field test in situ treatment technologies for remediating the high concentrations of CEs in these areas. The areas of interest are shown on Figure 2.

1.2 Purpose and Project Objectives

The purpose of the TS was to determine if in situ anaerobic biotic/abiotic treatment and biostimulation with bioaugmentation are viable alternatives for remediating the remaining CEs present in the upper and lower portions of the A-aquifer at IR Site 28.

The primary objectives of the study were to:

- Conduct additional site investigation using a Membrane Interface Probe (MIP), a nonaqueous phase liquid (NAPL) FLUTE™ system, and soil cores to further characterize the areas of interest so that the treatment tests are focused in the areas of highest CE concentrations and to identify a new location for extraction well EA1-1
- Generate site-specific data and evaluate the effectiveness of biotic/abiotic treatment and biostimulation with bioaugmentation treatment at reducing the CE concentrations in the areas of interest to concentrations below the ROD cleanup standard (EPA, 1989 and 1990) and maximum contaminant levels (MCL)
- Verify the applicability of the treatment technologies to remediate CEs to levels below the ROD cleanup standard and MCLs both cost-effectively and within a reasonable period of time

Decision criteria for achieving these objectives were developed in the project quality objectives (PQOs) process. The PQOs are presented in Worksheet (WS) #11 of the Sampling and Analysis Plan (SAP; Appendix A, Final Work Plan [Shaw, 2010a]).

1.3 *Technical Approach*

The TS consisted of a staged approach for achieving the purpose and objectives defined in Section 1.2. The approach included two stages: a hot spot characterization stage followed by a CE treatment test stage. Each stage was conducted at the three areas of interest: the Former Building 88 Area, the Traffic Island Area, and the Well W9-18 Area (Figure 2). The areas of interest were characterized to further define the lateral and vertical extent of the highest CE contamination and to confirm the presence or absence of dense nonaqueous phase liquid (DNAPL) PCE, or TCE. The resulting data was used to refine the design of the treatment pilot tests to focus on the locations of highest CE concentrations. The activities and results of the hot spot characterization stage were presented in the Final Progress Report (Shaw, 2010b) and therefore are not presented in this document.

The pilot tests were performed to evaluate the effectiveness of two remedial technologies, biotic/abiotic treatment and biostimulation with bioaugmentation treatment, to remediate dissolved CEs to concentrations below the ROD (EPA, 1989) cleanup standard and MCLs. Three pilot tests—one at each of the three areas of interest—were conducted simultaneously. The final location and configuration of each of the pilot tests were based on the results of the hot spot characterization effort (Shaw, 2010b). The technologies tested included one biotic/abiotic treatment process and two biostimulation with bioaugmentation treatment processes. The biotic/abiotic treatment process was conducted in a pilot test using EHC[®], a proprietary blend of organic substrate and zero valent iron (ZVI). The biostimulation with bioaugmentation treatment process was conducted in two separate pilot tests using different organic substrates, emulsified vegetable oil (EVO) and sodium lactate, and incorporating bioaugmentation. The pilot tests were performed by injecting the substrates into the aquifer to stimulate biological and chemical reduction of the CEs.

Several events of groundwater monitoring and sampling were performed before and after the substrates were injected to assess the progress of the treatment and the feasibility of the treatment technologies for further application. Related activities included observation well installation, laboratory analysis, and data reduction and evaluation.

1.4 *Technical Memorandum Organization*

This technical memorandum is organized as follows:

- **Section 1.0, Introduction:** Presents the project purpose, objectives, a brief background, technical approach, and document organization
- **Section 2.0, Abiotic and Biotic Degradation Pathways of Chlorinated Ethenes:** Provides a description of the abiotic and biological processes tested and observed during the TS

- **Section 3.0, General Site Activities:** Provides a brief description of the general site activities completed in support of the pilot tests including permitting and notifications, utility clearance, observation well installation, storm sewer line isolation, and as-built survey
- **Section 4.0, Pilot Test Implementation:** Provides a description of the activities performed to implement the pilot scale treatment tests including baseline groundwater sampling, substrate injections, and performance monitoring
- **Section 5.0, Performance Monitoring Parameters:** Describes the field and laboratory parameters analyzed and used to evaluate the biotic and abiotic degradation processes of CEs in the study areas
- **Section 6.0, Performance Monitoring Results:** Presents the results of the baseline and post injection groundwater monitoring events for each pilot test
- **Section 7.0, Status of the Project Quality Objectives:** Presents conclusions to the study questions and decision criteria
- **Section 8.0, Waste Handling and Disposal:** Describes the handling and disposal of the TS derived waste
- **Section 9.0, Treatability Study Conclusions:** Presents conclusions for each of the pilot tests
- **Section 10.0, Summary of Conclusions:** Summarizes the findings and conclusions of the TS
- **Section 11.0, Recommendations:** Presents recommendations based on the results and conclusions of the the TS
- **Section 12.0, References:** Provides a list of all the cited documents within the text, figures, and tables

Figures and tables are presented after Section 11.0. The following appendices are included after the figures and tables:

- **Appendix A, National Aeronautics and Space Administration Construction Permit:** Includes a copy of the National Aeronautics and Space Administration (NASA) construction permit secured for the TS
- **Appendix B, California Department of Water Resources Well Completion Reports, Well Boring/Construction Logs, and Santa Clara Valley Water District Well Construction Permits:** Includes a copy of the permits and logs for the observation wells installed during the TS
- **Appendix C, Santa Clara Valley Water District Injection Borings Permit:** Includes a copy of the permits obtained to perform the substrate injections deeper than 40 feet bgs

- **Appendix D, Well Development Logs:** Includes a copy of the development logs for the observation wells installed during the TS
- **Appendix E, As Built Survey Report:** Includes a copy of the as-built land survey report for the MIP test borings, continuous soil cores, and the new observation wells
- **Appendix F, Sample Collection Logs:** Includes copies of the groundwater sample collection logs for the baseline and performance monitoring events
- **Appendix G, Injection Field Logs:** Includes copies of the field logs for each injection point
- **Appendix H, Laboratory Analytical Reports and Chain-of-Custody Records:** Includes copies of the chain of custody records and laboratory analytical reports for the baseline and performance monitoring events
- **Appendix I, Data Quality Assessment:** Presents the findings of the data review and validation assessment of the groundwater samples from the baseline and performance monitoring events
- **Appendix J, Waste Manifests:** Includes copies of the waste manifests for the TS derived soil and solid waste streams

2.0 *Abiotic and Biotic Degradation Pathways of Chlorinated Ethenes*

Reductive dechlorination of CEs in groundwater and soil has been implemented at numerous U.S. Department of Defense and private sites, and has involved both abiotic and biotic agents and processes (Clarke et al., 2006). The abiotic process involves the introduction of a reducing agent into the subsurface, such as ZVI, and does not involve microorganisms, whereas the biotic process relies on microorganisms and uses organic carbon injected into the subsurface to stimulate degradation by native bacteria. The following subsections describe the abiotic and biotic degradation pathways of CEs.

2.1 *Abiotic Degradation Pathway*

CEs can be degraded to nontoxic end products abiotically. The abiotic pathway results in the complete conversion of CEs via several mechanisms including hydrogenolysis and beta-elimination (β -elimination). The abiotic hydrogenolysis and β -elimination pathways are shown on Figure 3.

Hydrogenolysis of CEs can first produce minor amounts of further reduced CEs including DCE isomers (cis- and trans-1,2-DCE and 1,1-DCE) and VC. Then, in the final steps of the mechanism, these isomers are subsequently degraded to nontoxic ethene and ethane and ultimately mineralized producing carbon dioxide and water.

The β -elimination pathway does not generate the daughter products typical of reductive dechlorination or hydrogenolysis pathways. The β -elimination pathway converts CEs to chloroacetylene, which is further dechlorinated to acetylene by hydrogenolysis. Acetylene degrades to ethene and ethane via hydrogenation. Both β -elimination and hydrogenolysis pathways instigated by reaction with ZVI result in the production of iron(II) (Fe^{2+}) and chloride ions (Cl^-). Iron(II) (Fe^{2+}) is typically removed from solution in aquifers as ferrous sulfide (FeS).

2.2 *Biotic Degradation Pathway*

CEs have also been demonstrated to degrade to nontoxic end products biologically. During this process, indigenous organisms ferment an electron donor such as organic carbon (i.e., the organic component of EHC[®], EVO, or lactate) and release volatile fatty acids (VFAs) (acetic, propionic, butyric) and molecular hydrogen (H_2), that diffuse from the site of fermentation into the groundwater plume and serve as electron donors for other bacteria. Indigenous heterotrophic bacteria utilize the VFAs and hydrogen (H_2) and consume the common electron acceptors present in aquifers: dissolved oxygen (DO), nitrate (NO_3^-), arsenic(V) (As^{5+}), manganese(IV) (Mn^{4+}), iron(III) (Fe^{3+}), sulfate (SO_4^{2-}), and carbon dioxide (CO_2), in a biologically-mediated oxidation-reduction reaction called respiration to generate energy for their life process. The

process involves the transfer of electrons from a relatively reduced electron donor to a relatively oxidized electron acceptor. In this process the electron donor is oxidized and the electron acceptor is reduced. When oxygen is utilized as the electron acceptor the process is called aerobic respiration. When the other electron acceptors are utilized the process is called anaerobic respiration. Reduction of the electron acceptors results in increased concentrations of carbon dioxide (CO₂), nitrite (NO₂⁻), arsenic(III) (As³⁺), manganese(II) (Mn²⁺), iron(II) (Fe²⁺), sulfide (S²⁻), and methane (CH₄), respectively, as reducing conditions progressively intensify. The sequence in which the electron acceptors are utilized and the relative reduction potential (Eh) of these reactions are presented on Figure 4.

In addition to the reduction of inorganic electron acceptors, dechlorinating and halorespiring bacteria also gain energy from the reductive dechlorination of CEs in a process called chlororespiration (Figure 3). This degradation process is similar to the abiotic hydrogenolysis process described above. During chlororespiration, dehalogenating and halorespiring microorganisms use the molecular hydrogen (H₂) generated by the fermentation of the VFAs to replace the chlorine atom on the CE molecule thereby sequentially dechlorinating the CEs eventually to nontoxic daughter products such as ethene and ethane, which are ultimately mineralized to carbon dioxide (CO₂), water (H₂O), and chloride ions (Cl⁻). Because the microorganisms use the CEs to sustain themselves, these organisms prefer to grow in areas where high concentrations of CEs are present.

3.0 *General Site Activities*

This section briefly describes the general site activities completed in support of the pilot tests. These include permitting and notifications, utility clearance, observation well installation, storm sewer line isolation, and an as-built survey.

3.1 *Permits and Notifications*

The following permits were obtained and notifications completed in support of the pilot test:

- A construction permit was obtained from the Moffett Field Permit Board of NASA Ames Research Center (ARC). The permit was designated 10Q027 and was approved March 25, 2010. Amendments to the permit were submitted to NASA ARC on June 18, 2010 and were approved between June 21 and June 25, 2010 (see Appendix A).
- Well construction permits were obtained from the Santa Clara Valley Water District (SCVWD). These permits were designated 10W00262 through 10W00285 and were issued on June 2 and 3, 2010 (see Appendix B). Grout inspections were performed by the SCVWD Well Inspection Department for all wells installed.
- An exploratory boring permit was obtained from the SCVWD to perform the substrate injections. This permit was designated 10E00103 and was issued on July 13, 2010 (see Appendix C). Grout inspections were performed by the SCVWD Well Inspection Department for all injection borings that extended deeper than 45 feet bgs.
- Underground Service Alert was notified at least 48 hours prior to the initiation of drilling activities and maintained throughout all subsurface intrusive activities

All site activities were coordinated with the Navy Resident Officer in Charge of Construction office.

3.2 *Utility Clearance*

Shaw reviewed the NASA ARC Geographic Information Systems drawing titled “Utilities South of Hangar 1,” generated March 16, 2010, prior to finalizing proposed boring locations in the field. The areas of the injection and well borings were then outlined in white paint and Underground Service Alert was notified at least 48 hours prior to the initiation of drilling activities. In addition to notifying Underground Service Alert, the location of underground utilities in vicinity of the planned monitoring well and injection borings was confirmed by Subtronic Corporation, a private underground utility locating service. Prior to the utility clearance survey, existing site utility maps were reviewed and all planned boring locations were marked on the ground using waterproof spray paint. The utility locating subcontractor marked out all suspected underground utility conduits and structures with color-coded marking paint

according to standards established by the American Public Works Association and noted each cleared boring location by marking the ground with paint immediately after clearing it. Upon completion of the utility marking activities, Shaw and Subtronic Corporation reviewed each of the proposed boring locations and adjusted the locations as necessary to damaging the underground utilities.

In addition to the utility clearance survey, prior to drilling or driving any tools into the subsurface, each borehole was cleared using a hand auger to a minimum depth of 5 feet bgs. Borings located along known sanitary sewer and storm drain utilities in the Traffic Island Area were hand-augered to a depth of 8 feet bgs, the depth of burial of those utilities as documented by available information. The diameter of the area cleared by hand-augering was greater than or equal to the maximum outside diameter of the drilling tools used to advance each boring.

3.3 Observation Well Installation

Prior to substrate injection, twenty-four new groundwater observation wells (28OW-01 through 28OW-24) were installed to monitor changes in groundwater quality conditions in and around the treatment areas. To monitor multiple depths within the treatment interval at different locations, the wells were installed in clusters upgradient, inside, and downgradient of the pilot test areas.

The wells were installed between June 14 and 24, 2010 by Woodward Drilling Company, Inc., a C-57 licensed subcontractor, under the supervision of a State of California-licensed Professional Geologist. The wells were constructed using 8-inch outside diameter hollow stem auger drilling techniques in accordance with Santa Clara Valley Water District requirements and California Department of Water Resources regulations (1981 and 1991). The wells were constructed of nominal 2-inch diameter polyvinyl chloride with 5-foot or 10-foot long screen intervals, as specified in the Final Work Plan (Shaw, 2010a) and Final Progress Report (Shaw, 2010b). Because the wells were installed in clusters, the soil lithology was only logged for the deepest borehole of each cluster. The well boring and completion logs are provided in Appendix B.

Following installation, each new well was developed no sooner than 48 hours after construction of the grout seal. The wells were developed by a process of surging, bailing, and purging. Development continued until a minimum of three well volumes were removed, the well water appears clear to the unaided eye, the well water was free of excessive turbidity (ideally less than or equal to five nephelometric turbidity units), and the indicator water quality parameters (pH, temperature, and electrical conductivity) had stabilized. Groundwater was considered stabilized when three consecutive readings of pH, temperature, and electrical conductivity changed less than 0.1 standard units (SU) for pH, 1 degree Celsius (°C), and 10 percent milliSiemens per centimeter, respectively. The well development logs are provided in Appendix D.

3.3.1 *Emulsified Vegetable Oil Pilot Test (Traffic Island Area)*

Three well clusters were installed in the Traffic Island Area. The wells were installed upgradient, within, and downgradient of the injection area in an alignment that generally corresponds with the regional groundwater flow direction, as shown on Figure 5 and Figure 6. Due to the highly stratified and heterogeneous nature of the sediments in the Traffic Island Area, the treatment intervals are monitored based on depth rather than distinct sedimentary units (i.e., fine-grained or coarse-grained). Four depths are monitored across the treatment area as follows:

- 12 to 17 feet bgs by wells 28OW-01, 28OW-05, and 28OW-09
- 24 to 29 feet bgs by wells 28OW-02, 28OW-06, and 28OW-10
- 40 to 50 feet bgs by wells 28OW-03, 28OW-07, and 28OW-11
- 55 to 65 feet bgs by wells 28OW-04, 28OW-08, and 28OW-12

Figure 7 illustrates the subsurface stratigraphy in and around the treatment zone based on the MIP investigation and shows the screen intervals for the observation wells. Because of accessibility issues, the upgradient wells that monitor the upper treatment interval (28OW-09, 28OW-10, and 28OW-11) were installed approximately 60 feet south of the treatment area (Figure 5). The upgradient well that was to monitor the lower treatment interval (28OW-12) was installed within the traffic island as planned (Shaw, 2010b) but because of a field modification to the injection layout and depth (see Section 4.2.1) the well is within the treatment zone (Figure 7); and consequently there was no upgradient well to monitor the lower interval.

3.3.2 *Lactate Pilot Test (Former Building 88 Area)*

Three well clusters, each including an upper and lower observation well, were installed in the Former Building 88 Area. The well clusters were installed upgradient, within, and downgradient of the injection area in an alignment that corresponds to the general regional groundwater flow direction, as shown on Figure 8.

Figure 9 illustrates the subsurface stratigraphy in and around the treatment zone based on the MIP investigation and shows the screen intervals for the observation wells. To evaluate the effectiveness of the treatment technology in medium-grained (relatively low permeability) sediments, the upper set of observation wells (28OW-19, 28OW-21, and 28OW-23) were installed to a total depth of 40 feet bgs and screened entirely in a medium-grained interval. These wells have 5-foot long screens extending from 35 to 40 feet bgs. To evaluate the effectiveness of the treatment technology in coarse-grained (relatively high permeability) sediments, the lower set of observation wells (28OW-20, 28OW-22, and 28OW-24) were installed to a total depth of 62 feet bgs and screened across the two coarse-grained intervals within the treatment zone. These wells have 10-foot long screens extending from 52 to 62 feet bgs.

3.3.3 EHC® Pilot Test (Well W9-18 Area)

Three well clusters, each including an upper and lower observation well, were installed in the Well W9-18 Area. The well clusters were installed upgradient, within, and downgradient of the injection area in an alignment that generally corresponds with the regional groundwater flow direction, as shown on Figure 10.

Figure 11 illustrates the subsurface stratigraphy in and around the treatment zone based on the MIP investigation and shows the screen intervals for the observation wells. To evaluate the effectiveness of the treatment technology in medium-grained (relatively low permeability) sediments, the upper set of observation wells (28OW-13, 28OW-15, and 28OW-17) were installed to a total depth of 18 feet bgs and screened entirely in a medium-grained interval. These wells have 5-foot long screens extending from 13 to 18 feet bgs. To evaluate the effectiveness of the treatment technology in coarse-grained (relatively high permeability) sediments, the lower set of observation wells (28OW-14, 28OW-16, and 28OW-18) were installed to a total depth of 32 feet bgs and screened across the two deepest coarse-grained intervals within the treatment zone. These wells have 10-foot long screens extending from 22 to 32 feet bgs.

3.4 Storm Drain Line Isolation

Prior to and during substrate injection the storm drain lines that pass through or nearby the pilot test areas were isolated with inflatable packers to contain any water that infiltrated the lines during injection or from a catastrophic aboveground release of substrate solution from the bulk mixing tanks. The 12-inch concrete storm drain line southwest (upstream) of manhole SD442, along Wescoat Road, was isolated by a packer at its inlet to SD442 (Figure 2). The 24-inch concrete storm drain line between manholes SD442 and SD443, along Cummins Avenue, was isolated by packers at both its outlet from SD442 and inlet to SD443. In addition, a packer was installed in the outlet of manhole SD443, as a backup to all the upstream packers and to allow SD443 to serve as a point for collecting all the liquids accumulated in the isolated lines, after the injection effort.

Once the injection effort was completed and the water table had returned to its pre-injection level, the water that accumulated in the isolated lines, from groundwater infiltration and surface water runoff, was collected by a vacuum truck and transported to the WATS for treatment and discharge under a National Pollutant Discharge Elimination System permit. On September 2 and 3, 2010 approximately 7,940 gallons of water was recovered from the isolated storm drain lines and transported to WATS. Once all the water was collected, the packers were removed from the storm drain lines.

3.5 As-Built Survey

The new monitoring wells and injection points were surveyed by Hunters Surveying, Inc. a State of California-certified land surveyor, after completion of the injections. The vertical elevation of each survey point was determined to the nearest 0.01 foot and referenced to the North American Vertical Datum of 1988. The horizontal location of each point was determined to the nearest 0.1 foot, and referenced to the California State Plane Coordinate System, Zone III (1983 North American Survey Datum), as published by the National Geodetic Survey. A copy of the survey report is provided in Appendix E.

4.0 Pilot Test Implementation

This section describes the activities performed to implement the pilot scale treatment tests. The activities include baseline groundwater sampling, substrate injections, and performance monitoring.

4.1 Baseline Groundwater Sampling

Baseline groundwater sampling was performed between July 6 and 12, 2010, prior to injecting the substrates, to define the pretreatment water quality conditions in and around the pilot test areas. Groundwater samples for laboratory analysis were collected from 3 existing wells (W9-18, W9-29, and W9-42) and the 24 new observation wells (28OW-01 through 28OW-24). The samples were collected following the low-flow purging and sampling techniques described in the SAP (Appendix A, Final Work Plan [Shaw, 2010a]) and were analyzed for the following parameters:

- VOCs
- Ferrous iron (using an on-site Hach colorimeter)
- Total organic carbon (TOC)
- Sulfate
- Nitrate
- Alkalinity
- Dissolved metals (manganese, arsenic, and iron)
- Dissolved gases (methane, ethane, ethene, and acetylene)

Six samples (four from the Traffic Island Area and two from the Former Building 88 Area) were also analyzed for VFAs and *Dehalococcoides sp* (DHC) deoxyribonucleic acid (DNA). In addition, general water quality parameters (pH, temperature, conductivity, turbidity, oxidation-reduction potential [ORP], and DO) and groundwater elevation data were measured in the field during sampling. The field measurements were recorded on the sample collection logs provided in Appendix F. Results for the site specific VOCs and other parameters are summarized in Tables 1 through 3 and discussed in Section 6.0 along with the post-injection sample results.

4.2 Emulsified Vegetable Oil Pilot Test (Traffic Island Area)

The following subsections describe implementation of the EVO pilot test. The conceptual design of this pilot test is presented in Section 6.5.1 of the Final Work Plan (Shaw, 2010a) and

modifications to the design are presented in Section 4.3 of the Final Progress Report (Shaw, 2010b).

4.2.1 Injection Layout

The conceptual design of the pilot test was based on the distribution of CEs as indicated by historical groundwater data. The design consisted of 21 injection points centered along the formerly collapsed section of sanitary sewer line on Cummins Avenue and groundwater sample location CPT-88-13, where the highest concentrations of PCE in groundwater were detected at the Traffic Island Area. The conceptual layout of the injection points is shown on Figures 6A and 6B of the Final Work Plan (Shaw, 2010a). Based on the vertical distribution of PCE in groundwater at location CPT-88-13 and local stratigraphy, a treatment interval of 10 to 50 feet bgs was proposed for eighteen of the locations and 10 to 65 feet bgs for three of the locations (Figure 8 of the Final Work Plan).

Based on the results of the Hot Spot characterization effort, the planned injection locations were re-arranged to focus the test on the upgradient area of highest CE concentrations as identified by the ECD data (Shaw, 2010b). The injection layout was revised to include 28MIP-09, 28MIP-11, 28MIP-12, and the original target location CPT-88-13 at the south end of the traffic island (Figures 9 and 10 of the Final Progress Report [Shaw, 2010b]). The revised layout included 20 injection points in the upper interval, with the five downgradient points extending deeper into the lower interval. The deeper injection points were located to act as a barrier to the upgradient contamination identified by the ECD data.

The injection layout was further modified during field implementation based on the baseline results of groundwater samples collected from the newly installed observation wells in the Traffic Island Area. The concentrations of VOCs detected in the samples from the deepest interval monitored, 50 to 65 feet bgs, were higher than expected. Specifically, the concentrations of PCE in the samples from the upgradient and downgradient wells (28OW-12 and 28OW-04, respectively) were an order of magnitude higher than the sample from the treatment area well (28OW-08). As a result of this data and verbal concurrence from the EPA and California Regional Water Quality Control Board – San Francisco Bay Region on August 6, 2010, the injection layout was further modified. The modification consisted of extending treatment to a total depth of 65 feet bgs at each injection point and reducing the injection array from twenty to fifteen points. Consequently, five points on the outer margin of the original injection array (28EVO-01, 28-EVO-05, 28-EVO-10, 28-EVO-11, and 28-EVO-20) were not completed during the TS. The injection locations and anticipated radius of distribution are shown in plan view on Figures 5 and 6. Injection at each of these locations extended from 10 to 65 feet bgs as modified in the field and shown on Figure 7 in cross-section view.

4.2.2 Emulsified Vegetable Oil Dosage

No changes to the EVO (LactOil™) dosage prescribed in the Final Work Plan (Shaw, 2010a) occurred during field implementation of the pilot test at the Traffic Island Area.

4.2.3 Emulsified Vegetable Oil and SDC-9™ Amendment Injection

A total of 28,086 gallons of EVO and SDC-9™ amendment were injected into the pilot test treatment area using DPT. The injection was performed between August 4 and August 16, 2010 by Vironex, Inc.

The EVO solution was delivered into the target horizon, 10 to 65 feet bgs, through a total of 15 points (Figures 5 and 6). At each point, the amendment was injected in twenty-two 2.5-foot intervals across the 55-foot target zone.

Prior to initiating injection of the EVO and SDC-9™ amendment, the EVO solution was prepared onsite in a large holding tank by mixing approximately 2,400 gallons of untreated groundwater from the WATS with each 250 gallon tote of LactOil™. The solution was circulated in the tank for several days allowing the indigenous organisms from the mix water to use the EVO substrate and establish highly reducing conditions before the bioaugmentation culture, SDC-9™, was added.

Immediately before injecting at each point, the SDC-9™ and EVO solution were blended in a smaller batch tank. Once mixed, the EVO and SDC-9™ amendment was delivered to the target horizon following the “bottom-up” injection procedure outlined in the Final Work Plan (Shaw, 2010a). The amendment was injected through a 2.5 feet long pressure activated injection tip and propelled by a positive displacement pump at flow rates ranging from 3 to 17.6 gpm and pressures ranging from 5 to 217 pounds per square inch gauge. The amendment volume and sustained flow rate and pressure for every injection interval at each location are summarized in the injection field logs provided in Appendix G.

It should be noted that due to an inaccurate in-line flow totalizer, the actual amount of amendment injected was tracked by measuring the EVO solution level in the large holding tank. Both the incorrect totalizer and corrected volumes are presented on the injection field logs.

Surfacing of the amendment was minimal and controlled by reducing the flow rate. No significant issues with plugging of the injection equipment or with the formation accepting the amendment were encountered.

Upon completing injection of the amendment at each point, the borehole was backfilled with a neat cement grout. The grout was emplaced through a tremie pipe from the bottom of the borehole (65 feet bgs) up to surface grade.

The direct capital cost for the EVO and SDC-9™ treatment application was approximately \$124,000. This equates to a unit cost of \$29 per cubic yard of aquifer amended with EVO and SDC-9™, assuming that approximately 4,300 cubic yards of aquifer was amended. This includes the cost of materials, labor, and equipment used to prepare and inject the slurry. This does not include indirect capital costs such as project administration, planning, design, procurement, permitting, construction management, utility locating, land surveying, performance monitoring, reporting, or technical meetings. The current unit price of the EVO (LacOil™) is approximately \$1.50 per pound.

4.3 Lactate Pilot Test (Former Building 88 Area)

The following subsections describe implementation of the lactate pilot test. The conceptual design of this pilot test is presented in Section 6.5.2 of the Final Work Plan (Shaw, 2010a) and modifications to the design are presented in Section 4.1 of the Final Progress Report (Shaw, 2010b).

4.3.1 Injection Layout

The conceptual design of the pilot test was originally based on the distribution of CEs as indicated by historical groundwater data. The design consisted of ten injection points surrounding sample location CPT-88-15, where the highest concentration of PCE in groundwater was detected at the Former Building 88 Area, as shown on Figure 6B of the Final Work Plan (Shaw, 2010a). Based on the vertical distribution of PCE in groundwater at location CPT-88-15, a treatment interval of 35 to 60 feet bgs was proposed for the test (Figure 7 of the Final Work Plan).

However, based on the results of the hot spot characterization effort, the planned injection locations were re-arranged to include the area of highest CE concentrations as identified by the MIP electron capture detector (ECD) data (Section 3.1.2 of the Final Progress Report [Shaw, 2010b]). The injection layout was revised to include 28MIP-29 and the original target location CPT-88-15, and was re-oriented in a north-northeast alignment to match the ECD isopleth trend, as shown on Figure 8. The revised layout included ten injection points arranged in an offset grid pattern on 13.5-foot centers. The injection spacing was slightly increased from the conceptual design (12.5-foot centers) because of the likelihood that the substrate would be distributed further by advective transport and molecular diffusion following injection.

No significant modifications to the layout were made during implementation of the test other than having to adjust the location of the injection points to avoid surface and subsurface hazards or obstructions such as utilities or a tree. The layout of the injection points are presented on Figure 8. Injection at each of the locations extended from 35 to 60 feet bgs as proposed in the Final Work Plan (Shaw, 2010a) and shown on Figure 9 in cross-section view.

4.3.2 Lactate Dosage

The mixture of the lactate solution was modified in the field as a result of preliminary site groundwater measurements and field bench testing that indicated the pH of the groundwater in the treatment zone may exceed 8.0 SU after injection of the WILCLEAR[®] sodium lactate solution. This is higher than the optimal pH range for biological reductive dechlorination (5.0 to 8.0 SUs). Therefore, the mixture was modified to create an injection solution with a pH of approximately 5.5 to 6.0 SUs. This was achieved by replacing 307 pounds of WILCLEAR[®] (containing 146 pounds of lactate) with 99 pounds of food grade 88 percent lactic acid (containing 86 pounds of lactate) to reduce the pH to levels more conducive to biological degradation of CEs. This modification resulted in an approximately 6 percent reduction of the mass of lactate injected (1,000 pounds versus 1,060 pounds). Considering that the original prescribed lactate dosage included a 4-fold safety factor (Shaw, 2010a), equal to a 300 percent surplus, the resulting modification to the solution was negligible and should not have had a significant impact on the degradation process.

The modification to the solution proved successful at maintaining the pH of the treatment zone groundwater within the optimal range for biological reductive dechlorination following injection, as observed during performance monitoring (see Section 6.2).

4.3.3 Lactate and SDC-9TM Amendment Injection

A total of 8,179 gallons of lactate and SDC-9TM amendment were injected into the pilot test treatment area using direct push technology (DPT). The injection was performed between July 28th and August 2nd, 2010 by Vironex, Inc.

The lactate solution was delivered into the target zone, 35 to 60 feet bgs, through a total of 10 points shown on Figure 8. At each point, the amendment was injected in ten 2.5-foot intervals across the 25-foot target zone.

The lactate solution was prepared onsite in a large holding tank by mixing approximately 8,400 gallons of untreated groundwater from the WATS with 220 gallons of WILCLEAR[®] sodium lactate and 9 gallons of lactic acid 88 percent, making 8,629 gallons of lactate solution, a week before injecting the lactate and SDC 9TM amendment. Prior to addition of the bioaugmentation culture, SDC-9TM, the solution was circulated in the large holding tank for several days allowing the indigenous organisms from the mix water to use the lactate substrate and establish highly reducing conditions in the tank.

Immediately prior to injection at each point, the SDC-9TM and lactate solution were blended in a smaller batch tank. Once mixed, the lactate and SDC-9TM amendment was delivered to the target zone following the “bottom-up” injection procedure outlined in the Final Work Plan (Shaw, 2010a). The amendment was injected through a 2.5 feet long pressure activated injection

tip and propelled by a positive displacement pump at flow rates ranging from 4 to 18 gallons per minute (gpm) and pressures ranging from 25 to 320 pounds per square inch gauge. The amendment volume and sustained flow rate and pressure for every injection interval at each location are summarized in the injection field logs provided in Appendix G.

It was observed that due to an inaccurate in-line flow totalizer, the actual amount of amendment injected at the first 8 points was approximately 17 percent less than planned. As a result, the surplus amendment (approximately 1,037 gallons) was injected into the last two, centrally located points (28LAC-04 and 28LAC-07). The remaining 450 gallons of amendment was transferred to the EVO solution mixing tank. Both the incorrect totalizer and corrected volumes are presented on the injection field logs (Appendix G).

Surfacing of the amendment was minimal and easily controlled by reducing the flow rate. No issues with plugging of the injection equipment or with the formation accepting the amendment were encountered.

Upon completing injection of the amendment at each point, the borehole was backfilled with a neat cement grout. The grout was emplaced through a tremie pipe from the bottom of the borehole (60 feet bgs) up to surface grade.

The direct capital cost for the lactate and SDC-9™ treatment application was approximately \$35,000. This equates to a unit cost of about \$27 per cubic yard of aquifer amended with lactate and SDC-9™, assuming that approximately 1,300 cubic yards of aquifer was amended. This includes the cost of materials, labor, and equipment used to prepare and inject the slurry. This does not include indirect capital costs such as project administration, planning, design, procurement, permitting, construction management, utility locating, land surveying, performance monitoring, reporting, or technical meetings. The current unit price of the lactate (Wilclear® 60 percent sodium lactate) is approximately \$1.30 per pound.

4.4 EHC® Pilot Test (Well W9-18 Area)

The following subsections describe implementation of the EHC® pilot test. The conceptual design of this pilot test is presented in Section 6.4 of the Final Work Plan (Shaw, 2010a) and modifications to the design are presented in Section 4.2 of the Final Progress Report (Shaw, 2010b).

4.4.1 Injection Layout

No significant changes to the layout were made during implementation of the test other than completing a step-out injection point (28EHC-04b) adjacent to point 28EHC-04, due to excessive surfacing of slurry when initiating injection at 28EHC-04. As described in the Final Work Plan (Shaw, 2010a), EHC® was injected at four locations centered near well W9-18. The

injection locations and anticipated radius of distribution are shown in plan view on Figure 10. Injection at each of these locations extended from 10 to 30 feet bgs as proposed in the Final Work Plan and shown on Figure 11 in cross-section view.

4.4.2 EHC[®] Dosage

The EHC[®] dose was modified in the field, based on results of the ongoing EHC[®] TS at IR Site 26 (Shaw, 2011). The results for the IR Site 26 TS available at the time the IR Site 28 TS was being implemented indicated the dosage of EHC[®] applied in the IR Site 26 TS may be insufficient to maintain highly reducing conditions conducive for complete degradation of the CEs. The EHC[®] dose specified in the Final Work Plan (Shaw, 2010a) for the IR Site 28 TS was the same dose applied in the IR Site 26 TS, as recommended by the EHC[®] vendor (Adventus Americas, Inc.). Based on the available results of the IR Site 26 TS and considering that the baseline total CE concentrations in the Well W9-18 test area were two orders of magnitude higher than in the IR Site 26 TS area, the prescribed EHC[®] dose was increased from 1,013 pounds to 2,026 pounds per injection point.

4.4.3 EHC[®] Slurry Injection

In total, approximately 8,000 pounds of EHC[®] were injected as slurry into the pilot test treatment area using DPT. The injection was performed between August 17th and August 24th, 2010 by Vironex, Inc.

The EHC[®] was delivered into the target horizon, 10 to 30 feet bgs, at 4 locations through a total of 5 points shown on Figure 10. At each location, slurry was injected in eight 2.5-foot intervals across the 20-foot target zone.

The slurry was mixed onsite in batches with potable water supplied from a nearby fire hydrant. Initially, for injection points 28EHC-02 and 28EHC-03, the slurry for the bottom two injection intervals was prepared using 5.5 sacks (275 pounds) of dry powder EHC[®] and 5 sacks (250 pounds) for each of the 6 upper intervals. To preempt equipment/tool plugging issues, the volume of water used to prepare the slurry was initially doubled, but then reduced over the course of these injections to mitigate surfacing of slurry. Surfacing primarily occurred while injecting in the four shallow, low permeability intervals, between 10 to 20 feet bgs. Surfacing of slurry was observed as far away as 25 feet from an injection point and was significant enough to cause the surrounding asphalt to noticeably heave and crack.

To address surfacing at the last two points (28EHC-04b and 28EHC-01) the amount of slurry injected into the top four intervals was reduced while the amount of slurry injected into the bottom four intervals was increased, maintaining the total mass of EHC[®] injected in each point at 2,026 pounds. This adjustment was made because the lower intervals were more permeable than

the upper intervals as shown in Figure 11. The slurry volume injected at each location and interval is summarized in the injection field logs provided in Appendix G.

The slurry was delivered following the “bottom-up” injection procedure outlined in the Final Work Plan (Shaw, 2010a), through a 2.5-foot long pressure activated injection tip and propelled by a positive displacement pump. The slurry was delivered at average flow rates ranging from 2.6 to 11.8 gpm at average injection pressures ranging from 40 to 255 pounds per square inch gauge. The average flow rate and pressure for every injection interval at each location are summarized in the injection field logs (Appendix G).

Upon completing injection of the slurry at each point, the borehole was backfilled with a neat cement grout. The grout was emplaced through a tremie pipe from the bottom of the borehole (30 feet bgs) up to surface grade.

The direct capital cost for the EHC[®] treatment application was approximately \$40,000. This equates to a unit cost of about \$93 per cubic yard of aquifer amended with EHC[®] slurry, assuming that approximately 430 cubic yards of aquifer was amended. This includes the cost of materials, labor, and equipment used to prepare and inject the slurry. This does not include indirect capital costs such as project administration, planning, design, procurement, permitting, construction management, utility locating, land surveying, performance monitoring, reporting, or technical meetings. The current unit price of EHC[®] is approximately \$2.50 per pound.

4.5 Performance Monitoring

Five post-injection performance monitoring events were completed in August and November 2010, and January, April, and June 2011. These events were performed to monitor and document changes of the groundwater quality in and around the pilot test area following injection of the substrates. Groundwater samples for laboratory analysis were collected from 3 existing wells (W9-18, W9-29, and W9-42) and the 24 new observation wells (28OW-01 through 28OW-24). The samples were collected following the low-flow purging and sampling techniques described in the SAP (Appendix A, Final Work Plan [Shaw, 2010a]) and were analyzed for the following parameters:

- VOCs
- Ferrous iron (using an on-site Hach colorimeter)
- TOC
- Sulfate
- Nitrate
- Alkalinity

- Dissolved metals—manganese, arsenic, and iron
- Dissolved gases—methane, ethane, ethene, and acetylene

Select samples from the Former Building 88 Area and Traffic Island Area were also analyzed for VFAs and DHC DNA. In addition, general water quality parameters (pH, temperature, conductivity, turbidity, ORP, and DO) and groundwater elevation data were measured in the field during sampling. The field measurements were recorded on the sample collection logs provided in Appendix F. Results for the site specific VOCs and other parameters are summarized in Tables 1 through 3 and discussed in Section 6.0 along with the baseline sample results. The sample pump intake was placed mid-screen or midway between the bottom of the screen and water table, if below the top of screen, to be consistent with the baseline event.

5.0 Performance Monitoring Parameters

This section describes the field and laboratory parameters used to evaluate the biotic and abiotic degradation processes for CEs in the study areas. The following wells were monitored during these events:

- Emulsified Vegetable Oil Pilot Test (Traffic Island Area; see Figures 5 and 6)
 - Downgradient: 28OW-01, 28OW-02, 28OW-03, 28OW-04
 - Treatment Area: 28OW-05, 28OW-06, 28OW-07, 28OW-08, 28OW-12
 - Upgradient: 28OW-09, 28OW-10, 28OW-11
 - Cross Gradient: W9-29, W9-42

- Lactate Pilot Test (Former Building 88 Area; see Figure 8)
 - Downgradient: 28OW-19, 28OW-20
 - Treatment Area: 28OW-21, 28OW-22
 - Upgradient: 28OW-23, 28OW-24

- EHC[®] Pilot Test (Well W9-18 Area; see Figure 10)
 - Downgradient: 28OW-13, 28OW-14
 - Treatment Area: 28OW-15, 28OW-16, W9-18
 - Upgradient: 28OW-17, 28OW-18

Groundwater samples collected from these wells were analyzed for the following parameters in accordance with the SAP (Appendix A, Final Work Plan [Shaw, 2010a]):

Physical parameters

- Hydrogen Ion Activity (pH)
- ORP
- Specific conductance (SC)
- Turbidity
- Temperature

Biogeochemical indicator parameters:

- DO
- Nitrate
- Arsenic
- Manganese
- Iron
- Sulfate
- Methane

Contaminants and degradation products:

- VOCs
- Ethene
- Ethane
- Acetylene

Organic substrate indicator parameters

- TOC
- Alkalinity
- VFAs (lactic, acetic, propionic, and butyric acids)

Dechlorinating microbial population:

- DHC DNA

The data were used to determine the effectiveness of each substrate for establishing progressively reducing conditions and confirmation of biotic and abiotic degradation of the CEs in each treatment area. The following subsections describe the purpose of each analysis.

5.1 Physical Parameters

During each sampling event, groundwater was analyzed in the field for various physical parameters including pH, ORP, SC, turbidity, and temperature. The following sections describe the purpose of those analyses.

5.1.1 *Hydrogen Ion Activity (pH)*

The addition of EHC[®] and organic substrates was anticipated to result in a slight decrease of the groundwater pH due to the release of VFAs from fermentation of the organic carbon in the substrate by indigenous microorganisms. Although a slight decrease in pH does not substantially affect the biotic degradation of the CEs, a large decrease in pH could have a significant effect on the biological reduction of the electron acceptors and CEs in the aquifer. The range of pH favorable for biological reductive dechlorination is between 5.0 and 8.0 SUs with an optimal pH of approximately 6.0 SU. Therefore, pH measurements are used to confirm that the pH remains within the range favorable for biological reductive dechlorination.

5.1.2 *Oxidation-Reduction Potential*

EHC[®] and organic carbon provide electron donors that are used to chemically and biologically reduce the ORP of the groundwater in the treatment area. Highly-reducing conditions (i.e., methanogenic conditions) are required for complete abiotic and biotic conversion of CEs to nontoxic ethene, including the complete conversion of VC to ethene, which occurs at an Eh of approximately -250 millivolts (mV; Figure 4).

The ORP of the aquifer is a field measurement that provides data on the magnitude of reducing conditions in the aquifer. The magnitude of the ORP is an indication of reducing or oxidizing (redox) conditions at the site but a range of values may apply to redox conditions at different sites. Therefore, the ORP values are measured to provide an indication of the Eh or oxidizing or reducing conditions and should be confirmed by biogeochemical changes in the aquifer, which are described in Section 5.2.

5.1.3 *Specific Conductance*

The SC of the groundwater is a measure of the groundwater's ability to conduct electricity and corresponds generally with the dissolved solids concentration of the groundwater. The dissolved solids concentration does not substantially affect the degradation process, but indicates the changes in aquifer geochemistry during the chemical and biological reduction processes. In addition, SC measurements are used to estimate areas where EHC[®] was distributed because the iron associated with the EHC[®] will increase the electrical conductivity of the aquifer as well as result in higher values of SC.

5.1.4 *Turbidity*

Turbidity is a measure of the total suspended solids in the groundwater. Turbidity is measured because the wells are new and the aquifer matrix was disturbed during well drilling which created relatively high turbidity within the immediate vicinity of the well. Adsorbed metals can be elevated in groundwater that exhibits elevated turbidity, which gives an inaccurate measure of dissolved metals. All of the groundwater samples analyzed for metals were filtered prior to

analysis to reduce the potential for adsorbed phase metals to be interpreted as dissolved phase metals.

5.1.5 *Temperature*

Groundwater temperatures between 15 and 35°C are considered optimal for biological activity. Biological processes can occur above and below this range; however the rates may be substantially slower. Because the process evaluated in the TS includes a biological component, higher temperatures are considered more favorable to the treatment process. Therefore, temperature measurements are used to confirm that the temperature is within the range favorable for biological reductive dechlorination. The range of groundwater temperatures measured at Moffett Field is not anticipated to significantly affect the abiotic degradation process.

5.2 *Biogeochemical Indicator Parameters*

Biogeochemical indicator parameters including DO, nitrate (NO_3^-), arsenic, manganese, iron, sulfate (SO_4^{2-}), and dissolved methane (CH_4) were analyzed during each sampling event of the TS. The purpose of analyzing for these parameters is to determine if conditions conducive to complete biotic or abiotic degradation have been established in the treatment area.

Microorganisms in the aquifer use these electron acceptors in the order in which they generate the most energy. When the electron acceptor that generates the most energy has been substantially reduced, then the microorganisms will reduce the electron acceptor that generates the next most amount of energy. The result is a progressive reduction of electron acceptors in the following order:

- DO
- nitrate (NO_3^-)
- arsenic(V) (As^{5+})
- manganese(IV) (Mn^{4+})
- iron(III) (Fe^{3+})
- sulfate (SO_4^{2-})
- carbon dioxide (CO_2)

The result of this reduction is the generation of carbon dioxide (CO_2), nitrite (NO_2^-), arsenic(III) (As^{3+}), manganese(II) (Mn^{2+}), sulfide (S^{2-}), and methane (CH_4), respectively. Methanogenic conditions are considered conducive to complete reductive dechlorination of CEs.

5.2.1 Dissolved Oxygen

During reductive dechlorination, indigenous microorganisms use substrate as an electron donor and various chemicals, including oxygen, as an electron acceptor in a process called respiration. During respiration, the electron donor is oxidized and the electron acceptor is reduced. During aerobic respiration, microorganisms use organic substrates resulting in the conversion of DO in groundwater to carbon dioxide (CO₂) and water (H₂O), and a decrease in the concentration of DO. The optimal range of DO during reductive dechlorination is less than 0.5 milligrams per liter (mg/L). Adding ZVI results in the abiotic reduction of DO to water (H₂O) and the oxidation of ZVI (Fe⁰) to iron(II) (Fe²⁺). The addition of organic substrates and ZVI are anticipated to result in the rapid depletion of DO in the aquifer.

5.2.2 Nitrate

Nitrate occurs naturally in most aquifers and is used as an electron acceptor by nitrate-reducing organisms in the biological-mediated oxidation of organic compounds. Nitrate is the most favorable electron acceptor after oxygen (Figure 4). A decrease in nitrate concentrations is considered confirmation that mildly reducing conditions have been established in the aquifer. Relatively high nitrogen concentrations may inhibit degradation of less oxidized electron acceptors such as arsenic, manganese, iron, sulfate, and carbon dioxide, and low concentrations of nitrate may not inhibit this reaction. Nitrogen derived from nitrate reduction is also an essential nutrient for protein synthesis in microorganisms. Therefore, the presence of nitrate in the aquifer is a source of this essential nutrient.

5.2.3 Arsenic

Arsenic is a metal that occurs naturally in many rocks common to California and soil derived from those rocks. Under aerobic or mildly reducing conditions, arsenic occurs in the relatively insoluble form of arsenic(V) (As⁵⁺). However, under moderately reducing conditions (Eh of ~+520 mV), arsenic(V) acts as an electron acceptor and is converted to arsenic(III) (As³⁺). Arsenic(III) is much more soluble than arsenic(V) and therefore, conversion of arsenic(V) to arsenic(III) increases the concentration of arsenic dissolved in groundwater. An increase in dissolved arsenic concentration would indicate that mildly reducing conditions have been established in the treatment zone.

Although the conversion of arsenic(V) to arsenic(III) results in an increase in the dissolved arsenic concentration, other factors act to reduce the dissolved arsenic concentration. Under progressively reducing conditions, iron(III) and sulfate are reduced to iron(II) and sulfide respectively. These tend to combine with the soluble arsenic(III) and subsequently are removed from solution as insoluble precipitates. The major inorganic factors that appear to maintain low concentrations are adsorption of arsenic by hydrous iron oxide or co-precipitation, or combination with sulfide (Hem, 1992). Therefore, establishment of oxidizing conditions or

sulfate reduction would be expected to result in a decrease in dissolved phase concentrations of arsenic. Following treatment and as ambient conditions return to the treatment area, arsenic(III) is anticipated to be oxidized to arsenic(V) and precipitate.

5.2.4 Manganese

Manganese is a naturally-occurring metal in most rocks, soil, and sediments and is one of the more abundant metallic elements. Under oxidizing conditions, manganese typically occurs as an insoluble oxidized form, manganese(IV) (Mn^{4+}). However, under slightly reducing conditions (Eh of $\sim +520$ mV), oxidized manganese is reduced and occurs in a soluble form, manganese(II) (Mn^{2+}), which is more easily detected in groundwater samples. During the abiotic/biotic degradation process, insoluble oxidized manganese(IV), if present, will be converted to soluble reduced manganese(II) as more reducing conditions are progressively established in the aquifer.

An increase in dissolved manganese concentration is therefore considered attributable to the establishment of slightly reducing conditions during the treatment process. Based on the oxidation-reduction reactions presented on Figure 4, manganese(IV) is anticipated to be reduced to manganese(II) after arsenic reduction and prior to iron reduction. As oxidizing conditions are re-established in the treatment area or as manganese(II) containing water mixes with more oxidized groundwater, soluble manganese(II) is anticipated to be slowly oxidized to the less soluble manganese(IV).

5.2.5 Iron

Iron is the second most abundant element in the earth's outer crust and a naturally-occurring metal in most rocks, soil, and sediments. Under oxidizing conditions, iron typically occurs in an insoluble oxidized form, iron(III) (Fe^{3+}). However, under moderately reducing conditions, iron(III) is reduced and occurs in a soluble form, iron(II) (Fe^{2+}). Conversion of iron(III) to iron(II) is expected to increase the dissolved iron concentration in groundwater. During the abiotic/biotic degradation process, insoluble oxidized iron(III), if present, will be converted to soluble reduced iron(II) as progressively greater reducing conditions are established. Moderate reducing conditions during the abiotic/biotic degradation process will cause an increase in iron(II) concentration. Under iron reducing conditions, PCE may be converted to TCE (Figure 4). More highly reducing conditions are considered necessary for further conversion of TCE to DCE.

5.2.6 Sulfate

Sulfate occurs naturally in most aquifers and is used as an electron acceptor by sulfate reducing organisms in the biological-mediated reduction of organic compounds. This process results in a decrease in sulfate concentration and an increase in sulfide concentration. Because sulfate is a thermodynamically favorable electron acceptor relative to VC, the presence of sulfate at elevated

concentrations can inhibit the reductive dechlorination of VC to ethene. Therefore, reduction of sulfate to sulfide is considered necessary to achieve reductive dechlorination of VC. If iron(II) is present, as it is in the treatment area, the sulfide produced during sulfate reduction combines with either the iron(II), iron(III), or arsenic(III) and precipitates as an insoluble iron sulfide or arsenic sulfide, respectively, or forms hydrogen sulfide gas. A decrease in sulfate concentrations is considered confirmation that sulfate reducing conditions have been established in the aquifer.

5.2.7 Methane

Methane is produced as a fermentation product of various organic compounds or by the reduction of carbon dioxide. The presence of methane indicates that highly-reducing (methanogenic) conditions have been established in the aquifer. Although methane is not a beneficial product of the biological process, methanogenic conditions are considered necessary for the conversion of VC to nontoxic ethene. Therefore, the presence of dissolved methane is considered confirmation that conditions necessary for complete reductive dechlorination of CEs to ethene has been established in the aquifer.

5.3 Organic Substrate Indicator Parameters

The substrates injected during the TS consist of two organic carbon substrates, emulsified oil and lactate, and a mixture of ZVI and organic carbon. Organic carbon is used by indigenous microorganisms in a biologically-mediated, oxidation-reduction reaction that results in the oxidation of the electron donor (organic substrate) and the reduction of the electron acceptor (oxygen, nitrate, arsenic, manganese, iron, sulfate, carbon dioxide). Under highly-reducing conditions, dechlorinating microorganisms (DHC) can use the hydrogen generated in the degradation of the substrate for the reductive dechlorination of CEs.

The organic component of EHC[®] (fibrous organic material) is nutrient-rich, hydrophilic, and has high surface area; thus, it is an ideal support for growth of bacteria in the groundwater environment. As indigenous heterotrophic bacteria grow on EHC[®] particle surfaces, they consume DO, thereby reducing the redox potential in groundwater. In addition, as the bacteria grow on the organic particles, they ferment carbon and release a variety of VFAs, for example, acetic, propionic, butyric, which diffuse from the site of fermentation into the groundwater plume and serve as electron donors for other bacteria, including dehalogenators and halorespiring species. Finally, the soluble iron(II) sulfate particles provide substantial reactive surface area that stimulates direct chemical dechlorination and an additional drop in the redox potential of the groundwater via chemical oxygen scavenging. These physical, chemical, and biological processes combine to create an extremely reduced environment that stimulates chemical and microbiological dechlorination of otherwise persistent compounds.

The presence of the organic substrate can be measured by several methods including dissolved organic carbon analysis, alkalinity, and organic acids analysis. The following section describes these organic substrate monitoring parameters.

5.3.1 Total Organic Carbon

Naturally-occurring organic carbon is present in most aquifers and the microbial use of organic carbon is responsible for establishment of slightly to highly reducing conditions typically observed with increasing carbon content. The organic substrates are used by the indigenous microorganisms to reduce the ambient electron acceptor (i.e., oxygen, nitrate, arsenic, manganese, iron, sulfate, and carbon dioxide) concentrations, which inhibit the degradation of the CEs. Organic carbon may also be used by dechlorination microorganisms (DHC) to degrade CEs to nontoxic ethene and ethane. The EHC[®] is a slow release carbon source intended to maintain reducing conditions for an extended period of time. Whereas, the two other substrates consist entirely of organic carbon which is used as an electron donor to enhance biological reductive dechlorination of the chemicals of concern (COCs). TOC is measured in groundwater to evaluate the distribution and persistence of the organic substrates during the TS. Organic carbon occurs as a solid or adsorbed phase or as a dissolved phase. The organic carbon in the groundwater samples therefore, accounts for only a portion of the organic carbon available for microbes to use.

5.3.2 Alkalinity

Carbon dioxide generated during the reduction of electron acceptors including oxygen, nitrate, manganese, iron, and sulfate, can be measured as alkalinity in the groundwater. Organic substrates are converted to various organic acids, such as acetic and propionic acids, by microbial processes in the aquifer. The presence of propionic and acetic acids contribute to groundwater alkalinity as well (Hem, 1992). Because the concentrations of acetic and propionic acids are very high, relative to the other sources of increased alkalinity, analysis of alkalinity can potentially be used as a surrogate for VFA or substrate analyses. Although alkalinity is an indicator of organic substrates, other non-organic sources of alkalinity are present in the aquifer as well. For instance, as acetic and propionic acid are utilized they generate inorganic alkalinity not attributable to organic substrates and that does not enhance biological degradation. Therefore, although alkalinity is a useful and relatively accurate indicator of substrate availability for several months following substrate distribution, it becomes less accurate as the organic alkalinity is converted to inorganic alkalinity.

5.3.3 Volatile Fatty Acids

Organic substrate is degraded by indigenous organisms to generate a variety of VFAs such as lactate. The fermentation of lactate results in the generation of hydrogen and the production predominantly of propionic, acetic, and butyric acids as well as minor amounts of other acids.

The fermentation of propionic acid also results in the production of hydrogen. The hydrogen generated during this process is used to promote reduction of electron acceptors such as nitrate, manganese, iron, sulfate, and carbon dioxide, and for the reductive dechlorination of CEs. The presence of lactic or propionic acids is considered necessary for the conversion of all CEs to ethene whereas acetic, butyric, and other organic acids may contribute to the conversion of PCE and TCE to DCE.

VFA analysis was not conducted during each monitoring event because TOC and alkalinity are considered cost effective surrogates for VFA. Periodic analysis of VFAs was conducted to evaluate the representativeness of the alkalinity and TOC analytical results.

5.4 *Volatile Organic Compounds*

Groundwater samples from each pilot test area were analyzed for VOCs including the COCs and their abiotic and biotic degradation products, during each sampling event of the TS. The COCs affecting each of the pilot study areas consist of CEs including PCE, TCE, DCE and VC. PCE is the COC in the study areas whose source is considered to be from operations in the former dry cleaning facility (former Building 88). It was distributed to the Traffic Island Area by means of a sanitary sewer line which was collapsed and leaked. TCE is also a principal COC. TCE is present in the aquifer as both a parent compound, resulting from migration of TCE from sources upgradient of the TS areas and as a reductive dechlorination product of PCE.

DCE and VC are not considered to have been discharged at the site but rather, exclusively represent daughter products resulting from the biotic and abiotic degradation of the parent PCE and TCE. DCE, the primary COC in the Well W9-18 Area is considered to result from biotic or abiotic reductive dechlorination of a PCE and TCE source. Ethene, ethane, and acetylene are the complete dechlorination daughter products of the CEs. Acetylene is considered to be exclusively the result of abiotic degradation of the CEs from the β -elimination pathway. Whereas, ethene and ethane are degradation products resulting from both biotic or abiotic processes.

5.4.1 *Tetrachloroethene (C₂Cl₄)*

PCE is the primary solvent discharged at the TS areas. PCE is the most highly oxidized CE and therefore is the first CE to be reduced during reductive dechlorination. Biological conversion of PCE to TCE occurs under moderately reducing conditions (Eh of ~ -50mV) as shown on Figure 4.

5.4.2 *Trichloroethene (C₂HCl₃)*

TCE is not a primary solvent discharged at the TS areas but rather is a degradation product of PCE and also is migrating into the TS areas from upgradient sources. TCE is the second most highly oxidized CE following PCE. Therefore, TCE is less readily dechlorinated than PCE but

more readily dechlorinated than DCE or VC. Biological conversion of TCE to DCE occurs under moderately reducing (i.e., iron reducing) conditions (Eh of ~ -100 mV) as shown on Figure 4.

5.4.3 *Dichloroethene (C₂H₂Cl₂)*

The presence of DCE isomers in groundwater at the TS areas is considered to be associated with the abiotic or biotic degradation of TCE by hydrogenolysis. TCE is reduced to DCE under moderately high reducing conditions (prior to sulfate reducing conditions) at an Eh of ~ -150 mV (Figure 4). Biological reduction of TCE to DCE primarily results in the production of the cis 1,2-DCE isomer (~90 percent) with almost all the remaining converted to the trans 1,2-DCE isomer (~10 percent). However, it has been observed at some sites that trans-1,2-DCE is the major biological degradation product of TCE degradation. Very little, if any, TCE is biologically converted to the 1,1-DCE isomer. However, 1,1-DCE may be generated during abiotic hydrogenolysis of TCE. Therefore, the presence of elevated concentrations of cis-1,2-DCE is considered indicative of biological degradation processes whereas increased concentrations of 1,1-DCE indicate abiotic degradation processes. The increase in total DCE is considered indicative of reductive dechlorination of TCE, either by abiotic hydrogenolysis or by biological chlororespiration.

5.4.4 *Vinyl Chloride (C₂H₃Cl)*

The presence of VC in groundwater at the TS areas is considered to be the result of degradation of the DCE isomers (1,1-DCE; cis-1,2-DCE; or trans-1,2-DCE) by either abiotic hydrogenolysis or by biological reductive dechlorination. Highly-reducing (methanogenic) conditions are necessary for the conversion of VC to ethene. The presence of elevated concentrations of sulfate (greater than [$>$] 25 mg/L) tends to inhibit this conversion and therefore, must be reduced first to achieve conversion of VC to the nontoxic degradation products.

5.4.5 *Ethene (C₂H₄)*

Ethene is the nonchlorinated, nontoxic product of chemical or biological degradation of CEs. Under highly-reducing (methanogenic) conditions, VC can be converted to ethene by reductive dechlorination processes including either abiotically (hydrogenolysis) or biologically (chlororespiration). Ethene can also be generated by the β -elimination pathway, bypassing CE degradation products. In this process parent compounds PCE and TCE are converted first to dichloroacetylene or chloroacetylene respectively, then reduced to acetylene by hydrogenolysis, and finally to ethene by hydrogenation. The presence of ethene can be directly attributed to the degradation of PCE, TCE, DCE, or VC either abiotically or biologically.

5.4.6 *Ethane (C₂H₆)*

Ethane is a nontoxic degradation product of CEs and ethanes. Ethane is formed by the further reduction of ethene under very highly reducing conditions. Ethane can be further degraded to

methane and ultimately mineralized to carbon dioxide and water. The presence of ethane can be attributed to the complete dechlorination of CEs and further reduction of ethene. Ethane can also be produced by the complete dechlorination of chlorinated ethanes.

5.4.7 Acetylene (C_2H_2)

Acetylene is a nontoxic degradation product of CEs generated by the abiotic β -elimination pathway instigated by the presence of ZVI or reactive iron sulfide minerals. Acetylene is highly labile and readily converted to ethene and ethane or biologically mineralized to carbon dioxide. The presence of acetylene is considered confirmation of the completion of the abiotic degradation of CEs by ZVI.

5.4.8 1,1-Dichloroethane ($C_2H_4Cl_2$)

1,1-DCA is degradable by biological reductive dechlorination and results in the production of chloroethane and ethane. The concentration of 1,1-DCA was monitored during the TS to further evaluate the effectiveness of each of these technologies to degrade this compound.

5.4.9 Chloroethane (C_2H_5Cl)

Under highly reducing conditions, chlorinated ethanes can be degraded by biological reductive dechlorination. The process results in the dechlorination of progressively reduced compounds. Chloroethane is the product of reductive dechlorination of chlorinated ethanes including 1,1-DCA and 1,2-DCA.

5.5 Biological Parameters

The organic substrates enhance the biological degradation of competing electron acceptors by the indigenous microbial consortium. Only one organism (DHC) has been shown to biologically degrade PCE and TCE to nontoxic ethene. If sufficient substrate and the appropriate dechlorinating culture (DHC) are present, and sufficiently reducing conditions are established, then DHC will degrade CEs by reductive dechlorination.

6.0 Performance Monitoring Results

This section presents the results of the baseline and post-injection groundwater monitoring events for each pilot test area of the TS. It discusses the results of sampling conducted during the monitoring period beginning with the first sampling event in July 2010 before the materials were injected and ending with the last groundwater samples collected in June 2011.

6.1 Emulsified Vegetable Oil Pilot Test (Traffic Island Area)

This section presents the results for each of the analytical parameters measured during the EVO pilot test in the Traffic Island Area.

6.1.1 Physical Parameters

During sample collection, the purge water was field analyzed for physical parameters including pH, ORP, SC, temperature, and turbidity. The following subsections describe the results of these physical parameter analyses.

6.1.1.1 pH

Baseline pH, in all wells monitored, ranged from 5.98 SU (28OW-05) to 10.25 SU (28OW-08). Following substrate injection, pH values in all wells trended toward a more neutral pH, value (7.0 SU) and the range decreased. By the final sample event the pH ranged from 6.49 SU (28OW-06) to 7.37 SU (28OW-04). The measured pH within and outside the treatment area, following substrate injection, was within the range conducive for biological and abiotic degradation of the CEs. The results of the pH analyses for the Traffic Island Area are listed in Table 1 and illustrated in Graph 1.

6.1.1.2 Oxidation-Reduction Potential

The baseline ORP, in all wells monitored, ranged from 200 mV (downgradient well 28OW-01) to -160 mV (crossgradient well W9-29). In the treatment area wells, the lowest baseline ORP was -50 mV (28OW-06). Following substrate injection the ORP decreased in all wells. During the second post-injection sampling event in November 2010 (approximately 90 days after injection) the ORP ranged from -139 mV (upgradient well 28OW-09) to -312 mV (crossgradient well W9-29). The ORP generally rose in subsequent sampling events and ranged from -225 mV (downgradient well 28OW-03) to -23 mV (downgradient well 28OW-01) by the final sampling event. The decrease in ORP indicates reducing conditions were established in the pilot test area following substrate injection. Following the initial drop, resulting from the injection of the substrate, the ORP rose in the subsequent sampling events. The rise in ORP indicates highly reducing conditions were not maintained in all treatment area wells during the degradation monitoring phase and that groundwater is returning to its more oxidizing ambient conditions.

The very low ORP measured following substrate distribution is conducive to biological degradation of the CEs. The results of the ORP analyses for the Traffic Island Area are listed in Table 1 and illustrated in Graph 2.

6.1.1.3 Specific Conductance

The baseline SC, in all wells monitored, ranged from 435.6 $\mu\text{S}/\text{cm}$ (treatment area well 28OW-08) to 1,454 $\mu\text{S}/\text{cm}$ (treatment area well 28OW-05). Following substrate injection, the SC increased substantially in three of the treatment area wells (28OW-05, 28OW-07 and 28OW-12) and remained relatively unchanged in the downgradient and other treatment area wells. The increase in the SC of the groundwater in the treatment area likely reflects the increase in dissolved metals such as manganese and iron which increased in solution following the establishment of reducing conditions. The results of the SC field measurements for the Traffic Island Area are listed in Table 1 and illustrated in Graph 3.

6.1.1.4 Temperature

The baseline groundwater temperature, in all wells monitored, ranged from 18.4°C (downgradient well 28OW-01) to 21.9°C (upgradient well 28OW-10). Immediately following substrate injection, the groundwater temperatures increased by the first post-injection sampling event (August 2010) but then decreased steadily during the next two sampling events (November 2010 and January 2011). The temperature remained relatively stable during the next event (April 2011) and rose substantially during the final event (June 2011). The change in temperature is attributed to seasonal changes in temperature. The range of temperature observed in all the wells during the TS was conducive to biological and abiotic degradation of CEs. The results of the temperature measurements for the Traffic Island Area are listed in Table 1 and illustrated in Graph 4.

6.1.1.5 Turbidity

The baseline groundwater turbidity measurements, in all wells monitored, ranged from 12 formazin nephelometric units (FNU; crossgradient well W9-29) to 1,296 FNU (downgradient well 28OW-04). Turbidity generally decreased during the TS with the exception of a notable increase in treatment area well 28OW-08, immediately following substrate injection (August 2010), and in the three upgradient wells, during the first two events following substrate injection (August and November 2010). Generally, turbidity declined in subsequent sampling events and ranged from 17 FNU (crossgradient well W9-29) to 815 FNU (upgradient well 28OW-11) by the final sampling event (June 2011).

The rapid increase in turbidity in well 28OW-08 is potentially attributable to an increase in particulate matter and organic substrate in the groundwater following high pressure injection. The cause for the increase in turbidity in the upgradient wells following substrate injection is not

determined. The results of the turbidity measurements for the Traffic Island Area are listed in Table 1 and illustrated in Graph 5.

6.1.2 Biogeochemical Parameters

Groundwater samples were analyzed for parameters indicative of biologically mediated changes in aquifer geochemistry, including DO, nitrate, arsenic, manganese, iron, sulfate, and methane. The following subsections describe the results of the biogeochemical parameter analyses.

6.1.2.1 Dissolved Oxygen

The baseline concentrations of DO, in all wells monitored, ranged from 0.06 mg/L (upgradient well 28OW-11 and crossgradient well W9-29) to 2.27 mg/L (upgradient well 28OW-10). Following substrate injection the concentrations of DO decreased substantially. In the sample event immediately following substrate injection (August 2010), the concentration of DO ranged from 0 mg/L (all treatment area wells) to 0.09 mg/L (upgradient well 28OW-09). The DO concentration in shallow wells 28OW-01 (downgradient) and 28OW-09 (upgradient) increased by the November 2010 event (approximately 90 days after injection) but remained low (less than [$<$] 0.13 mg/L, upgradient well 28OW-11) in all other wells. The DO remained less than 0.2 mg/L in all wells in the three subsequent sampling events.

The decrease in DO concentration is attributed to the establishment of oxygen reducing conditions in the aquifer following the addition of substrate. Anaerobic conditions (<0.5 mg/L) are required for biotic and abiotic reductive dechlorination of CEs. The results of the DO concentration measurements for the Traffic Island Area are listed in Table 1 and illustrated in Graph 6.

6.1.2.2 Nitrate

The baseline concentrations of nitrate, in all wells sampled, ranged from non-detect at or below the analysis reporting limit (RL) of 0.1 mg/L (most wells) to 0.434 mg/L (treatment area well 28OW-06). Immediately following substrate injection (August 2010), nitrate concentrations decreased to below the analysis RL in all wells except shallow downgradient well 28OW-01 (0.281 mg/L). Subsequently, nitrate concentrations generally increased in the treatment area wells and in upgradient wells, 28OW-10 and 28OW-11; however, the concentrations remained below 0.4 mg/L over the last three sampling events of the TS.

The initial decrease in nitrate concentration is consistent with the rapid establishment of nitrate reducing conditions following substrate injection. The observed rebound of nitrate at low concentrations during the TS suggests that nitrate migrated into the treatment area from an upgradient source. This may be associated with seasonal changes in groundwater flow conditions. The slight increase and persistence of nitrate in groundwater, in areas where highly reducing conditions (i.e., methanogenic) exist, suggest that nitrate is not readily utilized as an

electron donor by the indigenous or augmented organisms. The results of the nitrate concentration analyses in the Traffic Island Area are listed in Table 1 and illustrated in Graph 7.

6.1.2.3 Arsenic (Filtered)

The baseline concentrations of dissolved arsenic, in all wells sampled, ranged from an estimated value of 0.571 microgram per liter ($\mu\text{g/L}$) (treatment area well 28OW-06) to 4.1 $\mu\text{g/L}$ (upgradient well 28OW-09). Following substrate injection, dissolved arsenic concentrations increased in all treatment area wells and three of the four downgradient wells (28OW-02, 28OW-03, and 28OW-04). During the post-injection monitoring phase, dissolved arsenic concentrations generally remained stable with some fluctuations, except for deep treatment area well, 28OW-12, in which a constant rise in dissolved arsenic concentration occurred. By the final sampling event (June 2011), the concentration of dissolved arsenic in the treatment area wells ranged from 2.94 $\mu\text{g/L}$ (28OW-06) to 71 $\mu\text{g/L}$ (28OW-12).

The increase in dissolved arsenic concentrations confirms that moderately reducing conditions had been established in the treatment area. The results of the arsenic concentration analyses in the Traffic Island Area are listed in Table 1 and illustrated in Graph 8.

6.1.2.4 Manganese (Filtered)

The baseline concentrations of dissolved manganese, in all wells sampled, ranged from 3.3 $\mu\text{g/L}$ (treatment area well 28OW-08) to 471 $\mu\text{g/L}$ (upgradient well 28OW-09). Following substrate injection, dissolved manganese concentrations in all treatment area wells and in several downgradient wells (28OW-02, 28OW-03, and 28OW-04) increased during the August and November 2010 sample events. The concentration of dissolved manganese generally stabilized or decreased in most wells in the subsequent sampling events. By the last event (June 2011), the concentration of dissolved manganese in the treatment area wells ranged from 1,740 $\mu\text{g/L}$ (shallow well 28OW-05) to 9,150 $\mu\text{g/L}$ (deep well 28OW-12).

The increase in dissolved manganese concentrations confirms that moderately reducing conditions had been established in the treatment area. The results of the manganese concentration analyses in the Traffic Island Area are listed in Table 1 and illustrated in Graph 9.

6.1.2.5 Iron (Filtered)

The baseline concentrations of dissolved iron, in all wells sampled, ranged from an estimated value of 562 $\mu\text{g/L}$ (treatment area well 28OW-12) to 1,060 $\mu\text{g/L}$ (crossgradient well W9-42). Following substrate injection, dissolved iron concentrations increased in all treatment area wells and in several of the downgradient and crossgradient wells. The concentration of dissolved iron decreased in shallow treatment area well 28OW-05; however, dissolved iron concentrations continued to increase in most wells during the post-injection monitoring phase with the greatest increases observed in deep treatment area well 28OW-12. By the last sampling event

(June 2011), the concentration of dissolved iron in the treatment area wells ranged from 1,510 µg/L (deep well 28OW-08) to 85,600 µg/L (deep well 28OW-12).

The increase in dissolved iron concentrations confirms that substantially reducing conditions had been established in the treatment area. The results of the dissolved iron concentration analyses in the Traffic Island Area are listed in Table 1 and illustrated in Graph 10.

6.1.2.6 Iron (Ferrous)

The baseline concentrations of ferrous iron, in all wells sampled, ranged from zero (28OW-04, 28OW-11, and 28OW-12) to 0.97 mg/L (crossgradient well W9-42). Following substrate injection, ferrous iron concentrations increased in all treatment area wells. Following the initial increase, the concentration of ferrous iron generally decreased in the treatment area wells and remained low in other wells although a slight increase was observed in crossgradient well W9-42.

An elevated concentration of ferrous iron (25 mg/L) was reported in upgradient well 28OW-11 in the first post-injection sampling event (August 2010). Because no substrate was injected in this area and this is the only occurrence of elevated ferrous iron at that location, the reported concentration is considered anomalous.

The increase in ferrous iron concentrations confirms that substantially reducing conditions were established in the treatment area. The results of the ferrous iron concentration analyses in the Traffic Island Area are listed in Table 1 and illustrated in Graph 11.

6.1.2.7 Sulfate

The baseline concentrations of sulfate, in all wells sampled, ranged from 90 mg/L (treatment area well 28OW-08) to 489 mg/L (treatment area well 28OW-05). Following substrate injection, sulfate concentrations decreased in all treatment area wells and in several downgradient monitoring wells, and generally remained stable in the upgradient wells. Sulfate concentrations generally remained low in treatment area wells during the subsequent post-injection monitoring events; however, sulfate concentrations increased substantially in treatment area well 28OW-06 and in downgradient well 28OW-02. Sulfate concentrations decreased in crossgradient well W9-42. By the last sampling event (June 2011), the concentration of sulfate in the treatment area wells ranged from 1.1 mg/L (deep well 28OW-08) to 286 µg/L (shallow well 28OW-06).

The decrease in sulfate concentrations confirms that highly reducing conditions had been established in the treatment area. The results of the sulfate concentration analyses in the Traffic Island Area are listed in Table 1 and illustrated in Graph 12.

6.1.2.8 Methane

The baseline concentrations of dissolved methane, in all wells sampled, ranged from 0.45 µg/L (treatment area well 28OW-12) to 51 µg/L (downgradient well 28OW-04). Following substrate injection, the concentration of dissolved methane increased in all treatment area wells and in several downgradient and crossgradient wells. By the last sampling event (June 2011), the concentration of dissolved methane in the treatment area wells ranged from 6,700 µg/L (28OW-08) to 26,000 µg/L (28OW-07).

The increase in dissolved methane concentrations confirms that highly reducing conditions had been established in the treatment area. The results of the methane concentration analyses in the Traffic Island Area are listed in Table 1 and illustrated in Graph 13.

6.1.3 Organic Substrate Indicator Parameters

Alkalinity, TOC, and VFAs are analyzed to determine the presence of organic substrate in the groundwater. The following subsections describe the results of the substrate indicator analyses.

6.1.3.1 Alkalinity

The baseline concentrations of alkalinity, in all wells sampled, ranged from 43.9 mg/L (treatment area well 28OW-08) to 390 mg/L (downgradient well 28OW-01). Following substrate injection, alkalinity increased in all treatment area wells. The highest concentration of alkalinity was observed in wells 28OW-07 (2,450 mg/L) and 28OW-12 (2,230 mg/L) in the November 2010 sampling event. Alkalinity decreased in subsequent monitoring events and ranged from 346 mg/L (28OW-08) to 1,560 mg/L (28OW-07) in the treatment area wells by the final event (June 2011).

The increase in alkalinity concentrations confirms that substrate was distributed in the treatment area and in the vicinity of some downgradient wells. The results of the alkalinity concentration analyses in the Traffic Island Area are listed in Table 1 and illustrated in Graph 14.

6.1.3.2 Total Organic Carbon

The baseline concentrations of TOC, in all wells sampled, ranged from an estimated value of 0.618 mg/L (treatment area well 28OW-06) to 2.05 mg/L (downgradient well 28OW-03). Following substrate injection, TOC concentrations increased in all treatment area wells and several of the downgradient and crossgradient wells. The maximum concentrations of TOC were detected in treatment area wells 28OW-05 (9,680 mg/L) and 28OW-07 (9,590 mg/L). The concentration of TOC decreased in all wells in subsequent sampling events. By the last sampling event (June 2011), the concentration of TOC in the treatment area wells ranged from 2.7 mg/L (shallow well 28OW-05) to 670 mg/L (deep well 28OW-12).

The increase in TOC concentrations confirms that substrate was distributed in the treatment area and in the vicinity of some downgradient and crossgradient wells. The results of the TOC concentration analyses in the Traffic Island Area are listed in Table 1 and illustrated in Graph 15.

6.1.3 Volatile Fatty Acids

Periodic analysis of VFAs was conducted in select wells to verify that electron donor was present in the treatment area, as indicated by the alkalinity and TOC analyses. Analyses indicate that electron donor was present in the treatment area in the final sample event (June 2011). The highest concentration of VFAs was detected in deep treatment area well 28OW-12. Substantially lower concentrations of VFAs were detected in the other treatment area wells.

The presence of VFAs in treatment area wells indicate that substrate is present for continued biological degradation of CEs. The results of the VFA concentration analyses in the Traffic Island Area are listed in Table 1. Because minimal analyses of VFAs were conducted during the TS, the data are not graphed.

6.1.4 Volatile Organic Compounds

The groundwater samples for each event were analyzed for VOCs including the primary COCs PCE, TCE, DCE, and VC and their potential nontoxic degradation products (ethene, ethane, and acetylene). The following subsections describe the changes in concentration of these VOCs during the TS. The concentrations of these VOCs in groundwater for the baseline and post-injection sampling events are summarized in Table 1. The change in mass and molar concentrations of these compounds for each well are presented separately in Graphs 16a and 16b through Graphs 29a and 29b. The average mass and molar concentrations of COCs and degradation products in the treatment area, downgradient, and upgradient wells are illustrated in Graphs 30a and 30b through Graphs 32a and 32b, respectively. Concentrations of individual VOCs are presented separately in Graphs 33 through 44. It should be noted that results reported as non-detect are plotted on the concentration graphs as zero. The following subsections describe the results of the individual COC and degradation product analyses.

6.1.4.1 Tetrachloroethene

The baseline concentrations of PCE, in all the wells sampled, ranged from 0.49 µg/L (upgradient well 28OW-09) to 28,000 µg/L (treatment area well 28OW-12). Following substrate injection, PCE concentrations decreased in all treatment area wells. By the last sampling event (June 2011, approximately 45 weeks after injection), PCE concentrations in the treatment area wells ranged from an estimated value of 0.3 µg/L (28OW-07) to 12 µg/L (28OW-12). The maximum PCE concentrations detected in the final treatment area samples represent a 99.9 percent reduction in the concentration of PCE in the treatment zone groundwater.

The decrease in PCE concentration in the treatment area, in conjunction with other physical, biogeochemical, and degradation product analytical results, confirms that the biostimulation with bioaugmentation treatment process effectively treated the PCE to concentrations below the MCL of 5 µg/L. The PCE concentration in each well during the TS is illustrated in Graph 33.

6.1.4.2 *Trichloroethene*

The baseline concentrations of TCE, in all the wells sampled, ranged from 17 µg/L (treatment area well 28OW-05) to 12,000 µg/L (downgradient well 28OW-04). Following substrate injection, TCE concentrations decreased in all treatment area wells. With the exception of well 28OW-12, the concentration of TCE in the treatment area wells in the final sampling event (June 2011) ranged from an estimated value of 0.85 µg/L (28OW-08) to 1.5 µg/L (28OW-06). A slight increase from 2.7 µg/L (April 2011) to 12 µg/L was observed in well 28OW-12 by the last sampling event (June 2011), but all other wells remained below 1.5 µg/L.

The decrease of TCE concentrations in the treatment area, in conjunction with other physical, biogeochemical, and degradation product analytical results, confirms that the biostimulation with bioaugmentation treatment process effectively treated the TCE to concentrations below the ROD cleanup standard of 5 µg/L (EPA, 1989 and 1990). The TCE concentration in each well during the TS is illustrated in Graph 34.

6.1.4.3 *Total Dichloroethene*

The total DCE concentration is the sum of cis-1,2-DCE, trans-1,2-DCE and 1,1-DCE. The baseline concentrations of total DCE, in all the wells sampled, ranged from 4.8 µg/L (treatment area well 28OW-07) to 5,350 µg/L (downgradient well 28OW-04). Following substrate injection, total DCE concentrations increased in all treatment area wells. The maximum concentration of total DCE (44,963 µg/L) was observed in well 28OW-12 in the November 2010 sampling event (approximately 90 days after injection). The concentration of total DCE decreased in all treatment area wells during the subsequent sampling events. By the last sampling event (June 2011), the concentration of total DCE in the treatment area wells ranged from 2.9 µg/L (28OW-07) to 5,075 µg/L (28OW-12).

The increase and subsequent decrease in the concentration of DCE in the treatment area is attributable to the biological reductive dechlorination process whereby higher halogenated CEs (i.e., PCE and TCE) are sequentially reduced to less halogenated CEs (i.e., DCE and VC). The total DCE concentration in each well during the TS is illustrated in Graph 35.

6.1.4.4 *Cis-1,2-Dichloroethene*

The baseline concentrations of cis-1,2-DCE, in all the wells sampled, ranged from 3.7 µg/L (treatment area well 28OW-07) to 5,000 µg/L (downgradient well 28OW-04). Following substrate injection, the concentrations of cis-1,2-DCE increased in all treatment area wells. The

maximum concentration of cis-1,2-DCE (43,000 µg/L) was detected in well 28OW-12 in the November 2010 sampling event (approximately 90 days after injection). The concentration of cis-1,2-DCE decreased in all treatment area wells in subsequent sampling events. By the last sampling event (June 2011) the concentration of cis-1,2-DCE in the treatment area wells ranged from 1.4 µg/L (28OW-07) to 4,900 µg/L (28OW-12).

Cis-1,2-DCE is the primary DCE isomer generated during the biological degradation of PCE and TCE and is the primary DCE isomer observed in the TS area wells. The increase and subsequent decrease in concentrations of cis-1,2-DCE in the treatment area is attributable to the biological reductive dechlorination process whereby higher halogenated CEs (i.e., PCE and TCE) are sequentially reduced to less halogenated CEs (i.e., DCE and VC). The cis-1,2-DCE concentration in each well during the TS is illustrated in Graph 36.

6.1.4.5 Trans-1,2-Dichloroethene

The baseline concentrations of trans-1,2-DCE, in all the wells sampled, ranged from an estimated value of 0.21 µg/L (treatment area well 28W-07) to 100 µg/L (downgradient well 28OW-04). Following substrate injection, the concentrations of trans-1,2-DCE increased in all treatment area wells. The maximum concentration of trans 1,2-DCE (1,900 µg/L) was detected in well 28OW-12 in the November 2010 sampling event (approximately 90 days after injection). The concentration of trans-1,2-DCE decreased in all treatment area wells in subsequent sampling events. By the last sampling event (June 2011), the concentration of trans-1,2-DCE in the treatment area wells ranged from non-detect at or below the analysis RL (1 µg/L) to 170 µg/L (28OW-12).

Trans-1,2-DCE is the secondary DCE isomer generated during the biological degradation of TCE and PCE and is the DCE isomer observed in lower concentrations in the TS area wells. The increase and subsequent decrease in the concentrations of trans 1,2-DCE in treatment area is attributable to the biological reductive dechlorination process whereby higher halogenated CEs (i.e., PCE and TCE) are sequentially reduced to less halogenated CEs (i.e., DCE and VC). The trans-1,2-DCE concentration in each well during the TS is illustrated in Graph 37.

6.1.4.6 1,1-Dichloroethene

The baseline concentrations of 1,1-DCE, in all the wells sampled, ranged from an estimated value of 0.91 µg/L (treatment area well 28OW-07) to 150 µg/L (downgradient well 28OW-04). Following substrate injection, the concentrations of 1,1-DCE decreased in all treatment area and downgradient wells, but then increased in downgradient wells 28OW-03 and 28OW-04. The maximum concentration of 1,1-DCE observed during the TS (170 µg/L) was detected in wells 28OW-03 and 28OW-04 during the January and April 2011 sampling events. By the last sampling event (June 2011), the concentration of 1,1-DCE in the treatment area wells ranged

from an estimated value of 0.26 µg/L to 5.3 µg/L (28OW-12) and up to 140 µg/L in the deep downgradient well 28OW-04.

1,1-DCE is not generated during the biological degradation of PCE and TCE but may be biologically degraded. 1,1-DCE is generated by abiotic degradation processes. The reported increase in 1,1-DCE downgradient of the treatment area may be the result of abiotic degradation or, more likely, the result from variations of contaminant concentrations within the aquifer and movement of the solutes in response to the substrate injection process. The decrease in the concentration of 1,1-DCE within the treatment area is attributable to the biological reductive dechlorination process. The 1,1-DCE concentration in each well during the TS is illustrated in Graph 38.

6.1.4.7 Vinyl Chloride

The baseline concentrations of VC, in all the wells sampled, ranged from an estimated value of 0.28 µg/L (upgradient well 28OW-10) to 600 µg/L (downgradient well 28OW-04). Following substrate injection, the concentrations of VC increased in all treatment area wells and downgradient wells 28OW-02, 28OW-03 and 28OW-04. The maximum concentration of VC observed during the TS (7,700 µg/L) was detected in downgradient well 28OW-04 during the August 2010 sample event (approximately 90 days after injection). The concentrations of VC decreased in two of the treatment area wells (28OW-05 and 28OW-07) and remained elevated in the other three treatment area wells (28OW-06, 28OW-08, and 28OW-12). By the last sampling event (June 2011), the concentration of VC in the treatment area wells ranged from 2.7 µg/L (28OW-05) to 1,200 µg/L (28OW-12); and up to 4,100 µg/L in downgradient well 28OW-03; above the MCL of 0.5 µg/L.

VC is a degradation product of both abiotic and biotic degradation of PCE, TCE, and DCE. The change in VC concentrations during the post-injection monitoring phase is consistent with biological reductive dechlorination of the CEs. The VC concentration in each well during the TS is illustrated in Graph 39.

6.1.4.8 Total Chlorinated Ethenes

The baseline concentrations of total CEs (PCE, TCE, DCE, and VC), in all the wells sampled, ranged from 312 µg/L (upgradient well 28OW-11) to 36,126 µg/L (treatment area well 28OW-12). Immediately following substrate injection (August 2010), the concentrations of total CEs increased in treatment area wells 28OW-07 and 28OW-12 and in downgradient wells 28OW-03 and 28OW-04, but then decreased in the treatment area wells during subsequent sampling events. The maximum concentration of total CEs observed during the TS (48,830 µg/L) was detected in downgradient well 28OW-03 during the August 2010 sampling event. By the last sampling event, the concentration of total CEs in the treatment area wells

ranged from 7.1 µg/L (28OW-07) to 6,355 µg/L (28OW-12); and up to 35,840 µg/L in downgradient well 28OW-04.

The overall decrease in total CE concentrations in the treatment area wells during the post-injection monitoring phase is consistent with biological reductive dechlorination of the CEs. The total CE concentration in each well during the TS is illustrated in Graph 40.

6.1.4.9 Ethene

The baseline concentrations of ethene, in all the wells sampled, ranged from 0.058 µg/L (upgradient well 28OW-11) to 21 µg/L (downgradient well 28OW-04). Following substrate injection, the concentrations of ethene increased in all the treatment area wells and downgradient wells 28OW-02 and 28OW-03. The maximum concentration of ethene observed during the TS (7,100 µg/L) was detected in well 28OW-12 during the June 2011 sampling event. By the last sampling event, the concentration of ethene in the treatment area wells ranged from 69 µg/L (28OW-07) to 7,100 µg/L (28OW-12).

Ethene is the nonchlorinated degradation product of both abiotic and biotic degradation of PCE, TCE, DCE, and VC. The change in ethene concentrations during the post-injection monitoring phase is consistent with complete biological reductive dechlorination of the CEs. The maximum detected concentration of ethene (7,100 µg/L) is proportionally attributable to the complete reductive dechlorination of 41,970 µg/L of PCE. The ethene concentration in each well during the TS is illustrated in Graph 41.

6.1.4.10 Ethane

The baseline concentrations of ethane, in all the wells sampled, ranged from 0.029 µg/L (treatment area well 28OW-07) to 0.41 µg/L (treatment area well 28OW-08). Following substrate injection, the concentrations of ethane increased slightly in several treatment area wells however, ethane concentrations generally remained stable during the post-injection monitoring phase. The maximum concentration of ethane observed during the TS (4.8 µg/L) was detected in treatment area well 28OW-07 during the June 2011 sampling event. By the last sampling event, the concentration of ethane in the treatment area wells ranged from 0.18 µg/L (28OW-08) to 4.8 µg/L (28OW-07).

Ethane is the nonchlorinated degradation product of both abiotic and biotic degradation of PCE, TCE, DCE, and VC. The increase in ethane concentrations during the post-injection monitoring phase is consistent with complete biological reductive dechlorination of the CEs. The ethane concentration in each well during the TS is illustrated in Graph 42.

6.1.4.11 Acetylene

The baseline concentrations of acetylene, in all the wells sampled, ranged from an estimated value of 0.11 µg/L (treatment area well 28OW-05) to 6.2 µg/L (treatment area well 28OW-12). Following substrate injection, the concentrations of acetylene decreased in most treatment area wells and were generally below the analysis RL of 0.5 µg/L. However, acetylene was occasionally detected at low concentrations in a few of the treatment area wells (28OW-05, 28OW-07, and 28OW-12) and in one downgradient well (28OW-03) during the post-injection monitoring phase. The maximum concentration of acetylene observed during the TS (6.2 µg/L) was detected in treatment area well 28OW-12 during the baseline sampling event, prior to treatment. By the last sampling event (June 2011), the concentration of acetylene in all wells was not detected at or below the analysis RL of 0.5 µg/L.

Acetylene is the nonchlorinated degradation product of only abiotic degradation of PCE, TCE, DCE, and VC. The concentrations of acetylene in the baseline samples correlates well with the concentration of CEs in those wells, with the highest concentration of acetylene detected in wells exhibiting the highest concentration of CEs. The presence of acetylene in the baseline samples confirms that abiotic degradation of the CEs was occurring prior to the TS. The acetylene concentration in each well during the TS is illustrated in Graph 43.

6.1.4.12 1,1-Dichloroethane

The baseline concentrations for 1,1-DCA, in all the wells sampled, ranged from an estimated value of 0.21 µg/L (treatment area well 28OW-08) to 36 µg/L (treatment area well 28OW-05). Following substrate injection, the concentrations of 1,1-DCA in the treatment area wells decreased (most notably in well 28OW-05) or remained very low (<1 µg/L). The concentration of 1,1-DCA in downgradient wells 28OW-03 and 28OW-04 initially decreased and then fluctuated slightly during the remainder of the TS at concentrations below 1.6 µg/L. By the last sampling event (June 2011), the concentrations of 1,1-DCA in the treatment area wells ranged from an estimated value of 0.22 µg/L (28OW-12) to 4.3 µg/L (28OW-06)

A slight increase in the concentration of chloroethane (7 µg/L) was observed in 28OW-05 during the TS (Table 1). The change in 1,1-DCA concentrations, in conjunction with an increase in chloroethane, confirms that 1,1-DCA underwent reductive dechlorination during the TS. The increase in chloroethane is less than the stoichiometric amount if all the 1,1-DCA was converted to chloroethane. Therefore, the data indicate that reductive dechlorination of 1,1-DCA is proceeding past chloroethane to nontoxic compounds such as ethane. The 1,1-DCA concentration in each well during the TS is illustrated in Graph 44.

6.1.4.13 Percent Change in Total Chlorinated Ethenes Mass Concentration

The percent change in total CE mass concentration during the post-injection monitoring phase was tracked to confirm the destruction of the contaminants, as indicated by a reduction in mass

concentration of CEs. Following substrate injection, a substantial increase in CE concentrations was observed in treatment area wells 28OW-06 (405 percent) and 28OW-07 (181 percent) and downgradient wells 28OW-02 (263 percent) and 28OW-03 (168 percent). After the initial post-injection sampling event (August 2010) the concentration of CEs decreased in all treatment area wells and in downgradient wells 28OW-02 and 28OW-03. The decrease in CE mass concentration in treatment area wells ranged from 98.8 percent (28OW-07) to 16 percent (28OW-06).

The data indicate that the mass concentration of CEs was substantially reduced by the treatment process. The percent change in total CE mass concentration during the TS is illustrated in Graph 45.

6.1.4.14 Percent Change in Total Ethenes, Ethane, and Acetylene Molar Concentrations

The percent change in total ethenes, ethane, and acetylene molar concentration was tracked to evaluate the reductive dechlorination process during the post-injection monitoring phase. For instance, an increase in molar concentration relative to mass concentration would indicate that the COCs were undergoing reductive dechlorination. Following substrate injection, the molar concentration in the treatment area wells remained relatively constant, except for well 28OW-07 in which a substantial decrease was observed (88 percent). By the last sampling event (June 2011), the change in the total molar concentration of total ethenes, ethane, and acetylene concentration in the treatment area wells ranged from a decrease of 88 percent (28OW-07) to an increase of 40 percent (28OW-06).

The molar concentration data, relative to the mass concentration data, indicate that the primary degradation process was reductive dechlorination. The percent change in total ethenes, ethane, and acetylene molar concentration during the TS is illustrated in Graph 46.

6.1.4.15 Summary of Volatile Organic Compound Analyses

The analytical results for VOCs confirm that the distribution of EVO and SDC-9™ in the treatment zone have resulted in the degradation of CEs to nontoxic degradation products including ethene and ethane. The degradation process has resulted in a conversion of relatively oxidized VOCs (PCE and TCE) to more reduced VOCs (DCE, VC, ethene, and ethane). The conversion to more reduced compounds is demonstrated by a shift in the molar fraction of each of these parameters. The changes in the molar fraction of PCE, TCE, DCE, VC, ethene, and ethane in groundwater for each of the TS wells are shown in pie charts provided as Figure 12 for the treatment area wells, Figure 13 for the downgradient wells, and Figure 14 for the crossgradient and upgradient wells. The pie charts present the molar fraction of ethenes and ethane detected in each sample on a per mole basis. As reductive dechlorination progresses, the chemical composition of each sample will change from more chlorinated (PCE and TCE) to less

chlorinated (DCE and VC) ethenes and eventually to nonchlorinated ethene and ethane, which is reflected by a progressive change in color from red to yellow to green and blue on the pie charts.

The pie charts for the upgradient wells show no change in color (or chemical composition) which is expected for wells that should be unaffected by the treatment. Whereas, the pie charts for the treatment area wells show a sequential change in color from red to green with time as reductive dechlorination progresses.

The charts for the crossgradient wells show a change from primarily PCE, TCE, and DCE to primarily VC and ethene indicating a shift to more reduced ethenes in those wells. These data, along with other analytical results, confirm the substrate was distributed laterally further than the anticipated radius of influence and that the distribution resulted in reductive dechlorination in those areas. Although the pie chart for crossgradient well W9-42 indicates conditions remained relatively constant from Month 6 through Month 12, the pie chart for well W9-29 indicates that following Month 9 more oxidized CEs are returning to that location. This shift in the ratio of more oxidized CEs (i.e., PCE, TCE) corresponds to an overall increase in the CE concentration at that location (Graphs 29a and 29b), indicating a return to ambient conditions at that location.

The charts for the downgradient wells show a variety of changes in color indicating the effect of substrate distribution downgradient varied with depth, which likely resulted from variations in the aquifer hydrogeology. Although ethene was detected in the shallowest downgradient well (28OW-01), indicating dechlorination, only slight changes in the overall ratio were observed at this location. In the next deepest well (28OW-02), substantial dechlorination to ethene was observed following substrate injection indicating that the substrate distribution had more of an effect at that depth. In the next deepest well (28OW-03), substantial conversion of PCE and TCE to DCE and VC was observed; however, the dechlorination process was not as complete as it was in well 28OW-02. The pie charts indicate that substantial dechlorination occurred relatively quickly at the deepest downgradient well (28OW-04); however, following the rapid dechlorination observed by Month 3, an increase in the more oxidized compound was observed. This also corresponds to an overall increase in the concentrations of PCE and TCE, to near pre-treatment concentrations. Because the upgradient CE concentrations in wells 28OW-08 and 28OW-12 remain low, the cause for the increase in more oxidized compounds at well 28OW-04 is likely due to matrix diffusion, desorption, or dissolution of a NAPL.

6.1.5 Biological Parameter - *Dehalococcoides* sp

The concentration of DHC was measured in select treatment area and downgradient wells during the baseline (July 2010) and a couple of the post-injection monitoring events (January 2011 and June 2011). DHC was only detected in one of the four wells analyzed for DHC during the baseline event, downgradient well 28OW-02. Following substrate injection, DHC was detected in treatment area wells 28OW-05, 28OW-06, 28OW-08, and 28OW-12 at concentrations up to

1.3 x10⁶ cells per milliliter, during the January 2011 and June 2011 sampling events. The DHC analytical results are summarized in Table 1.

6.2 Lactate Pilot Test (Former Building 88 Area)

This section presents the results for each of the analytical parameters measured during the lactate pilot test in the Former Building 88 Area.

6.2.1 Physical Parameters

During sample collection, the purge water was field analyzed for physical parameters including pH, ORP, SC, temperature, and turbidity. The following subsections describe the results of these physical parameter analyses.

6.2.1.1 pH

The baseline pH in all the wells monitored, ranged from 6.26 SU (28OW-23) to 7.43 SU (28OW-19). Following substrate injection, pH values in all wells trended toward a more neutral pH value (7.0 SU) and the range decreased. Following the initial post injection sample event, pH remained generally stable in all wells, with the exception of 28OW-19, in which a consistent increase in pH was observed during the TS. By the final sampling event the pH ranged from 6.48 SU (28OW-21) to 8.77 SU (28OW-19). The measured pH is within the range conducive to biological and abiotic degradation of the CEs, with exception of downgradient well 28OW-19 which is slightly above the upper end of the range. The results of the pH analyses for the Former Building 88 Area are listed in Table 2 and illustrated in Graph 47.

6.2.1.2 Oxidation-Reduction Potential

The baseline ORP, in all the wells monitored, ranged from 230 mV (treatment area well 28OW-22) to -90 mV (treatment area well 28OW-21). Following substrate injection the ORP decreased in all wells. During the second post injection sampling event, in November 2010 (approximately 90 days after injection), the ORP ranged from -280 mV (upgradient well 28OW-23) to -321 mV (treatment area well 28OW-21). The ORP generally rose in subsequent sampling events and ranged from -48 mV (upgradient well 28OW-23) to -247 mV (treatment area well 28OW-21) by the final sampling event, with the ORP in the two treatment area wells at -105 mV (28OW-22) and -247 mV (28OW-21). The decrease in ORP indicates reducing conditions were established in the pilot test area following substrate injection. Following the initial drop resulting from the injection of the substrate, the ORP rose in the subsequent sampling events. The rise in ORP indicates highly reducing conditions were not maintained in all treatment area wells during the post-injection monitoring phase and that groundwater is returning to its more oxidizing ambient conditions. The very low ORP measured following substrate distribution is conducive to biological degradation of the CEs. The results of

the ORP analyses for the Former Building 88 Area are listed in Table 2 and illustrated in Graph 48.

6.2.1.3 Specific Conductance

The baseline SC, in all the wells monitored, ranged from 899 $\mu\text{S}/\text{cm}$ (treatment area well 28OW-22) to 1,239 $\mu\text{S}/\text{cm}$ (treatment area well 28OW-21). Immediately following substrate injection, the SC increased in the treatment area wells, the upgradient wells, and downgradient well 28OW-20 by the first post-injection sampling event (August 2010). In the subsequent sampling events, the SC decreased in all TS wells except in treatment area well 28OW-21 in which the SC remained generally elevated during the TS. The increase in the SC of the groundwater in the TS wells likely reflects the increase in dissolved metals such as manganese and iron which increased in solution following the establishment of reducing conditions. The results of the SC field measurements for the Former Building 88 Area are listed in Table 2 and illustrated in Graph 49.

6.2.1.4 Temperature

The baseline groundwater temperature, in all the wells monitored, ranged from 19.8°C (treatment area well 28OW-22) to 22.2°C (downgradient well 28OW-20). Immediately following substrate injection, the groundwater temperatures increased by the first post-injection sampling event (August 2010) and then decreased steadily during the next two sampling events (November 2010 and January 2011). The temperature remained relatively stable during the April 2011 event and rose substantially by the final event (June 2011). The change in temperature is attributed to seasonal changes in temperature. The range of temperature observed in all the wells during the TS was conducive to biological and abiotic degradation of CEs. The results of the temperature measurements for the Former Building 88 Area are listed in Table 2 and illustrated in Graph 50.

6.2.1.5 Turbidity

The baseline groundwater turbidity measurements, in all the wells monitored, ranged from 51 FNU (upgradient well 28OW-24) to 572 FNU (downgradient well 28OW-20). Following substrate injection, the turbidity generally increased and then decreased. By the final sampling event (June 2011), the turbidity ranged from 138 FNU (downgradient well 28OW-19) to 848 FNU (downgradient well 28OW-20). The increase in turbidity is potentially attributable to an increase in particulate matter and organic substrate in the groundwater following high pressure injection. The results of the turbidity measurements for the Former Building 88 Area are listed in Table 2 and illustrated in Graph 51.

6.2.2 Biogeochemical Parameters

Groundwater samples were analyzed for parameters indicative of biologically mediated changes in aquifer geochemistry, including DO, nitrate, arsenic, manganese, iron, sulfate, and methane. The following subsections describe the results of the biogeochemical parameter analyses.

6.2.2.1 Dissolved Oxygen

The baseline concentrations of DO, in all the wells monitored, ranged from 0.17 mg/L (treatment area well 28OW-21) to 0.43 mg/L (downgradient well 28OW-20). Following substrate injection the concentrations of DO decreased substantially in all wells with the exception of treatment area well 28OW-21 in which a slight increase was observed only in the sample event immediately following substrate injection (August 2010). An increase in DO was observed in well 28OW-23 in one sample event. A general rise in DO was observed in downgradient well 28OW-19 during the post-injection monitoring phase with the exception of the last sampling event. However, DO remained generally low in all wells during the post-injection monitoring phase. By the last sampling event (June 2011), the concentrations of DO in the two treatment area wells were below 0.1 mg/L.

The decrease in DO concentration is attributed to the establishment of anaerobic conditions in the aquifer following the addition of substrate. Anaerobic conditions (less than 0.5 mg/L) are required for biotic and abiotic reductive dechlorination of CEs. The results of the DO concentration measurements for the Former Building 88 Area are listed in Table 2 and illustrated in Graph 52.

6.2.2.2 Nitrate

The baseline concentrations of nitrate, in all the wells sampled, ranged from 0.135 mg/L (downgradient well 28OW-20) to an estimated value of 1.06 mg/L (upgradient well 28OW-24). Immediately following substrate injection (August 2010), nitrate concentrations decreased in all the wells except shallow downgradient well 28OW-19 in which the concentration increased. Subsequent to the initial post-injection event, the nitrate concentration in well 28OW-19 decreased in the remaining monitoring events. Nitrate concentrations in the other wells, except upgradient well 28OW-24, remained below 0.1 mg/L for the remainder of the TS. In upgradient well 28OW-24, the nitrate concentration rebounded to near its baseline concentration following the August 2010 event and was generally stable for the remainder of the TS.

The initial decrease in nitrate concentration is consistent with the rapid establishment of nitrate reducing conditions following substrate injection. The concentration of nitrate in treatment area wells ranged from an estimated value of 0.0503 mg/L (28OW-21) to an estimated value of 0.0631 mg/L (28OW-22) in the last sampling event (June 2011). The low concentrations of nitrate during the post-injection monitoring phase in treatment area wells indicates that nitrate reducing conditions were maintained in the treatment area during the post-injection monitoring phase. The results of the nitrate concentration analyses in the Former Building 88 Area are listed in Table 2 and illustrated in Graph 53.

6.2.2.3 Arsenic (Filtered)

The baseline concentrations of dissolved arsenic, in all the wells sampled, ranged from an estimated value of 0.762 µg/L (treatment area well 28OW-22) to 3.63 µg/L (upgradient well 28OW-23). Immediately following substrate injection (June 2011), dissolved arsenic concentrations increased in both treatment area wells, one upgradient well (28OW-23), and one downgradient well (28OW-20). The concentration of arsenic in well 28OW-21 increased by the next sampling event (November 2010) but remained stable or decreased in all the other wells. Then arsenic concentrations decreased in all wells in the subsequent sampling events. By the last sampling event (June 2011), the concentrations of dissolved arsenic in the treatment area wells were 1.4 µg/L (28OW-22) and 6.8 µg/L (28OW-21).

The increase in arsenic concentrations confirms that moderately reducing conditions were established in the treatment area. The results of the arsenic concentration analyses in the Former Building 88 Area are listed in Table 2 and illustrated in Graph 54.

6.2.2.4 Manganese (Filtered)

The baseline concentrations of dissolved manganese, in all the wells sampled, ranged from an estimated value of 64 µg/L (upgradient well 28OW-19) to 361 µg/L (treatment area well 28OW-21). Immediately following substrate injection (August 2010), dissolved manganese concentrations increased in all the wells except downgradient well (28OW-19) which remained relatively stable throughout the TS. During the subsequent sampling events, the concentrations of dissolved manganese generally decreased in the other wells. By the last sampling event (June 2011), the concentrations of dissolved manganese in the treatment area wells were 1,200 µg/L (28OW-22) and 1,510 µg/L (28OW-21).

The increase in manganese concentration confirms that moderately reducing conditions were established in the treatment area. The results of the manganese concentration analyses in the Former Building 88 Area are listed in Table 2 and illustrated in Graph 55.

6.2.2.5 Iron (Filtered)

The baseline concentrations of dissolved iron, in all the wells sampled, ranged from non-detect at or below the analysis RL (1,000 µg/L) to an estimated value of 509 µg/L (upgradient well 28OW-24). Following substrate injection, dissolved iron concentrations increased in both treatment area wells and upgradient well 28OW-23 by the initial post injection sampling event (August 2010). The highest concentration of dissolved iron (5,240 µg/L) detected during the TS was observed in treatment area well 28OW-21. By the last sampling event (June 2011), the concentrations of dissolved iron in the treatment area wells were non-detect at or below the analysis RL of 1,000 µg/L (28OW-22) and 3,360 µg/L (28OW-21).

The increase in dissolved iron concentrations confirms that substantially reducing conditions were established in the treatment area. The results of the dissolved iron concentration analyses in the Former Building 88 Area are listed in Table 2 and illustrated in Graph 56.

6.2.2.6 Iron (Ferrous)

The baseline concentrations of ferrous iron, in all the wells monitored, ranged from 0.07 mg/L (upgradient well 28OW-24 and downgradient well 28OW-20) to 0.58 mg/L (treatment area well 28OW-21). Following substrate injection, ferrous iron concentrations increased in both treatment area wells, downgradient well 28OW-19, and slightly in upgradient well 28OW-23. During the post-injection monitoring phase, ferrous iron concentrations generally remained stable in all the other wells. By the last sampling event, the concentration of ferrous iron in the treatment area wells were 0.33 mg/L (28OW-22) and 2.36 mg/L (28OW-21).

The increase in ferrous iron concentration confirms that substantially reducing conditions were established in the treatment area. The results of the ferrous iron concentration analyses in the Former Building 88 Area are listed in Table 2 and illustrated in Graph 57.

6.2.2.7 Sulfate

The baseline concentrations of sulfate, in all the wells sampled, ranged from 182 mg/L (treatment area well 28OW-22) to 347 mg/L (treatment area well 28OW-21). Immediately following substrate injection (August 2010), sulfate concentrations decreased substantially in treatment area well 28OW-21 and only slightly in 28OW-22. Sulfate concentrations generally remained stable in the upgradient wells but decreased in downgradient well 28OW-19 during the post-injection monitoring phase. The lowest concentration of sulfate (81 mg/L) was detected in treatment area well 28OW-21 during the November 2010 sampling event. By the last sampling event (June 2011), the concentrations of sulfate in the treatment area wells were 194 mg/L (28OW-22) and 196 mg/L (28OW-21).

The decrease in sulfate concentration confirms that highly reducing conditions were established in treatment area well 28OW-21. However, the rise in sulfate concentrations in that well in subsequent sampling events indicate that sulfate reducing conditions were not maintained for the duration of the post-injection monitoring phase. The results of the sulfate concentration analyses in the Former Building 88 Area are listed in Table 2 and illustrated in Graph 58.

6.2.2.8 Methane

The baseline concentrations of dissolved methane, in all the wells sampled, ranged from 0.95 µg/L (treatment area well 28OW-22) to 3.7 µg/L (upgradient well 28OW-23). Following substrate injection, the concentrations of dissolved methane increased in treatment area well 28OW-21 and remained relatively stable in all the other wells during the post-injection monitoring phase. The maximum concentration of dissolved methane detected during the TS

(41 µg/L) was observed in treatment area well 28OW-21 (January 2011). By the last sampling event (June 2011), the concentrations of dissolved methane in the treatment area wells were 1.6 µg/L (28OW-22) and 19 µg/L (28OW-21).

The increase in methane concentration confirms that highly reducing (methanogenic) conditions were established in treatment area well 28OW-21 but not in treatment area well 28OW-22. The results of the methane concentration analyses in the Former Building 88 Area are listed in Table 1 and illustrated in Graph 59.

6.2.3 Organic Substrate Indicator Parameters

Alkalinity, TOC and VFAs are analyzed to determine the presence of organic substrate in the groundwater. The following subsections describe the results of the substrate indicator analyses:

6.2.3.1 Alkalinity

The baseline concentrations of alkalinity, in all the wells sampled, ranged from 292 mg/L (upgradient well 28OW-24) to 322 mg/L (treatment area well 28OW-21). Following substrate injection, alkalinity increased in both treatment area wells, most significantly in well 28OW-21, and also in deep downgradient well 28OW-20. The highest concentration of alkalinity detected during the TS (1,020 mg/L) was observed in treatment area well 28OW-21 in the second post-injection sampling event (November 2010). Alkalinity decreased in subsequent sampling events and by the last sampling event (June 2011), was 301 mg/L (28OW-22) and 875 mg/L (28OW-21) in the treatment area wells

The increase in alkalinity in the wells is a confirmation that substrate was distributed in the treatment area and the deep downgradient well 28OW-20. The results of the alkalinity concentration analyses in the Former Building 88 Area are listed in Table 2 and illustrated in Graph 60.

6.2.3.2 Total Organic Carbon

The baseline concentrations of TOC, in all the wells sampled, ranged from an estimated value of 0.767 mg/L (upgradient well 28OW-24) to 4.7 mg/L (treatment area well 28OW-21). Following substrate injection, TOC concentrations increased in both treatment area wells and in deep downgradient well 28OW-20. The maximum concentration of TOC detected during the TS (332 mg/L) was observed in treatment area well 28OW-21 in the first post injection sampling event (August 2010). The concentration of TOC decreased in all wells in subsequent sampling events. By the last sampling event, the concentrations of TOC in the treatment area wells had decreased to an estimated value of 0.555 mg/L (28OW-22) and 2.0 mg/L (28OW-21).

The increase in TOC is confirmation that substrate was distributed in the treatment area wells and in the deep downgradient well. The rapid decrease in TOC concentration indicates that

substrate did not persist in the treatment area for an extended period. The results of the TOC concentration analyses in the Former Building 88 Area are listed in Table 2 and illustrated in Graph 61.

6.2.3.3 Volatile Fatty Acids

Periodic analysis of VFAs was conducted in select wells to verify that electron donor was present in the treatment area, as indicated by the alkalinity and TOC analyses. The Propionate, the only VFA detected in any of the samples, was reported only in downgradient well 28OW-20 in the baseline sampling event (July 2010).

The absence of VFAs in the treatment area wells during the post-injection monitoring phase indicates that substrate did not persist in the treatment area. The results of the VFA concentration analyses in the Former Building 88 Area are listed in Table 2. Because minimal analysis of VFAs was conducted the data are not graphed.

6.2.4 Volatile Organic Compounds

The groundwater samples for each event were analyzed for VOCs including the primary COCs PCE, TCE, DCE, and VC and their potential nontoxic degradation products (ethene, ethane, and acetylene). The following subsections describe the changes in concentration of these VOCs during the TS. The concentrations of these VOCs in groundwater for the baseline and post-injection sampling events are summarized in Table 2. The change in mass and molar concentrations of these compounds for each well are presented separately in Graphs 62a and 62b through Graphs 67a and 67b. The average mass and molar concentrations of COCs and degradation products in the treatment area, downgradient, and upgradient wells are illustrated in Graphs 68a and 68b through Graphs 70a and 70b, respectively. Concentrations of individual VOCs are presented separately in Graphs 71 through 82. It should be noted that results reported as non-detect are plotted on the concentration graphs as zero. The following sections describe the results of the analyses of the individual COC and degradation product analyses.

6.2.4.1 Tetrachloroethene

The baseline concentrations of PCE, in all the wells sampled, ranged from 1.9 µg/L (upgradient well 28OW-24) to 19,000 µg/L (upgradient well 28OW-23), with the concentrations in the treatment area wells ranging from 13 µg/L (28OW-22) to 320 µg/L (28OW-21). Following substrate injection (August 2010), PCE concentrations decreased in both treatment area wells and in downgradient well 28OW-20. By the last sampling event (June 2011), PCE concentrations in the treatment area wells were 7.6 µg/L (28OW-21) and 10 µg/L (28OW-22). The change in PCE concentration, in treatment area well 28OW-21, represents a 97.6 percent reduction in the concentration of PCE in groundwater in the treatment area.

The decrease in PCE concentration in the treatment area, in conjunction with other physical, biogeochemical, and degradation product analytical results, confirms that the biostimulation with bioaugmentation treatment process effectively treated the PCE to concentrations below the MCL of 5 µg/L. The PCE concentration in each well during the TS is illustrated in Graph 71.

6.2.4.2 *Trichloroethene*

The baseline concentrations of TCE, in all the wells sampled, ranged from 2,400 µg/L (treatment area well 28OW-21) to 4,300 µg/L (downgradient well 28OW-20). Following substrate injection, TCE concentrations decreased in both treatment area wells and downgradient well 28OW-20. The concentrations of TCE in the treatment area wells by the November 2010 sampling event were 27 µg/L and 91 µg/L, and 8.3 µg/L in downgradient well 28OW-20. The concentration of TCE rebounded in 28OW-22 but remained low in 28OW-20 and 28OW-21 in the subsequent sampling events. By the last sampling event (June 2011), the concentrations of TCE in the treatment area wells were 45 µg/L (28OW-21) and 1,700 µg/L (28OW-22), and 20 µg/L in downgradient well 28OW-20.

The decrease of TCE concentrations in the treatment area wells, in conjunction with other physical, biogeochemical, and degradation product analytical results, confirms that the biostimulation with bioaugmentation treatment process substantially degraded TCE. However, degradation to levels below the ROD cleanup standard of 5 µg/L (EPA, 1989 and 1990) was not achieved. The TCE concentration in each well during the TS is illustrated in Graph 72.

6.2.4.3 *Total Dichloroethene*

The total DCE concentration is the sum of cis-1,2-DCE, trans-1,2-DCE and 1,1-DCE. The baseline concentrations of total DCE, in all the wells sampled, ranged from 150 µg/L (downgradient well 28OW-20) to 5,276 µg/L (upgradient well 28OW-23). Following substrate injection, total DCE concentrations increased in both treatment area wells, upgradient well 28OW-23, and downgradient well 28OW-20. The maximum concentration of total DCE (15,077 µg/L) was observed in upgradient well 28OW-23 during the August 2010 sampling event (9 days after substrate injection). During the subsequent sampling events, the concentrations of total DCE decreased in both treatment area wells and upgradient well 28OW-23, remained elevated in downgradient well 28OW-20, and increased in downgradient well 28OW-19. By the last sampling event (June 2011), the concentrations of total DCE in the treatment area wells were 416 µg/L (28OW-21) and 1,430 µg/L (28OW-22).

The increase and subsequent decrease in the concentration of total DCE in the treatment area wells is attributable to the biological reductive dechlorination process whereby higher halogenated CEs (i.e., PCE and TCE) are sequentially reduced to less halogenated CEs (i.e., DCE and VC). The total DCE concentration in each well during the TS is illustrated in Graph 73.

6.2.4.4 *Cis-1,2-Dichloroethene*

The baseline concentrations of *cis*-1,2-DCE, in all the wells sampled, ranged from 120 µg/L (downgradient well 28OW-20) to 5,200 µg/L (upgradient well 28OW-23). Following substrate injection, *cis*-1,2-DCE concentrations increased in both treatment area wells, upgradient well 28OW-23, and downgradient well 28OW-20. The maximum concentration of *cis*-1,2-DCE (15,000 µg/L) was observed in upgradient well 28OW-23 during the August 2010 sampling event. During the subsequent sampling events, the concentrations of *cis*-1,2-DCE decreased in both treatment area wells and upgradient well 28OW-23, remained elevated in downgradient well 28OW-20, and increased in downgradient well 28OW-19. By the last sampling event (June 2011), the concentrations of *cis*-1,2-DCE in the treatment area wells were 400 µg/L (28OW-21) to 1,400 µg/L (28OW-22).

Cis-1,2-DCE is the primary DCE isomer generated during the biological degradation of PCE and TCE and is the primary DCE isomer observed in the TS area wells. The increase and subsequent decrease in concentrations of *cis*-1,2-DCE in the treatment area is attributable to the biological reductive dechlorination process whereby higher halogenated CEs (i.e., PCE and TCE) are sequentially reduced to less halogenated CEs (i.e., DCE and VC). The *cis*-1,2-DCE concentration in each well during the TS is illustrated in Graph 74.

6.2.4.5 *Trans-1,2-Dichloroethene*

The baseline concentrations of *trans*-1,2-DCE, in all the wells sampled, ranged from 1.2 µg/L (treatment area well 28OW-21) to 38 µg/L (upgradient well 28OW-23). Following substrate injection, the concentrations of *trans*-1,2-DCE increased in both treatment area wells and in downgradient well 28OW-20. The maximum concentration of *trans*-1,2-DCE observed during the TS (41 µg/L) was detected in upgradient well 28OW-23 in the August and November 2010 sampling events. The concentrations of *trans*-1,2-DCE decreased in all the wells during the subsequent sampling events, except in downgradient well 28OW-19 in which *trans*-1,2-DCE had slightly increased (2.9 µg/L) by the last event (June 2011). The concentrations of *trans*-1,2-DCE in the treatment area wells during the last sampling event (June 2011) were 5 µg/L (28OW-22) and 13 µg/L (28OW-21).

Trans-1,2-DCE is a secondary DCE isomer generated during the biological degradation of PCE and TCE and is the DCE isomer observed in lower concentrations in the TS area wells. The increase and subsequent decrease in the concentration of *trans*-1,2-DCE is attributable to the biological reductive dechlorination process whereby higher halogenated CEs (i.e., PCE and TCE) are sequentially reduced to less halogenated CEs (i.e., DCE and VC). The *trans*-1,2-DCE concentration in each well during the TS is illustrated in Graph 75.

6.2.4.6 1,1-Dichloroethene

The baseline concentrations of 1,1-DCE, in all the wells sampled, ranged from 28 µg/L (treatment area well 28OW-22) to 39 µg/L (upgradient well 28OW-23). Following substrate injection (August 2010), the concentrations of 1,1-DCE increased in treatment area well 28OW-21 and in downgradient well 28OW-19 by the initial post-injection sampling event (August 2010) but then decreased in these wells during the subsequent sampling events. 1,1-DCE remained relatively stable in all other wells during the post-injection monitoring phase. The maximum concentration of 1,1-DCE (39 µg/L) was detected in upgradient well 28OW-23 during the January 2011 sampling event. By the last sampling event (June 2011), the concentrations of 1,1-DCE in the treatment area wells were 3.2 µg/L (28OW-21) and 25 µg/L (28OW-22), and 25 µg/L in downgradient well (28OW-19).

1,1-DCE is not generated during the biological degradation of PCE and TCE but may be biologically degraded. 1,1-DCE is generated by abiotic degradation processes. The increase in 1,1-DCE may be the result of abiotic degradation or, more likely, result from variations in aquifer contaminant concentration and movement of the solutes due to the injection of substrate. The decrease in the concentration of 1,1-DCE is attributable to the biological reductive dechlorination process. The 1,1-DCE concentration in each well during the TS is illustrated in Graph 76.

6.2.4.7 Vinyl Chloride

The baseline concentrations of VC, in all the wells sampled, ranged from 0.51 µg/L (downgradient well 28OW-19) to 2.2 µg/L (upgradient well 28OW-23). Following substrate injection, the concentrations of VC increased in all the TS wells during the post-injection monitoring phase. The maximum concentration of VC (270 µg/L) was detected in downgradient well 28OW-20 during the last event (June 2011). The concentrations of VC in the treatment area wells by the last sampling event ranged from 22 µg/L (28OW-22) to 210 µg/L (28OW-21).

VC is a product of both abiotic and biotic degradation of PCE, TCE, and DCE. The increase in VC concentrations during the post-injection monitoring phase is consistent with biological reductive dechlorination of the CEs. The VC concentration in each well during the TS is illustrated in Graph 77.

6.2.4.8 Total Chlorinated Ethenes

The baseline concentrations of total CEs, (PCE, TCE, DCE and VC), in all the wells sampled, ranged from 3,003 µg/L (treatment area well 28OW-21) to 27,279 µg/L (upgradient well 28OW-23). Following substrate injection, the concentrations of total CEs initially increased and then decreased in treatment area well 28OW-21 by the second post-injection sampling event (November 2010), and were relatively stable in the subsequent events. The concentrations of total CEs were relatively stable in all other wells during the post-injection monitoring phase. The

concentrations of total CEs in the treatment area wells by the last sampling event were 679 µg/L (28OW-21) and 3,162 µg/L (28OW-22).

The change in total CE concentration during the post-injection monitoring phase is consistent with biological reductive dechlorination of the CEs. The total CE concentration in each well during the TS is illustrated in Graph 78.

6.2.4.9 Ethene

The baseline concentrations of ethene, in all the wells sampled, ranged from 0.13 µg/L (treatment area well 28OW-22) to 0.57 µg/L (upgradient well 28OW-23). Following substrate injection, the concentration of ethene increased in both treatment area wells and in both downgradient wells. The maximum concentration of ethene observed during the TS (660 µg/L) was detected in well 28OW-21 in the November 2010 sampling event. By the last event (June 2011), the concentrations of ethene in the treatment area wells were 1.9 µg/L (28OW-22) and 540 µg/L (28OW-21).

Ethene is the nonchlorinated product of both abiotic and biotic degradation of PCE, TCE, DCE, and VC. The rapid increase in ethene concentrations indicates complete reductive dechlorination occurred very rapidly in the treatment area following substrate distribution. However, the stable or decreasing concentrations of ethene following the second post-injection sampling event (November 2010), along with other biogeochemical parameters, indicates that complete degradation was inhibited, most likely from a lack of substrate. The maximum detected concentration of ethene (660 µg/L) equates to the complete reductive dechlorination of 3,901 µg/L of PCE. The ethene concentration in each well during the TS is illustrated in Graph 79.

6.2.4.10 Ethane

The baseline concentrations of ethane, in all the wells sampled, ranged from 0.054 µg/L (treatment area well 28OW-22) to 0.19 µg/L (downgradient well 28OW-20). Following substrate injection, the concentrations of ethane initially increased slightly in both treatment area wells and then slowly decreased during the subsequent sampling events. Ethane concentrations were generally stable in all the other wells during the post-injection monitoring phase. The maximum concentration of ethane observed during the TS (2 µg/L) was detected in treatment area well 28OW-21 in the November 2010 sampling event. The concentrations of ethane in the treatment area wells by the last sampling event (June 2011) were 0.064 µg/L (28OW-22) and 1.2 µg/L (28OW-21).

Ethane is the nonchlorinated product of both abiotic and biotic degradation of PCE, TCE, DCE, and VC. The presence of ethane during the post-injection monitoring phase is consistent with

complete biological reductive dechlorination of the CEs. The ethane concentration in each well during the TS is illustrated in Graph 80.

6.2.4.11 Acetylene

The baseline concentrations of acetylene, in all the wells sampled, ranged from non-detect at or below the analysis RL of 0.5 µg/L to an estimated value of 0.12 µg/L (upgradient well 28OW-23). Immediately following substrate injection, the concentrations of acetylene increased slightly in both treatment area wells and decreased in upgradient well 28OW-23 and downgradient well 28OW-20 by the first post-injection sampling event (August 2010). Acetylene was not detected in any of the wells following the November 2010 sampling event. The maximum concentration of acetylene observed during the TS (0.21 µg/L) was detected in treatment area well 28OW-22 in the November 2010 sampling event.

Acetylene is the nonchlorinated product of only abiotic degradation of PCE, TCE, DCE, and VC. The concentrations of acetylene in the baseline samples correlate well with the concentrations of CEs in those wells, with the highest concentration of acetylene detected in wells exhibiting the highest concentration of CEs. The presence of acetylene in the baseline samples confirms that abiotic degradation of the CEs was occurring prior to the substrate injection. The acetylene concentration in each well during the TS is illustrated in Graph 81.

6.2.4.12 1,1-Dichloroethane

The baseline concentrations of 1,1-DCA, in all the wells sampled, ranged from 7.7 µg/L (treatment area well 28OW-22) to 14 µg/L (upgradient well 28OW-23). Following substrate injection, the concentrations of 1,1-DCA increased in upgradient well 28OW-24 and in treatment area well 28OW-21 by the first post-injection sampling event (August 2010). The concentrations of 1,1-DCA decreased in all the wells during the subsequent events. By the last event (June 2011), the concentrations of 1,1-DCA in the treatment area wells were 7.1 µg/L (28OW-22) and 11 µg/L (28OW-21).

1,1-DCA can be biologically reductively dechlorinated to produce chloroethane. A slight increase in the concentration of chloroethane was observed in treatment area well 28OW-21 and in upgradient well 28OW-23 during the TS (Table 2). The change in 1,1-DCA concentrations, in conjunction with an increase in chloroethane, confirms that 1,1-DCA underwent reductive dechlorination during the TS. The 1,1-DCA concentration in each well during the TS is illustrated in Graph 82.

6.2.4.13 Percent Change in Total Chlorinated Ethenes Mass Concentration

The percent change in total CE mass concentrations during the post-injection monitoring phase was tracked to confirm the destruction of the contaminants, as indicated by a reduction in the mass concentration of CEs. Following substrate injection, the total CE concentrations initially

increased in treatment area wells 28OW-21 (47 percent) and 28OW-22 (12 percent) by the first post-injection sampling event (August 2010). Subsequently, the concentrations of total CEs decreased in both treatment area wells. By the last sampling event (June 2011), the decrease of total CE mass concentrations in the treatment area wells ranged from 16 percent (28OW-22) to 77 percent (28OW-21).

The data indicate that the mass concentration of total CEs was substantially reduced by the treatment process. The Percent Change in Total CE Mass Concentration during the TS is illustrated in Graph 83.

6.2.4.14 Percent Change in Total Ethenes, Ethane, and Acetylene Molar Concentrations

The percent change in the molar concentrations of total ethenes, ethane, and acetylene during the post-injection monitoring phase were tracked to evaluate the reductive dechlorination process. For instance, an increase in molar concentration relative to mass concentration would indicate that the COCs were undergoing reductive dechlorination. Following substrate injection, the molar concentrations in the treatment area wells initially increased by up to 90 percent (28OW-21) and then decreased subsequently. By the last sampling event, the change of the total molar concentrations in the treatment area wells were a decrease of 3 percent (28OW-22) and an increase of 18 percent (28OW-21). The total molar concentrations in all the other wells remained relatively stable during the post-injection monitoring phase.

The molar concentration data, relative to the mass concentration data, indicate that the primary degradation process was reductive dechlorination. The Percent Change in Total Ethenes, Ethane, and Acetylene Molar Concentrations during the TS is illustrated in Graph 84.

6.2.4.15 Summary of Volatile Organic Compound Analyses

The analytical results for VOCs confirm that the distribution of lactate and SDC-9™ in the treatment zone have resulted in the degradation of CEs to the nontoxic degradation product ethene. The degradation process has resulted in a conversion of relatively oxidized VOCs (PCE and TCE) to more reduced VOCs (DCE, VC, and ethene). The conversion to more reduced compounds is demonstrated by a shift in the molar fraction of each of these parameters. The changes in the molar fraction of PCE, TCE, DCE, VC, and ethene in groundwater for each of the TS wells are shown in pie charts provided as Figure 15 for the treatment area and downgradient wells and Figure 16 for the upgradient wells. The pie charts present the molar fraction of ethenes and ethane detected in each sample on a per mole basis. As reductive dechlorination progresses, the chemical composition of each sample will change from more chlorinated (PCE and TCE) to less chlorinated (DCE and VC) ethenes and eventually to nonchlorinated ethene and ethane, which is reflected by a progressive change in color from burnt red to red to orange to yellow to green and blue on the pie charts.

The pie chart for the deeper upgradient well, 28OW-24, shows no change in color (or chemical composition) which is expected for a well that should be unaffected by the treatment. Whereas, the chart for the shallower upgradient well, 28OW-23, shows a shift in molar composition from PCE and TCE to DCE (i.e., the change in color from burnt red to orange) during the first two post-injection events indicating that this well was briefly affected by the treatment.

The pie chart for the shallower treatment area well (28OW-21), screened in lower permeability materials, shows a sequential change in color from primarily red to primarily green indicating substantial dechlorination occurred rapidly at that location by Month 4. Following Month 4, however, the ratio of the CEs remains relatively unchanged, indicating dechlorination generally stopped. The cessation of dechlorination is attributed to a lack of substrate as indicated by the decrease in TOC shown in Graph 61. The pie chart for the deeper treatment area well (28OW-22), screened across higher permeability materials, shows a shift in molar composition from PCE and TCE to DCE (i.e., change in color from burnt red to orange) as reductive dechlorination was initiated, but then a rebound in molar composition after the second post-injection event (Month 4). The reduced amount of dechlorination is attributed to insufficient substrate distributed in the deeper well as indicated by the alkalinity and TOC data shown on Graphs 60 and 61, respectively. The cessation of dechlorination by Month 4 is attributed to the depletion of substrate at that location by day 90 as indicated by the alkalinity and TOC data shown on Graphs 60 and 61 respectively.

The pie chart for the shallower downgradient well (28OW-19), screened in lower permeability materials, shows no change in color (or chemical composition) because it was unaffected by the treatment. Whereas, the deeper downgradient well (28OW-20), screened across higher permeability materials, shows a change in color from red (TCE) to orange (DCE) and yellow (VC). The conversion of TCE to DCE and VC indicates partial dechlorination occurred in the deeper downgradient well. The concentrations of alkalinity (Graph 60) and TOC (Graph 61) increased at that location immediately following injection indicating substrate was distributed to that location during the injection process. The gradual increase and decrease in alkalinity following injection indicates lactate continued to migrate through that area following injection. These data suggest that, rather than being utilized, the lactate was transported from the treatment area by advective transport.

6.2.5 Biological Parameter - *Dehalococcoides* sp

The concentration of DHC was measured in select treatment area and downgradient wells during the baseline (July 2010) and a couple of the post-injection monitoring events (January and June 2011). DHC was detected in both wells analyzed for DHC during the baseline event at concentrations of 3.2×10^2 cells per mL (treatment area well 28OW-22) and 2.9×10^3 cells per mL (downgradient well 28OW-20). However, DHC was not detected in any of the samples during

either of the post-injection sampling events. The DHC analytical results are summarized in Table 2.

6.3 EHC[®] Pilot Test (Well W9-18 Area)

This section presents the results for each of the analytical parameters measured during the EHC[®] pilot test in the Former Building 88 Area.

6.3.1 Physical Parameters

During sample collection, the purge water was field analyzed for physical parameters including pH, ORP, SC, temperature, and turbidity. The following subsections describe the results of these physical parameter analyses.

6.3.1.1 pH

The baseline pH, in all the wells monitored, ranged from 5.75 SU (downgradient well 28OW-13) to 6.57 SU (upgradient well 28OW-18) with the exception of downgradient well 28OW-14 which had a pH of 11.27 SU. Following substrate injection, the pH initially decreased in well 28OW-14 to 6.27 SU by the first post-injection sampling event (August 2010) but then rebounded to 9.5 SU by the second post-injection sampling event (November 2010). Following the second post-injection sampling event, the pH remained generally stable in all the TS wells, with the exception of 28OW-14, in which a steady decrease in pH was observed. By the last sampling event (June 2011), the pH ranged from 6.57 SU (downgradient well 28OW-13) to 7.69 SU (treatment area well W9-18).

The measured pH was within the range conducive to biological and abiotic degradation of the CEs. The results of the pH analyses for the Well 9-18 Area are listed in Table 3 and illustrated in Graph 85.

6.3.1.2 Oxidation-Reduction Potential

The baseline ORP, in all the wells monitored, ranged from 250 mV (treatment area well 28OW-15) to -110 mV (treatment area well W9-18). Following substrate injection, the ORP decreased in all the TS wells. By the second post injection sampling event, in November 2010 (approximately 90 days after injection), the ORP ranged from -199 mV (downgradient well 28OW-13) to -248 mV (upgradient well 28OW-18). The ORP generally rose in the subsequent sampling events and ranged from -12 mV (upgradient well 28OW-18) to -225 mV (downgradient well 28OW-14) by the final sampling event (June 2011), with the ORP in the treatment area wells between -75 mV (28OW-15) and -201 mV (W9-18).

The decrease in ORP indicates reducing conditions were established in the pilot test area following substrate injection. Following the initial drop resulting from the injection of the substrate, the ORP rose in the subsequent sampling events. The rise in ORP indicates highly

reducing conditions were not maintained in all treatment area wells during the post-injection monitoring phase and that groundwater is returning to it is more oxidizing ambient conditions. The very low ORP measured following substrate distribution is conducive to biological degradation of the CEs. The results of the ORP analyses for the Well W9-18 Area are listed in Table 3 and illustrated in Graph 86.

6.3.1.3 Specific Conductance

The baseline SC, in all the wells monitored, ranged from 696 $\mu\text{S}/\text{cm}$ (treatment area well W9-18) to 1,706 $\mu\text{S}/\text{cm}$ (treatment area well 28OW-15). Following substrate injection, the SC increased in treatment area well W9-18 by the first post-injection sampling event (August 2010) and then decreased in the subsequent sampling events. The SC also increased in downgradient well 28OW-13 during the first four post-injection sampling events but decreased by the last event (June 2011). The SC generally decreased in all the other TS wells during the post-injection monitoring phase. By the last sampling event (June 2010), the SC in all the TS wells, except downgradient well 28OW-13, ranged from .899 $\mu\text{S}/\text{cm}$ (treatment area well W9-18) to 1,367 $\mu\text{S}/\text{cm}$ (treatment area well 28OW-16). The SC in 28OW-13 was 2,248 $\mu\text{S}/\text{cm}$ during the last event.

The increase in the SC in treatment area well W9-18 is attributable to the distribution of the iron containing substrate at that location. The increase in SC in downgradient well 28OW-13 reflects the increase in dissolved metals such as manganese and iron (described in the following sections) which increased in solution following the establishment of reducing conditions. The results of the SC field measurements for the Well W9-18 Area are listed in Table 3 and illustrated in Graph 87.

6.3.1.4 Temperature

The baseline groundwater temperature, in all the wells monitored, ranged from 20.0°C (downgradient well 28OW-13) to 21.4°C (treatment area well W9-18). Following substrate injection, the groundwater temperatures increased by the first post-injection sampling event (August 2010) and then decreased steadily during the next two sampling events (November 2010 and January 2011). The temperature remained relatively stable during the April 2011 event and rose substantially by the final event (June 2011). The change in temperature is attributed to seasonal changes in temperature. The range of temperature observed in all wells during the TS were conducive to biological and abiotic degradation of CEs. The results of the temperature measurements for the Well W9-18 Area are listed in Table 3 and illustrated in Graph 88.

6.3.1.5 Turbidity

The baseline groundwater turbidity measurements, in all the wells monitored, ranged from 78 FNU (upgradient well 28OW-17) to 1,608 FNU (upgradient well 28OW-18). Following substrate injection, the turbidity increased in the treatment area wells and then decreased during

the subsequent sampling events, but increased in well 28OW-16 during the final two sampling events (April 2011 and June 2011). A large increase in turbidity was observed in one up-gradient well (28OW-17) in the November 2010 sample event but turbidity decreased in that well in subsequent sampling events. By the last sampling event (June 2010), the turbidity ranged from 27 FNU (treatment area well W9-18) to 952 FNU (upgradient well 28OW-18); and 4,339 FNU in treatment area well 28OW-16.

The increase in turbidity in the treatment area wells is potentially attributable to an increase in particulate matter and organic substrate following high pressure injection of the substrate. The results of the turbidity measurements for the Well W9-18 Area are listed in Table 3 and illustrated in Graph 89.

6.3.2 Biogeochemical Parameters

Groundwater samples were analyzed for parameters indicative of biologically mediated changes in aquifer geochemistry, including DO, nitrate, arsenic, manganese, iron, sulfate, and methane. The following subsections describe the results of the biogeochemical parameter analyses.

6.3.2.1 Dissolved Oxygen

The baseline concentrations of DO, in all the wells monitored, ranged from 0.18 mg/L (treatment area well 28OW-16) to 2.89 mg/L (upgradient well 28OW-17). Following substrate injection, the concentration of DO decreased substantially in all the TS wells. Although, an increase in DO was observed in upgradient well 28OW-17 and downgradient well 28OW-13 during the second post-injection sampling event (November 2010), and a gradual rise in DO was observed in treatment area well 28OW-15 during the November 2010 and January 2011 events. However, DO decreased in 28OW-15 in the subsequent sampling events. The DO remained generally low in all wells during the post-injection monitoring phase. By the last sampling event (June 2011), the concentrations of DO in all the TS wells ranged from less than 0.1 mg/L to 0.12 mg/L (treatment area well 28OW-15).

The decrease in DO concentration is attributed to the establishment of anaerobic conditions in the aquifer following the addition of substrate. Anaerobic conditions (less than 0.5 mg/L) are required for biotic and abiotic reductive dechlorination of CEs. The results of the DO concentration measurements for the Well W9-18 Area are listed in Table 3 and illustrated in Graph 90.

6.3.2.2 Nitrate

The baseline concentrations of nitrate, in all the wells sampled, ranged from non-detect at or below the analysis RL of 0.1 mg/L (downgradient well 28OW-14 and treatment area well W9-18) to 2.46 mg/L (downgradient well 28OW-13). Following substrate injection, nitrate concentrations increased in upgradient well 28OW-18 and fluctuated in the other TS wells.

Nitrate concentrations remained low (less than 0.3 mg/L) in all TS wells during the post-injection monitoring phase. By the last sampling event (June 2011), the concentrations of nitrate in all the TS wells ranged from an estimated value of 0.065 mg/L (treatment area well W9-18) to 0.265 mg/L (upgradient well 28OW-18).

The initial decrease in nitrate concentrations is consistent with the rapid establishment of nitrate reducing conditions following substrate injection. The low concentrations of nitrate during the post-injection monitoring phase in the treatment area wells indicates that nitrate reducing conditions were maintained in the treatment area during the post-injection monitoring phase. The results of the nitrate concentration analyses in the Well W9-18 Area are listed in Table 3 and illustrated in Graph 91.

6.3.2.3 Arsenic (filtered)

The baseline concentrations of dissolved arsenic, in all the wells sampled, ranged from non-detect at or below the analysis RL of 1 µg/L (downgradient well 28OW-14 and treatment area well W9-18) to 2.94 µg/L (treatment area well 28OW-15). Following substrate injection, dissolved arsenic concentrations increased slightly in all the treatment area wells. The highest concentrations of dissolved arsenic observed during the post-injection monitoring phase (46.2 µg/L and 13.6 µg/L) were detected in the downgradient wells. The concentrations of dissolved arsenic in the treatment area wells by the last sampling event (June 2011) ranged from 0.669 µg/L (W9-18) to 2.96 µg/L (28OW-16); and up to 29.8 µg/L in the downgradient wells.

The increase in dissolved arsenic concentrations confirms that moderately reducing conditions were established in the treatment area following substrate injection. The relatively low concentration of dissolved arsenic observed in the treatment area wells, relative to the downgradient wells, suggests that the ZVI in the substrate actively sequesters the arsenic which may otherwise be mobilized by the reduction in ORP. The results of the dissolved arsenic concentration analyses in the Well W9-18 Area are listed in Table 3 and illustrated in Graph 92.

6.3.2.4 Manganese (Filtered)

The baseline concentrations of dissolved manganese, in all the wells sampled, ranged from non-detect at or below the analysis RL of 1 µg/L (downgradient well 28OW-14) to 558 µg/L (upgradient well 28OW-18). Following substrate injection, by the first post-injection sampling event (August 2010), dissolved manganese concentrations increased in all the treatment area wells and in downgradient well 28OW-13. During the subsequent events, the concentrations of dissolved manganese continued to increase in downgradient well 28OW-13 but generally decreased in the treatment area wells. By the last sampling event (June 2011), the concentrations of dissolved manganese in the treatment area wells ranged from 363 µg/L (28OW-15) to 1,120 µg/L (28OW-16), and was 2,520 µg/L in downgradient well 28OW-13.

The increase in dissolved manganese concentrations confirms that moderately reducing conditions were established in the treatment area. The results of the manganese concentration analyses in the Well W9-18 Area are listed in Table 3 and illustrated in Graph 93.

6.3.2.5 Iron (Filtered)

The baseline concentrations of dissolved iron, in all the wells sampled, were non-detect at or below the analysis RL of 1,000 µg/L, except in treatment area well W9-18 in which an estimated value of 766 µg/L was detected. Following substrate injection, dissolved iron concentrations increased substantially in treatment area well W9-18 and downgradient well 28OW-13. The highest concentration of dissolved iron detected during the TS (58,200 µg/L) was observed in treatment area well W9-18 (August 2010). By the last sampling event (June 2011), the concentrations of dissolved iron in the treatment area wells ranged from non-detect at or below the analysis RL of 1,000 µg/L (28OW-15) to 7,280 µg/L (W9-18).

The large increase in dissolved iron concentrations in treatment area well W9-18 is considered to be attributable to the distribution of the ZVI containing substrate at that location. The increase in dissolved iron concentrations in the downgradient wells is considered to be attributable to the establishment of substantially reducing conditions in that area. The results of the filtered iron concentration analyses in the Well W9-18 Area are listed in Table 3 and illustrated in Graph 94.

6.3.2.6 Iron (Ferrous)

The baseline concentrations of ferrous iron, in all the wells monitored, ranged from zero to 3.3 mg/L (treatment area well 28OW-16). Following substrate injection, ferrous iron concentrations increased in treatment area well W9-18 and in downgradient well 28OW-13. During the post-injection monitoring phase, ferrous iron concentrations generally remained stable in all the other wells. By the last sampling event, the concentrations of ferrous iron in the treatment area wells ranged from 0.11 mg/L (28OW-15) to 1.95 mg/L (28OW-16), and was 1.97 mg/L in downgradient well 28OW-13.

The increase in ferrous iron in well W9-18 is considered to be attributable to the oxidation of ZVI following substrate injection. The increase in ferrous iron concentrations in downgradient well 28OW-13 is considered to be attributable to the establishment of substantially reducing conditions following migration of substrate to that area. The results of the ferrous iron concentration analyses in the Well W9-18 Area are listed in Table 3 and illustrated in Graph 95.

6.3.2.7 Sulfate

The baseline concentrations of sulfate, in all the wells sampled, ranged from 187 mg/L (treatment area well W9-18) to 390 mg/L (upgradient well 28OW-17). Following substrate injection, sulfate concentrations decreased in treatment area wells W9-18 and 28OW-16 but remained elevated in treatment area well 28OW-15 (>350 mg/L). Sulfate concentrations also

decreased in both downgradient wells during the post-injection monitoring phase. The lowest concentration of sulfate (0.48 mg/L) was detected in treatment area well W9-18 during the April 2011 event. The decrease in sulfate concentration confirms that highly reducing conditions were established in treatment area wells W9-18 and 28OW-16, and in both downgradient wells. By the last sampling event (June 2011), sulfate concentrations remained low in treatment area well W9-18 and the downgradient wells (<50 mg/L) but had increased in treatment area well 28OW-16 to 172 mg/L.

The low concentration of sulfate in the treatment area well W9-18 and in the two downgradient wells throughout the duration of the post-injection monitoring phase indicates that substantially reducing conditions were maintained in those areas for at least 3 quarters. The results of the sulfate concentration analyses in the Well W9-18 Area are listed in Table 3 and illustrated in Graph 96.

6.3.2.8 Methane

The baseline concentrations of dissolved methane, in all the wells sampled, ranged from 0.91 µg/L (upgradient well 28OW-17) to 6.5 µg/L (downgradient well 28OW-14). Following substrate injection the concentrations of dissolved methane increased substantially in treatment area wells W9-18 and 28OW-16 and in both downgradient wells. The concentrations of dissolved methane in all the other wells remained low (<8 µg/L) and stable during the post-injection monitoring phase. The maximum concentration of dissolved methane (24,000 µg/L) was detected in well W9-18 during the third post-injection sampling event (January 2011). By the last sampling event (June 2011), the concentrations of dissolved methane in treatment area wells 28OW-16 and W9-18 were 4,300 µg/L and 18,000 µg/L, respectively; and 16,000 µg/L (28OW-13) and 20,000 µg/L (28OW-14) in the downgradient wells.

The increase in dissolved methane concentrations confirms that highly reducing (methanogenic) conditions were established in the area of treatment area wells W9-18 and 28OW-16 but not in the area of treatment area well 28OW-15. Methanogenic conditions also were established in the area of both downgradient wells. The results of the dissolved methane concentration analyses in the Well W9-18 Area are listed in Table 3 and illustrated in Graph 97.

6.3.3 Organic Substrate Indicator Parameters

Alkalinity, TOC, and VFAs are analyzed to determine the presence of organic substrate in the groundwater. The following subsections describe the results of the substrate indicator analyses:

6.3.3.1 Alkalinity

The baseline concentrations of alkalinity, in all the wells sampled, ranged from 118 mg/L (downgradient well 28OW-14) to 417 mg/L (upgradient well 28OW-18). Following substrate injection, alkalinity increased in treatment area wells W9-18 and 28OW-16 and in both

downgradient wells. The alkalinity in all the other wells remained stable during the post-injection monitoring phase. The highest concentration of alkalinity observed during the TS (1,820 mg/L) was detected in downgradient well 28OW-13 in the third post-injection sampling event (January 2011). By the last sampling event (June 2011), the concentrations of alkalinity in treatment area wells W9-18 and 28OW-16 were 480 µg/L and 594 µg/L, respectively; and 731 µg/L (28OW-14) and 1,290 µg/L (28OW-13) in the downgradient wells.

The increase in alkalinity in the treatment area wells W9-18 and 28OW-16 and in both downgradient wells is confirmation that organic substrate was distributed in the area of these wells. The results of the alkalinity concentration analyses in the Well W9-18 Area are listed in Table 3 and illustrated in Graph 98.

6.3.3.2 Total Organic Carbon

The baseline concentrations of TOC, in all the wells sampled, ranged from an estimated value of 0.849 mg/L (treatment area well 28OW-16) to 3.02 mg/L (downgradient well 28OW-14). Following substrate injection, TOC concentrations increased in treatment area well W9-18 and in both downgradient wells. TOC concentrations in all the other wells remained low (<6 mg/L) during the post-injection monitoring phase. The maximum concentration of TOC observed during the TS (413 mg/L) was detected in treatment area well W9-18 in the first post-injection sampling event (August 2010), but decreased in subsequent sampling events. The concentration of TOC increased in both downgradient wells during the subsequent sampling events. By the last sampling event (June 2011), the concentration of TOC in treatment area well W9-18 was 413 mg/L; and 18.5 mg/L (28OW-13) and 157 mg/L (28OW-14) in the downgradient wells.

The increase in TOC is confirmation that organic substrate was distributed in the area of treatment area well W9-18 but little, if any, substrate was distributed in the area of the other two treatment area wells. The gradual increase of TOC in both downgradient wells indicates that organic substrate migrated into that area following substrate injection. The decrease in TOC in downgradient well 28OW-13 during the April and June 2011 sampling events indicates organic substrate is diminishing in that area whereas the continual increase in TOC in downgradient well 28OW-14 in all sampling events indicates that substrate continues to migrate into that area. The results of the TOC concentration analyses in the Well W9-18 Area are listed in Table 3 and illustrated in Graph 99.

6.3.3.3 Volatile Fatty Acids

VFAs were not analyzed for in any of the samples collected from the Well W9-18 Area during the TS.

6.3.4 Volatile Organic Compounds

The groundwater samples for each event were analyzed for VOCs including the primary COCs PCE, TCE, DCE, and VC and their potential nontoxic degradation products (ethene, ethane, and acetylene). The following subsections describe the changes in concentration of these VOCs during the TS. The concentrations of these VOCs in groundwater for the baseline and post-injection sampling events are summarized in Table 3. The change in mass and molar concentrations of these compounds for each well are presented separately in Graphs 100a and 100b through Graphs 106a and 106b. The average mass and molar concentrations of COCs and degradation products in the treatment area, downgradient, and upgradient wells are illustrated in Graphs 107a and 107b through Graphs 109a and 109b, respectively. Concentrations of individual VOCs are presented separately in Graphs 110 through 121. It should be noted that results reported as non-detect are plotted on the concentration graphs as zero. The following sections describe the results of the analyses of the individual COC and degradation product analyses.

6.3.4.1 Tetrachloroethene

The baseline concentrations of PCE, in all the wells sampled, ranged from 0.37 µg/L (treatment area well 28OW-15) to 130 µg/L (upgradient well 28OW-18). Following substrate injection, PCE concentrations decreased in all three treatment area wells and in both downgradient wells, and in shallow, upgradient well 28OW-17. By the last sampling event (June 2011), PCE concentrations in the treatment area and downgradient wells ranged from non-detect at the analysis RL of 1 µg/L (28OW-13 and W9-18) and 5 µg/L (28OW-15), respectively, to 1.6 µg/L (28OW-16), below the MCL (5 µg/L). The change in PCE concentration, in treatment area well 28OW-16, represents a 97.6 percent reduction in the concentration of PCE in groundwater in the treatment area.

The decrease in PCE concentrations in the treatment area, in conjunction with other physical, biogeochemical, and degradation product analytical results, confirms that the biotic/abiotic treatment process effectively treated the PCE to concentrations below the MCL of 5 µg/L. The PCE concentration in each well during the TS is illustrated in Graph 110.

6.3.4.2 Trichloroethene

The baseline concentrations of TCE, in all the wells sampled, ranged from 3.3 µg/L (treatment area well W9-18) to 2,100 µg/L (treatment area well 28OW-16). Following substrate injection, TCE concentrations decreased substantially in treatment area wells 28OW-16 and W9-18 but only slightly in treatment area well 28OW-15. The concentrations of TCE also decreased in both downgradient wells and in upgradient well 28OW-17. By the last sampling event (June 2011), the concentrations of TCE in the treatment area and downgradient wells ranged from non-detect at or below the analysis RL of 1 µg/L (W9-18) to 29 µg/L (28OW-16). The change in TCE

concentration, in the treatment area well 28OW-16, represents a 98.6 percent reduction in the concentration of TCE in groundwater in the treatment area.

The decrease in TCE concentrations, in conjunction with other physical, biogeochemical, and degradation product analytical results, confirms that the combined biotic/abiotic treatment process degraded TCE significantly in the treatment area where substantial substrate was distributed (in vicinity of wells 28OW-16 and W9-18). The TCE concentration in each well during the TS is illustrated in Graph 111.

6.3.4.3 Total Dichloroethene

The total DCE concentration is the sum of cis-1,2-DCE, trans-1,2-DCE and 1,1-DCE. The baseline concentrations of total DCE, in all the wells sampled, ranged from 557 µg/L (treatment area well 28OW-16) to 7,284 µg/L (downgradient well 28OW-14). Following substrate injection, during the first two post-injection monitoring events (August and November 2010), total DCE concentrations increased in treatment area wells 28OW-15 and 28OW-16 and in upgradient well 28OW-17, but decreased in treatment area well W9-18 and both downgradient wells. During the subsequent sampling events, total DCE concentrations decreased in 28OW-16, W9-18, and both downgradient wells, but remained relatively stable in treatment area well 28OW-15 and in the upgradient wells. The maximum concentration of total DCE observed during the TS (8,268 µg/L) was detected in upgradient well 28OW-17 during the November 2010 sampling event. By the last sampling event (June 2011), the concentrations of total DCE in all the treatment area and downgradient wells, except treatment area well 28OW-15 (7,373 µg/L) ranged from 9.5 µg/L (W9-18) to 460 µg/L (28OW-16). The decrease in concentration of total DCE in treatment area well W9-18 from 7,245 µg/L (baseline) to 9.6 µg/L (June 2011) represents a 99.8 percent reduction in the concentration of total DCE in the treatment area.

The decrease in the concentrations of total DCE in the treatment area wells is attributable to the biological or abiotic reductive dechlorination process whereby a higher halogenated CE (i.e., 1,2-DCE) is sequentially reduced to a less halogenated CE (i.e., VC). The decrease in total DCE associated with a near stoichiometric increase in VC in well W9-18 suggests that the primary DCE degradation process is biological reductive dechlorination. The total DCE concentration in each well during the TS is illustrated in Graph 112.

6.3.4.4 Cis-1,2-Dichloroethene

The baseline concentrations of cis-1,2-DCE, in all the wells sampled, ranged from 530 µg/L (treatment area well 28OW-16) to 7,200 µg/L (treatment area well W9-18). Following substrate injection, during the first two post-injection sampling events (August and November 2010), cis-1,2-DCE concentrations increased in treatment area wells 28OW-15 and 28OW-16 and in upgradient well 28OW-17, but decreased in treatment area well W9-18 and in both downgradient

wells. During the subsequent sampling events, cis-1,2-DCE concentrations decreased in 28OW-16, W9-18, and both downgradient wells, but remained relatively stable in treatment area well 28OW-15 and in the upgradient wells. The maximum concentration of cis-1,2-DCE observed during the TS (8,200 µg/L) was detected in upgradient well 28OW-17 in the November 2010 sampling event. By the last sampling event (June 2011), the concentrations of cis-1,2-DCE in all the treatment area and downgradient wells, except treatment area well 28OW-15 (7,300 µg/L), ranged from 6.8 µg/L (W9-18) to 450 µg/L (28OW-16).

Although cis-1,2-DCE can be produced by both abiotic and biotic degradation of TCE, cis-1,2-DCE is the primary DCE isomer generated during the biological degradation of TCE. Because cis-1,2-DCE is the primary DCE isomer observed in the TS area wells, and because cis-1,2-DCE is not considered to be a discharged contaminant, the presence of cis-1,2-DCE is considered to be attributable to the biological degradation of PCE or TCE. The decrease in the concentrations of cis-1,2-DCE in conjunction with a near stoichiometric increase in the concentration of VC, as shown in Graphs 106a and 106b is considered attributable primarily to the biological reductive dechlorination process. The minimum concentration of cis-1,2-DCE measured in the treatment area (6.8 µg/L, W9-18) during the June 2011 sampling event is slightly above the ROD cleanup standard of 6 µg/L (EPA, 1989 and 1990). However, a decreasing trend in the concentration of cis-1,2-DCE at that location was observed suggesting that the concentration may be reduced to below the cleanup level in the future. The concentration of cis-1,2-DCE in downgradient well 28OW-13 was reduced by 99.9 percent, from 3,100 µg/L to 3.8 µg/L during the post-injection monitoring phase further indicating that the cis-1,2-DCE can be degraded to below the cleanup level of 6 µg/L. The cis-1,2-DCE concentration in each well during the TS is illustrated in Graph 113.

6.3.4.5 *Trans-1,2-Dichloroethene*

The baseline concentrations of trans-1,2-DCE, in all the wells sampled, ranged from 2.9 µg/L (treatment area well 28OW-16) to 20 µg/L (treatment area well W9-18). Following substrate injection, by the first post-injection sampling event (August 2010), the concentrations of trans-1,2-DCE decreased in treatment area well W9-18, but increased in all the other TS wells. During the subsequent events, trans-1,2-DCE concentrations decreased in well W9-18 and in both downgradient wells. The maximum concentration of trans-1,2-DCE detected during the TS was 42 µg/L in upgradient well 28OW-17, during the April 2011 sampling event. By the last event (June 2011), the concentrations of trans-1,2-DCE ranged from 2.7 µg/L (treatment area well W9-18) to 18 µg/L (treatment area well 28OW-15).

Trans-1,2-DCE can be produced by both abiotic and biological degradation of TCE and PCE. Trans-1,2-DCE is a secondary DCE isomer generated during the biological degradation of TCE and PCE and is the DCE isomer observed in lower concentrations in the TS area wells. The decrease in the concentration of trans-1,2-DCE is attributable to either the biological or abiotic

reductive dechlorination process. However, because the concentration of trans-1,2-DCE is small relative to the concentration of VC generated, it is undetermined if the degradation process is biological or abiotic. The trans-1,2-DCE concentration in each well during the TS is illustrated in Graph 114.

6.3.4.6 1,1-Dichloroethene

The baseline concentrations of 1,1-DCE, in all the wells sampled, ranged from 17 µg/L (upgradient well 28OW-18) to 69 µg/L (downgradient well 28OW-14). Following substrate injection, by the first post-injection sampling event (August 2010), the concentrations of 1,1-DCE initially decreased in treatment area well W9-18 and in downgradient well 28OW-14, but increased in all the other TS wells. During the subsequent events, the concentrations of 1,1-DCE decreased in treatment area wells 28OW-16 and W9-18 and in the downgradient wells. The concentrations of 1,1-DCE remained relatively stable in the other TS wells. The maximum concentration of 1,1-DCE detected during the TS was 73 µg/L in upgradient well 28OW-17 during the June 2011 sampling event. By the last event (June 2011), the concentrations of 1,1-DCE in the treatment area and downgradient wells, except for treatment area well 28OW-15 (55 µg/L), ranged from non-detect at or below the analysis RL of 1 µg/L (W9-18) to 2.1 µg/L (28OW-16).

1,1-DCE is not generated during the biological degradation of TCE and PCE but may be biologically degraded. 1,1-DCE is generated by abiotic degradation processes. The increase in 1,1-DCE may be the result of abiotic degradation of TCE or PCE which decreased in concentration during the post-injection monitoring phase. The decrease in the concentration of 1,1-DCE is attributable to either the biological or abiotic reductive dechlorination process. The 1,1-DCE concentration in each well during the TS is illustrated in Graph 115.

6.3.4.7 Vinyl Chloride

The baseline concentrations of VC, in all the wells sampled, ranged from 0.96 µg/L (upgradient well 28OW-18) to 890 µg/L (treatment area well W9-18). Following substrate injection, by the second post-injection sampling event (November 2010), the concentrations of VC increased in all the TS wells with the greatest increase observed in treatment area well W9-18 and in both downgradient wells. During the subsequent events, the VC concentrations decreased in well W9-18 and in both downgradient wells, and continued to increase in all the other TS wells. The maximum concentration of VC detected during the TS was 5,800 µg/L (November 2010) in treatment area well W9-18. By the last event, the concentration of VC in well W9-18 was 15 µg/L (99.7 percent reduction from its peak concentration), and the concentrations in the other treatment area wells were 2.8 µg/L (28OW-15) and 1,900 µg/L (28OW-16).

VC is a product of both abiotic and biotic degradation of PCE, TCE, and DCE. The near stoichiometric increase in the concentration of VC in conjunction with a decrease in DCE

concentrations in the treatment area and downgradient wells, during the post-injection monitoring phase, is consistent with biological reductive dechlorination of the CEs. The VC concentration in each well during the TS is illustrated in Graph 116.

6.3.4.8 Total Chlorinated Ethenes

The baseline concentrations of total CEs (PCE, TCE, DCE, and VC), in all the wells sampled, ranged from 2,382 µg/L (upgradient well 28OW-18) to 8,140 µg/L (treatment area well W9-18). Following substrate injection, the concentrations of total CEs in treatment area well W9-18 and both downgradient wells began to decrease after the second post-injection sampling event (November 2010). The concentrations of total CEs in the other wells remained relatively stable during the post-injection monitoring phase. By the last sampling event (June 2011), the concentration of total CEs in treatment area well W9-18 decreased to 25 µg/L, and to 131 µg/L (28OW-14) and 450 µg/L (28OW-13) in the downgradient wells. The change in total CE concentrations in treatment area well W9-18 and downgradient wells 28OW-13 and 28OW-14 represents a 99.7 percent, 85 percent, and 98 percent reduction in the total CE concentration, respectively.

The change in total CE concentrations during the post-injection monitoring phase is consistent with biological and abiotic reductive dechlorination of the CEs. The total CE concentration in each well during the TS is illustrated in Graph 117.

6.3.4.9 Ethene

The baseline concentrations of ethene, in all the wells sampled, ranged from 0.27 µg/L (treatment area well 28OW-16) to 22 µg/L (treatment area well W9-18). Following substrate injection, by the second post-injection sampling event, the concentrations of ethene increased in all the treatment area wells and in both downgradient wells. During the subsequent sampling events, the concentrations of ethene continued to increase in treatment area wells 28OW-16 and W9-18 and in both downgradient wells. By the last event (June 2011), the concentrations of ethene in these wells ranged from 27 µg/L (treatment area well 28OW-16) to 900 µg/L (downgradient well 28OW-14). The concentrations of ethene in the other wells remained low (<3.5 µg/L) during the post-injection monitoring phase.

Ethene is the nonchlorinated product of both abiotic and biotic degradation of PCE, TCE, DCE, and VC. The presence of ethene indicates complete reductive dechlorination is occurring in the treatment area and downgradient of the treatment area. The maximum detected concentration of ethene (900 µg/L) equates to the complete reductive dechlorination of 5,320 µg/L of PCE. The ethene concentration in each well during the TS is illustrated in Graph 118.

6.3.4.10 Ethane

The baseline concentrations of ethane, in all the wells sampled, ranged from 0.061 µg/L (treatment area well 28OW-15) to 1.5 µg/L (treatment area well W9-18). Following substrate injection, the concentrations of ethane increased slightly in all the treatment area and downgradient wells, however, ethane concentrations generally remained stable during the post-injection monitoring phase. The maximum concentration of ethane detected was 22 µg/L in treatment area well W9-18 during the November 2010 sampling event. By the last sampling event (June 2011), the concentrations of ethane in the treatment area wells ranged from 0.22 µg/L (28OW-15) to 2.8 µg/L (28OW-16).

Ethane is the nonchlorinated product of both abiotic and biotic degradation of PCE, TCE, DCE, and VC. The presence of ethane during the post-injection monitoring phase is consistent with complete biological and abiotic reductive dechlorination of the CEs. The ethane concentration in each well during the TS is illustrated in Graph 119.

6.3.4.11 Acetylene

The baseline concentrations of acetylene, in all the wells sampled, ranged from below the analysis RL (0.5 µg/L) to 0.78 µg/L (upgradient well 28OW-18). The concentrations of acetylene decreased in all TS wells during the post-injection monitoring phase. Acetylene was not detected in any sample following the November 2010 sampling event. The maximum concentration of acetylene (0.78 µg/L) was detected in well 28OW-18 during the baseline sampling event (July 2010).

Acetylene is the nonchlorinated product of only abiotic degradation of PCE, TCE, DCE, and VC. The presence of acetylene in the baseline samples confirms that abiotic degradation of the CEs was occurring prior to the substrate injection. The acetylene concentration in each well during the TS is illustrated in Graph 120.

6.3.4.12 1,1-Dichloroethane

The baseline concentrations of 1,1-DCA, in all the wells sampled, ranged from 7.4 µg/L (upgradient well 28OW-18) to 31 µg/L (upgradient well 28OW-17). Following substrate injection, the concentrations of 1,1-DCA decreased significantly in treatment area well W9-18 and in both downgradient wells. A slight decrease was also observed in treatment area well 28OW-16. The concentration of 1,1-DCA remained relatively constant in all other wells during the TS. By the last sampling event (June 2011), the concentrations of 1,1-DCA in the treatment area and downgradient wells ranged from an estimated value of 0.22 µg/L (W9-18) to 12 µg/L (28OW-15).

1,1-DCA can be biologically reductively dechlorinated to produce chloroethane. A slight increase in the concentrations of chloroethane were observed in treatment area wells W9-18 and

28OW-16 and in both downgradient wells during the TS (Table 3). The change in 1,1-DCA concentrations, in conjunction with an increase in chloroethane, confirms that 1,1-DCA underwent reductive dechlorination during the TS. The 1,1-DCA concentration in each well during the TS is illustrated in Graph 121.

6.3.4.13 Percent Change in Total Chlorinated Ethenes Mass Concentration

The percent change in total CE mass concentrations during the post-injection monitoring phase was tracked to confirm the destruction of the contaminants, as indicated by a reduction in mass concentration of total CEs. Following substrate injection, a substantial increase (114 percent) in the total CE mass concentrations was observed in upgradient well 28OW-17. Total CE concentrations decreased substantially in treatment area well W9-18 (99.7 percent) and in downgradient wells 28OW-13 (85 percent) and 28OW-14 (98 percent). The total CE mass concentration remained relatively stable in all other wells.

The data indicate that the mass concentration of CEs was substantially reduced by the treatment process in areas where substrate was distributed or migrated. The Percent Change in Total CE Mass Concentration during the TS is illustrated in Graph 122.

6.3.4.14 Percent Change in Total Ethenes, Ethane, and Acetylene Molar Concentrations

The percent changes in the molar concentrations of total ethenes, ethane, and acetylene, during the post-injection monitoring phase, were tracked to evaluate the reductive dechlorination process. For instance, an increase in molar concentration relative to mass concentration would indicate that the COCs were undergoing reductive dechlorination. Following substrate injection, the molar concentration in upgradient well 28OW-17 increased by 136 percent. The molar concentrations in treatment area well W9-18 decreased by 82 percent, and 51 percent to 57 percent in downgradient wells 28OW-13 and 28OW-14, respectively. The total molar concentrations remained relatively stable in all other wells during the post-injection monitoring phase.

The molar concentration data, relative to the mass concentration data, indicate that the primary degradation process was reductive dechlorination. The Percent Change in Total Ethenes, Ethane, and Acetylene Molar Concentration during the TS is illustrated in Graph 123.

6.3.4.15 Summary of Volatile Organic Compound Analyses

The analytical results for VOCs confirm that the distribution EHC[®] in the treatment zone have resulted in the degradation of CEs to the nontoxic degradation product ethene. The degradation process has resulted in a conversion of relatively oxidized VOCs (PCE and TCE) to more reduced VOCs (DCE, VC, and ethene). The conversion to more reduced compounds is demonstrated by a shift in the molar fraction of each of these parameters. The changes in the molar fraction of PCE, TCE, DCE, VC, and ethene in groundwater for each of the TS wells are

shown in pie charts provided as Figure 17 for the treatment area wells and downgradient wells and Figure 18 for the upgradient wells. The pie charts present the molar fraction of ethenes and ethane detected in each sample on a per mole basis. As reductive dechlorination progresses, the chemical composition of each sample will change from more chlorinated (PCE and TCE) to less chlorinated (DCE and VC) ethenes and eventually to nonchlorinated ethene and ethane, which is reflected by a progressive change in color from burnt red to red to orange to yellow to green and blue on the pie charts.

The pie charts for the upgradient wells 28OW-17 and 28OW-18 remained relatively unchanged during the TS. The total concentration of CEs remained relatively unchanged in these wells during the TS as shown in Graphs 104a, 104b, 105a, and 105b. These data indicate that the upgradient area was not affected by the distribution of the substrate.

The pie charts for treatment area well 28OW-15 remained unchanged during the TS indicating substrate was not distributed to that location. This well is located approximately 6 feet from the nearest injection point, demonstrating that substrate distribution by hydraulic injection was less than 6 feet laterally at this location. A change in color from primarily red to primarily yellow was observed in the pie charts of treatment area well 28OW-16 indicating gradual dechlorination at that area. The iron, alkalinity, and TOC data do not indicate that substrate was distributed at that location during injection (Graphs 94, 98, and 99, respectively). However, a gradual increase in dissolved iron (Graph 94), dissolved methane (Graph 97), and alkalinity (Graph 98) were observed during the TS as was a decrease in sulfate (Graph 96), suggesting that the change is the result of migration of substrate or partially degraded contaminants into that area by advective transport. The pie chart for well W9-18 shows a near complete conversion of orange and yellow to green indicating near complete dechlorination at that location. The change in ratios corresponds to a near complete decrease in total CE concentration, indicating complete degradation of the CEs. The TOC and alkalinity data (Graphs 98 and 99, respectively) indicate that substantial substrate was distributed to that location during the injection process. This well is located approximately 4 feet from the nearest injection point, confirming that substrate distribution during injection of at least 4 feet. The data indicate that, if sufficient substrate is provided, near complete dechlorination occurs within one year.

The pie charts for downgradient well 28OW-13 show a general change in color from orange to green and yellow indicating substantial conversion of DCE to ethene by Month 9. An increase in VC was observed during the Month 11 sampling event. The conversion corresponds to an increase in the concentrations of DCE and VC indicating CEs may be rebounding at that location. The TOC data (Graph 99) indicate a gradual increase in concentration to day 154 followed by a gradual decrease in concentration. Alkalinity (Graph 98) also increased and decreased during this same period. The rise in TOC concentration immediately following injection indicate that substrate was distributed to that location during injection. This well is

located approximately 16 feet from the nearest injection point. These data, along with the substrate distribution data from the other wells, indicate that the substrate distribution radius is highly irregular and likely controlled by heterogeneity in the aquifer matrix. The gradual increase in alkalinity indicates that either soluble substrate migrated into that area following injection or the distributed substrate was converted to acetate and propionate which are detected as alkalinity. The rebound during the last sampling event may be due to matrix diffusion, advective transport from an upgradient location, or by depletion of substrate at that location.

6.3.5 Biological Parameter - *Dehalococcoides sp*

The concentrations of DHC in the Well W9-18 Area were not measured during the EHC pilot test. DHC was not measured at this study area because the degradation process evaluated was anticipated to be primarily abiotic. However, the degradation process observed appears to be a combination of biotic and abiotic processes.

7.0 Status of the Project Quality Objectives

As described in Section 1.2, the primary objectives of the study were to

- Conduct additional site investigation using a MIP, a NAPL FLUTE™ system, and soil cores to further characterize the areas of interest so that the treatment tests are focused in the areas of highest CE concentrations and to identify a new location for extraction well EA1-1
- Generate site-specific data and evaluate the effectiveness of biotic/abiotic treatment and biostimulation with bioaugmentation treatment at reducing the CE concentrations in the areas of interest to concentrations below the ROD cleanup standard (EPA, 1989 and 1990) and MCLs
- Verify the applicability of the treatment technologies to remediate CEs to levels below the ROD cleanup standard and MCLs both cost-effectively and within a reasonable period of time

Study questions and decision criteria for achieving these objectives were developed in the PQOs process presented in WS #11 of the SAP (Appendix A, Final Work Plan [Shaw, 2010a]). Conclusions to the study questions and decision criteria are described as follows.

Based on the results of the site characterization effort that was performed in support of the treatability study (Shaw, 2010b) and the results of groundwater samples collected from the treatability study observation wells, the most appropriate location for a new extraction well to replace EA1-1 would have been within the treatment area near well W9-18. However, the EHC® treatment successfully degraded the contaminants within the W9-18 study area, thereby eliminating this area as an optimal location for a new extraction well. Also, because the technologies evaluated in the pilot tests are considered potentially applicable for treatment of contaminants in the area of EA1-1, the necessity and location of a replacement for EA1-1 should also consider the remedy the EPA selects from the forthcoming Feasibility Study for the regional groundwater plume. Therefore, a new location for EA1-1 is not identified in this report.

7.1 Study Questions

1. Are DNAPLs present in the A-aquifer in the vicinity of former Building 88, the Traffic Island area, or well W9-18?

- Based on the results of the MIP tests, soil cores, and NAPL FLUTE™ tests completed as part of the hot spot characterization stage of the TS (Shaw, 2011) along with previous soil and groundwater sample data (TtECI, 2008), there is no evidence of DNAPLs being present in the A-aquifer in the vicinity of former Building 88, the traffic island, or well W9-18. However, the results of groundwater samples collected

in the downgradient area of the EVO Pilot Test (Traffic Island Area) indicate the possible presence of a NAPL. This is suggested by the rebound in concentrations of more oxidized CEs (i.e., PCE and TCE) at downgradient well 28OW-04, compared to the low concentrations of these compounds in the upgradient wells 28OW-08 and 28OW-12 (Section 6.1.4.15). The concentrations of PCE and TCE in these three wells were substantially reduced following substrate injection.

2. Have the CE concentrations in groundwater at the study area been reduced to levels equal to or below the ROD cleanup standard (EPA, 1989 and 1990) and MCLs?

- For one or more of the post-injection sampling events, the concentration of PCE in groundwater was reduced to below its MCL (5 µg/L) in all the treatment area wells at the EVO, lactate, and EHC[®] pilot test areas.
- For one or more of the post-injection sampling events, the concentration of TCE in groundwater was reduced to below its ROD cleanup standard (5 µg/L) in all five treatment area wells at the EVO pilot test area and in only one treatment area well at the EHC[®] pilot test area.
- For one or more of the post-injection sampling events, the concentration of 1,2-DCE in groundwater was reduced to below its MCL (6 µg/L) in two treatment area wells at the EVO pilot test area and in one treatment area well at the lactate pilot test area.
- For one or more of the post-injection sampling events, the concentration of 1,1-DCE in groundwater was reduced to below its MCL (6 µg/L) in all five treatment area wells at the EVO pilot test area and in one treatment area well at each of the lactate and EHC[®] pilot test areas.
- The concentration of VC in groundwater was not reduced to below its MCL (0.5 µg/L) in any of the study areas during the performance monitoring period.

3. Are reducing conditions established based on the detection of select metals (arsenic, iron, and manganese), anions (nitrate and sulfate), dissolved gases (oxygen, ethane, ethane, methane, and acetylene), and VOCs in the treatment area?

- Reducing conditions was established in each of the treatment areas as indicated by the increase in arsenic, iron, manganese, ethene, ethane, and methane; and the decrease in DO, nitrate, and sulfate.

4. Are reducing conditions sufficient (i.e., methanogenic) for complete anaerobic abiotic and biotic degradation as established by injection of the substrates?

- Sufficient reducing conditions for complete anaerobic abiotic and biotic degradation was established in each treatment area following substrate injection as indicated by the substantial increase in methane in each area.

5. *Is degradation of the CEs primarily biotic, as indicated by the generation of sequential dehalogenation products, or abiotic, as indicated by the presence of acetylene?*

- The degradation process appears to be primarily biological in each of the study areas; however, abiotic degradation may have been enhanced in the Well W9-18 Area by the distribution of the EHC[®] which is an organic substrate combined with ZVI.

6. *Does the application of the selected substrate maintain highly reducing conditions in the study area throughout the period of performance?*

- EVO Pilot Test (Traffic Island Area): The treatment did not maintain highly reducing conditions for the duration of the TS as indicated by the ORP data; however, continued dechlorination was observed throughout the duration of the TS.
- Lactate Pilot Test (Former Building 88 Area): The treatment did not maintain highly reducing conditions in the study area throughout the period of performance. This is likely due to transport of the lactate out of the study area by advective transport, although lactate is not anticipated to persist in the aquifer at sufficient concentrations to maintain highly reducing conditions for more than about 6 months.
- EHC[®] Pilot Test (Well W9-18 Area): The treatment did not maintain highly reducing conditions for the duration of the TS as indicated by the ORP data; however, dechlorination continued for the duration of the TS.

7. *Is substrate persistent for a sufficient length of time within the period of performance to achieve degradation of the CEs as indicated by alkalinity, dissolved organic carbon, and VFA concentrations in groundwater?*

- Each of the substrates persisted in each of the treatment areas long enough to achieve dechlorination of the CEs to nontoxic ethene; however, the substrates did not persist for a sufficient length of time to achieve complete degradation of all the CEs in each of the areas. Continued degradation was occurring in the EVO Pilot Test and EHC[®] Pilot Test areas at the end of the monitoring period but not at the Lactate Pilot Test area.

7.2 Decision Criteria

The treatment will be considered an effective remedial technology for treatment of CEs at IR Site 28 if:

- *Concentrations of CEs are reduced to levels equal to or below the ROD cleanup standard (EPA, 1989 and 1990) and MCLs.*
 - Although substantial dechlorination was observed, degradation to below the ROD cleanup standard and MCLs was not achieved in any of the TS areas during the monitoring period.

- *Dissolved arsenic concentrations at the completion of the TS are comparable to baseline concentrations before substrate injection.*
 - Dissolved arsenic concentrations in the Lactate Pilot Test and EVO Pilot Test areas increased during the TS, but generally returned to near pre-treatment concentrations by the end of the monitoring period. Dissolved arsenic concentrations increased in the downgradient wells in the EHC[®] Pilot Test area during the post-injection monitoring phase. A decrease in the highest concentrations was observed in the shallow downgradient well (28OW-13) at the end of the study while a gradual increase in the deeper downgradient well (28OW-14) continued throughout the study.
- *No rebound in CE concentrations above on-flow concentrations is observed.*
 - No rebound above on-flow concentrations was observed in any of the treatment area wells during the study.

7.3 Decision Process

If the decision criteria are not achieved by the end of the monitoring period the potential causes for the non attainment of these goals will be evaluated by the decision process described as follows. The following decisions will be made after the end of the test period:

1a. If the MIP and FLUTE[™] tests or soil cores indicate small veins (ganglia) of DNAPL, then the DNAPL on site will be considered potentially treatable using the proposed abiotic/biotic treatment techniques.

- No evidence of small veins (ganglia) of DNAPL was indicated by the MIP tests, FLUTE[™] tests, or soil cores. Based on the Hot Spot characterization data and historical soil and groundwater sample data, DNAPL, if present, is sufficiently small such that the target areas are considered potentially treatable using the proposed abiotic/biotic treatment techniques (Shaw, 2011).

1b. If the MIP and FLUTE[™] tests or soil cores indicate pools or large ganglia of DNAPLs, then the quality and quantity of DNAPL on site will be considered too great to be effectively treated using the proposed abiotic/biotic treatment techniques alone.

- No evidence of pools or large ganglia of DNAPL was indicated by the MIP tests, FLUTE[™] tests, or soil cores (Shaw, 2011).

1c. If the FLUTE[™] tests or soil cores do not identify DNAPL, then the amount of DNAPL present will be considered to be sufficiently small (i.e., not a continuous layer or pool; ganglia at most) in the tested area and treatment of the CEs with the proposed technologies will be considered feasible.

- No evidence of DNAPL was identified by the MIP tests, soil cores, or FLUTE™ tests. Based on the Hot Spot characterization data and historical soil and groundwater sample data, DNAPL, if present, is sufficiently small such that treatment of the CEs with the proposed abiotic/biotic treatment techniques is feasible and should proceed as planned (Shaw, 2011).

2a. If the concentrations of CEs in groundwater at the test area are reduced to levels below the ROD cleanup standard (EPA, 1989 and 1990) and MCLs, then the applicability of selected substrate remediation will be considered for hot spots or other areas of IR Site 28.

- EVO Pilot Test (Traffic Island Area): The concentrations of PCE and TCE in groundwater were reduced to below their MCL and ROD cleanup standard, respectively, in all the treatment area wells during the TS; although, the concentrations in one well rebounded above the cleanup levels by the last event. The concentration of 1,2-DCE in groundwater was reduced to below its MCL in two of the treatment area wells during the TS and was significantly reduced (81 percent to 98 percent) in the other three treatment area wells after initially increasing in concentration. The concentration of 1,1-DCE in groundwater was reduced to below its MCL in all the treatment area wells. The concentration of VC in groundwater was not reduced to its MCL in any of the wells during the monitoring period, but was reduced 3 percent to 97 percent after initially increasing in concentration. However, substantial substrate remained in the treatment area at the end of the TS and degradation was continuing. Therefore, attainment of the MCLs may occur in the future.
- Lactate Pilot Test (Former Building 88 Area): The concentration of PCE in groundwater was reduced below its MCL in both treatment area wells but then increased to concentrations above the MCL after the substrate was consumed. The concentration of TCE in groundwater was not reduced to its ROD cleanup standard in either of the treatment area wells during the TS, but was reduced 98 percent before increasing once the substrate was consumed. The concentration of 1,2-DCE in groundwater was not reduced to its MCL in either of the treatment area wells, but was reduced 44 percent to 89 percent after initially increasing. The concentration of 1,1-DCE in groundwater was reduced to below its MCL in two of the treatment area wells during the TS. The concentration of VC in groundwater was not reduced to its MCL in any of the wells during the TS, but rather increased, along with ethene, in the treatment area wells during the monitoring period. Because substrate is not present in the study area, it is not likely that continued degradation will occur which would result in the attainment of these cleanup levels.
- EHC® Pilot Test (Well W9-18 Area): The concentration of PCE in groundwater was reduced to below its MCL, during the TS, in the one treatment area well that exceeded the level prior to treatment. The concentration of TCE in groundwater was briefly reduced 99 percent, to below its ROD cleanup standard, in one treatment area well but then increased to a concentration above the cleanup standard by the last sampling event. The concentration of 1,2-DCE in groundwater was not reduced to its MCL in any of the treatment area wells during the TS, but was reduced 5 percent to 99.9

percent after initially increasing. The concentration of 1,1-DCE in groundwater was reduced to below its MCL in two of the treatment area wells during the TS. The concentration of VC in groundwater was not reduced to its MCL in any of the wells, but rather increased, along with ethene, in two of the treatment area wells; and decreased 99.7 percent after initially increasing in the other well. However, substantial substrate remains in the treatment area and degradation was continuing at the end of monitoring period. Therefore, attainment of the MCLs may occur in the future.

2b. If the concentrations of CEs in groundwater at the test area are not reduced to levels below the ROD cleanup standard (EPA, 1989 and 1990) and MCLs, then further evaluation of other geochemical indicators (i.e., pH, DO, ORP, nitrate, manganese, arsenic, ferrous iron, sulfate, and methane) will be conducted to determine the reason for the lack of degradation.

- EVO Pilot Test (Traffic Island Area): The biogeochemical parameters indicate that highly reducing conditions conducive to degradation of the CEs were rapidly established in the treatment area and that these conditions were present in some of the treatment area wells at the end of the monitoring period.
- Lactate Pilot Test (Former Building 88 Area): The biogeochemical parameters indicate that sulfate reducing and methanogenic conditions were established only in one well (treatment area well 28OW-21) during the TS. This was also the well in which substantial reductive dechlorination occurred. Sulfate reducing and methanogenic conditions are considered necessary for complete reductive dechlorination. The lack of sufficiently reducing conditions in the other treatment area wells is considered attributable to insufficient distribution of substrate in that area.
- EHC[®] Pilot Test (Well W9-18 Area): The biogeochemical parameters indicate that sulfate reducing and methanogenic conditions were initially established only in treatment area well W9-18 and in both downgradient wells. Sulfate reducing and methanogenic conditions were later established in treatment area well 28OW-16. Only slightly reducing (oxygen reducing) conditions were established in treatment area well 28OW-15 during the TS. The wells in which highly reducing conditions were established correspond to wells in which substantial degradation of the CEs occurred. The lack of sufficient reducing conditions in treatment area well 28OW-15 is considered attributable to insufficient distribution of substrate in the lower permeability materials.

3a. If the concentrations of arsenic, manganese, and iron in groundwater increase over the baseline concentrations, then moderately reducing conditions will be considered to have been established and the acceptability of selected substrate application at IR Site 28 may be further evaluated through additional monitoring of the persistence of these metals in the aquifer (depending on the results of item 1a and 1b, above).

- EVO Pilot Test (Traffic Island Area): The concentrations of arsenic, manganese, and iron in groundwater increased over the baseline concentrations in all the treatment area

wells indicating that moderately reducing conditions were established in the treatment area.

- Lactate Pilot Test (Former Building 88 Area): The concentrations of arsenic, manganese, and iron in groundwater increased over the baseline concentrations in all the treatment area wells indicating that moderately reducing conditions were established in the treatment area.
- EHC[®] Pilot Test (Well W9-18 Area): The concentrations of arsenic, manganese, and iron in groundwater increased over the baseline concentrations in all the treatment area wells, except iron in well (28OW-15), indicating that moderately reducing conditions were established in the treatment area.

3b. If the concentrations of arsenic, manganese, and iron in groundwater do not increase over the baseline concentrations, then moderately reducing conditions will not be considered to have been established.

- EVO Pilot Test (Traffic Island Area): Not Applicable
- Lactate Pilot Test (Former Building 88 Area): Not Applicable
- EHC[®] Pilot Test (Well W9-18 Area): Not Applicable

3c. If the concentrations of nitrate in groundwater decrease below the baseline concentrations, then nitrate reducing conditions will be considered to have been established.

- EVO Pilot Test (Traffic Island Area): The concentration of nitrate in groundwater decreased over the baseline concentrations in all the treatment area wells indicating that nitrate reducing conditions were established in that area.
- Lactate Pilot Test (Former Building 88 Area): The concentration of nitrate in groundwater decreased over the baseline concentrations in the treatment area wells indicating that nitrate reducing conditions were established in that area.
- EHC[®] Pilot Test (Well W9-18 Area): The concentration of nitrate in groundwater decreased over the baseline concentrations in the treatment area wells indicating that nitrate reducing conditions were established in that area.

3d. If the concentrations of nitrate in groundwater do not decrease below the baseline concentrations, then nitrate reducing conditions will not be considered to have been established, in which case other potential causes for the persistence of the nitrate will be evaluated.

- EVO Pilot Test (Traffic Island Area): Not Applicable
- Lactate Pilot Test (Former Building 88 Area): Not Applicable
- EHC[®] Pilot Test (Well W9-18 Area): Not Applicable

3e. If the concentrations of sulfate in groundwater decrease below the baseline concentrations then sulfate reducing conditions will be considered to have been established.

- EVO Pilot Test (Traffic Island Area): The concentration of sulfate in groundwater decreased over the baseline concentrations in all the treatment area wells indicating that sulfate reducing conditions were established in that area.
- Lactate Pilot Test (Former Building 88 Area): The concentration of sulfate in groundwater decreased over the baseline concentrations in only one well (28OW-21) in the treatment area indicating that sulfate reducing conditions were only established in that area. Although, the concentration of sulfate in well 28OW-21 increased in all samples following the Day 81 post-injection sampling event (November 2010), indicating sulfate reducing conditions were not maintained at that location.
- EHC[®] Pilot Test (Well W9-18 Area): The concentration of sulfate in groundwater decreased substantially below background concentrations in two of the three treatment area wells and in both downgradient wells, indicating sulfate reducing conditions were established in those locations. The concentration of sulfate did not decrease in one treatment area well (28OW-15) indicating sulfate reducing conditions were not established at that location.

3f. If the concentrations of sulfate in groundwater do not decrease below the baseline concentrations, then sulfate reducing conditions will not be considered to have been established, in which case other potential causes for the persistence of the sulfate will be evaluated.

- EVO Pilot Test (Traffic Island Area): Not Applicable
- Lactate Pilot Test (Former Building 88 Area): The concentrations of sulfate in groundwater decreased over the baseline concentrations in only one well in the treatment area (28OW-21) indicating that sulfate reducing conditions were only established in that area. The concentration of sulfate in well 28OW-21 increased in all samples following the Day 81 post-injection sampling event (November 2010), indicating sulfate reducing conditions were not maintained at that location. The persistence of sulfate in the area of treatment area well 28OW22 is attributed to insufficient substrate distribution in that area as indicated by the alkalinity and TOC analytical results.
- EHC[®] Pilot Test (Well W9-18 Area): The concentrations of sulfate in groundwater decreased substantially below background concentrations in two of the three treatment area wells and in both downgradient wells, indicating sulfate reducing conditions were established in those locations. The concentration of sulfate did not decrease in one treatment area well (28OW-15) indicating sulfate reducing conditions were not established at that location. The persistence of sulfate in well 28OW-15 is attributed to the lack of substrate distribution in that area as indicated by the alkalinity and TOC analytical results. Sulfate reducing condition were established in wells in which substrate was distributed.

3g. If the concentration of oxygen in groundwater decreases relative to baseline concentrations, then oxygen reducing and anaerobic conditions (DO <0.5 mg/L) have been established in the treatment area.

- EVO Pilot Test (Traffic Island Area): Anaerobic conditions (DO less than 0.5 mg/L) were established in the treatment area during the TS.
- Lactate Pilot Test (Former Building 88 Area): Anaerobic conditions (DO less than 0.5 mg/L) were established in the treatment area during the TS.
- EHC[®] Pilot Test (Well W9-18 Area): Anaerobic conditions (DO less than 0.5 mg/L) were established in the treatment area during the TS.

3h. If oxygen concentrations in groundwater in the treatment area do not decrease below baseline concentrations, then oxygen reducing and anaerobic (DO <0.5 mg/L) conditions have not been established in the treatment area.

- EVO Pilot Test (Traffic Island Area): Not Applicable
- Lactate Pilot Test (Former Building 88 Area): Not Applicable
- EHC[®] Pilot Test (Well W9-18 Area): Not Applicable

3i. If the concentrations of ethene, ethane, methane, and acetylene in groundwater increase over the baseline concentrations, then reducing conditions for complete degradation of the VOCs will be considered to have been established.

- EVO Pilot Test (Traffic Island Area): The concentrations of ethene, ethane, and methane substantially increased in the treatment area wells over baseline concentrations indicating reducing conditions conducive for complete degradation of the VOCs was established in the treatment area. The concentrations of acetylene decreased relative to baseline concentrations. The decrease in acetylene concentrations is considered attributable to increased biological degradation of acetylene resulting from enhancement of the indigenous and augmented microbial populations.
- Lactate Pilot Test (Former Building 88 Area): The concentrations of ethene, ethane, and methane substantially increased in the treatment area wells over baseline concentrations indicating reducing conditions conducive for complete degradation of the VOCs was established in that area. The concentrations of acetylene decreased relative to baseline concentrations. The decrease in acetylene concentrations is considered attributable to increased biological degradation of acetylene resulting from enhancement of the indigenous and augmented microbial populations.
- EHC[®] Pilot Test (Well W9-18 Area): The concentrations of ethene, ethane, and methane substantially increased in the treatment area wells over baseline concentrations indicating reducing conditions conducive for complete degradation of

the VOCs was established in that area. The concentrations of acetylene decreased relative to baseline concentrations. The decrease in acetylene concentrations is considered attributable to increased biological degradation of acetylene resulting from enhancement of the indigenous and augmented microbial populations.

3j. If the concentrations of ethene, ethane, methane, and acetylene in groundwater do not increase over the baseline concentrations, then reducing conditions for complete degradation of the VOCs may not be considered to have been established, in which case other potential causes for the lack of these dissolved gases will be evaluated.

- EVO Pilot Test (Traffic Island Area): Not Applicable, see the discussion under 3i.
- Lactate Pilot Test (Former Building 88 Area): Not Applicable, see the discussion under 3i.
- EHC[®] Pilot Test (Well W9-18 Area): Not Applicable, see the discussion under 3i.

3k. If the concentrations of individual VOCs in groundwater decrease below the baseline concentrations, then reducing conditions to degrade each VOC will be considered to have been established.

- EVO Pilot Test (Traffic Island Area): The concentrations of PCE, TCE, and 1,1-DCE decreased to below baseline concentrations in the treatment area wells indicating reducing conditions conducive to degrading these VOCs was established in the treatment area. 1,2-DCE concentrations decreased below the baseline concentrations in two of the treatment area wells and was significantly reduced in the other three treatment area wells after initially increasing from being produced by the degradation of PCE and TCE. Based on the presence of VC and these observed decreases of 1,2-DCE, reducing conditions conducive to degrading 1,2-DCE was established in the treatment area. The concentration of VC decreased to below baseline concentrations in only one treatment area well and decreased significantly (97 percent) in another of the treatment area wells. In the other three treatment area wells, VC increased (accumulated) during the monitoring period as a product of the sequential degradation of PCE, TCE, and DCE. At the same time VC is accumulating in these wells, ethene is also increasing in these wells indicating the VC is being degraded. Based on these observations of VC and ethene, reducing conditions conducive to degrading VC was established in the treatment area. Because substrate is still present at this location, it is likely that all VOCs will be treated to below background concentrations.
- Lactate Pilot Test (Former Building 88 Area): The concentrations of PCE, TCE, and 1,1-DCE decreased to below baseline concentrations in the treatment area wells indicating reducing conditions conducive to degrading these VOCs was established in the treatment area. Although 1,2-DCE and VC were not degraded to below baseline concentrations, the presence of VC confirms that sufficiently reducing conditions for the degradation of DCE had been established, and the presence of ethene indicates that sufficiently reducing conditions for the degradation of VC had been established. It is

considered likely that provided sufficient substrate and time DCE and VC concentrations would be reduced to below background concentrations.

- EHC[®] Pilot Test (Well W9-18 Area): The concentrations of PCE, TCE, and DCE decreased to below baseline concentrations in two of the three treatment area wells and in both downgradient wells, indicating reducing conditions conducive to degrading these VOCs was established in those areas. The concentration of VC decreased substantially in treatment area well W9-18 but did not decrease substantially in the other wells. The CEs, alkalinity, and TOC data indicate that sufficient reducing conditions for treatment of all VOCs was established in portions of the TS area in which sufficient substrate was distributed.

3l. If the concentrations of individual VOCs in groundwater do not decrease below the baseline concentrations, then reducing conditions to degrade each VOC may not be established, in which case other potential causes for the persistence of the VOCs will be evaluated.

- EVO Pilot Test (Traffic Island Area): Not Applicable, see the discussion under 3k.
- Lactate Pilot Test (Former Building 88 Area): The persistence of VC above background concentrations is attributed to very low initial background VC concentrations and incomplete dechlorination of TCE and DCE resulting from insufficient substrate.
- EHC[®] Pilot Test (Well W9-18 Area): Not Applicable, see the discussion under 3k.

4a. If dissolved methane is detected above method RLs (WS #15) in groundwater at the test area at the end of the monitoring period, then reducing conditions for complete conversion of VC to ethene by reductive processes will be considered established.

- EVO Pilot Test (Traffic Island Area): Methane was detected above method RLs at the end of the monitoring period indicating reducing conditions for complete conversion of VC to ethene by reductive processes had been established.
- Lactate Pilot Test (Former Building 88 Area): Methane was detected above method RLs at the end of the monitoring period indicating reducing conditions for complete conversion of VC to ethene by reductive processes had been established.
- EHC[®] Pilot Test (Well W9-18 Area): Methane was detected above method RLs at the end of the monitoring period indicating reducing conditions for complete conversion of VC to ethene by reductive processes had been established.

4b. If dissolved methane is not detected above method RLs (WS #15) in groundwater at the test area prior to the end of the monitoring period, then reducing conditions for complete degradation of CEs by reductive processes may not be considered established and an evaluation of other geochemical parameters (i.e., ORP, electron acceptors) will be completed to determine if reducing conditions have been attained.

- EVO Pilot Test (Traffic Island Area): Not Applicable
- Lactate Pilot Test (Former Building 88 Area): Not Applicable
- EHC[®] Pilot Test (Well W9-18 Area): Not Applicable

5a. If acetylene is detected above method RLs (WS #15) in groundwater at the test area, then the abiotic remediation process will be confirmed.

- EVO Pilot Test (Traffic Island Area): Acetylene was detected in groundwater in baseline samples indicating abiotic degradation was occurring prior to the initiation of the pilot test.
- Lactate Pilot Test (Former Building 88 Area): Acetylene was detected in groundwater in baseline samples indicating abiotic degradation was occurring prior to the initiation of the pilot test.
- EHC[®] Pilot Test (Well W9-18 Area): Acetylene was detected in groundwater in baseline samples indicating abiotic degradation was occurring prior to the initiation of the pilot test.

5b. If acetylene is not detected above method RLs (WS #15) in groundwater at the test area, then the abiotic remediation process will not be confirmed.

- EVO Pilot Test (Traffic Island Area): Not Applicable
- Lactate Pilot Test (Former Building 88 Area): Not Applicable
- EHC[®] Pilot Test (Well W9-18 Area): Not Applicable

6a. If the ORP of the groundwater at the test area is lower than -150mV by the end of the period of performance, then the application of substrate has maintained highly reducing conditions throughout the monitoring period.

- EVO Pilot Test (Traffic Island Area): The ORP ranged from -56 mV to -169 mV in the treatment area wells during the final sampling event. The data indicates that moderately to highly reducing conditions were maintained in the treatment area throughout the monitoring period.
- Lactate Pilot Test (Former Building 88 Area): The ORP ranged from -105 mV to -247 mV in the treatment area wells during the final sampling event. The data indicates that highly reducing conditions were maintained in the treatment area throughout the monitoring period.
- EHC[®] Pilot Test (Well W9-18 Area): The ORP ranged from -75 mV to -201 mV in the treatment area wells during the final sampling event. The data indicates that

moderately to highly reducing conditions were maintained in the treatment area throughout the monitoring period.

6b. If the ORP of the groundwater at the test area is higher than -150mV by the end of the monitoring period, then the application of substrate may not have maintained highly reducing conditions throughout the monitoring period and the level of reducing conditions will be evaluated relative to other geochemical parameters (i.e., electron acceptor data), VOCs, and dissolved gases.

- EVO Pilot Test (Traffic Island Area): Not Applicable
- Lactate Pilot Test (Former Building 88 Area): Not Applicable
- EHC[®] Pilot Test (Well W9-18 Area): Not Applicable

6c. If the DO concentrations are reduced to below 1.0 mg/L in the test area, then anaerobic conditions will be considered to have been established.

- EVO Pilot Test (Traffic Island Area): DO concentrations in the treatment area were reduced to below 1.0 mg/L confirming that anaerobic conditions were established in that area.
- Lactate Pilot Test (Former Building 88 Area): DO concentrations in the treatment area were reduced to below 1.0 mg/L confirming that anaerobic conditions were established in that area.
- EHC[®] Pilot Test (Well W9-18 Area): DO concentrations in the treatment area were reduced to below 1.0 mg/L confirming that anaerobic conditions were established in that area.

6d. If the pH of the groundwater in the test area drops and remains below 5 SU, then the pH will be considered too low for biological degradation of the CEs and may require pH adjustment.

- EVO Pilot Test (Traffic Island Area): The minimum pH of the groundwater in the treatment area during the monitoring period was reported at 5.8 SU. Therefore, the pH is considered sufficiently high for biological degradation of the CEs and does not require adjustment.
- Lactate Pilot Test (Former Building 88 Area): The minimum pH of the groundwater in the treatment area during the monitoring period was reported at 6.34 SU. Therefore, the pH is considered sufficiently high for biological degradation of the CEs and does not require adjustment.
- EHC[®] Pilot Test (Well W9-18 Area): The minimum pH of the groundwater in the treatment area during the monitoring period was reported at 5.86 SU. Therefore, the

pH is considered sufficiently high for biological degradation of the CEs and does not require adjustment.

6e. If dissolved manganese concentrations increase significantly (>25 percent) in the test area, then manganese reducing conditions will be considered to be established.

- EVO Pilot Test (Traffic Island Area): The concentration of manganese in the treatment area wells increased >25 percent during the monitoring period indicating manganese reducing conditions had been established in the treatment area.
- Lactate Pilot Test (Former Building 88 Area): The concentration of manganese in the treatment area wells increased >25 percent during the monitoring period indicating manganese reducing conditions had been established in the treatment area.
- EHC[®] Pilot Test (Well W9-18 Area): The concentration of manganese in the treatment area wells increased >25 percent during the monitoring period indicating manganese reducing conditions had been established in the treatment area.

6f. If ferrous iron is detected above method RLs in groundwater at the test area, then iron reducing conditions will be considered potentially established, although it is recognized that ferrous iron may be derived from oxidation of the ZVI in the EHC[®] substrate.

- EVO Pilot Test (Traffic Island Area): Ferrous iron was detected above method RLs in treatment area groundwater confirming that iron reducing conditions had been established.
- Lactate Pilot Test (Former Building 88 Area): Ferrous iron was detected above method RLs in treatment area groundwater confirming that iron reducing conditions had been established.
- EHC[®] Pilot Test (Well W9-18 Area): Ferrous iron was detected above method RLs in treatment area groundwater confirming that iron reducing conditions had been established.

6g. If sulfate concentrations in groundwater decrease from the concentrations measured during the baseline sampling in the treated area relative to upgradient groundwater concentrations, then sulfate reducing conditions will be considered to be established in the test area.

- EVO Pilot Test (Traffic Island Area): The concentration of sulfate in treatment area wells decreased relative to upgradient wells during the monitoring period indicating that sulfate reducing conditions had been established in the test area.
- Lactate Pilot Test (Former Building 88 Area): The concentration of sulfate in treatment area wells decreased relative to upgradient wells during the monitoring period indicating that sulfate reducing conditions had been established in the test area.

- EHC[®] Pilot Test (Well W9-18 Area): The concentration of sulfate in treatment area wells decreased relative to upgradient wells during the monitoring period indicating that sulfate reducing conditions had been established in the test area.

7a. If alkalinity, TOC, and VFA concentrations indicate that substrate is present and geochemical parameters (i.e., DO, nitrate, manganese, ferrous iron, sulfate, methane) indicate that reducing conditions are maintained in the treatment area, then substrate is present for continued degradation of the CEs.

- EVO Pilot Test (Traffic Island Area): Alkalinity data indicate that substrate was present in all treatment area wells at the end of the monitoring period. TOC data indicate that substrate is present in the area of well 28OW-12. Geochemical parameters indicate reducing conditions are maintained for continued degradation of the CEs beyond the monitoring period.
- Lactate Pilot Test (Former Building 88 Area): Alkalinity data indicate substrate was present in treatment area well 28OW-21 at the end of the monitoring period. However, TOC data indicate that no substrate is present in the treatment area at the end of the monitoring period. Geochemical data indicate that insufficient substrate is available for continued degradation beyond the end of the monitoring period.
- EHC[®] Pilot Test (Well W9-18 Area): Alkalinity data indicate that substrate remained present in two treatment area wells (W9-18 and 28OW-16) at the end of the monitoring period. TOC data indicate that substrate is present in the area of well W9-18 and both downgradient wells at the end of the monitoring period. Geochemical parameters indicate reducing conditions are maintained for continued degradation of the CEs beyond the monitoring period.

7b. If alkalinity, TOC, and VFA concentrations indicate that substrate has been depleted and geochemical parameters (i.e., DO, nitrate, manganese, ferrous iron, sulfate, methane) indicate that conditions are becoming less reducing, then substrate is present for continued degradation of the CEs.

- EVO Pilot Test (Traffic Island Area): Not Applicable
- Lactate Pilot Test (Former Building 88 Area): Alkalinity, TOC and geochemical data indicate that insufficient substrate is present for continued degradation of the CEs.
- EHC[®] Pilot Test (Well W9-18 Area): Not Applicable

8.0 *Waste Handling and Disposal*

The handling and disposal of the solid and liquid waste streams generated during the TS are described in the following subsections.

8.1 *Solid Waste*

The solid waste stream consisted primarily of soil cuttings generated during the installation of monitoring wells with some concrete/asphalt debris and sediment from equipment decontamination, well development, groundwater sampling, and surfaced liquid recovery. The solid waste was contained in two 20-cubic yard roll-off bins and temporarily stored in Shaw's temporary staging area at Moffett Field pending characterization and disposal at an approved off-site facility. A waste characterization soil sample was collected from the bins in August 2010 for profiling in accordance with the receiving facility's requirements, which required analysis for VOCs by EPA Method 5035/8260B, Title 22 Metals by Method 3050B/6010B and Method 7471A, and STLC by Method 6010B. The laboratory analytical report for the waste characterization soil sample is provided in Appendix H. Based on the detection of PCE in the sample and because this chemical originated from use as a dry cleaning solvent at the site, the waste was designated as Resource Conservation and Recovery Act (RCRA)-regulated hazardous waste.

On November 22, 2010, approximately 29 tons (two bins) of RCRA-regulated hazardous solid waste were transported and disposed at an EPA-approved Class I landfill (Chemical Waste Management, Inc. facility) in Kettleman City, California. The waste manifests are included in Appendix J.

In addition to the soil waste, the empty drums and totes that had temporarily contained liquid waste (Section 8.2) and the non-hazardous lactate and EVO products were disposed appropriately at an off-site facility. On November 10, 2010, 28 containers (seventeen 55-gallon drums and eleven 250 gallon totes) were transported and disposed as non-hazardous solid waste at a California-approved Class II landfill (Republic Services Forward Landfill) in Manteca, California. The waste manifest is included in Appendix J.

8.2 *Liquid Waste*

The liquid waste consisted of several streams including equipment decontamination rinsate water, well development water, well sampling purge water, liquids that surfaced during injection, liquids recovered from the temporarily isolated storm drain lines, and rinsate from cleanout of the substrate solutions bulk holding tanks and amendments batch tank. The equipment decontamination rinsate water, well development water, well sampling purge water, and the

liquids that surfaced during injection were contained in 55-gallon steel drums and temporarily stored at Shaw's temporary staging area at Moffett Field pending transport to WATS for treatment. The liquids recovered from the temporarily isolated storm drain lines and the rinsate from cleanout of the bulk holding tanks and batch tank were collected by a vacuum truck and immediately transported to WATS for treatment and discharge (Section 3.4).

Between June 2010 and June 2011, a total of approximately 11,670 gallons of liquid waste was delivered to WATS for treatment and discharge under a National Pollutant Discharge Elimination System permit. Following are the estimated volumes for each liquid stream:

- 570 gallons of equipment decontamination rinsate water
- 1,940 gallons of well development water
- 320 gallons of well sampling purge water
- 400 gallons of liquids that surfaced during injection
- 7,940 gallons of liquids recovered from the temporarily isolated storm drain lines
- 500 gallons of rinsate from cleanout of the bulk holding tanks and batch tank

9.0 *Treatability Study Conclusions*

The purpose of the TS was to determine if biotic/abiotic treatment and biostimulation with bioaugmentation treatment are viable alternatives for remediating the remaining CEs present in the upper and lower portions of the A-aquifer at IR Site 28.

The following conclusions are based on the results of the biostimulation with bioaugmentation treatment pilot test performed in the Traffic Island Area that used an EVO and SDC-9™ amendment.

- The presence of acetylene in baseline samples indicates that intrinsic abiotic degradation of the CEs was occurring prior to the pilot test.
- It was acceptable to use untreated site groundwater, obtained from the WATS influent, as the mix water for the substrate solution. The addition of LactOil™ to the WATS water rapidly established reducing conditions in the substrate solution prior to augmentation with SDC-9™ and injection into the treatment zone.
- The LactOil™ solution left a residue on the inner walls of the mixing tanks which required an additional effort to clean out the tanks.
- The bioaugmentation process used at the site (i.e., amending the substrate solution with the microbial culture prior to injection) was an effective method for delivering the dechlorinating culture (SDC-9™) to the treatment zone.
- Direct injection was an effective mechanism for delivering the LactOil™ and SDC-9™ amendment through the treatment area to a depth of 65 feet bgs.
- Injection of the LactOil™ and SDC-9™ amendment rapidly established highly reducing conditions conducive to biological degradation of the CEs in the treatment area.
- Changes in the aquifer biogeochemistry indicative of the progressive establishment of highly reducing conditions, including oxygen, nitrate, arsenic, manganese, iron, and sulfate reduction and methanogenesis, were observed in the treatment area after injection of the LactOil™ and SDC-9™ amendment.
- Upon the establishment of highly reducing conditions, sequential reductive dechlorination of the CEs was observed in the treatment area and in several downgradient wells.
- The concentrations of PCE and TCE in groundwater were reduced to below their MCL and ROD cleanup standard (EPA, 1989 and 1990), respectively, in all the treatment area wells during the performance monitoring period; although, the concentrations in one well increased back above the cleanup levels by the last event.

- The concentration of 1,2-DCE in groundwater was reduced to below its MCL in two of the treatment area wells during the TS and was significantly reduced (81 percent to 98 percent) in the other three treatment area wells after initially increasing in concentration.
- The concentrations of 1,1-DCA and 1,1-DCE in groundwater were reduced to below their MCLs in all the treatment area wells during the TS.
- The concentration of VC in groundwater was not reduced to its MCL in any of the wells, but was reduced 3 percent to 97 percent after initially increasing in concentration from the sequential degradation PCE, TCE, and DCE.
- Substantial substrate remained in the treatment area at the end of the performance monitoring period and degradation was continuing. Therefore, attainment of MCLs may occur in the future.
- The reductive dechlorination process continued to ethene and ethane. The concentrations of ethene and ethane substantially increased in the treatment area wells over baseline concentrations indicating reducing conditions conducive for complete degradation of the VOCs was established in the treatment area.
- The highest concentration of ethene observed (7,100 µg/L) can be equated to the complete dechlorination of 41,970 µg/L of PCE to nontoxic ethene.
- Alkalinity data indicate that substrate remained in the treatment area at the end of the performance monitoring period. However, TOC data indicate that the substrate had been substantially utilized by the end of the TS.
- Biogeochemical data indicate that highly reducing conditions had been maintained throughout the TS.
- The EVO and SDC-9™ amendment was relatively easy to prepare and inject. Surfacing of the amendment was minimal and controlled by reducing the injection flow rate. No significant issues with plugging of the injection equipment or with the formation accepting the amendment were encountered. Although, cleanup of the EVO mixing tanks was more difficult than expected due to a residue that formed on the tank walls. According to JRW Bioremediation LLC, the residue was comprised mostly of scale formed by a combination of biological and chemical activity that occurred over an extended period of time. In order to prevent this type of scale buildup in the future, JRW Bioremediation LLC recommended to regularly clean the tanks, pumps, and hoses and to not store dilute substrate for more than several days before injecting.

The following conclusions are based on the results of the biostimulation with bioaugmentation treatment pilot test performed in the Former Building 88 Area that used a lactate and SDC-9™ amendment.

- It was acceptable to use untreated site groundwater, obtained from the WATS influent, as the mix water for the substrate solution. The addition of WILCLEAR® sodium

lactate to the WATS water rapidly established reducing conditions in the substrate solution prior to augmentation with SDC-9™ and injection into the treatment zone.

- The bioaugmentation process used at the site (i.e., amending the substrate solution with the microbial culture prior to injection) was an effective method for delivering the dechlorinating culture (SDC-9™) to the treatment zone.
- Substantial substrate was only observed in one treatment area well following injection of the WILCLEAR® and SDC-9™ amendment indicating non-uniform distribution of substrate in the treatment area.
- Following injection of the WILCLEAR® and SDC-9™, highly reducing conditions conducive to biological degradation of CEs were established rapidly in the vicinity of the treatment area well where substrate was distributed.
- Changes in the aquifer biogeochemistry indicative of the progressive establishment of highly reducing conditions, including oxygen, nitrate, arsenic, manganese, iron, and sulfate reduction and methanogenesis, were observed in the amended treatment area well.
- Upon the establishment of highly reducing conditions, sequential reductive dechlorination of the CEs was observed in the treatment area where sufficient substrate was distributed.
- The concentration of PCE in groundwater was reduced below its MCL in both treatment area wells but then returned to concentrations above the MCL after the substrate was consumed.
- The concentration of TCE in groundwater was not reduced to its ROD cleanup standard in either of the treatment area wells during the TS, but was reduced 98 percent before increasing once the substrate was consumed.
- The concentration of 1,2-DCE in groundwater was not reduced to its MCL in either of the treatment area wells during the TS, but was reduced 44 percent to 89 percent after initially increasing from degradation of PCE and TCE.
- The concentration of 1,1-DCE in groundwater was reduced to below its MCL in both treatment area wells during the TS.
- The concentration of VC in groundwater was not reduced to its MCL in any of the wells, but rather increased, along with ethene, in the treatment area wells during the monitoring period. The increase of VC was the result of the sequential degradation of PCE, TCE, and DCE.
- The concentration of 1,1-DCA in groundwater was not reduced to below its MCL in the treatment area wells. An approximately 20 percent decrease in concentration of 1,1 DCA was observed along with a slight increase in chloroethane and ethane indicating that 1,1-DCA underwent reductive dechlorination.

- It is considered likely that provided sufficient substrate and time 1,2-DCE, VC, and 1,1-DCA concentrations would be reduced to below their MCLs.
- The reductive dechlorination process continued to ethene and ethane. The concentrations of ethene and ethane substantially increased in the treatment area wells over baseline concentrations indicating reducing conditions conducive for complete degradation of the VOCs was established in the treatment area.
- The highest concentration of ethene observed (660 µg/L) can be equated to the complete dechlorination of 3,901µg/L of PCE to nontoxic ethene.
- Alkalinity data indicate that substrate remained present in the treatment area at the end of the TS. However, TOC data indicate that no substrate was present in the treatment area at the end of the TS. Geochemical data indicate that insufficient substrate is available for continued degradation beyond the end of the monitoring period.
- Biogeochemical data indicate that highly reducing conditions (i.e., sulfate reducing and methanogenic) were not maintained throughout the TS in the treatment area.
- The lactate and SDC-9™ amendment was easy to prepare and inject. Surfacing of the amendment was minimal and easily controlled by reducing the injection flow rate. No issues with plugging of the injection equipment or with the formation accepting the amendment were encountered. Cleanup of the lactate mixing tanks was straightforward and did not require any extra level of effort to complete beyond simply rinsing.

The following conclusions are based on the results of the biotic/abiotic treatment pilot test in the Well W9-18 Area that used EHC®:

- The injection process slightly mounded the overlying asphalt surface.
- Distribution of the EHC®, conducted using DPT, required relatively high injection pressures to achieve an adequate radius of influence, particularly in the lower permeability aquifer matrices. The upper bound injection pressure was limited by surfacing of the EHC® slurry during injection. These upper bound pressures decreased as the injection intervals approached surface grade. Therefore, the radius of distribution in the shallower (lower permeability) intervals is not as large as in the deeper (higher permeability) intervals. Other injection techniques, such as pneumatic fracturing and injection are available but at substantially higher costs and would also likely result in slurry surfacing issues.
- Substantial substrate was only observed in one treatment area well following injection of the EHC® indicating non-uniform distribution of the substrate in the treatment area.
- Changes in the aquifer biogeochemistry indicative of the progressive establishment of highly reducing conditions, including oxygen, nitrate, arsenic, manganese, iron, and sulfate reduction and methanogenesis, were observed in the affected treatment area well and both downgradient wells.

- Following injection of EHC[®], highly reducing conditions conducive to the biotic and abiotic degradation of CEs were established rapidly in the vicinity of the treatment area and downgradient wells where sufficient substrate was distributed.
- Upon establishment of highly reducing conditions, reductive dechlorination of PCE, TCE, DCE, and VC was observed.
- The concentration of PCE in groundwater was reduced to below its MCL, during the monitoring period, in the one treatment area well that exceeded the level prior to treatment.
- The concentration of TCE in groundwater was briefly reduced 99 percent, to below its ROD cleanup standard, in one treatment area well but then returned to a concentration above the cleanup standard by the last sampling event.
- The concentration of 1,2-DCE in groundwater was not reduced to its MCL in any of the treatment area wells during the TS, but was reduced 5 percent to 99.9 percent after initially increasing from the degradation of PCE and TCE.
- The concentration of 1,1-DCE in groundwater was reduced to below its MCL in two of the treatment area wells during the TS.
- The concentration of VC in groundwater was not reduced to its MCL in any of the wells during the TS, but rather increased, along with ethene, in two of the treatment area wells; and decreased 99.7 percent after initially increasing in the other treatment area well. The increase of VC was the result of the sequential degradation of PCE, TCE, and DCE.
- The concentration of 1,1-DCA in groundwater was reduced to below its MCL in only one treatment area well during the TS. A slight increase in chloroethane and ethane were observed along with the decrease in 1,1-DCA indicating that 1,1-DCA underwent reductive dechlorination.
- Substrate remains in the treatment area and degradation was continuing at the end of monitoring period. Therefore, attainment of the ROD cleanup standard and MCLs may occur in the future.
- DCE stall did not occur in the treatment area following injection of EHC[®].
- Degradation of the CEs appears to be primarily by biological processes; however, abiotic degradation pathways were confirmed as well.
- The EHC[®] slurry was the easiest to prepare but was relatively difficult to inject due to the high solids content of the slurry combined with the heterogeneity of the aquifer matrix that limited the amount of slurry the formation could accept. Surfacing was frequent and difficult to control without forfeiting distribution or encountering equipment plugging issues. It took more time per point to inject the EHC[®] slurry than either the EVO or lactate amendments. Cleanup of the EHC[®] slurry mixing tank was straightforward and did not require any extra level of effort to complete beyond simply rinsing.

10.0 Summary of Conclusions

Based on the test results, each treatment process was determined to be effective in degrading PCE, TCE, and DCE to below the MCLs and ROD cleanup standard (EPA, 1989 and 1990) within the timeframe of this TS. Although substantial degradation of VC was observed in each treatment area, VC remained above its MCL at each test area. It is considered likely that ongoing degradation will continue in each of the areas where substrate is present.

Baseline analysis confirmed that acetylene was present in the groundwater prior to substrate injection. Acetylene is the nonchlorinated product of abiotic degradation of CEs and its presence confirms that intrinsic abiotic degradation of the CEs is occurring in the aquifer. It is notable that the highest concentrations of acetylene correspond to areas of high CE concentration. A possible cause for the accumulation of acetylene in these areas is that the high concentrations of CEs inhibit the biological degradation of the acetylene by indigenous microorganisms. Because acetylene is highly prone to chemical breakdown, its presence suggests that intrinsic abiotic degradation of the CEs is an important attenuating process at the site. Therefore, abiotic degradation processes should be considered when evaluating the natural attenuation of the CEs in the plume.

The TS successfully demonstrated that each of the substrates and the bioaugmentation culture could be distributed throughout the treatment areas in each of the separate study areas. Conversion of DCE to VC and of VC to ethene occurred in each bioaugmentation area. Because biological reductive dechlorination of DCE and VC requires the presence of DHC, the presence of substantial VC and ethene indicate that the bioaugmentation culture (SDC-9™) was effectively distributed with the substrates and remained viable following injection. These data confirm that the process for conditioning the injection water prior to injection was sufficient for establishing suitable conditions in the aquifer very shortly after substrate injection. Therefore, preconditioning of the aquifer (i.e., establishing methanogenic conditions) is not considered required prior to bioaugmentation.

The data indicate that substrate distribution is substantially affected by the aquifer heterogeneity and hydrogeology. The data from the EHC® Pilot Test (Well W9-18 Area) indicated that substrate distribution transverse to the paleochannels and general groundwater flow direction may be less than 6 feet in some areas but may have been distributed as far as 15 feet or more in the direction of the paleochannels/groundwater flow direction. Data from the EVO Pilot Test (Traffic Island Area) indicate that substrate was distributed into downgradient well 28OW-02 but not in the other downgradient wells indicating the presence of zones of preferential substrate distribution.

The data from the Lactate Pilot Test (Former Building 88 Area) indicate that the substrate was not observed in the higher permeability zones following injection, suggesting that the substrate may have been widely dispersed during injection and moved out of the treatment area by advective transport.

The treatment technique (biostimulation with bioaugmentation) applied in the EVO Pilot Test (Traffic Island Area) and Lactate Pilot Test (Former Building 88 Area) relied entirely on the enhancement of biological degradation processes. As anticipated, the analytical results are consistent with biological reductive dechlorination of CEs. The detection of minor amounts of acetylene in the baseline samples in the Traffic Island Area wells indicates that intrinsic abiotic degradation may be occurring as well. The likely generation of reactive iron-sulfide species resulting from the biological process following injection of the organic substrate, may also have enhanced the abiotic degradation as well.

The data from the biotic/abiotic treatment technique applied in the EHC[®] Pilot Test (Well W9-18 Area) indicates that the primary degradation process (biological or abiotic) is not determined. The biological reductive dechlorination pathway is indicated by the near stoichiometric increase in VC following the degradation of cis-1,2-DCE as shown in treatment area wells W9-18 and 28OW-16 and in downgradient wells 28OW-13 and 28OW-14. As discussed previously, the abiotic degradation of DCE by hydrogenolysis would result in the production of minor amounts of VC. Substantial ethene was generated in the Well W9-18 Area, however, ethene is the nonchlorinated product of both biological and abiotic degradation processes. No acetylene was detected that would confirm the abiotic degradation process; however, acetylene is very prone to chemical breakdown and is not anticipated to persist in areas where substantial biological activity is occurring. Therefore, the absence of acetylene does not confirm or refute the occurrence of the abiotic degradation processes.

Although the data indicate that dechlorination may be occurring biologically in the area of the EHC[®] Pilot Test (Well W9-18 Area), the complete biological dechlorination of DCE to ethene requires the presence of DHC. Bioaugmentation was not conducted at this location and therefore analysis for the presence of DHC was not conducted during the TS. However, data suggest that an indigenous population of DHC is likely present in this area. DHC were detected in the area of the Lactate Pilot Test (Former Building 88 Area), upgradient of the EHC[®] Pilot Test area (Well W9-18 Area), and VC and ethene were detected in the EHC[®] Pilot Test Area prior to treatment. Therefore, if biological degradation is occurring biostimulation of the indigenous dechlorinating population may be sufficient to achieve complete dechlorination of CEs.

The distribution of each of the substrates resulted in the rapid establishment of conditions conducive to the biological or abiotic degradation of the CEs. The reductive dechlorination of the CEs occurred immediately following the injection of each of the substrates. As anticipated, PCE

was sequentially converted to TCE, DCE, VC, and ethene. Because of this conversion process, the concentrations of DCE and VC increased when PCE and TCE decreased resulting in an accumulation of these less chlorinated daughter products. The substantial increase in ethene in each of the treatment areas indicate that the dechlorination of the CEs to nontoxic ethene was occurring in each area.

The longevity of each substrate for sustaining conditions conducive to CE degradation varied. The lactate injected into the aquifer at the Lactate Pilot Test Area (Former Building 88 Area) did not persist in the treatment area resulting in a shift toward ambient conditions in less than 6 months and before complete degradation of the CEs. The EVO distributed in the EVO Pilot Test (Traffic Island Area) persisted in the aquifer and maintained reducing conditions longer than lactate, and elevated TOC remained present in one treatment area well (28OW-12) at the end of the monitoring period. However, a trend towards less reducing conditions was observed in the treatment area after 6 months. The EHC[®] was observed to be more effective in maintaining reducing conditions than either the EVO or lactate. In the treatment area well in which EHC[®] was effectively distributed (well W9-18), sulfate reducing and methanogenic conditions were maintained and CE degradation was occurring throughout the TS.

Substantial degradation of CEs was observed in downgradient wells in both the EHC[®] Pilot Test (Well W9-18 Area) and the EVO Pilot Test (Traffic Island Area). The TOC and alkalinity data from the EHC[®] Pilot Test (Well W9-18 Area) indicate that substrate was injected, or migrated by advective transport or molecular diffusion, into the downgradient wells where degradation occurred. The degradation in the downgradient wells in the EHC[®] Pilot Test (Well W9-18 Area) was ongoing at the end of the TS. The degradation observed in two of the downgradient wells in the EVO Pilot Test (Traffic Island Area) was ongoing at the end of the monitoring period but substantial rebound following initial rapid degradation was observed in the deeper downgradient well.

In summary, each of the processes evaluated achieved substantial degradation of CEs in each of the TS areas. The Lactate Pilot Test in the Former Building 88 Area determined that the lactate was relatively easy to inject and distribute in the treatment area, rapidly established reducing conditions, resulted in complete biological destruction of 77 percent of the CE mass, however, the substrate was not maintained in the treatment area throughout the TS and therefore, using a one-time injection by DPT, rather than continuous recirculation of lactate, does not maintain sufficiently reducing conditions for the time required to treat the CEs. Lactate may be an effective substrate for distribution over larger areas. The EVO substrate is relatively easy to handle and distribute through direct injection and releases ethyl lactate to achieve rapid establishment of reducing conditions which are maintained in the treatment area approximately twice as long as the lactate. The EHC[®] is more difficult to distribute in the aquifer but rapidly

established appropriate conditions and maintains those conditions for substantially longer than either of the organic substrates alone. The application of each of these technologies is considered to be appropriate for treatment of CEs at the site.

11.0 Recommendations

The following recommendations are based on the results and conclusions of the TS:

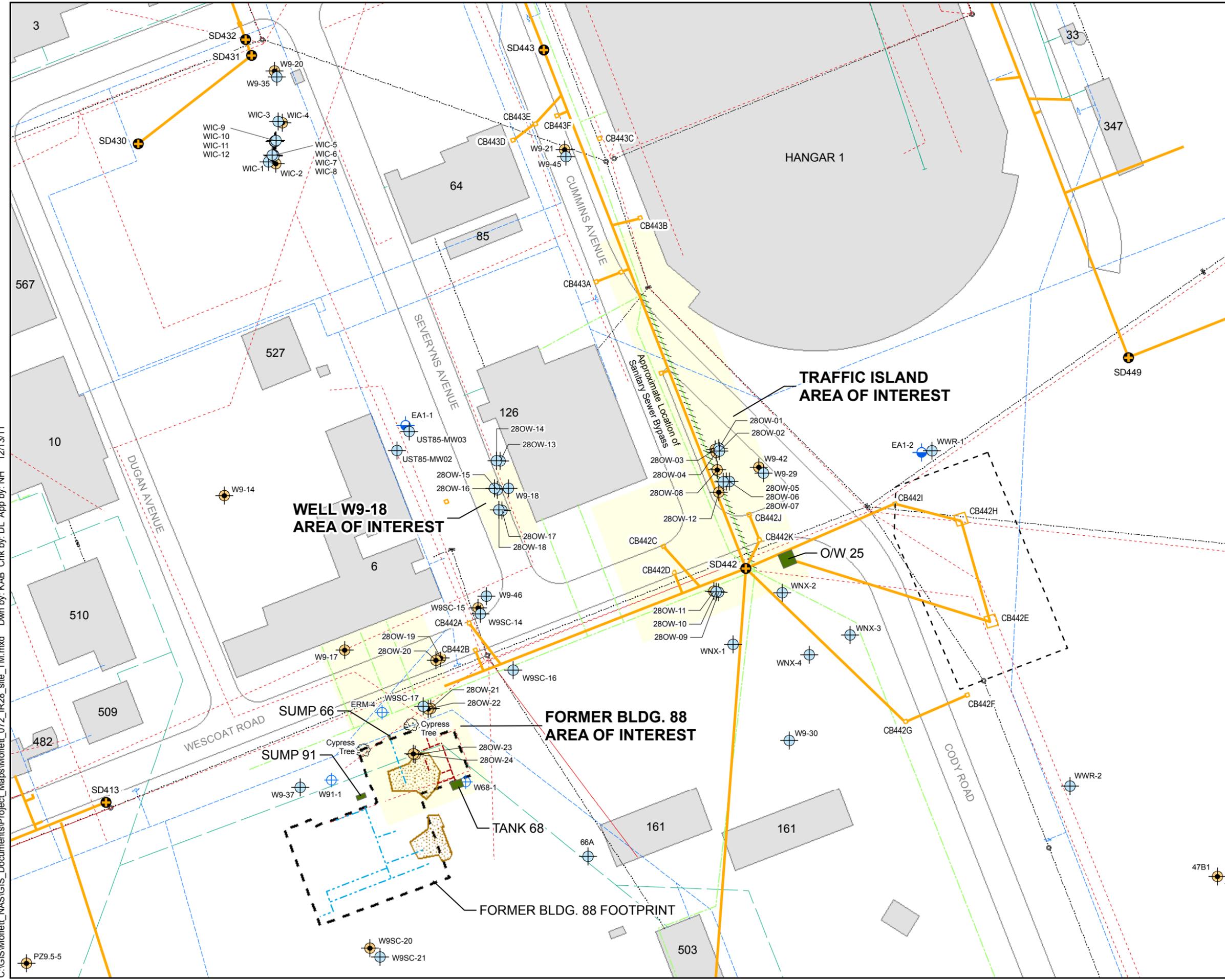
- Additional groundwater monitoring should be conducted in the areas of the EVO Pilot Test (Traffic Island Area) and EHC[®] Pilot Test (Well W9-18 Area) to evaluate the continued degradation of the CEs, because substrate is still available and conditions conducive to continued degradation were maintained at the end of the TS and to monitor for rebound of CEs within and downgradient of the treatment areas. Because substrate does not remain in the area of the Lactate Pilot Test (Former Building 88 Area), no further monitoring is recommended for wells in that area.
- Analysis should be conducted on groundwater samples from select wells in the EHC[®] Pilot Test Area (Well W9-18 Area) to evaluate the presence of the dechlorinating microorganism DHC in order to better define the degradation process at that study area.

12.0 References

- California Department of Water Resources, 1981, *Water Well Standards: State of California, Bulletin 74-81*, December.
- California Department of Water Resources, 1991, *California Well Standards Bulletin 74-90 (Supplement to Bulletin 74-81)*, June.
- Clarke, S., D. P. Leigh, and S. Anderson, 2006, *Accelerated Anaerobic In Situ Bioremediation Coupled with an EHC[®] Permeable Reactive Barrier*, Battelle Press Papers from the Proceedings of the Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, CA, May 22-25.
- Hem, J. D., 1992, *Study and Interpretation of the Chemical Characteristics of Natural Water, (3d ed.)*, U.S. Geological Survey Water Supply Paper 1473, U. S. Government Printing Office, Washington, D.C.
- SES-TECH, 2008, *Draft, West-Side Aquifers Treatment System, Site 28 Optimization Evaluation Report, Installation Restoration Site 28, Former Naval Air Station Moffett Field, Moffett Field, California*, November 21.
- Shaw Environmental, Inc. (Shaw), 2010a, *Final Work Plan, In Situ Anaerobic Biotic/Abiotic Treatability Study, IR Site 28, Former Naval Air Station Moffett Field, Moffett Field, California*, March 12.
- Shaw, 2010b, *Final Progress Report, In Situ Anaerobic Biotic/Abiotic Treatability Study, IR Site 28, Former Naval Air Station Moffett Field, Moffett Field, California*, July 14.
- Shaw, 2011, *Final Technical Memorandum, Abiotic/Biotic Treatability Study, IR Site 26, Former Naval Air Station Moffett Field, Moffett Field, California*, March 23.
- Tetra Tech EC, Inc., 2008, *Final Former Building 88 Investigation Report, Former Naval Air Station Moffett Field, Moffett Field, California*, March 7.
- U.S. Department of the Navy, 1993, *Federal Facilities Agreement Amendment of December 17, 1993, NAS Moffett Field, California*, December 17.
- U.S. Environmental Protection Agency (EPA), 1989, *Record of Decision for the Fairchild, Intel, and Raytheon Sites, Middlefield/Ellis/Whisman Study Area, Mountain View, California*, June 9.
- EPA, 1990, *Explanation of Significant Differences for the Fairchild, Intel, and Raytheon Sites, Middlefield/Ellis/Whisman (MEW) Study Area, Mountain View, California*, September.

Figures

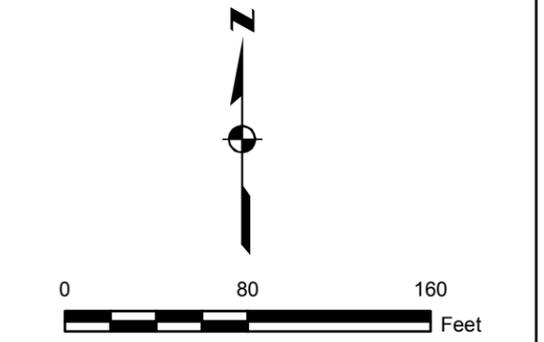
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Legend

- UPPER A-AQUIFER MONITORING WELL
- LOWER A-AQUIFER MONITORING WELL
- EXTRACTION WELL
- FORMER GROUNDWATER MONITORING WELL LOCATION
- STORM DRAIN MANHOLE
- STORM DRAIN LINE AND CATCH BASIN
- SANITARY SEWER LINE
- SECTION OF THE SANITARY SEWER LINE THAT REPORTEDLY COLLAPSED (PRC, 1995)
- COMMUNICATION
- ELECTRIC
- GAS
- WATER
- CONCRETE-LINED WASTEWATER COLLECTION TRENCH (REMOVED)
- FLOOR DRAIN PIPING (REMOVED)
- FORMER AIRCRAFT WASH RACK
- PREVIOUS REMEDIAL EXCAVATION AREA (7 TO 8 FT. BGS)
- AREA OF INTEREST
- SUMP, TANK, OR OIL/WATER SEPARATOR (REMOVED)
- 503 BUILDING AND BUILDING NUMBER

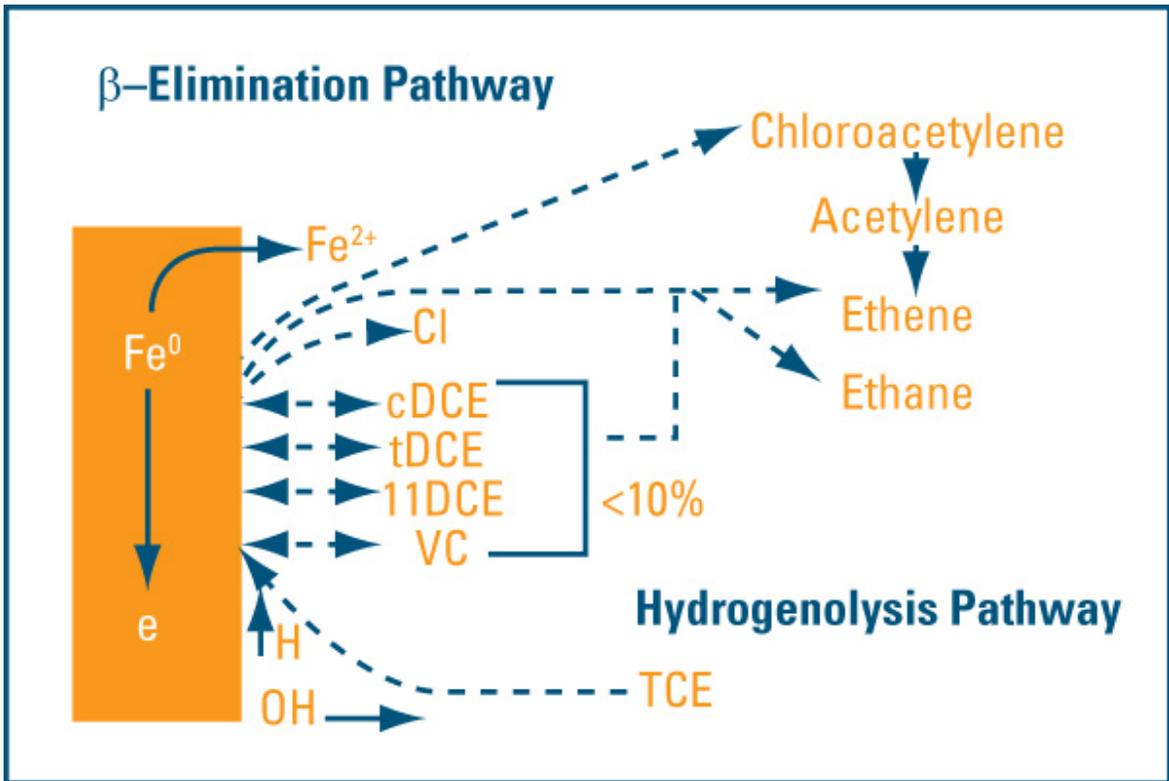
PRC, 1995 - "Final Horizontal Conduit Study Technical Memorandum Text, Tables, and Figures," dated August 4, 1995, prepared by PRC Environmental Management, Inc.



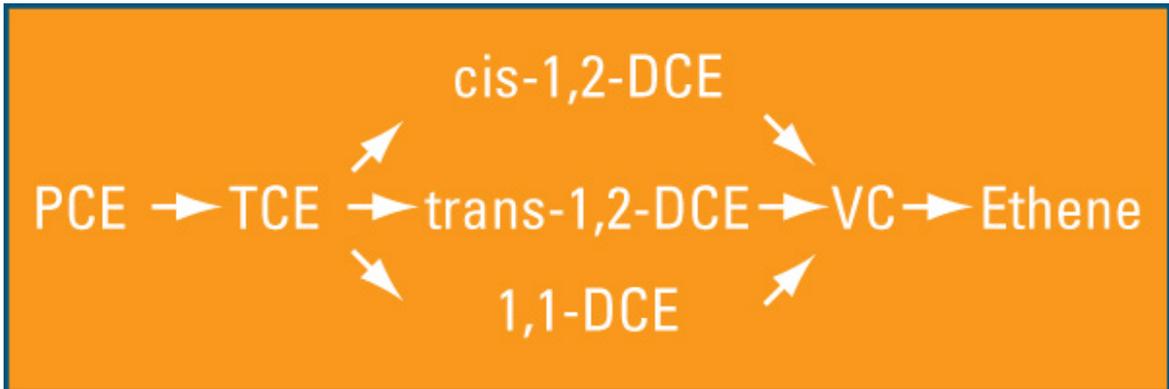
BASE REALIGNMENT AND CLOSURE PROGRAM MANAGEMENT OFFICE WEST
NAVAL FACILITIES ENGINEERING COMMAND
SAN DIEGO, CALIFORNIA

FIGURE 2
SITE FEATURES MAP
FORMER NAS MOFFETT FIELD
MOFFETT FIELD, CALIFORNIA

ABIOTIC DEGRADATION PATHWAYS



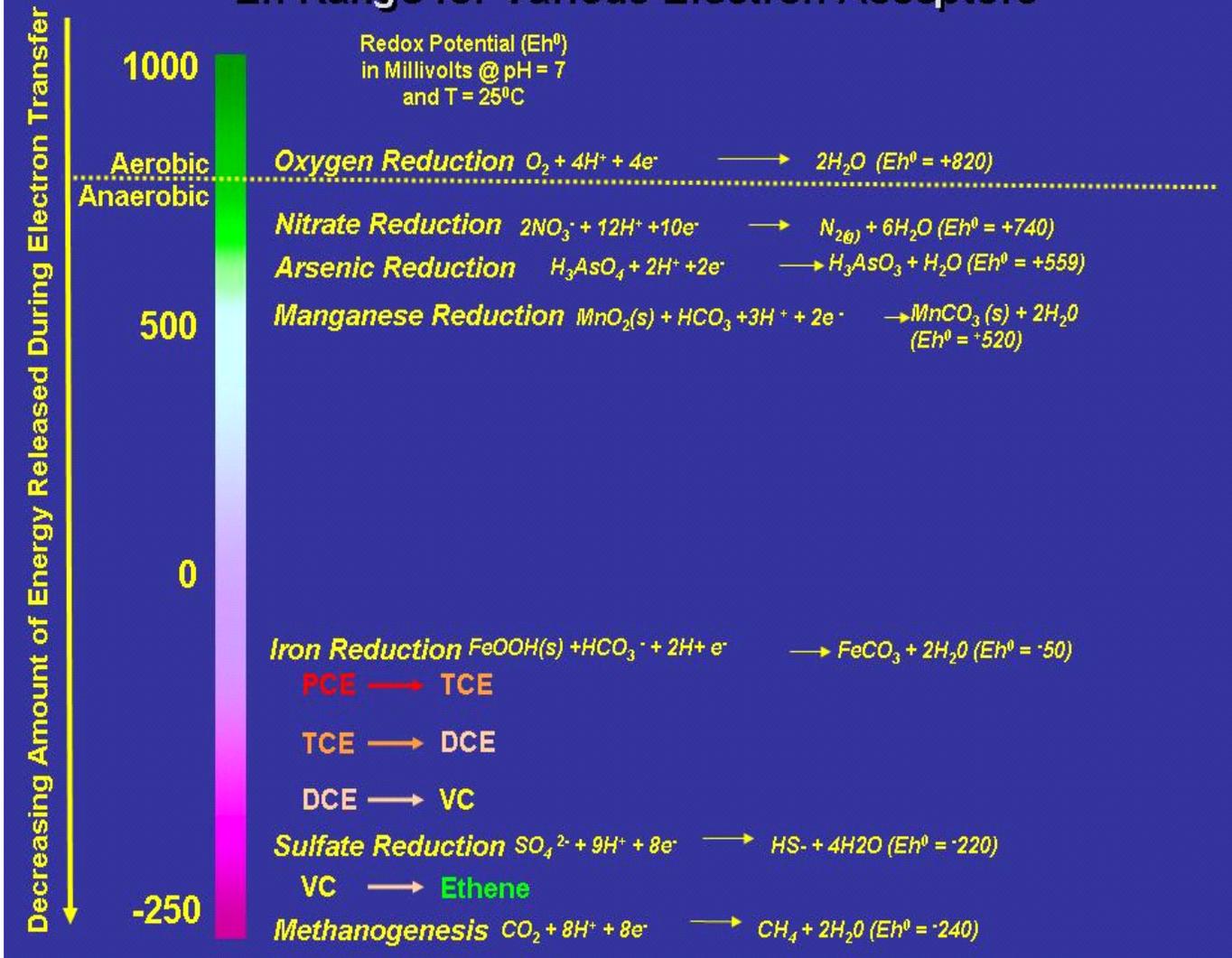
BIOLOGICAL DEGRADATION PATHWAYS



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PROGRAM MANAGEMENT OFFICE WEST
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ENGINEERING COMMAND
SAN DIEGO, CALIFORNIA

FIGURE 3
ABIOTIC AND BIOLOGICAL DEGRADATION
PATHWAYS OF
CHLORINATED ETHENES
FORMER NAS MOFFETT FIELD
MOFFETT FIELD, CALIFORNIA

Eh Range for Various Electron Acceptors



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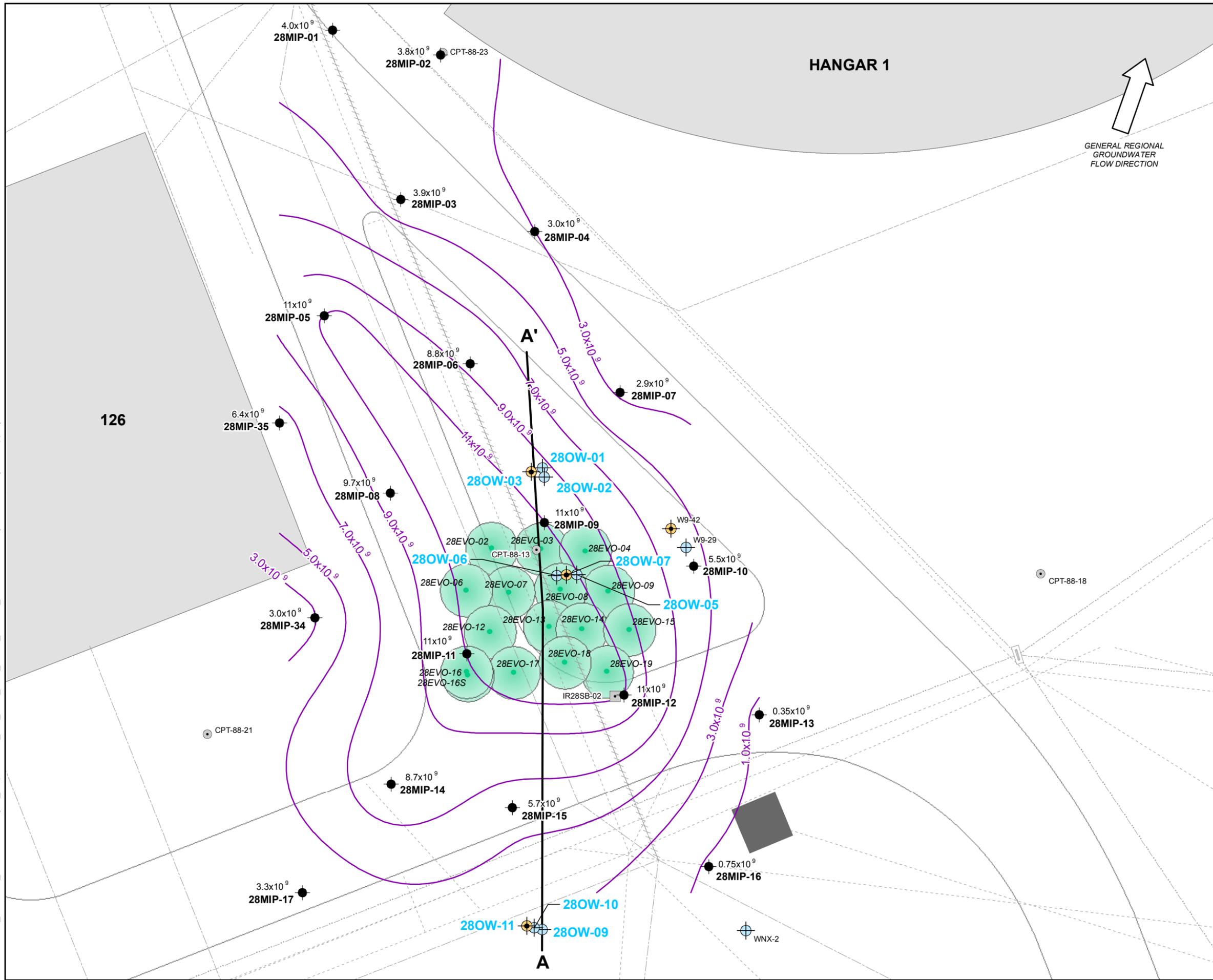
Note:
Derived from Wiedemeier et al., 1996, "Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater."



BASE REALIGNMENT AND CLOSURE
PROGRAM MANAGEMENT OFFICE WEST
NAVAL FACILITIES
ENGINEERING COMMAND
SAN DIEGO, CALIFORNIA

FIGURE 4
Eh RANGE FOR VARIOUS ELECTRON ACCEPTORS
FORMER NAS MOFFETT FIELD
MOFFETT FIELD, CALIFORNIA

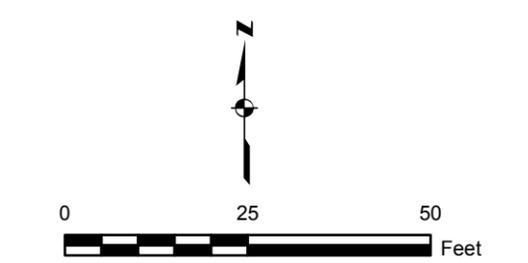
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Legend

- MIP LOCATION
- 3.4x10⁹ SUM OF ECD RESPONSE IN MICROVOLTS (μV) FOR 10-50 FT. BGS INTERVAL
- ~ ECD RESPONSE ISOPLETH (μV)
- INJECTION LOCATION, SHOWING ESTIMATED RADIUS OF INFLUENCE
- ⊕ UPPER A-AQUIFER MONITORING WELL
- ⊕ LOWER A-AQUIFER MONITORING WELL
- CPT LOCATION
- CONTINUOUS CORE LOCATION
- LINE OF CROSS SECTION (SEE FIG. 7)
- - - - STORM DRAIN LINE
- - - - SANITARY SEWER LINE
- - - - SECTION OF THE SANITARY SEWER LINE THAT REPORTEDLY COLLAPSED (PRC, 1995)
- - - - COMMUNICATION
- - - - ELECTRIC
- - - - GAS
- - - - WATER
- SUMP, TANK, OR OIL/WATER SEPARATOR (REMOVED)
- 126 BUILDING AND BUILDING NUMBER

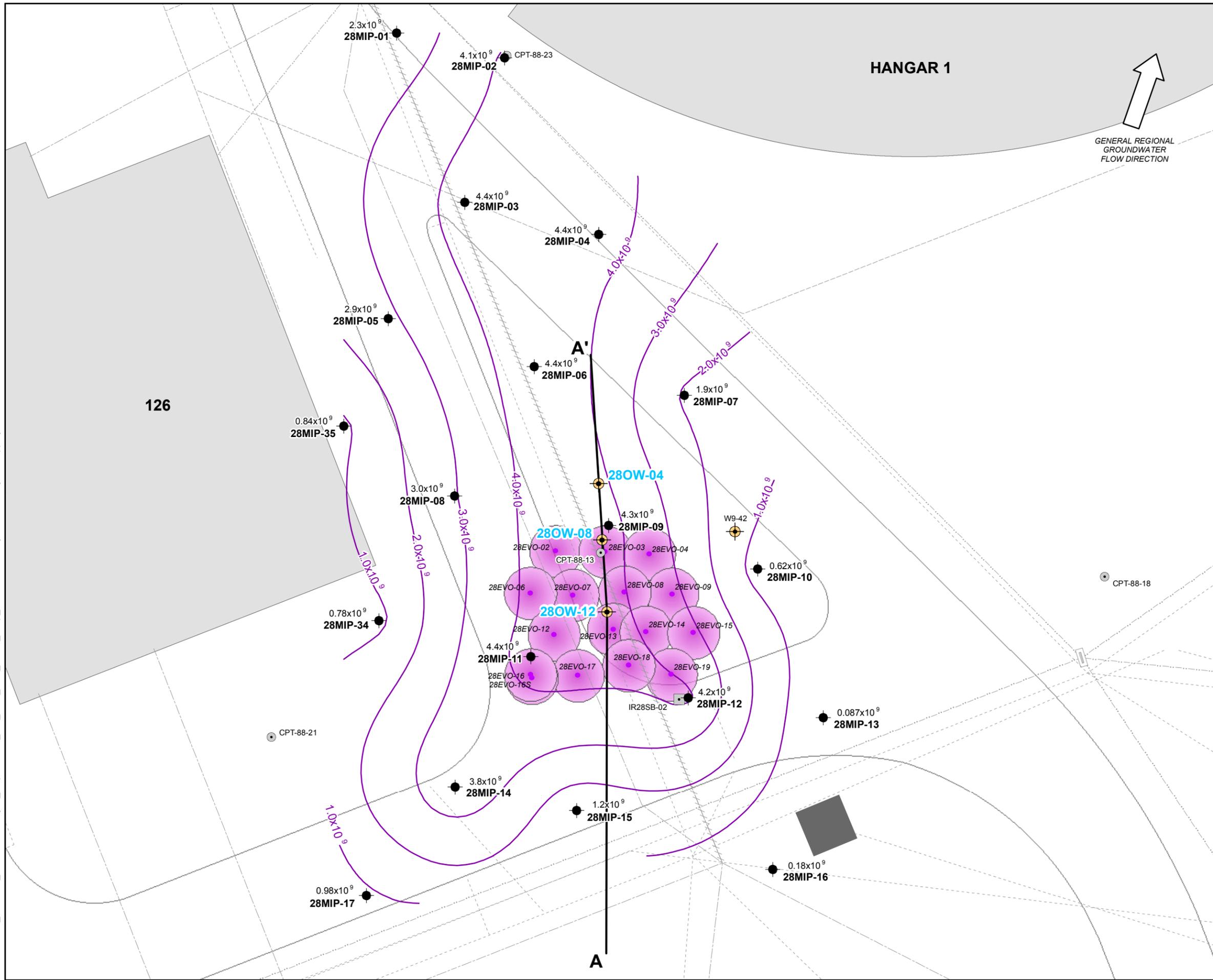
NOTES:
MIP - Membrane Interface Probe
ECD - Electron Capture Detector
ECD results presented are based on MIP testing performed between 3/29 and 4/14/10.



Shaw BASE REALIGNMENT AND CLOSURE PROGRAM MANAGEMENT OFFICE WEST
NAVAL FACILITIES ENGINEERING COMMAND
SAN DIEGO, CALIFORNIA

FIGURE 5
EVO PILOT TEST LAYOUT
10 TO 50 FT BGS INTERVAL
TRAFFIC ISLAND AREA
FORMER NAS MOFFETT FIELD
MOFFETT FIELD, CALIFORNIA

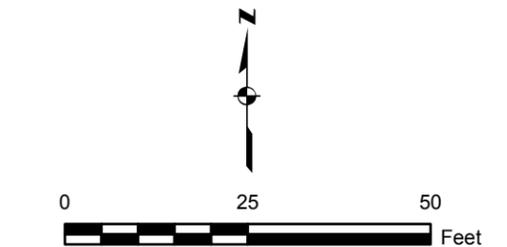
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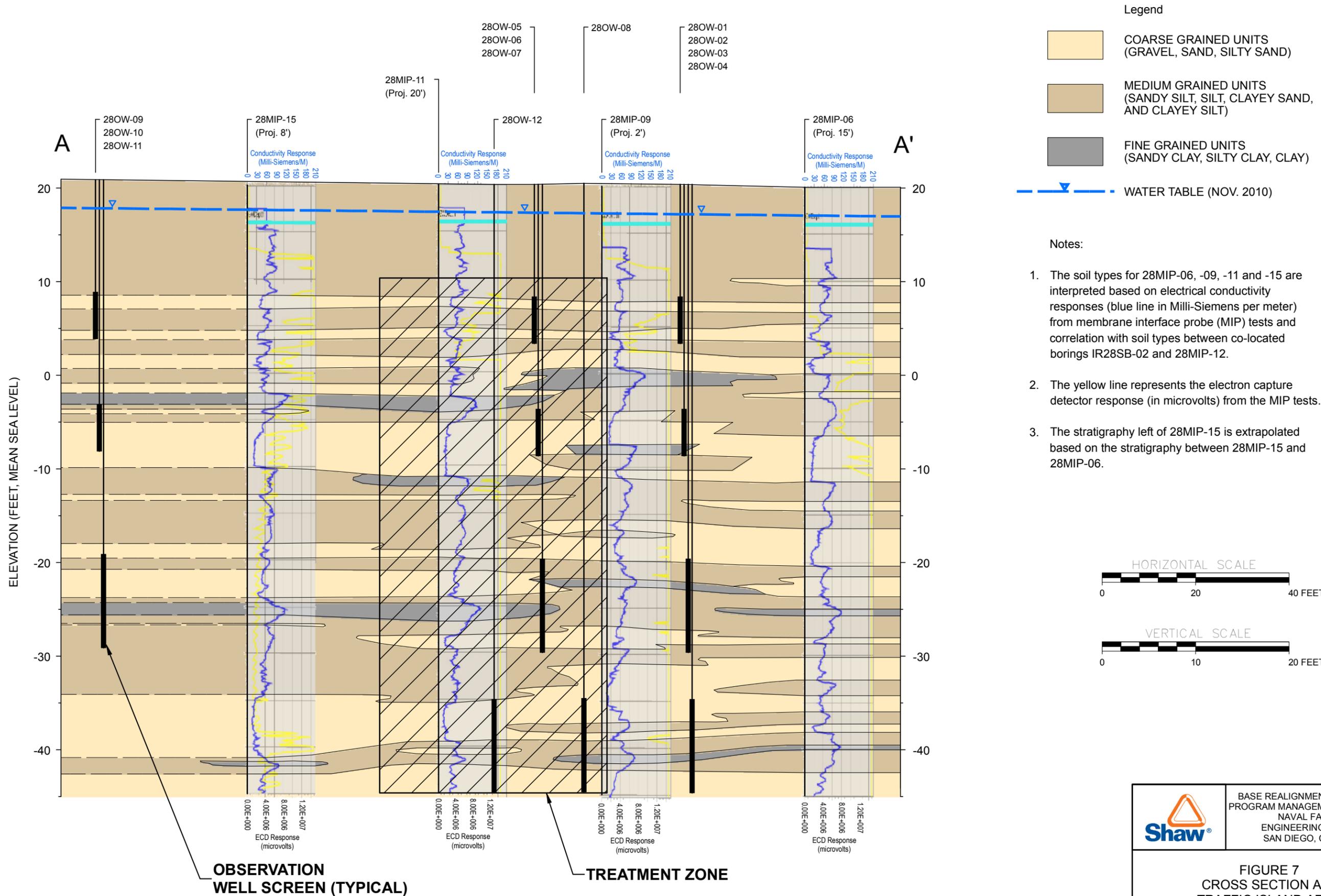
- MIP LOCATION
- 3.4x10⁹ SUM OF ECD RESPONSE IN MICROVOLTS (μV) FOR 50-65 FT. BGS INTERVAL
- ~ ECD RESPONSE ISOPLETH (μV)
- INJECTION LOCATION, SHOWING ESTIMATED RADIUS OF INFLUENCE
- ⊕ LOWER A-AQUIFER MONITORING WELL
- CPT LOCATION
- CONTINUOUS CORE LOCATION
- LINE OF CROSS SECTION (SEE FIG. 7)
- - - - - STORM DRAIN LINE
- - - - - SANITARY SEWER LINE
- //// SECTION OF THE SANITARY SEWER LINE THAT REPORTEDLY COLLAPSED (PRC, 1995)
- - - - - COMMUNICATION
- - - - - ELECTRIC
- - - - - GAS
- - - - - WATER
- SUMP, TANK, OR OIL/WATER SEPARATOR (REMOVED)
- 126 BUILDING AND BUILDING NUMBER

NOTES:
MIP - Membrane Interface Probe
ECD - Electron Capture Detector
ECD results presented are based on MIP testing performed between 3/29 and 4/14/10.



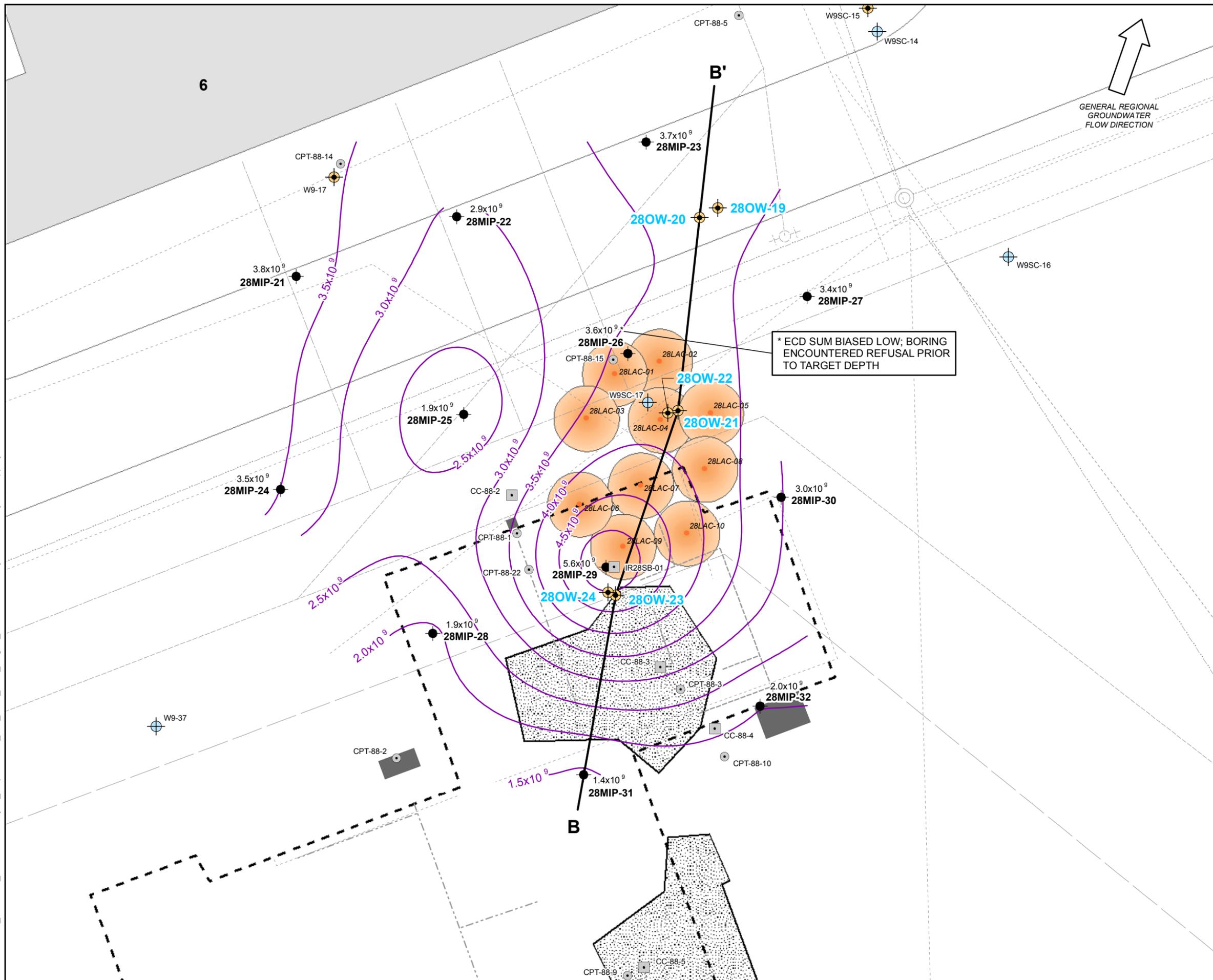
BASE REALIGNMENT AND CLOSURE PROGRAM MANAGEMENT OFFICE WEST
NAVAL FACILITIES ENGINEERING COMMAND
SAN DIEGO, CALIFORNIA

FIGURE 6
EVO PILOT TEST LAYOUT
50 TO 65 FT BGS INTERVAL
TRAFFIC ISLAND AREA
FORMER NAS MOFFETT FIELD
MOFFETT FIELD, CALIFORNIA



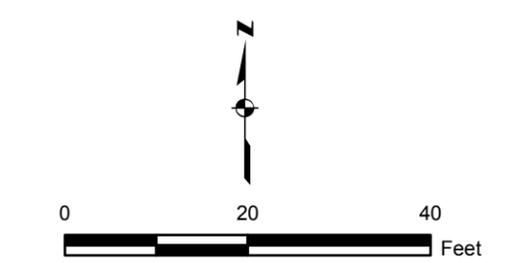
	BASE REALIGNMENT AND CLOSURE PROGRAM MANAGEMENT OFFICE WEST NAVAL FACILITIES ENGINEERING COMMAND SAN DIEGO, CALIFORNIA
	<p align="center">FIGURE 7 CROSS SECTION A-A' TRAFFIC ISLAND AREA</p> <p align="center">FORMER NAS MOFFETT FIELD MOFFETT FIELD, CALIFORNIA</p>

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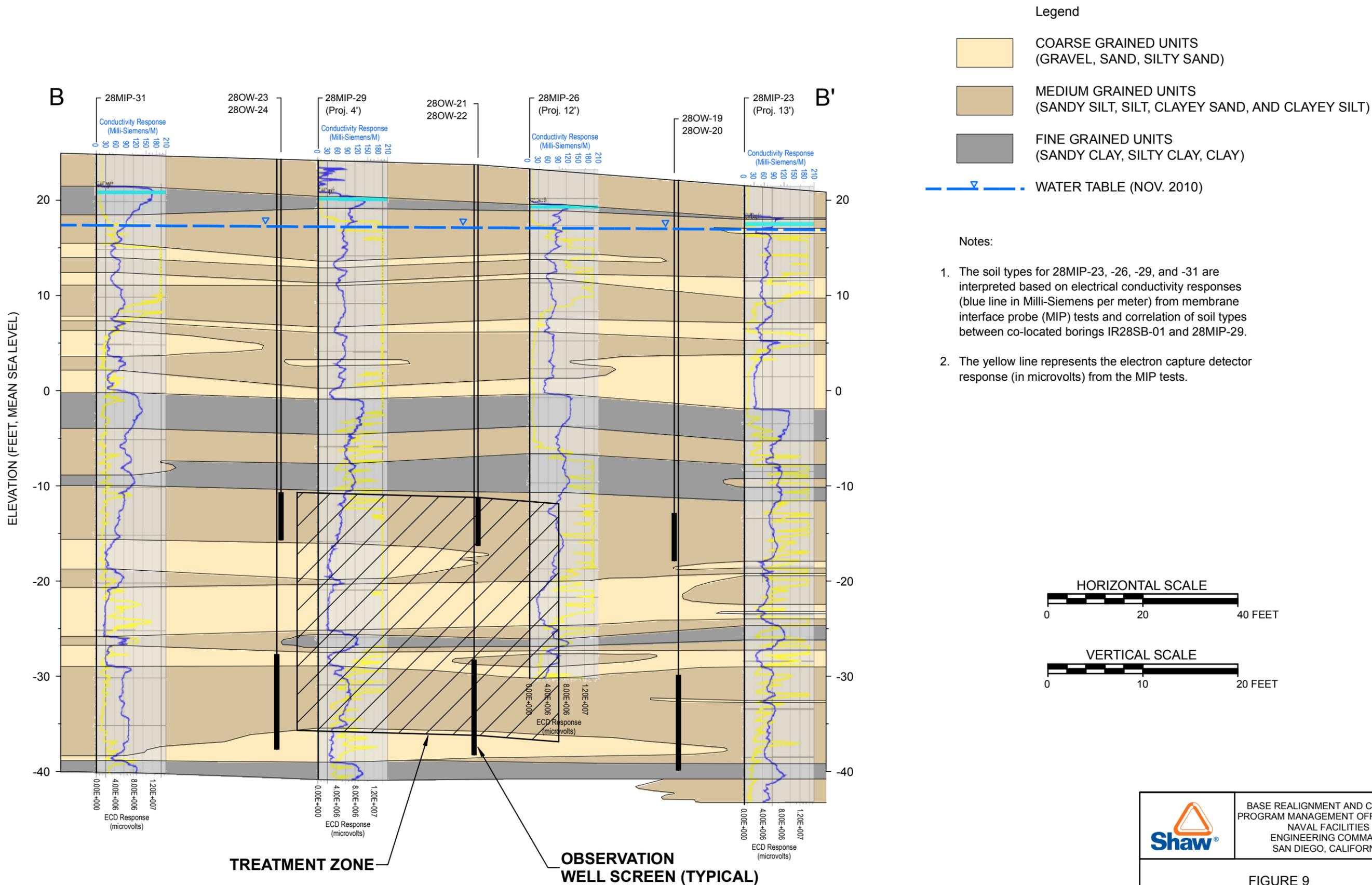
- Legend**
- MIP LOCATION
 - 3.4x10⁹ SUM OF ECD RESPONSE IN MICROVOLTS (μV) FOR 35-60 FT. BGS INTERVAL
 - ~ ECD RESPONSE ISOPLETH (μV)
 - INJECTION LOCATION, SHOWING ESTIMATED RADIUS OF INFLUENCE
 - ⊕ UPPER A-AQUIFER MONITORING WELL
 - ⊕ LOWER A-AQUIFER MONITORING WELL
 - CPT LOCATION
 - CONTINUOUS CORE LOCATION
 - LINE OF CROSS SECTION (SEE FIG. 9)
 - - - STORM DRAIN LINE
 - - - SANITARY SEWER LINE
 - - - COMMUNICATION
 - - - ELECTRIC
 - - - GAS
 - - - WATER
 - - - CONCRETE-LINED WASTEWATER COLLECTION TRENCH (REMOVED)
 - - - FLOOR DRAIN PIPING (REMOVED)
 - ▨ PREVIOUS REMEDIAL EXCAVATION AREA
 - 6 SUMP, TANK, OR OIL/WATER SEPARATOR (REMOVED)
 - BUILDING AND BUILDING NUMBER
 - - - FORMER BUILDING 88

NOTES:
MIP - Membrane Interface Probe
ECD - Electron Capture Detector
ECD results presented are based on MIP testing performed between 3/29 and 4/14/10.



Shaw
BASE REALIGNMENT AND CLOSURE PROGRAM MANAGEMENT OFFICE WEST
NAVAL FACILITIES ENGINEERING COMMAND
SAN DIEGO, CALIFORNIA

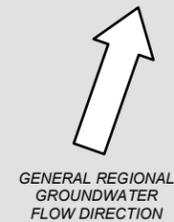
FIGURE 8
LACTATE PILOT TEST LAYOUT
35 TO 60 FT BGS INTERVAL
FORMER BLDG 88 AREA
FORMER NAS MOFFETT FIELD
MOFFETT FIELD, CALIFORNIA



 BASE REALIGNMENT AND CLOSURE PROGRAM MANAGEMENT OFFICE WEST
NAVAL FACILITIES ENGINEERING COMMAND
SAN DIEGO, CALIFORNIA

FIGURE 9
CROSS SECTION B-B'
FORMER BUILDING 88 AREA
FORMER NAS MOFFETT FIELD
MOFFETT FIELD, CALIFORNIA

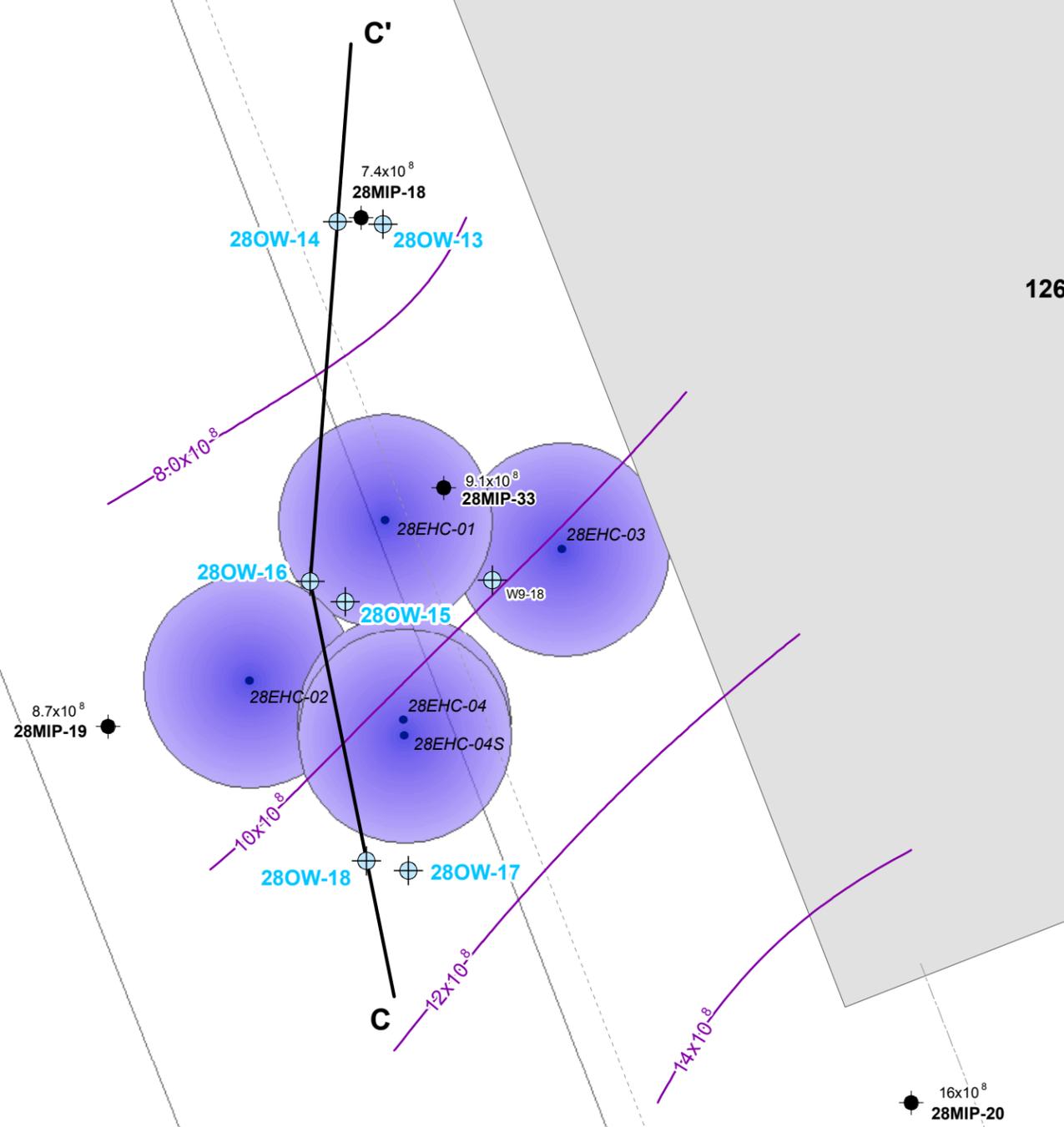
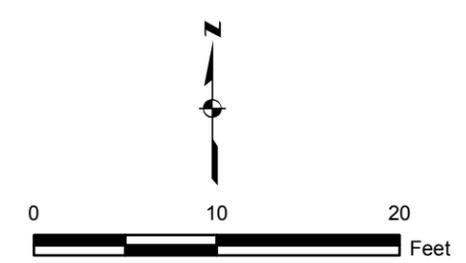
C:\GIS\Moffett_NAS\GIS_Documents\Project_Maps\Moffett_074_IR28_ECD_W9_18_TM.mxd Dwn by: KAB Chk by: DL App by: NH 12/12/11



Legend

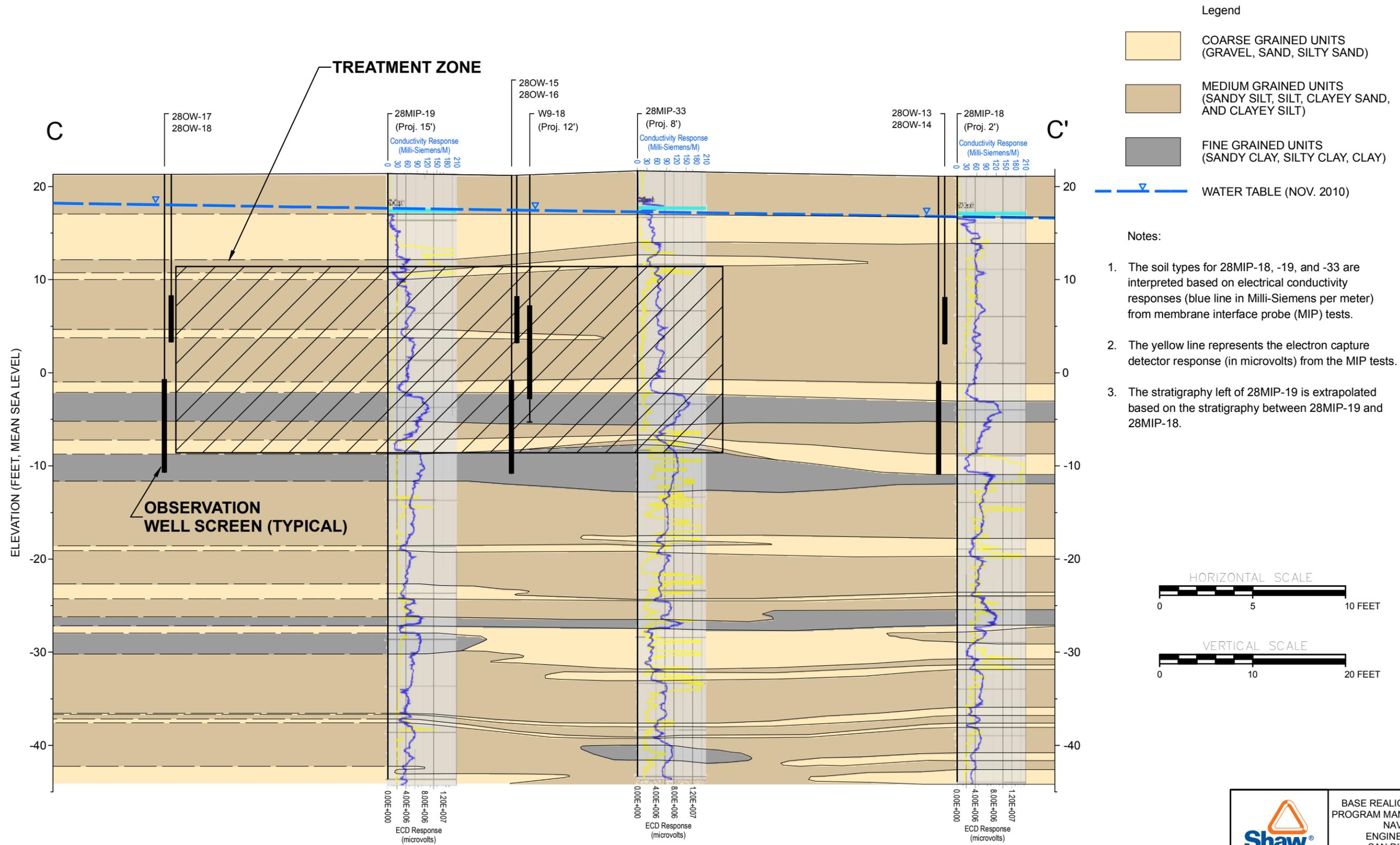
- MIP LOCATION
- 12×10^8 SUM OF ECD RESPONSE IN MICROVOLTS (μV) FOR 10-30 FT. BGS INTERVAL
- ECD RESPONSE ISOPLETH (μV)
- INJECTION LOCATION, SHOWING ESTIMATED RADIUS OF INFLUENCE
- UPPER A-AQUIFER MONITORING WELL
- LOWER A-AQUIFER MONITORING WELL
- LINE OF CROSS SECTION (SEE FIG. 11)
- STORM DRAIN LINE
- SANITARY SEWER LINE
- COMMUNICATION
- ELECTRIC
- GAS
- WATER
- SUMP, TANK, OR OIL/WATER SEPARATOR (REMOVED)
- BUILDING AND BUILDING NUMBER

NOTES:
 MIP - Membrane Interface Probe
 ECD - Electron Capture Detector
 ECD results presented are based on MIP testing performed between 3/29 and 4/14/10.



BASE REALIGNMENT AND CLOSURE
PROGRAM MANAGEMENT OFFICE WEST
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ENGINEERING COMMAND
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FIGURE 10
EHC[®] PILOT TEST LAYOUT
10 TO 30 FT BGS INTERVAL
WELL W9-18 AREA
 FORMER NAS MOFFETT FIELD
 MOFFETT FIELD, CALIFORNIA

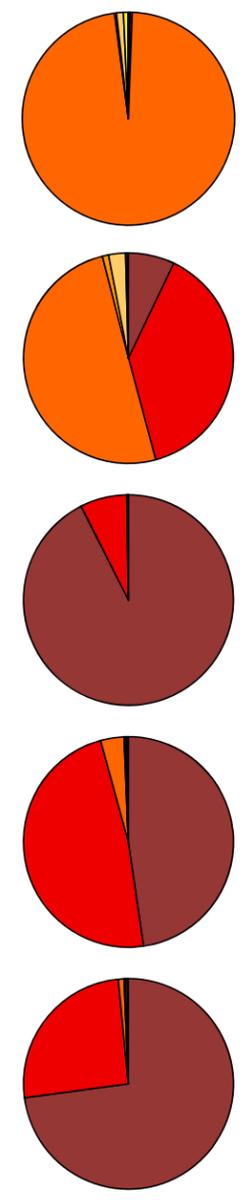


Shaw
BASE REALIGNMENT AND CLOSURE PROGRAM MANAGEMENT OFFICE WEST
NAVAL FACILITIES ENGINEERING COMMAND
SAN DIEGO, CALIFORNIA

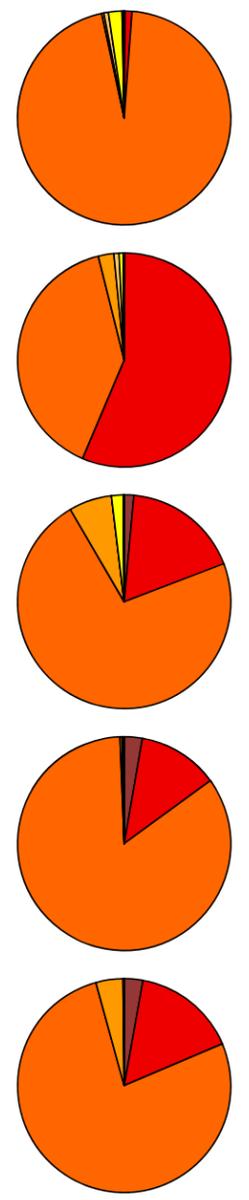
FIGURE 11
CROSS SECTION C-C'
WELL W9-18 AREA
FORMER NAS MOFFETT FIELD
MOFFETT FIELD, CALIFORNIA

28OW-05 Screened 12 to 17 ft bgs
 28OW-06 Screened 24 to 29 ft bgs
 28OW-07 Screened 40 to 50 ft bgs
 28OW-08 Screened 55 to 65 ft bgs
 28OW-12 Screened 55 to 65 ft bgs

Pre-Injection



Week 1

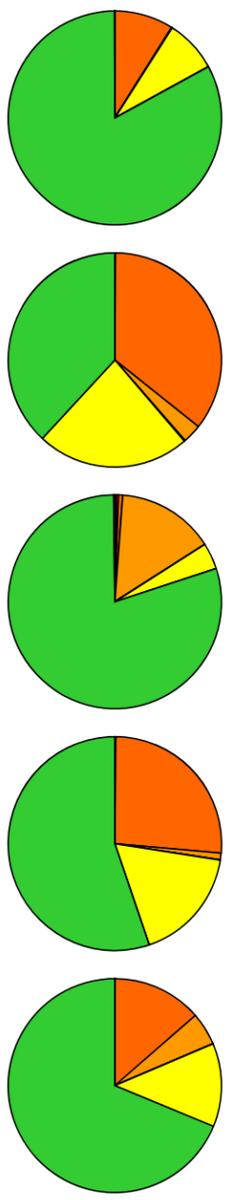


Month 3

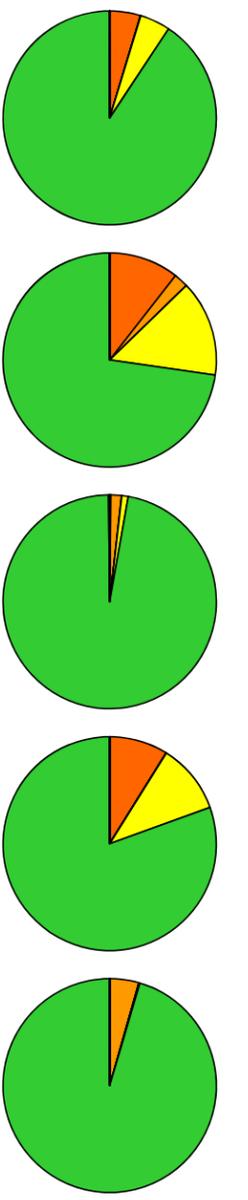


Post-Injection

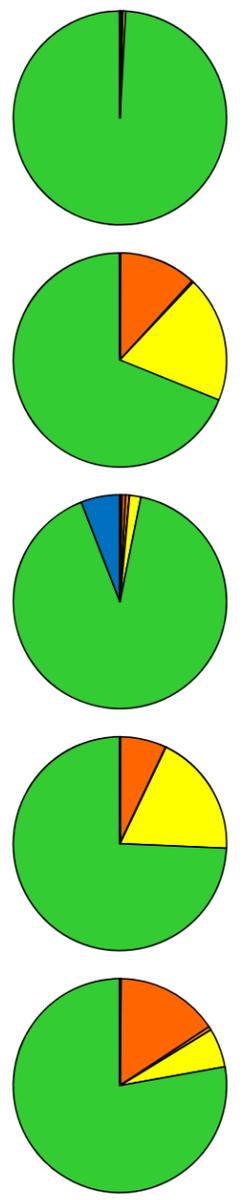
Month 6



Month 9



Month 12



■ PCE ■ TCE ■ c-DCE ■ t-DCE ■ 1,1-DCE ■ VC ■ Ethene ■ Ethane ■ Acetylene



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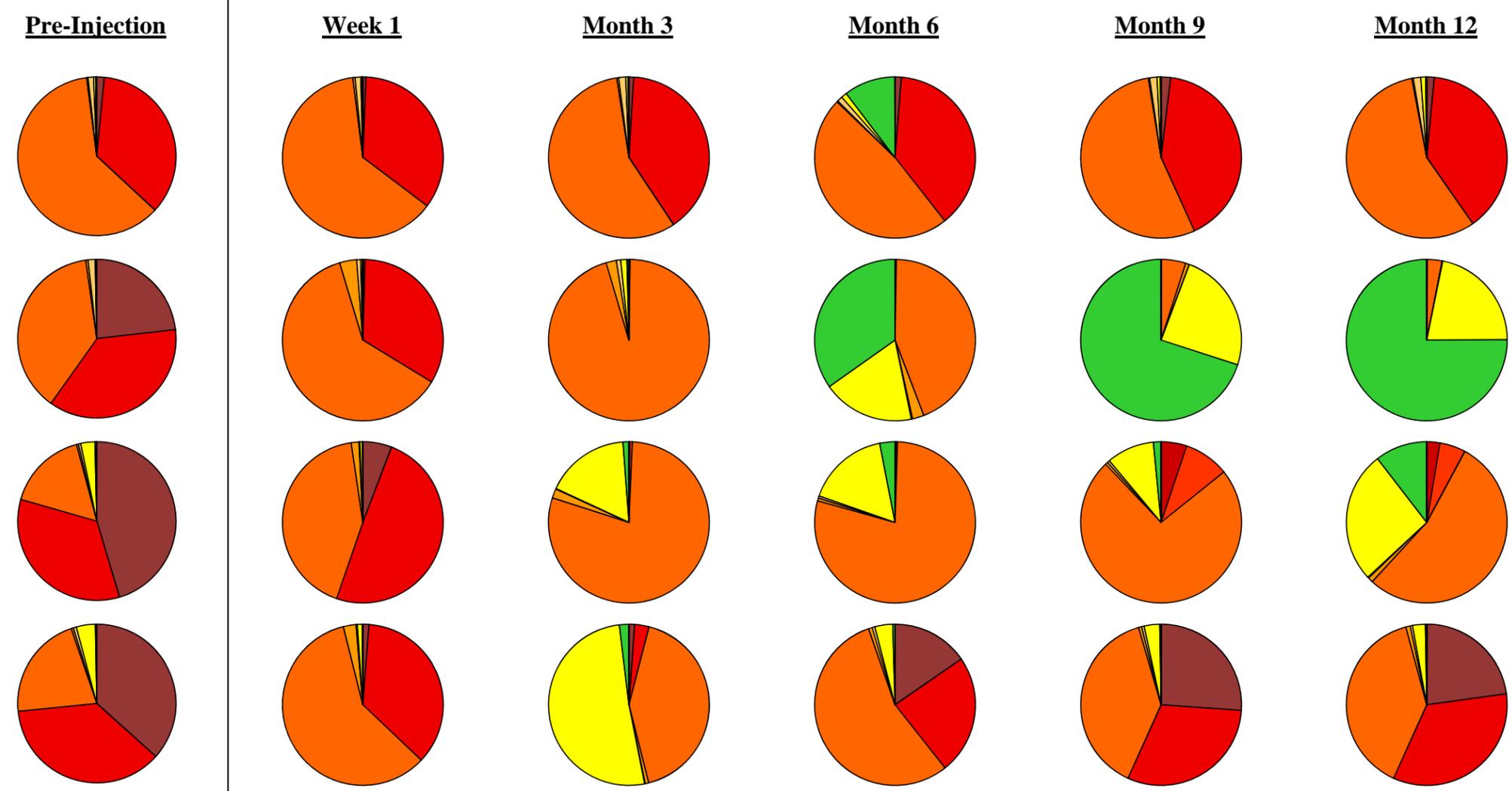
Figure 12
 Molar Fractions of Chlorinated Ethenes, Ethene, and Ethane
 in Groundwater - Treatment Area Wells
 EVO Pilot Test, Traffic Island Area, IR Site 28
 Former Naval Air Station Moffett Field, Moffett Field, CA

28OW-01
Screened 12 to 17 ft bgs

28OW-02
Screened 24 to 29 ft bgs

28OW-03
Screened 40 to 50 ft bgs

28OW-04
Screened 55 to 65 ft bgs



■ PCE ■ TCE ■ c-DCE ■ t-DCE ■ 1,1-DCE ■ VC ■ Ethene ■ Ethane ■ Acetylene


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Figure 13
 Molar Fractions of Chlorinated Ethenes, Ethene, and Ethane
 in Groundwater - Downgradient Wells
 EVO Pilot Test, Traffic Island Area, IR Site 28
 Former Naval Air Station Moffett Field, Moffett Field, CA

W9-29
Screened 7 to 17 ft bgs

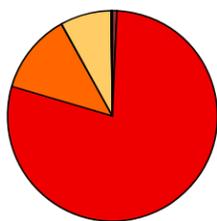
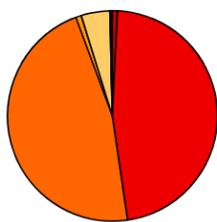
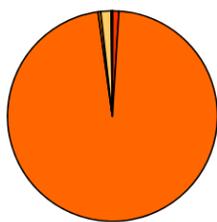
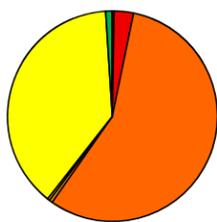
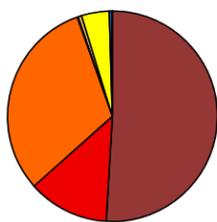
W9-42
Screened 29 to 39 ft bgs

28OW-09
Screened 12 to 17 ft bgs

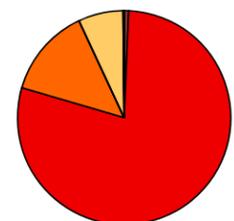
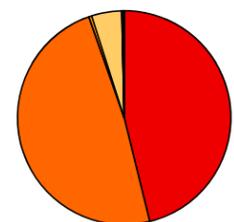
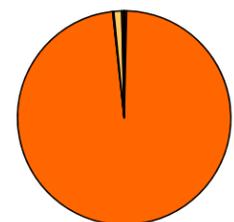
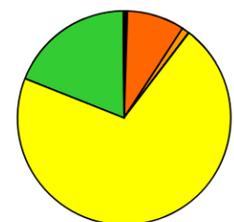
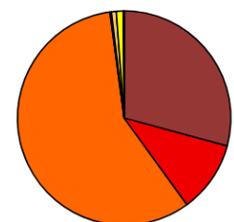
28OW-10
Screened 24 to 29 ft bgs

28OW-11
Screened 40 to 50 ft bgs

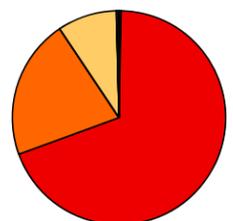
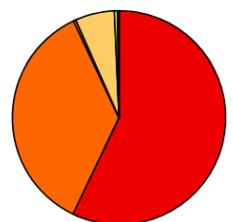
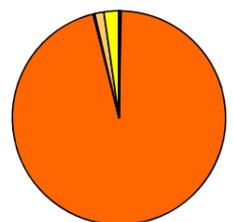
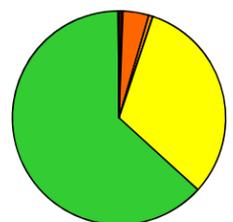
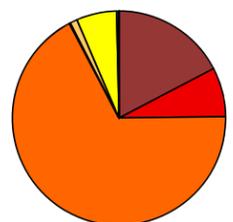
Pre-Injection



Week 1

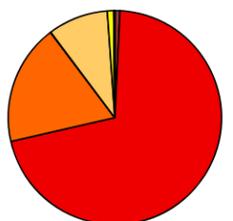
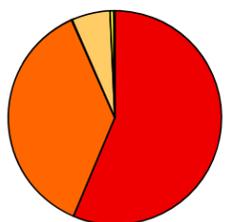
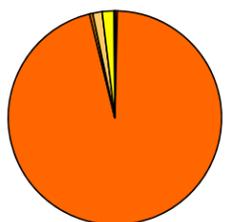
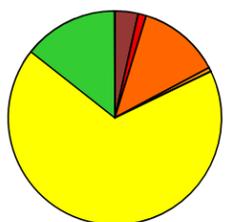
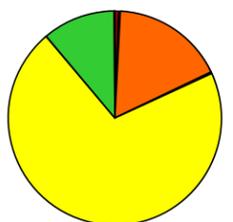


Month 3

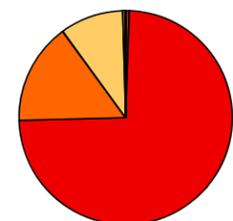
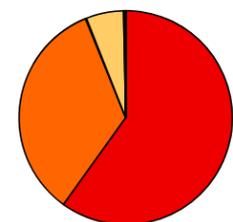
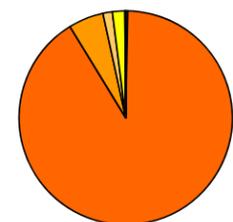
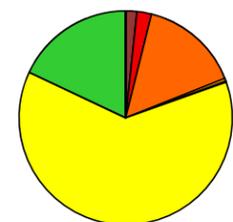
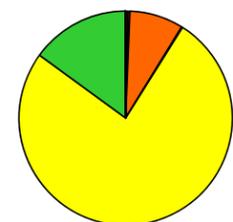


Post-Injection

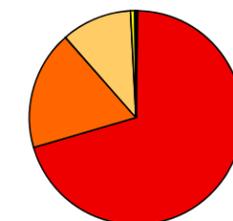
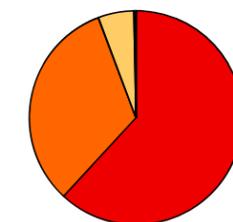
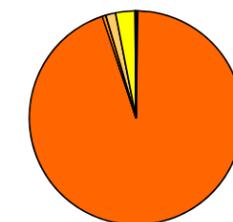
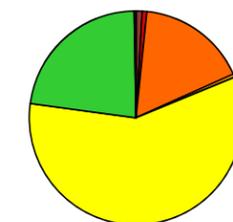
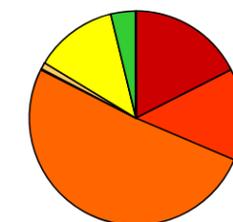
Month 6



Month 9



Month 12



Crossgradient Wells

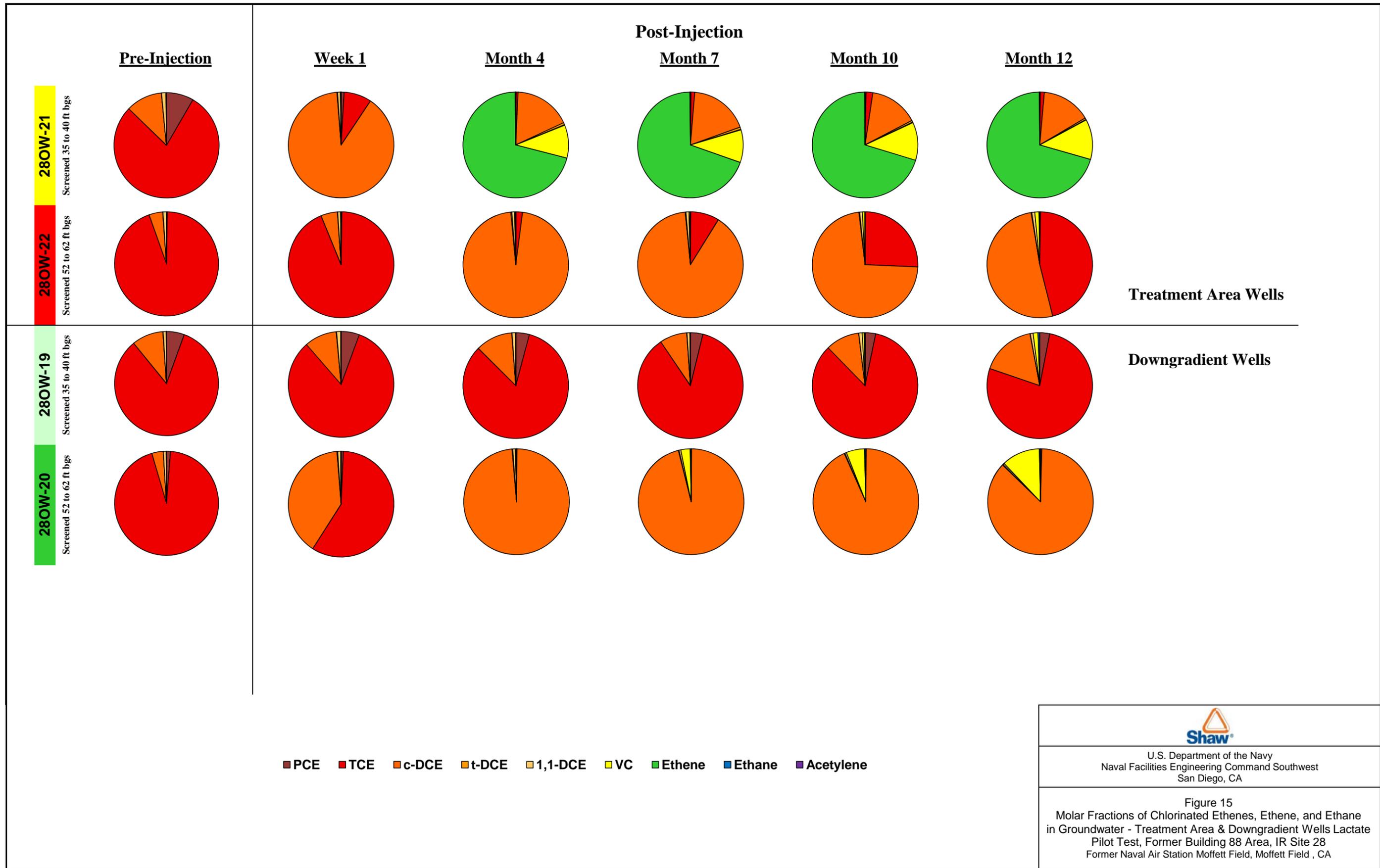
Upgradient Wells

■ PCE ■ TCE ■ c-DCE ■ t-DCE ■ 1,1-DCE ■ VC ■ Ethene ■ Ethane ■ Acetylene



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Figure 14
Molar Fractions of Chlorinated Ethenes, Ethene, and Ethane
in Groundwater - Crossgradient & Upgradient Wells
EVO Pilot Test, Traffic Island Area, IR Site 28
Former Naval Air Station Moffett Field, Moffett Field, CA



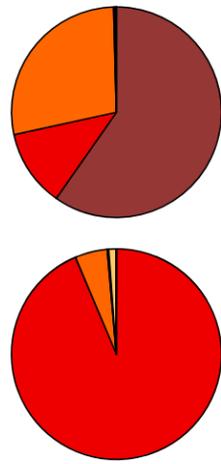

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Figure 15
 Molar Fractions of Chlorinated Ethenes, Ethene, and Ethane
 in Groundwater - Treatment Area & Downgradient Wells Lactate
 Pilot Test, Former Building 88 Area, IR Site 28
 Former Naval Air Station Moffett Field, Moffett Field, CA

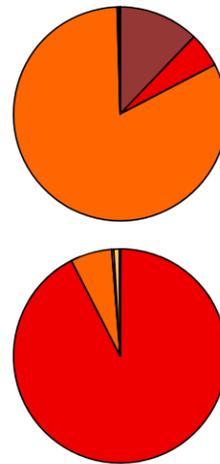
28OW-23
Screened 35 to 40 ft bgs

28OW-24
Screened 52 to 62 ft bgs

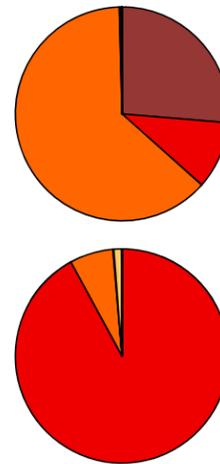
Pre-Injection



Week 1

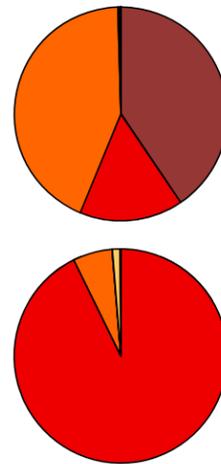


Month 4

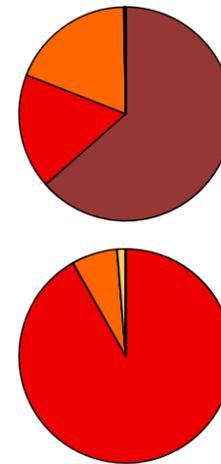


Post-Injection

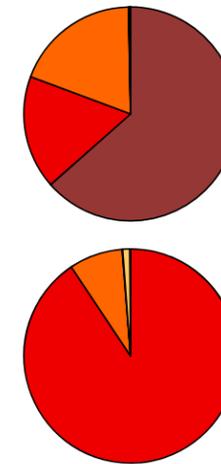
Month 7



Month 10



Month 12

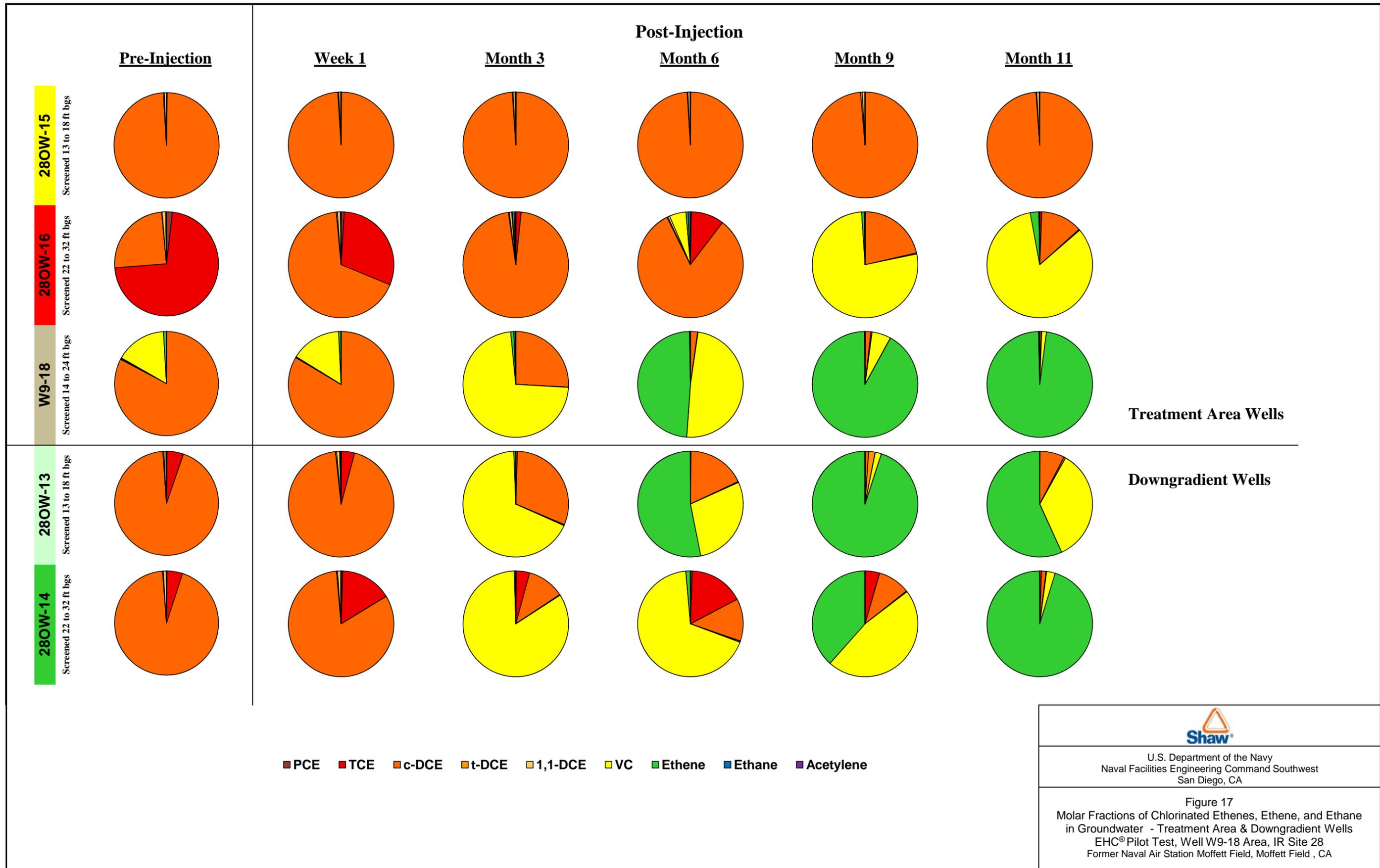


■ PCE ■ TCE ■ c-DCE ■ t-DCE ■ 1,1-DCE ■ VC ■ Ethene ■ Ethane ■ Acetylene



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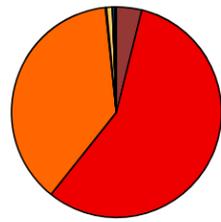
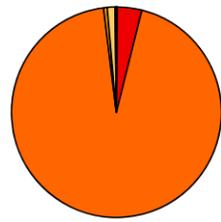
Figure 16
Molar Fractions of Chlorinated Ethenes, Ethene, and Ethane
in Groundwater - Upgradient Wells
Lactate Pilot Test, Former Building 88 Area, IR Site 28
Former Naval Air Station Moffett Field, Moffett Field, CA



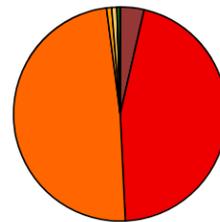
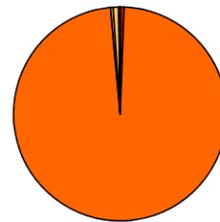
28OW-17
Screened 35 to 40 ft bgs

28OW-18
Screened 52 to 62 ft bgs

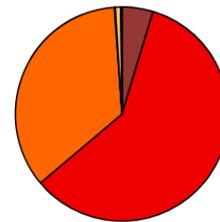
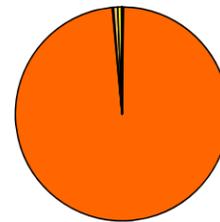
Pre-Injection



Week 1

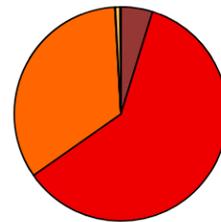
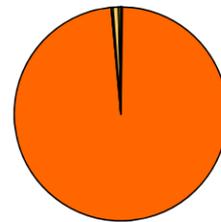


Month 3

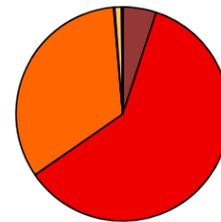
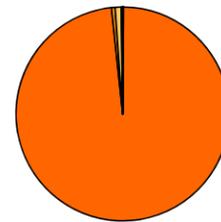


Post-Injection

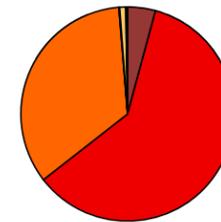
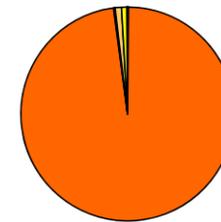
Month 6



Month 9



Month 11



■ PCE ■ TCE ■ c-DCE ■ t-DCE ■ 1,1-DCE ■ VC ■ Ethene ■ Ethane ■ Acetylene



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Naval Facilities Engineering Command Southwest
San Diego, CA

Figure 18
Molar Fractions of Chlorinated Ethenes, Ethene, and Ethane
in Groundwater - Upgradient Wells
EHC® Pilot Test, Well W9-18 Area, IR Site 28
Former Naval Air Station Moffett Field, Moffett Field, CA

Tables

Table 1
Baseline and Post-Injection Groundwater Data
EVO Pilot Test
Traffic Island Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-01 (Downgradient; 12 to 17 ft bgs)						28OW-02 (Downgradient; 24 to 29 ft bgs)						
Sample ID	28OW-1-20100709	28OW-01-082010	28OW01-111010	28OW-01-012611	28OW01-041311	28OW01-062111	28OW-2-20100709	28OW-02-082010	28OW02-111010	28OW-02-012611	28OW02-041311	28OW02-062111	
Date Sampled	7/9/10	8/20/10	11/10/10	1/26/11	4/13/11	6/21/11	7/9/10	8/20/10	11/10/10	1/26/11	4/13/11	6/21/11	
Site-Specific VOCs													
Tetrachloroethene	µg/L	20	9.9	11	16	17	13	230	18	1.8	3.3	1.7	2.5
Trichloroethene	µg/L	370	420	370	380	290	270	290	1,100	2.4	6	1	0.66 J
cis-1,2-Dichloroethene	µg/L	470	560	390	350	280	290	220	1,500	1,300	960	84	42
trans-1,2-Dichloroethene	µg/L	2.2	4.1	2.7	1.7	1.5	1.6	2.7	83	28	51	13	1.6
1,1-Dichloroethene	µg/L	8.4	10	9.6	8.1	7.6	7.6	8.2	19	12	5.2	1 U	1 U
Total DCE	µg/L	481	574	402	360	289	299	231	1,602	1,340	1,016	97	44
Vinyl Chloride	µg/L	2.1	1.8	2	5.3	2	3.2	0.61	5.3	11	260	270	200
1,1-Dichloroethane	µg/L	6.1	6.2	6.6	5.6	4.8	4.5	8.1	10	4.7	5.4	6.4	5.2
Chloroethane	µg/L	1 U	1 U	1 U	1 U	1 U	0.38 J	1 U	1 U	2.6	1 U	0.62 J	0.71 J
Dissolved Gases													
Methane	µg/L	3.7	2.6	3,400	13,000	12,000	10,000	2.6	6.4	24,000	26,000	25,000	23,000
Ethene	µg/L	0.34	0.16	0.27	22	0.21	0.23	0.16	0.32	1.5	220	350	310
Ethane	µg/L	0.24	0.13	0.1	0.055	0.08	0.088	0.18	0.59	0.071	0.051	0.14	0.12
Acetylene	µg/L	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors													
Nitrate-N	mg/L	0.198 J	0.281 J	0.41	0.389	0.317	0.264	0.395 J	0.1 UJ	0.1 U	0.0593 J	0.0513 J	0.1 U
Arsenic (filtered)	µg/L	1.37	0.893 J	1.14	0.708 J	0.631 J	0.727 J	1.04	4.97	13.4	12.2	13.4	12.9
Manganese (filtered)	µg/L	370	358	351	386	383	362	33	4,240	6,200	5,120	5,630	6,570
Iron (filtered)	µg/L	1,000 U	1,000 U	1,000 UJ	1,000 U	1,000 U	1,000 U	1,000 U	216 J	3,020 J	2,000	3,640	3,770
Sulfate	mg/L	475	457	496	456	437	472	396	286	78.9	94.7	243	333
General Chemistry													
Alkalinity	mg/L	390	402	395	396	387	396	304	660	783	756	611	566
Total Organic Carbon	mg/L	1.01	1.24	1.26	0.911 J	0.775 J	0.748 J	1.05	2,130	23	5	4	3
Volatile Fatty Acids													
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA	0.5 U	NA	NA	0.5 U	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA	0.5 U	NA	NA	0.5 U	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA	0.5 U	NA	NA	0.5 U	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA	0.5 U	NA	NA	0.5 U	NA	NA
Field Parameters													
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.37	0.35	0.4	0.11	0.46	0.17	0.34	1.51	2.18	1.28	1.02	0.8
Dissolved Oxygen	mg/L	0.13	0.04	1.95	0.07	0.06	0.12	0.13	0.01	0	0	0	0.02
Oxidation-Reduction Potential	mV	200	6	-239	-40	-53	-23	140	-172	-277	-60	-67	-51
pH	SU	7.3	7.2	7.0	7.0	7.0	6.9	7.2	7.0	6.6	6.7	6.7	6.6
Specific Conductance	µS/cm	1,414	1,410	1,354	1,277	1,233	1,432	1,202	1,680	1,360	1,330	1,312	1,466
Temperature	°C	18.4	20.1	19.7	17.4	17.7	22.5	20.1	22.0	19.4	18.9	19.5	25.5
Turbidity	FNU	111	1,174	157	3	570	272	40	58	111	177	211	246
Biological Parameter													
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	2.2E+04	NA	NA	9.7E+02	NA	NA	NA	NA	NA

Table 1
Baseline and Post-Injection Groundwater Data
EVO Pilot Test
Traffic Island Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-03 (Downgradient; 40 to 50 ft bgs)						28OW-04 (Downgradient; 55 to 65 ft bgs)						
Sample ID	28OW-3-20100709	28OW-03-082010	28OW03-111010	28OW-03-012611	28OW03-041311	28OW03-062211	28OW-4-20100709	28OW-04-082010	28OW04-111010	28OW-04-012611	28OW04-041311	28OW04-062211	
Date Sampled	7/9/10	8/20/10	11/10/10	1/26/11	4/13/11	6/22/11	7/9/10	8/20/10	11/10/10	1/26/11	4/13/11	6/22/11	
Site-Specific VOCs													
Tetrachloroethene	µg/L	9,900	4,000	120	98	3,000	1,100	15,000	820	460	8,100	15,000	11,000
Trichloroethene	µg/L	5,900	27,000	270	130	4,200	1,700	12,000	19,000	920	10,000	14,000	13,000
cis-1,2-Dichloroethene	µg/L	2,100	17,000	32,000	25,000	25,000	13,000	5,000	23,000	9,800	17,000	13,000	11,000
trans-1,2-Dichloroethene	µg/L	46	630	760	190	180	240	100	990	160	230	200	240
1,1-Dichloroethene	µg/L	59	70	34	130	170	62	150	110	32	170	170	140
Total DCE	µg/L	2,205	17,700	32,794	25,320	25,350	13,302	5,250	24,100	9,992	17,400	13,370	11,380
Vinyl Chloride	µg/L	240	130	4,400	3,400	2,100	4,100	600	240	7,700	710	680	460
1,1-Dichloroethane	µg/L	0.54 J	25 U	0.65 J	1.3 J	25 U	1.2 J	0.97 J	25 U	0.53 J	1.5 J	10 U	1.6 J
Chloroethane	µg/L	1 U	25 U	1 U	5 U	25 U	5 U	1 U	25 U	1 U	5 U	10 U	5 U
Dissolved Gases													
Methane	µg/L	29	22	1,300	1,000	410	2,700	51	36	200	45	80	290
Ethene	µg/L	12	8.8	140	280	150	730	21	16	130	40	26	23
Ethane	µg/L	0.23	0.2	0.2	0.097	0.07	0.077	0.15	0.18	0.27	0.096	0.074	0.069
Acetylene	µg/L	1.4	0.5 U	0.05 J	0.5 U	0.5 U	0.5 U	0.37 J	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors													
Nitrate-N	mg/L	0.1 UJ	0.1 UJ	0.1 U	0.1 U	0.1 U	0.1 U	0.1 UJ	0.1 UJ	0.1 U	0.1 U	0.1 U	0.1 U
Arsenic (filtered)	µg/L	3.86	8.51	13	13.8	12.5	7.42	10.7	19.7	30.1	25	24.5	21.8
Manganese (filtered)	µg/L	364	1,040	2,030	953	559	786	264	1,280	2,230	457	303	287
Iron (filtered)	µg/L	1,000 U	386 J	1,590 J	509 J	1,670	444 J	1,000 U	437 J	5,560 J	1,350	525 J	367 J
Sulfate	mg/L	134	71	49	78	90	77	98	82	17	95	90.4	96.1
General Chemistry													
Alkalinity	mg/L	215	404	559	319	256	312	227	378	751	229	236	244
Total Organic Carbon	mg/L	2.05	59	40	10	3.5	10.9	1.05	17	70	0.971 J	0.763 J	0.754 J
Volatile Fatty Acids													
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA	0.5 U	NA	NA	0.5 U	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA	0.5 U	NA	NA	0.5 U	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA	0.255 J	NA	NA	0.5 U	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA	0.5 U	NA	NA	0.5 U	NA	NA
Field Parameters													
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.28	0.4	0.85	0.44	1.2	0.51	0	1.35	3.5	1.42	0.48	0
Dissolved Oxygen	mg/L	1.16	0	0	0	0	0	1.26	0	0	0	0	0
Oxidation-Reduction Potential	mV	70	-218	-280	-205	-84	-225	170	-165	-250	-149	-73	-110
pH	SU	7.9	6.7	6.9	7.2	7.1	7.2	7.7	6.3	6.8	7.3	7.4	7.4
Specific Conductance	µS/cm	712	788	1,132	767	675	761	670	919	1,396	658	659	688
Temperature	°C	19.2	20.2	20.7	18.6	18.9	21.0	21.6	21.3	20.4	18.8	19.3	20.2
Turbidity	FNU	484	777	72	140	1,007	220	1,296	1,628	485	576	1,085	164
Biological Parameter													
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	NA	NA	NA	3.6E+01 U	NA	NA	2.0E+01 U	NA	NA

Table 1
Baseline and Post-Injection Groundwater Data
EVO Pilot Test
Traffic Island Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-05 (Treatment Area: 12 to 17 ft bgs)						28OW-06 (Treatment Area: 24 to 29 ft bgs)						
Sample ID	28OW-5-20100709	28OW-05-081910	28OW05-111010	28OW-05-012711	28OW05-041211	28OW05-062211	28OW-6-20100712	28OW-06-081910	28OW06-110810	28OW-06-012711	28OW06-041311	28OW06-062211	
Date Sampled	7/9/10	8/19/10	11/10/10	1/27/11	4/12/11	6/22/11	7/12/10	8/19/10	11/8/10	1/27/11	4/13/11	6/22/11	
Site-Specific VOCs													
Tetrachloroethene	µg/L	19	11	2.2	0.78 J	0.3 J	1.7	51	3.4	0.84 J	0.53 J	0.36 J	0.55 J
Trichloroethene	µg/L	17	63	8.8	1.0	1 U	1.0	220	1,600	2.9	3.9	0.87 J	1.5
cis-1,2-Dichloroethene	µg/L	4,000	4,300	2,800	260	69	3	210	830	1,100	1,000	180	200
trans-1,2-Dichloroethene	µg/L	12	14	2.9	0.3 J	1 U	1 U	3.9	49	26	81	37	3.2
1,1-Dichloroethene	µg/L	42	31	40	2.4	0.8 J	1 U	11	17	10	4.4	0.65 J	0.89 J
Total DCE	µg/L	4,054	4,345	2,843	263	70	3	225	896	1,136	1,085	218	204
Vinyl Chloride	µg/L	19	60	670	150	44	2.7	0.79	8.1	16	420	160	210
1,1-Dichloroethane	µg/L	36	43	45	13	4.6	0.69 J	8.1	9.8	4.9	3.9	5	4.3
Chloroethane	µg/L	1 U	2.2 J	2.3	5.5	7	6.1	1 U	1 U	2.2	1	3.9	5.9
Dissolved Gases													
Methane	µg/L	6.1	14	6,600	21,000	10,000	22,000	1.5	10	22,000	21,000	27,000	24,000
Ethene	µg/L	0.4	1.4	320	700	390	310	0.084	0.25	1.5	310	360	340
Ethane	µg/L	0.18	2.3	0.88	0.29	0.15	0.35	0.08	0.7	0.056	0.11	0.13	0.56
Acetylene	µg/L	0.11 J	0.4 J	0.069 J	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors													
Nitrate-N	mg/L	0.1 UJ	5 UJ	0.5 U	0.12	0.0538 J	0.0528 J	0.434	0.1 UJ	0.0797 J	0.0613 J	0.0517 J	0.0551 J
Arsenic (filtered)	µg/L	2.28	42.3	4.88	6.09	11.5	20.5	0.571 J	8.96	8.19	4.79	3.63	2.94
Manganese (filtered)	µg/L	397	3,330	11,900	3,430	1,910	1,740	19	2,760	7,750	8,220	6,420	7,210
Iron (filtered)	µg/L	403 J	4,350 J	39,600 J	9,090	4,860	5,930	1,000 U	343 J	3,230	4,730	5,810	7,530
Sulfate	mg/L	489	60	13	43	34	8	398	338	103	179	210	286
General Chemistry													
Alkalinity	mg/L	380	1,110	1,730	1,060	1,020	1,040	335	570	965	855	794	738
Total Organic Carbon	mg/L	1.13	9,680	2,000	304	120	58	0.618 J	1,980	26	3.93	3.00	2.70
Volatile Fatty Acids													
Lactic Acid	mg/L	NA	NA	NA	NA	NA	0.5 U	0.5 U	NA	NA	0.5 U	NA	0.5 U
Acetic Acid	mg/L	NA	NA	NA	NA	NA	47	0.5 U	NA	NA	6.85	NA	0.5 U
Propionic Acid	mg/L	NA	NA	NA	NA	NA	6.6	0.5 U	NA	NA	0.5 U	NA	0.5 U
Butyric Acid	mg/L	NA	NA	NA	NA	NA	0.5 U	0.5 U	NA	NA	0.5 U	NA	0.5 U
Field Parameters													
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.56	5.2	5.56	8.05	1.44	0.7	0.17	0.24	0.55	NA	5.76	1.04
Dissolved Oxygen	mg/L	0.24	0	0	0	0	0	0.30	0	0.01	0	0	0
Oxidation-Reduction Potential	mV	-50	-262	-262	-156	-127	-103	190	-118	-217	-131	-68	-56
pH	SU	7.3	6.0	5.8	6.8	6.9	6.8	7.1	6.8	6.7	6.6	6.6	6.5
Specific Conductance	µS/cm	1,454	2,254	3,734	2,046	1,794	1,805	1,235	1,622	1,586	1,543	1,458	1,706
Temperature	°C	20.2	20.6	19.3	17.8	20.1	22.4	20.5	21.5	20.0	18.6	17.5	23.2
Turbidity	FNU	16	102	239	0	79	21	82	88	84	122	28	88
Biological Parameter													
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	NA	NA	3.3E+05	2.2E+01 U	NA	NA	2.6E+01 U	NA	1.7E+04

Table 1
Baseline and Post-Injection Groundwater Data
EVO Pilot Test
Traffic Island Area, IR Site 28, Former NAS Moffett Field

Well ID		28OW-07 (Treatment Area: 40 to 50 ft bgs)						28OW-08 (Treatment Area: 55 to 65 ft bgs)					
Sample ID		28OW-7-20100709	28OW-07-081910	28OW07-111010	28OW-07-012711	28OW07-041311	28OW07-062211	28OW-8-20100712	28OW-08-082410	28OW08-111010	28OW-08-012611	28OW08-041311	28OW08-062211
Date Sampled		7/9/10	8/19/10	11/10/10	1/27/11	4/13/11	6/22/11	7/12/10	8/24/10	11/10/10	1/26/11	4/13/11	6/22/11
Site-Specific VOCs													
Tetrachloroethene	µg/L	3,400	240	4.1	1.4	1 U	0.3 J	2,500	190	10	6.8	4	1.5
Trichloroethene	µg/L	210	2,300	1.2	1.7	0.28 J	0.87 J	2,000	670 J	8.2	3.9	2.2	0.85 J
cis-1,2-Dichloroethene	µg/L	3.7	6,900	2,400	2.4	0.8 J	1.4	110	3,400	4,400	1,200	490	310
trans-1,2-Dichloroethene	µg/L	0.21 J	620	110	55	7.9	1.5	4.9	12	96	46	3.1	1.9
1,1-Dichloroethene	µg/L	0.91 J	25 U	1.7	1 U	1 U	1 U	4.3	4.8	6.8	1.3	0.35 J	0.26 J
Total DCE	µg/L	5	7,520	2,512	57	8.7	2.9	119	3,417	4,503	1,247	493	312
Vinyl Chloride	µg/L	0.5 U	110	37	9.5	3.2	2.9	3.9	2.2	36	510	380	530
1,1-Dichloroethane	µg/L	1 U	25 U	1 U	1 U	1 U	1 U	0.21 J	1 U	0.25 J	1 U	1 U	1 U
Chloroethane	µg/L	1 U	25 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Dissolved Gases													
Methane	µg/L	0.53	1,100	18,000	23,000	24,000	26,000	5	6.5	7,900	6,800	6,000	6,700
Ethene	µg/L	0.18	0.82	0.91	86	140	69	1.0	1.3	0.67	730	1,300	950
Ethane	µg/L	0.029	2.6	0.021 J	0.21	0.28	4.8	0.41	0.21	0.062	0.1	0.12	0.18
Acetylene	µg/L	0.5 U	0.5 U	0.55	0.5 U	0.5 U	0.5 U	0.12 J	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors													
Nitrate-N	mg/L	0.1 UJ	5 UJ	0.5 U	0.0689 J	0.5 U	0.0582 J	0.1 U	0.1 U	0.1 U	0.0573 J	0.0501 J	0.1 U
Arsenic (filtered)	µg/L	2.02	27.7	18.3	59.6	51.1	40.5	1.71	5.68	13.5	14.1	9.41	10.1
Manganese (filtered)	µg/L	172	5,630	7,070	2,690	1,850	2,420	3.3	456	3,300	5,240	3,750	2,430
Iron (filtered)	µg/L	1,000 U	4,390 J	9,090 J	10,600	11,700	14,400	1,000 U	1,000 U	647 J	1,930	1,300	1,510
Sulfate	mg/L	164	25 U	2.5	1.1	3.5	1.1	90	33	3.7	11.1	29.4	48.5
General Chemistry													
Alkalinity	mg/L	224	1,220	2,450	1,750	1,610	1,560	43.9	239	411	495	425	346
Total Organic Carbon	mg/L	0.756 J	9,590	1,380	274	109	47	0.993 J	102	54	99	57	12
Volatile Fatty Acids													
Lactic Acid	mg/L	NA	NA	NA	NA	NA	0.5 U	0.5 U	NA	NA	0.5 U	NA	0.5 U
Acetic Acid	mg/L	NA	NA	NA	NA	NA	4.6	0.5 U	NA	NA	158	NA	15
Propionic Acid	mg/L	NA	NA	NA	NA	NA	2.3	0.5 U	NA	NA	18.5	NA	0.84
Butyric Acid	mg/L	NA	NA	NA	NA	NA	0.5 U	0.5 U	NA	NA	5.5	NA	0.5 U
Field Parameters													
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.61	8.6	6.2	10.4	13.65	0.62	0.35	0.34	0.22	0.72	0.72	0.38
Dissolved Oxygen	mg/L	0.85	0	0.06	0	0	0	1.87	0	0	0	0	0
Oxidation-Reduction Potential	mV	0	-150	-270	-136	-91	-92	0	-306	-273	-178	-155	-169
pH	SU	7.6	6.2	6.6	6.9	6.8	6.7	10.3	8.5	7.2	7.1	7.2	7.3
Specific Conductance	µS/cm	741	1,747	3,582	2,763	2,205	2,573	436	597	762	939	800	811
Temperature	°C	21.4	21.2	19.8	18.8	17.3	24.3	20.1	21.0	20.2	20.9	19.7	23.8
Turbidity	FNU	292	287	451	639	183	410	171	2,939	82	0	181	620
Biological Parameter													
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	NA	NA	1.0E+01 U	2.1E+01 U	NA	NA	4.7E+05	NA	1.0E+01 U

Table 1
Baseline and Post-Injection Groundwater Data
EVO Pilot Test
Traffic Island Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-09 (Upgradient: 12 to 17 ft bgs)												
Sample ID	28OW-9-20100708	MW9903-20100708*	28OW-09-081810	MW9902-081810*	28OW09-110810	MW9901-110810*	28OW-09-012411	MW9901-012411*	28OW09-041111	MW9901-041111 *	28OW09-062011	MW9903-062011 *	
Date Sampled	7/8/10		8/18/10		11/8/10		1/24/11		4/11/11		6/20/11		
Site-Specific VOCs													
Tetrachloroethene	µg/L	0.38 J	0.49 J	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	0.43 J	0.43 J
Trichloroethene	µg/L	21	23	9.5	8.5	6.1	5.8	7.3	6.8	5.1	5.4	4.6	4.2
cis-1,2-Dichloroethene	µg/L	1,700	1,700	1,800	1,700	1,400	1,300	1,400	960	1,200	1,200	1,200	1,200
trans-1,2-Dichloroethene	µg/L	4.8	6.6	3.1	5.5	3.9	4.1	6.9	14	40	70	6.7	5.9
1,1-Dichloroethene	µg/L	28	27	22	22	20	18	21	22	19	19	19	18
Total DCE	µg/L	1,733	1,734	1,825	1,728	1,424	1,322	1,428	996	1,259	1,289	1,226	1,224
Vinyl Chloride	µg/L	1.6	1.6	3.5	3.2	21	22	17	17	17	16	24	23
1,1-Dichloroethane	µg/L	25	25	22	21	21	21	19	20	18	20	19	18
Chloroethane	µg/L	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Dissolved Gases													
Methane	µg/L	2.5	NA	2.2	NA	2.2	NA	2.9	NA	2.8	NA	2.8	NA
Ethene	µg/L	0.24	NA	0.31	NA	0.14	NA	0.27	NA	0.39	NA	0.45	NA
Ethane	µg/L	0.098	NA	0.079	NA	0.085	NA	0.11	NA	0.094	NA	0.086	NA
Acetylene	µg/L	0.5 U	NA	0.5 U	NA	0.5 U	NA	0.5 U	NA	0.5 U	NA	0.5 U	NA
Electron Acceptors													
Nitrate-N	mg/L	0.1 UJ	NA	0.1 U	NA	0.1 U	NA	0.1 U	NA	0.1 U	NA	0.1 U	NA
Arsenic (filtered)	µg/L	4.1	NA	3.06	NA	1.46	NA	0.89 J	NA	0.789 J	NA	0.937 J	NA
Manganese (filtered)	µg/L	471	NA	519	NA	443	NA	518	NA	500	NA	448	NA
Iron (filtered)	µg/L	1,000 U	NA	339 J	NA	412 J	NA	274 J	NA	463 J	NA	1,020	NA
Sulfate	mg/L	477	NA	466	NA	464	NA	481	NA	444	NA	476	NA
General Chemistry													
Alkalinity	mg/L	373	NA	381	NA	390	NA	377	NA	380	NA	374	NA
Total Organic Carbon	mg/L	0.989 J	NA	1.17	NA	1.22	NA	0.782 J	NA	1.18	NA	1.04	NA
Volatile Fatty Acids													
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Field Parameters													
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.37		0.73		0.78		0.39		0.68		1.04	
Dissolved Oxygen	mg/L	0.19		0.09		1.88		0.01		0.01		0	
Oxidation-Reduction Potential	mV	-70		-34		-139		-140		-38		-87	
pH	SU	7.1		6.3		7.2		7.2		7.2		7.1	
Specific Conductance	µS/cm	1,430		1,471		1,368		1,363		1,325		1,445	
Temperature	°C	21.3		22.2		21.1		20.7		20.4		23.5	
Turbidity	FNU	16		64		2,124		93		50		40	
Biological Parameter													
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 1
Baseline and Post-Injection Groundwater Data
EVO Pilot Test
Traffic Island Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-10 (Upgradient; 24 to 29 ft bgs)						28OW-11 (Upgradient; 40 to 50 ft bgs)						
Sample ID	28OW-10-20100708	28OW-10-081810	28OW10-110810	28OW-10-012411	28OW10-041111	28OW10-062011	28OW-11-20100708	28OW-11-081810	28OW11-110810	28OW-11-012411	28OW11-041111	28OW11-062011	
Date Sampled	7/8/10	8/18/10	11/8/10	1/24/11	4/11/11	6/20/11	7/8/10	8/18/10	11/8/10	1/24/11	4/11/11	6/20/11	
Site-Specific VOCs													
Tetrachloroethene	µg/L	5.2	1 U	1 U	1 U	0.23 J	0.29 J	2.8	2.9	1.1	2.8	2	0.84 J
Trichloroethene	µg/L	260	220	260	290	360	390	260	270	200	200	210	170
cis-1,2-Dichloroethene	µg/L	190	170	120	140	150	150	30	33	45	38	32	32
trans-1,2-Dichloroethene	µg/L	3.5	1.6	1.2	0.45 J	0.71 J	0.46 J	1 U	1 U	1 U	1 U	1 U	1 U
1,1-Dichloroethene	µg/L	18	16	20	22	25	25	19	17	19	19	20	19
Total DCE	µg/L	212	188	141	162	176	175	49	50	64	57	52	51
Vinyl Chloride	µg/L	0.28 J	0.5 U	0.95	1.4	0.61	0.55	0.5 U	0.5 U	0.5 U	1.3	0.44 J	0.71
1,1-Dichloroethane	µg/L	7.6	5.5	8.1	8.3	8.4	7.5	4.2	3.8	4.4	4.1	4.0	3.9
Chloroethane	µg/L	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Dissolved Gases													
Methane	µg/L	1.3	1.1	1.4	1.5	1.5	1.2	1.3	1	0.8	0.79	0.76	0.8
Ethene	µg/L	0.25	0.26	0.16	0.1	0.072	0.093	0.058	0.056	0.18	0.055	0.038	0.058
Ethane	µg/L	0.078	0.056	0.065	0.069	0.068	0.057	0.044	0.04	0.034	0.034	0.033	0.031
Acetylene	µg/L	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors													
Nitrate-N	mg/L	0.1 UJ	0.1 U	0.0626 J	0.124	0.13	0.114	0.1 UJ	0.1 U	0.0522 J	0.0683 J	0.1 U	0.0511 J
Arsenic (filtered)	µg/L	1.25	1.08	0.819 J	0.687 J	0.665 J	0.732 J	1.38	0.999 J	1.11	1.12	1.00	0.95 J
Manganese (filtered)	µg/L	430	957	885	791	703	715 J	122	123	47	56	40	40
Iron (filtered)	µg/L	1,000 U	214 J	1,000 U	1,000 U	1,000 U	1,000 U	1,000 U	284 J	1,000 U	698 J	179 J	105 J
Sulfate	mg/L	217	188	238	231	248	251	189	188	210	206	198	220
General Chemistry													
Alkalinity	mg/L	204	221	250	241	252	252	251	327	533	233	234	234
Total Organic Carbon	mg/L	0.946 J	0.666 J	1.57	0.596 J	0.578 J	0.509 J	0.821 J	0.735 J	1.29	0.535 J	0.638 J	0.568 J
Volatile Fatty Acids													
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Field Parameters													
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.18	0.42	0.42	0.35	0.35	0.37	0	25	0.4	0.63	0.06	0.92
Dissolved Oxygen	mg/L	2.27	0.02	0.01	0.05	0.03	0.04	0.06	0.04	0.13	0.03	0	0.2
Oxidation-Reduction Potential	mV	70	18	-187	-141	-77	-64	70	91	-191	-188	-103	-48
pH	SU	7.7	7.7	7.5	7.4	7.4	7.3	7.0	6.6	7.5	7.4	7.4	7.4
Specific Conductance	µS/cm	816	805	870	903	924	1,036	821	910	813	797	784	883
Temperature	°C	21.9	21.8	20.6	20.6	20.9	24.8	21.8	21.8	21.3	20.2	20.3	24.6
Turbidity	FNU	439	553	2,402	1,765	352	743	378	1,004	2,081	1,135	1,133	815
Biological Parameter													
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 1
Baseline and Post-Injection Groundwater Data
EVO Pilot Test
Traffic Island Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-12 (Treatment Area: 55 to 65 ft bgs)						W9-29 (Crossgradient: 7 to 17 ft bgs)						
Sample ID	28OW-12-20100712	28OW-12-081810	28OW12-110810	28OW-12-012611	28OW12-041311	28OW12-062211	W9-29-20100712	W9-29-082410	W9-29-111010	W9-29-012611	W9-29-041111	W9-29-062011	
Date Sampled	7/12/10	8/18/10	11/8/10	1/26/11	4/13/11	6/22/11	7/12/10	8/24/10	11/10/10	1/26/11	4/11/11	6/20/11	
Site-Specific VOCs													
Tetrachloroethene	µg/L	28,000	2,000	240	9.3	2.7	12	2,100	950	440	7.9	4.4	270
Trichloroethene	µg/L	7,800	8,900	930	3.5	0.56 J	68	410	280 J	150	3.5	2.2	170
cis-1,2-Dichloroethene	µg/L	200	32,000	43,000	3,000	8.5	4,900	750	1,100	1,000	150	55	460
trans-1,2-Dichloroethene	µg/L	51	1,700	1,900	1,100	920	170	3.2	4.2	3	0.37 J	0.22 J	1.5
1,1-Dichloroethene	µg/L	74	45	63	2.7	1 U	5.3	13	14	16	1.5	0.64 J	9.1
Total DCE	µg/L	325	33,745	44,963	4,103	929	5,075	766	1,118	1,019	152	56	471
Vinyl Chloride	µg/L	0.97	16	180	1,800	22	1,200	66	13	58	400	330	73
1,1-Dichloroethane	µg/L	0.57 J	5 U	0.74 J	1 U	1 U	0.22 J	9.4	12	12	7.9	5.8	7.5
Chloroethane	µg/L	1 U	5 U	1 U	1 U	1 U	0.7 J	1 U	1 U	1 U	1 U	1 U	1 U
Dissolved Gases													
Methane	µg/L	0.45	17	13,000	14,000	23,000	15,000	2.4	5	45	2,500	1,200	3,500
Ethene	µg/L	0.52	0.81	3.6	4,400	5,800	7,100	3.4	0.6	1.5	28	29	9.8
Ethane	µg/L	0.12	1.1	0.38	0.35	0.66	0.83	0.13	0.1	0.089	0.25	0.21	0.094
Acetylene	µg/L	6.2	0.5 U	0.25 J	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors													
Nitrate-N	mg/L	0.1 U	0.2 U	0.158 J	0.5 U	0.282 J	0.2 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Arsenic (filtered)	µg/L	3.0	18.5	27.2	40.6	53	71	1 U	1 U	1 U	1 U	1 U	0.233 J
Manganese (filtered)	µg/L	182	1,700	13,200	9,210	8,920	9,150	201	244	209	162	119	211
Iron (filtered)	µg/L	562 J	1,520	53,700	62,100	81,300	85,600	1,000 U	206 J	527 J	1,150	1,220	338 J
Sulfate	mg/L	118	5.3	0.859 J	1.41 J	1.75 J	1.88	437	477	481	409	389	489
General Chemistry													
Alkalinity	mg/L	224	577	2,230	1,700	1,600	1,440	369	382	394	294	277	370
Total Organic Carbon	mg/L	0.788 J	2,760	1,830	996	797	670	0.656 J	0.888 J	1.0	0.8 J	0.8 J	0.7 J
Volatile Fatty Acids													
Lactic Acid	mg/L	NA	NA	NA	NA	NA	0.5 U	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	1,140	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	179	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	41	NA	NA	NA	NA	NA	NA
Field Parameters													
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0	0.84	23.5	18.08	16.2	0.72	0.22	0.45	0.47	1.28	0.96	0.87
Dissolved Oxygen	mg/L	0.36	0	0	0	0	0	0.06	0.04	0	0	0	0
Oxidation-Reduction Potential	mV	100	-277	-216	-342	-86	-116	-160	-137	-312	-157	-102	-146
pH	SU	7.7	6.6	6.1	6.4	6.4	6.5	7.2	7.2	7.2	7.6	7.6	7.3
Specific Conductance	µS/cm	676	1,425	4,101	3,078	2,749	3,236	1,291	1,488	1,339	1,168	1,094	1,345
Temperature	°C	21.3	21.8	20.7	20.5	15.8	24.0	20.0	22.5	19.1	19.3	19.3	22.5
Turbidity	FNU	795	530	578	261	349	788	12	6	52	25	41	17
Biological Parameter													
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	NA	NA	1.3E+06	NA	NA	NA	NA	NA	NA

Table 1
Baseline and Post-Injection Groundwater Data
EVO Pilot Test
Traffic Island Area, IR Site 28, Former NAS Moffett Field

Well ID	W9-42 (Crossgradient: 29 to 39 ft bgs)						
Sample ID	W9-42-20100712	W9-42-082410	W9-42-111010	W9-42-012611	W9-42-041111	W9-42-062011	
Date Sampled	7/12/10	8/24/10	11/10/10	1/26/11	4/11/11	6/20/11	
Site-Specific VOCs							
Tetrachloroethene	µg/L	2.4	3.2	3.2	29	17	8.4
Trichloroethene	µg/L	23	2.9	0.87 J	8	18	4.7
cis-1,2-Dichloroethene	µg/L	320	66	17	60	90	84
trans-1,2-Dichloroethene	µg/L	2.7	8.4	2.7	2.9	2.7	2.5
1,1-Dichloroethene	µg/L	2.1	0.31 J	1 U	0.24 J	1.0	0.26 J
Total DCE	µg/L	325	75	20	63	94	87
Vinyl Chloride	µg/L	140	350	88	210	240	190
1,1-Dichloroethane	µg/L	6.5	5.5	5.6	6.2	5.4	3.9
Chloroethane	µg/L	1 U	0.4 J	1 U	1 U	1 U	0.52 J
Dissolved Gases							
Methane	µg/L	2	3	1,000	1,700	3,800	4,500
Ethene	µg/L	1.6	42	79	20	31	33
Ethane	µg/L	0.077	0.16	0.17	0.06	0.096	0.4
Acetylene	µg/L	0.5 U	0.12 J	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors							
Nitrate-N	mg/L	0.1 U	0.1 U	0.5 U	0.1 U	0.1 U	0.1 U
Arsenic (filtered)	µg/L	1 U	1 U	1 U	1 U	1 U	0.338 J
Manganese (filtered)	µg/L	9.7	402	89	104	141	305
Iron (filtered)	µg/L	1,060	1,000 U	1,000 UJ	541 J	2,990	15,200
Sulfate	mg/L	398	266	279	382	295	175
General Chemistry							
Alkalinity	mg/L	357	461	380	349	370	392
Total Organic Carbon	mg/L	0.701 J	347	2.78	0.843 J	0.801 J	0.882 J
Volatile Fatty Acids							
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA
Field Parameters							
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.97	0.28	0.12	0.57	1.26	2.18
Dissolved Oxygen	mg/L	0.09	0.04	0	0	0	0
Oxidation-Reduction Potential	mV	-130	-313	-300	-179	-113	-157
pH	SU	7.3	7.2	7.3	7.2	7.3	7.2
Specific Conductance	µS/cm	1,260	1,363	1,056	1,217	1,112	1,094
Temperature	°C	20.7	22.5	19.0	20.5	20.7	24.8
Turbidity	FNU	28	90	22	0	18	30
Biological Parameter							
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	NA	NA	NA

Table 2
Baseline and Post-Injection Groundwater Data
Lactate Pilot Test
Former Building 88 Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-19 (Downgradient; 35 to 40 ft bgs)										
Sample ID	28OW-19-20100707	28OW-19-081110	28OW19-111110	MW9903-111110*	28OW-19-012711	MW9903-012711*	28OW19-041311	MW9903-041311	28OW19-062211	MW9901-062211*	
Date Sampled	7/7/10	8/11/10	11/11/10		1/27/11		4/13/11		6/22/11		
Site-Specific VOCs											
Tetrachloroethene	µg/L	300	280	220	210	210	200	150	130	150	150
Trichloroethene	µg/L	3,600	3,300	3,500	3,400	3,800	3,700	3,100	2,800	2,900	3,000
cis-1,2-Dichloroethene	µg/L	310	290	350	340	270	250	280	260	450	480
trans-1,2-Dichloroethene	µg/L	2.5	3.2	2.7	2.4	1.7	1.9	1.3	1.3	2.4	2.9
1,1-Dichloroethene	µg/L	30	37	32	34	29	30	29	26	24	25
Total DCE	µg/L	343	330	385	376	301	282	310	287	476	508
Vinyl Chloride	µg/L	0.51	0.64	0.7	0.71	1.8	1.9	10	9.4	27	27
1,1-Dichloroethane	µg/L	12	12	12	12	9	9.1	9.4	8.1	8.5	8.6
Chloroethane	µg/L	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U
Dissolved Gases											
Methane	µg/L	2.9	2.9	2.6	NA	2.6	NA	2.3	NA	2.3	NA
Ethene	µg/L	0.57	0.54	0.46	NA	0.68	NA	2.1	NA	4.5	NA
Ethane	µg/L	0.18	0.16	0.15	NA	0.1	NA	0.084	NA	0.11	NA
Acetylene	µg/L	0.5 U	0.5 U	0.5 U	NA	0.5 U	NA	0.5 U	NA	0.5 U	NA
Electron Acceptors											
Nitrate-N	mg/L	0.685	0.921	0.86	NA	0.688	NA	0.495	NA	0.411	NA
Arsenic (filtered)	µg/L	1.52	1.13	1.26	NA	0.935 J	NA	0.799 J	NA	0.686 J	NA
Manganese (filtered)	µg/L	64 J	54	44 J	NA	4.5	NA	29.7	NA	10.7	NA
Iron (filtered)	µg/L	1,000 U	1,000 U	1,000 U	NA	1,000 U	NA	542 J	NA	1,000 U	NA
Sulfate	mg/L	306	300	284	NA	242	NA	219	NA	241	NA
General Chemistry											
Alkalinity	mg/L	293	298	301	NA	196	NA	224	NA	224	NA
Total Organic Carbon	mg/L	0.888 J	0.748 J	1.12	NA	1.16	NA	0.886 J	NA	0.712 J	NA
Volatile Fatty Acids											
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Field Parameters											
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.5	1.31	1.6		0.3		0.3		0.2	
Dissolved Oxygen	mg/L	0.28	0.02	0.34		0.30		0.84		0.11	
Oxidation-Reduction Potential	mV	140	87	-310		-118		-62		-54	
pH	SU	7.4	6.9	7.3		8.3		8.4		8.8	
Specific Conductance	µS/cm	1,138	1,092	1,055		878		738		800	
Temperature	°C	21.3	21.7	21.5		20.1		18.8		21.8	
Turbidity	FNU	205	56	1,133		78		888		138	
Biological Parameter											
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 2
Baseline and Post-Injection Groundwater Data
Lactate Pilot Test
Former Building 88 Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-20 (Downgradient: 52 to 62 ft bgs)						28OW-21 (Treatment Area: 35 to 40 ft bgs)							
Sample ID	28OW-20-20100707	28OW-20-081110	28OW20-111110	28OW-20-012711	28OW20-041311	28OW20-062211	28OW-21-20100707	28OW-21-081010	MW9901-081010*	28OW21-111110	28OW-21-012411	28OW21-041111	28OW21-062011	
Date Sampled	7/7/10	8/11/10	11/11/10	1/27/11	4/13/11	6/22/11	7/7/10	8/10/10		11/11/10	1/24/11	4/11/11	6/20/11	
Site-Specific VOCs														
Tetrachloroethene	µg/L	70	32	1 U	0.34 J	1 U	0.24 J	320	65	46	4.5	7.8	15	7.6
Trichloroethene	µg/L	4,300	2,200	8.3	7.4	7.2	20	2,400	490	310	27	41	79	45
cis-1,2-Dichloroethene	µg/L	120	1,100	3,900	3,700	3,600	3,100	250	3,800	3,800	560	480	420	400
trans-1,2-Dichloroethene	µg/L	1.2	6	9.4	6.9	8.8	6.9	1.2	7.2	8.1	22	19	16	13
1,1-Dichloroethene	µg/L	29	26	30	21	19	16	31	37	33	4.4	3.7	4.8	3.2
Total DCE	µg/L	150	1,132	3,939	3,728	3,628	3,123	282	3,844	3,841	586	503	441	416
Vinyl Chloride	µg/L	0.93	0.75	7	71	140	270	0.63	4.3	4.3	210	170	210	210
1,1-Dichloroethane	µg/L	7.7	7.1	7.6	6.0	7.0	7.2	12	13	14	12	11	11	11
Chloroethane	µg/L	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	0.36 J	1 U	1 U	1.1 J
Dissolved Gases														
Methane	µg/L	1.4	1.1	2.3	4.2	3.0	1.7	2.8	3.0	NA	17	41	21	19
Ethene	µg/L	0.39	0.57	0.9	3.3	4.3	3.8	0.45	0.58	NA	660	530	570	540
Ethane	µg/L	0.19	0.098	0.15	0.12	0.094	0.076	0.14	0.19	NA	2.0	1.4	1.3	1.2
Acetylene	µg/L	0.064 J	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.047 J	0.11 J	NA	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors														
Nitrate-N	mg/L	0.135	0.0503 J	0.1 U	0.0565 J	0.1 U	0.1 U	0.336	0.1 U	NA	0.0837 J	0.0685 J	0.1 U	0.0503 J
Arsenic (filtered)	µg/L	2.22	3.85	3.25	2.7	1.93	1.86	2.92	9.5	NA	19	13.3	9.1	6.8
Manganese (filtered)	µg/L	183 J	613	1,100 J	925	770	762	361 J	2,360	NA	2,260 J	2,010	1,660	1,510
Iron (filtered)	µg/L	1,000 U	238 J	433 J	329 J	318 J	1,530	1,000 U	1,560	NA	5,220	5,240	5,000	3,360
Sulfate	mg/L	190	184	150	165	180	188	347	270	NA	81	133	164	196
General Chemistry														
Alkalinity	mg/L	299	355	426	384	350	336	322	814	NA	1,020	956	927	875
Total Organic Carbon	mg/L	2.71	48	1.72	0.997 J	0.948 J	0.968 J	4.7	332	NA	14.4	2.38	2.02	2.0
Volatile Fatty Acids														
Lactic Acid	mg/L	0.5 U	NA	NA	0.5 U	NA	NA	NA	NA	NA	NA	NA	NA	0.5 U
Acetic Acid	mg/L	0.5 U	NA	NA	0.5 U	NA	NA	NA	NA	NA	NA	NA	NA	0.5 U
Propionic Acid	mg/L	0.275 J	NA	NA	0.5 U	NA	NA	NA	NA	NA	NA	NA	NA	0.5 U
Butyric Acid	mg/L	0.5 U	NA	NA	0.5 U	NA	NA	NA	NA	NA	NA	NA	NA	0.5 U
Field Parameters														
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.07	0.6	0.22	0.73	0.96	0.72	0.58	0.46	0.76	2.34	2.91	2.36	
Dissolved Oxygen	mg/L	0.43	0.04	0.02	0.01	0	0	0.17	0.62	0	0	0	0	
Oxidation-Reduction Potential	mV	40	-130	-321	-163	-91	-95	-90	-276	-321	-247	-189	-247	
pH	SU	7.4	6.5	7.2	7.3	7.2	7.1	7.3	6.3	6.5	6.5	6.5	6.5	
Specific Conductance	µS/cm	969	1,035	1,032	994	903	960	1,239	1,883	1,707	1,686	1,665	1,729	
Temperature	°C	22.2	22.2	21.6	20.6	18.9	21.9	21.4	22.8	20.2	19.4	19.8	21.9	
Turbidity	FNU	572	816	100	50	1,073	848	114	1,344	550	371	397	325	
Biological Parameter														
<i>Dehalococcoides</i> sp.	cells/mL	2.90E+03	NA	NA	1.4E+01 U	NA	NA	NA	NA	NA	NA	NA	NA	1E+01 U

Table 2
Baseline and Post-Injection Groundwater Data
Lactate Pilot Test
Former Building 88 Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-22 (Treatment Area: 52 to 62 ft bgs)								
Sample ID	28OW-22-20100708	MW9901-20100708*	28OW-22-081010	28OW22-111110	28OW-22-012411	28OW22-041111	28OW22-062011	28OW22-081211	
Date Sampled	7/8/10		8/10/10	11/11/10	1/24/11	4/11/11	6/20/11	8/12/11	
Site-Specific VOCs									
Tetrachloroethene	µg/L	13	12	13	1.2	3.7	6.1	NA	10
Trichloroethene	µg/L	3,600	3,500	4,000	91	360	1,200	NA	1,700
cis-1,2-Dichloroethene	µg/L	120	120	160	3,200	2,700	2,500	NA	1,400
trans-1,2-Dichloroethene	µg/L	3	2.5	1.6	9.6	7.5	7.6	NA	5.0
1,1-Dichloroethene	µg/L	28	27	28	28	27	28	NA	25
Total DCE	µg/L	151	150	190	3,238	2,735	2,536	NA	1,430
Vinyl Chloride	µg/L	0.88	0.89	2.2	5	5.9	16	NA	22
1,1-Dichloroethane	µg/L	9.1	8.7	8.2	8.1	7.4	7.9	NA	7.1
Chloroethane	µg/L	1 U	1 U	1 U	1 U	1 U	1 U	NA	1 U
Dissolved Gases									
Methane	µg/L	0.95	NA	1.6	2.0	1.6	2.0	1.6	NA
Ethene	µg/L	0.13	NA	0.25	1.1	1.2	0.93	1.9	NA
Ethane	µg/L	0.054	NA	0.13	0.1	0.079	0.077	0.064	NA
Acetylene	µg/L	0.5 U	NA	0.21 J	0.5 U	0.5 U	0.5 U	0.5 U	NA
Electron Acceptors									
Nitrate-N	mg/L	1 J	NA	0.1 U	0.1 U	0.1 U	0.1 U	0.0631 J	NA
Arsenic (filtered)	µg/L	0.762 J	NA	5.23	3.86	2.74	1.93	1.41	NA
Manganese (filtered)	µg/L	82	NA	1,190	1,450 J	1,340	1,290	1,200	NA
Iron (filtered)	µg/L	1,000 U	NA	360 J	1,000 U	1,000 U	1,000 U	1,000 U	NA
Sulfate	mg/L	182	NA	155	186	184	177	194	NA
General Chemistry									
Alkalinity	mg/L	312	NA	431	316	305	304	301	NA
Total Organic Carbon	mg/L	0.925 J	NA	126	1.22	0.609 J	0.758 J	0.555 J	NA
Volatile Fatty Acids									
Lactic Acid	mg/L	0.5 U	NA	NA	NA	0.5 U	NA	0.5 U	NA
Acetic Acid	mg/L	0.5 U	NA	NA	NA	0.5 U	NA	0.5 U	NA
Propionic Acid	mg/L	0.5 U	NA	NA	NA	0.5 U	NA	0.5 U	NA
Butyric Acid	mg/L	0.5 U	NA	NA	NA	0.5 U	NA	0.5 U	NA
Field Parameters									
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.10	0.63	0.70	0.31	0.68	0.42	0.33	
Dissolved Oxygen	mg/L	0.20	0.06	0	0.01	0	0	1.08	
Oxidation-Reduction Potential	mV	230	-215	-312	-157	-116	-105	-37	
pH	SU	6.3	7.2	7.2	7.2	7.2	7.2	7.3	
Specific Conductance	µS/cm	899	1,211	889	874	853	942	880	
Temperature	°C	19.8	22.6	19.8	19.7	19.6	22.4	20.6	
Turbidity	FNU	431	42	313	139	522	348	204	
Biological Parameter									
<i>Dehalococcoides</i> sp.	cells/mL	9.0E+02	NA	NA	NA	1E+01 U	NA	NA	NA

Table 2
Baseline and Post-Injection Groundwater Data
Lactate Pilot Test
Former Building 88 Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-23 (Upgradient; 35 to 40 ft bgs)							28OW-24 (Upgradient; 52 to 62 ft bgs)						
Sample ID	28OW-23-20100708	MW9902-20100708*	28OW-23-081110	28OW23-111110	28OW-23-012511	28OW23-041111	28OW23-062011	28OW-24-20100708	28OW-24-081010	28OW24-111110	28OW-24-012511	28OW24-041111	28OW24-062011	
Date Sampled	7/8/10		8/11/10	11/11/10	1/25/11	4/11/11	6/20/11	7/8/10	8/10/10	11/11/10	1/25/11	4/11/11	6/20/11	
Site-Specific VOCs														
Tetrachloroethene	µg/L	19,000	19,000	3,800	10,000	12,000	22,000	20,000	1.9	3.5	2.2	1.7	1.4	1.0
Trichloroethene	µg/L	3,000	2,900	1,300	3,100	3,700	4,800	4,300	4,100	3,200	3,600	3,400	3,800	3,800
cis-1,2-Dichloroethene	µg/L	5,200	5,000	15,000	14,000	7,500	3,800	3,500	160	160	190	160	210	250
trans-1,2-Dichloroethene	µg/L	37	38	41	41	29	18	14	7.8	8.3	3.2	1.7	2.0	1.7
1,1-Dichloroethene	µg/L	39	38	36	38	39	32	26	36	22	33	32	36	34
Total DCE	µg/L	5,276	5,076	15,077	14,079	7,568	3,850	3,540	204	190	226	194	248	286
Vinyl Chloride	µg/L	2.2	2.2	2.3 J	5.2	4.7	5	12	0.83	0.6	0.82	0.73	0.96	1.2
1,1-Dichloroethane	µg/L	14	14	12	11	10	9.7 J	8.3 J	12	10	11	9.1	11	9.9
Chloroethane	µg/L	1 U	1 U	5 U	0.41 J	5 U	10 U	10 U	1 U	1 U	1 U	1 U	1 U	1 U
Dissolved Gases														
Methane	µg/L	3.7	NA	3.9	4.5	3.3	3.3	4.7	1.2	1.1	1.8	1.2	1.1	1.4
Ethene	µg/L	0.48	NA	0.9	1.5	0.54	0.39	0.3	0.18	0.28	0.25	0.19	0.16	0.25
Ethane	µg/L	0.12	NA	0.14	0.17	0.15	0.17	0.16	0.095	0.094	0.11	0.072	0.063	0.068
Acetylene	µg/L	0.12 J	NA	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors														
Nitrate-N	mg/L	0.1 UJ	NA	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	1.06 J	0.779	1.08	1	1.05	1.03
Arsenic (filtered)	µg/L	3.63	NA	5.97	5.33	4.38	3.84	3.91	0.803 J	0.811 J	0.712 J	0.877 J	0.725 J	0.576 J
Manganese (filtered)	µg/L	178	NA	592	327 J	210	204	175	168	1,340	165 J	319	186	52
Iron (filtered)	µg/L	1,000 U	NA	779 J	202 J	215 J	536 J	1,000 U	509 J	1,000 U	1,000 U	1,370	675 J	1,000 U
Sulfate	mg/L	230	NA	246	213	198	207	223	197	194	210	218	206	234
General Chemistry														
Alkalinity	mg/L	301	NA	310	274	262	275	264	292	348	290	295	297	299
Total Organic Carbon	mg/L	1.18	NA	9.81	1.58	0.946 J	0.767 J	0.825 J	0.767 J	2.09	0.916 J	0.588 J	0.634 J	0.611 J
Volatile Fatty Acids														
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Field Parameters														
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.24	0.37	0.36	0.21	0.48	0.4	0.07	0.08	0.66	0.14	0.44	0.6	
Dissolved Oxygen	mg/L	0.24	0	1.57	0.01	0.05	0.36	0.18	0.03	0.01	0	0.02	0.01	
Oxidation-Reduction Potential	mV	130	-183	-280	-184	-23	-48	160	65	-301	-189	-92	-77	
pH	SU	6.3	7.1	7.2	7.2	7.2	7.1	7.2	6.1	7.3	7.2	7.2	7.1	
Specific Conductance	µS/cm	1,051	1,080	979	888	867	913	910	1067	930	903	887	948	
Temperature	°C	20.2	21.1	20.6	19.7	18.6	20.8	20.8	23.2	21.0	19.6	19.3	21.3	
Turbidity	FNU	165	1,720	259	32	451	575	51	2,253	898	150	339	195	
Biological Parameter														
<i>Dehalococcoides</i> sp.	cells/mL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 3
Baseline and Post-Injection Groundwater Data
EHC Pilot Test
Well W9-18 Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-13 (Downgradient; 13 to 18 ft bgs)									28OW-14 (Downgradient; 22 to 32 ft bgs)						
	Sample ID	28OW-13-20100706	28OW-13-082610	28OW13-110910	28OW-13-012511	MW9902-012511*	28OW13-041211	MW9902-041211*	28OW13-062111	MW9902-062111*	28OW-14-20100706	28OW-14-082510	28OW14-110910	28OW-14-012411	28OW14-041211	28OW14-062111
	Date Sampled	7/6/10	8/26/10	11/9/10	1/25/11		4/12/11		6/21/11		7/6/10	8/25/10	11/9/10	1/24/11	4/12/11	6/21/11
Site-Specific VOCs																
Tetrachloroethene	µg/L	7.7	5.6	0.84 J	0.46 J	0.41 J	1 U	1 U	1 U	1 U	19	48	23	48	13	1.1
Trichloroethene	µg/L	210	180	26	8.2	8	0.7 J	0.66 J	1.3	0.86 J	510	1,200 J	540	1,200	290	23
cis-1,2-Dichloroethene	µg/L	2,800	3,100	1,200	580	550	3.8	3.9	110	90	7,200	4,600	1,100	680	490	45
trans-1,2-Dichloroethene	µg/L	11	13	8.7	7.8	7.3	8	7.9	7.6	6.5	15	18	8.8	6.0	6.2	6.0
1,1-Dichloroethene	µg/L	19	29	3.2	1.1	1	1 U	1 U	1 U	1 U	69	51	9.9	15	6.1	0.65 J
Total DCE	µg/L	2,830	3,142	1,212	589	558	12	12	118	97	7,284	4,669	1,119	701	502	52
Vinyl Chloride	µg/L	1.2	2.8	1,700	600	470	4.9	4.8	330	250	3	2.3	5,200	2,300	1,500	55
1,1-Dichloroethane	µg/L	12	17	7.2	4.7	4.4	0.65 J	0.71 J	2.1	1.6	21	16	15	14	13	5.9
Chloroethane	µg/L	1 U	1 U	3.7	3.3	3.1	7.5	7.5	4.3	4.2	1 U	1 U	0.95 J	0.55 J	1 U	4.9
Dissolved Gases																
Methane	µg/L	5.5	19	5,500	15,000	NA	6,000	NA	16,000	NA	6.5	3.7	8.8	1,700	6,700	20,000
Ethene	µg/L	0.31	1.5	5.7	500	NA	110	NA	240	NA	0.58	0.94	12	21	550	900
Ethane	µg/L	0.48	1.6	1.1	0.66	NA	0.057	NA	0.2	NA	0.34	0.2	0.75	0.61	0.57	0.6
Acetylene	µg/L	0.5 U	0.19 J	0.5 U	0.5 U	NA	0.5 U	NA	0.5 U	NA	0.23 J	0.36 J	0.5 U	0.5 U	0.5 U	0.5 U
Electron Acceptors																
Nitrate-N	mg/L	2.46	0.254	0.5 U	0.0696 J	NA	0.1 U	NA	0.108	NA	0.1 U	0.103	0.1 U	0.21	0.0771 J	0.1 U
Arsenic (filtered)	µg/L	2.05	4.55	39	46	NA	27	NA	30	NA	1 U	1.72	8.89	8.45	9.47	13.6
Manganese (filtered)	µg/L	122	929	3,910	3,130	NA	4,430	NA	2,520	NA	1 U	21.1	448	371	378	507
Iron (filtered)	µg/L	1,000 U	1,000 U	5,600	13,100	NA	21,600	NA	14,700	NA	1,000 U	1,000 U	333 J	462 J	768 J	2,000
Sulfate	mg/L	266	288	29	63	NA	2.4	NA	48	NA	232	287	33	214	145	15
General Chemistry																
Alkalinity	mg/L	366	487	980	946	NA	1820	NA	1,290	NA	118	104	318	334	414	731
Total Organic Carbon	mg/L	1.87	52	101	120	NA	81.4	NA	18.5	NA	3.02	11	99	98	142	157
Volatile Fatty Acids																
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Field Parameters																
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	1.83	0.23	0.98	8.56		3.09		1.97		0.62	0.15	0	0.08	0.09	0.43
Dissolved Oxygen	mg/L	0.90	0.15	2.51	0.05		0		0		0.28	0.01	0	0	0	0
Oxidation-Reduction Potential	mV	220	-42	-199	-99		-118		-95		110	-34	-247	-213	-192	-225
pH	SU	5.8	6.1	6.8	6.5		6.7		6.6		11.3	6.3	9.5	8.2	7.5	7.1
Specific Conductance	µS/cm	1,327	1,374	1,709	2,208		2,561		2,248		1,521	839	654	1,077	997	1,294
Temperature	°C	20.0	20.7	19.9	17.5		17.5		19.9		21.4	22.0	20.8	20.4	18.3	20.2
Turbidity	FNU	141	52	327	0		161		40		124	263	37	120	60	195

Table 3
Baseline and Post-Injection Groundwater Data
EHC Pilot Test
Well W9-18 Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-15 (Treatment Area: 13 to 18 ft bgs)						28OW-16 (Treatment Area: 22 to 32 ft bgs)							
	Sample ID	28OW-15-082610	28OW-15-110910	28OW-15-012511	28OW-15-041211	28OW-15-062111	28OW-16-20100706	28OW-16-082610	28OW-16-110910	MW9902-110910*	28OW-16-012511	28OW-16-041211	28OW-16-062111	
Date Sampled	7/6/10	8/26/10	11/9/10	1/25/11	4/12/11	6/21/11	7/6/10	8/26/10	11/9/10		1/25/11	4/12/11	6/21/11	
Site-Specific VOCs														
Tetrachloroethene	µg/L	0.37 J	0.25 J	1 U	5 U	5 U	5 U	68	44	2.6	2.4	13	0.55 J	1.6
Trichloroethene	µg/L	16	11	13	9.4	8.4	5.9	2,100	1,100	66	62	400	4.6	29
cis-1,2-Dichloroethene	µg/L	6,300	6,300	7,700	7,200	6,800	7,300	530	1,800	2,900	2,900	2,400	640	450
trans-1,2-Dichloroethene	µg/L	20	18	18	17	35	18	2.9	8.6	8.8	9	8.2	9.1	7.6
1,1-Dichloroethene	µg/L	38	39	49	50	55	55	24	25	22	23	18	0.98 J	2.1
Total DCE	µg/L	6,358	6,357	7,767	7,267	6,890	7,373	557	1,834	2,931	2,932	2,426	650	460
Vinyl Chloride	µg/L	1.2	1.2	2.1	1.8 J	2.7	2.8	2.6	2.1	4.2	4.2	95	1,500	1,900
1,1-Dichloroethane	µg/L	12	12	12	13	14	12	12	11	8.7	9.1	9.5	8.7	7.2
Chloroethane	µg/L	1 U	1 U	1 U	5 U	5 U	5 U	1 U	1 U	0.38 J	0.27 J	1 U	1 U	1 U
Dissolved Gases														
Methane	µg/L	1	0.93	2.1	2.2	1.1	3.3	2.8	3.1	14	NA	130	1,300	4,300
Ethene	µg/L	0.76	1.4	3.3	0.68	0.23	1.8	0.27	0.6	4.6	NA	5.6	6.4	27
Ethane	µg/L	0.061	0.085	0.22	0.17	0.086	0.22	0.13	0.19	4.6	NA	6.4	2.7	2.8
Acetylene	µg/L	0.5 U	0.076 J	0.5 U	0.5 U	NA	0.5 U	0.5 U	0.5 U					
Electron Acceptors														
Nitrate-N	mg/L	0.168	0.0514 J	0.1 U	0.0568 J	0.1 U	0.1 U	0.459	0.1 U	0.1 U	NA	0.1 U	0.2 U	0.1 U
Arsenic (filtered)	µg/L	2.94	4.17	4.74	2.91	2.21	2.35	1.01	2.26	4.85	NA	4.24	4.37	2.96
Manganese (filtered)	µg/L	69.3	238	439	231	41.3	363	159	3,200	2,010	NA	1,910	1,710	1,120
Iron (filtered)	µg/L	1,000 U	1,000 U	1,000 U	659 J	NA	1,510	2,300	3,320					
Sulfate	mg/L	390	363	377	356	349	393	340	347	310	NA	209	85	172
General Chemistry														
Alkalinity	mg/L	321	306	314	279	265	258	339	369	463	NA	720	708	594
Total Organic Carbon	mg/L	2.57	5.37	2.13	1.63	1.26	1.17	0.849 J	4.02	2.14	NA	4.09	5.18	1.28
Volatile Fatty Acids														
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Field Parameters														
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0	0.02	0	0.09	0.16	0.11	3.3	0.84	1.86		1.09	0.75	1.95
Dissolved Oxygen	mg/L	1.88	0.09	0.49	1.52	0.84	0.12	0.18	0.05	0.04		0	0	0.1
Oxidation-Reduction Potential	mV	250	-137	-230	-72	-132	-75	220	-150	-211		-166	-272	-83
pH	SU	6.0	5.9	7.0	7.2	7.2	7.2	6.4	6.5	7.2		6.7	6.9	6.9
Specific Conductance	µS/cm	1,706	1,556	1,359	1,169	1,112	1,249	1,193	1,325	1,259		1,423	1,224	1,367
Temperature	°C	21.3	22.3	21.7	18.4	18.9	23.1	20.4	22.5	21.4		19.5	19.9	24.0
Turbidity	FNU	227	1,096	411	0	31	50	465	731	343		250	618	4,339

Table 3
Baseline and Post-Injection Groundwater Data
EHC Pilot Test
Well W9-18 Area, IR Site 28, Former NAS Moffett Field

Well ID	28OW-17 (Upgradient: 13 to 18 ft bgs)							28OW-18 (Upgradient: 22 to 32 ft bgs)							
	Sample ID	28OW-17-20100706	28OW-17-082510	MW9903-082510*	28OW17-110910	28OW-17-012511	28OW17-041211	28OW17-062111	28OW-18-080310	28OW-18-082510	28OW18-110910	28OW-18-012511	28OW-18-012711	28OW18-041211	28OW18-062111
	Date Sampled	7/6/10	8/25/10		11/9/10	1/25/11	4/12/11	6/21/11	8/3/10	8/25/10	11/9/10	1/25/11	1/27/11	4/12/11	6/21/11
Site-Specific VOCs															
Tetrachloroethene	µg/L	5.9	0.88 J	0.89 J	0.61 J	5 U	5 U	5 U	130	140	170	180	NA	170	150
Trichloroethene	µg/L	170	54	55	25	21	16	12	1,500	1,400 J	1,700	1,800	NA	1,600	1,700
cis-1,2-Dichloroethene	µg/L	3,100	7,000	7,000	8,200	7,100	7,500	7,600	730	1,100	740	740	NA	650	710
trans-1,2-Dichloroethene	µg/L	18	28	27	15	19	42	17	3.6	17	2.8	2.5	NA	3.7	2.7
1,1-Dichloroethene	µg/L	40	59	61	53	61	69	73	17	18	17	15	NA	19	19
Total DCE	µg/L	3,158	7,087	7,088	8,268	7,180	7,611	7,690	751	1,135	760	758	NA	673	732
Vinyl Chloride	µg/L	2.2	3.1	3.3	30	15	11	43	0.96	0.76	1.3	0.77	NA	1.8	2.6
1,1-Dichloroethane	µg/L	31	34	34	28	31	33	30	7.4	7.9	7.2	6.9	NA	8.7	7.9
Chloroethane	µg/L	1 U	0.22 J	1 U	1 U	5 U	5 U	5 U	1 U	1 U	1 U	1 U	NA	1 U	1 U
Dissolved Gases															
Methane	µg/L	0.91	1.8	NA	2.6	7.2	2.0	6.5	2.9	2.9	2.3	NA	2.5	2.6	4.7
Ethene	µg/L	0.75	2.6	NA	1.6	0.35	0.21	1.3	1.9	2.4	0.5	NA	0.27	0.17	0.43
Ethane	µg/L	0.091	0.17	NA	0.16	0.19	0.069	0.25	0.47	0.45	0.16	NA	0.099	0.13	0.12
Acetylene	µg/L	0.5 U	0.5 U	NA	0.5 U	0.5 U	0.5 U	0.5 U	0.78	0.5 U	0.5 U	NA	0.5 U	0.5 U	0.5 U
Electron Acceptors															
Nitrate-N	mg/L	0.552	0.1 U	NA	0.1 U	0.1 U	0.0534 J	0.1 U	0.119	0.122	0.235	0.282	NA	0.269	0.265
Arsenic (filtered)	µg/L	2.18	4.3	NA	4.88	3.09	2.71	3.66	2.09	2.13	1.26	1.02	NA	1.26	0.938 J
Manganese (filtered)	µg/L	22	217	NA	254	94	9.6	315	558	530	310	154	NA	411	272
Iron (filtered)	µg/L	1,000 U	1,000 U	NA	1,000 U	1,000 U	1,000 U	1,000 U	1,000 U	373 J	1,000 U	1,000 U	NA	1,770	1,000 U
Sulfate	mg/L	390	374	NA	341	306	285	356	347	379	362	348	NA	345	378
General Chemistry															
Alkalinity	mg/L	397	349	NA	260	265	265	282	417	399	383	347	NA	355	355
Total Organic Carbon	mg/L	2.27	2.1	NA	1.69	1.53	1.66	1.11	1.31	1.32	1.07	0.71 J	NA	0.819 J	0.729 J
Volatile Fatty Acids															
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Field Parameters															
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0	0.04	0.05	0.08	0.01	0.14	2.73	0.33	0.64	0.42	NA	1.25	0.61	
Dissolved Oxygen	mg/L	2.89	0.17	3.14	1.18	0.93	0.1	0.23	0.08	0.02	0.01	0.01	0.04	0.11	
Oxidation-Reduction Potential	mV	100	-23	-231	-72	-61	-18	192	57	-249	-99	-90	-65	-12	
pH	SU	6.2	7.3	7.5	7.4	7.3	7.3	6.6	6.4	7.2	7.1	7.1	7.1	7.1	
Specific Conductance	µS/cm	1,490	1,598	1,231	1,055	1,009	1,235	1,299	1,406	1,211	1,177	1,159	1,194	1,304	
Temperature	°C	21.4	24.2	21.5	19.1	19.4	24.7	21.2	20.3	21.0	20.2	19.2	20.8	24.4	
Turbidity	FNU	78	81	2,939	0	25	40	1,608	427	448	479	532	441	952	

Table 3
Baseline and Post-Injection Groundwater Data
EHC Pilot Test
Well W9-18 Area, IR Site 28, Former NAS Moffett Field

Well ID	W9-18 (Treatment Area: 14 to 24 ft bgs)						
Sample ID	W9-18-20100706	W9-18-082610	W9-18-110910	W9-18-012511	W9-18-041211	W9-18-062111	
Date Sampled	7/6/10	8/26/10	11/9/10	1/25/11	4/12/11	6/21/11	
Site-Specific VOCs							
Tetrachloroethene	µg/L	1.2	0.74 J	0.46 J	0.3 J	1 U	1 U
Trichloroethene	µg/L	3.3	1.8	0.92 J	1 U	1 U	1 U
cis-1,2-Dichloroethene	µg/L	7,200	5,700	3,200	26	8.0	6.8
trans-1,2-Dichloroethene	µg/L	20	12	13	1.8	1.4	2.7
1,1-Dichloroethene	µg/L	25	10	3	1 U	1 U	1 U
Total DCE	µg/L	7,245	5,722	3,216	28	9.4	9.5
Vinyl Chloride	µg/L	890	680	5,800	380	17	15
1,1-Dichloroethane	µg/L	13	9.4	0.71 J	1 U	1 U	0.22 J
Chloroethane	µg/L	1 U	1 U	9.1	0.9 J	0.93 J	2.3
Dissolved Gases							
Methane	µg/L	3.2	5.5	17,000	24,000	5,800	18,000
Ethene	µg/L	22	14	35	170	120	450
Ethane	µg/L	1.5	1.5	22	0.97	0.31	1.8
Acetylene	µg/L	0.5 U	0.5 U				
Electron Acceptors							
Nitrate-N	mg/L	0.1 U	0.1 U	0.5 U	0.0607 J	0.1 U	0.065 J
Arsenic (filtered)	µg/L	1 U	1 U	1 U	1.1	0.706 J	0.669 J
Manganese (filtered)	µg/L	41	1,400	568	1,100	1,180	633
Iron (filtered)	µg/L	766 J	58,200	8,170	7,310	11,200	7,280
Sulfate	mg/L	187	99	3 U	1.41	0.48 J	0.62
General Chemistry							
Alkalinity	mg/L	172	561	780	488	443	480
Total Organic Carbon	mg/L	1.01	413	170	94	141	55
Volatile Fatty Acids							
Lactic Acid	mg/L	NA	NA	NA	NA	NA	NA
Acetic Acid	mg/L	NA	NA	NA	NA	NA	NA
Propionic Acid	mg/L	NA	NA	NA	NA	NA	NA
Butyric Acid	mg/L	NA	NA	NA	NA	NA	NA
Field Parameters							
Ferrous Iron (Iron II, Fe ²⁺)	mg/L	0.33	2.43	4.1	2.71	5.22	1.13
Dissolved Oxygen	mg/L	0.23	0	0	0	0	0
Oxidation-Reduction Potential	mV	-110	-198	-248	-225	-201	-201
pH	SU	6.3	6.3	7.7	7.8	7.7	7.7
Specific Conductance	µS/cm	696	1,552	1,479	884	883	899
Temperature	°C	21.4	22.2	22.2	18.1	19.3	20.9
Turbidity	FNU	137	86	495	1.9	39	27

Notes to Tables:

* indicates duplicate sample.

°C denotes degrees celsius.

µg/L denotes micrograms per liter.

µS/cm denotes microSiemens per centimeter.

bgs denotes below ground surface.

EHC[®] is a proprietary blend of controlled-release carbon and zero-valent iron of Adventus Americas, Inc.

EVO denotes emulsified vegetable oil.

FNU denotes Formazin Nephelometric Unit.

ID denotes identification.

J qualifier indicates that the analyte was positively identified but the associated numerical value is estimated.

mg/L denotes milligrams per liter.

mV denotes milliVolts.

NA denotes not analyzed.

SDC-9[™] is a proprietary dechlorinating microbial consortium of Shaw Environmental and Infrastructure.

SU denotes standard units.

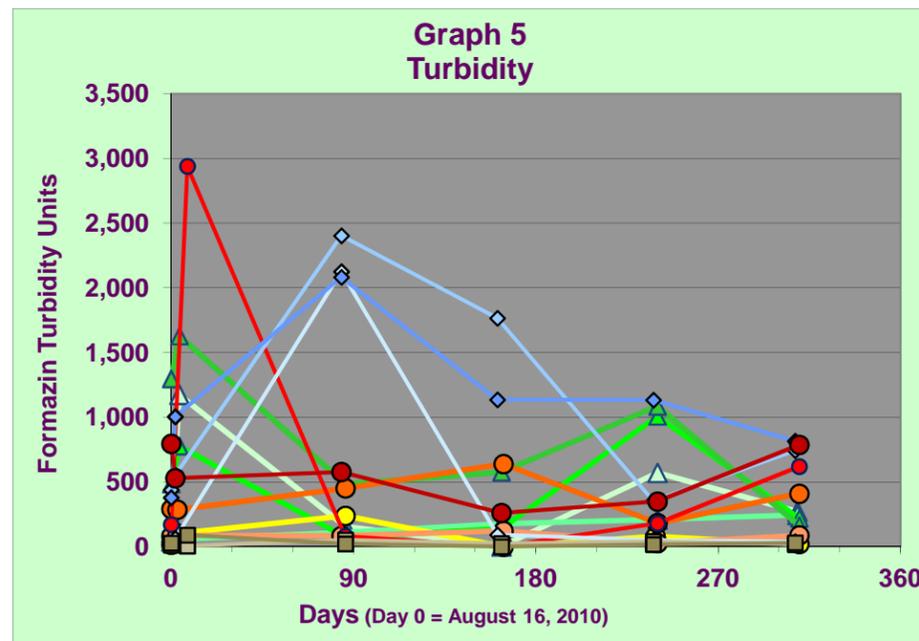
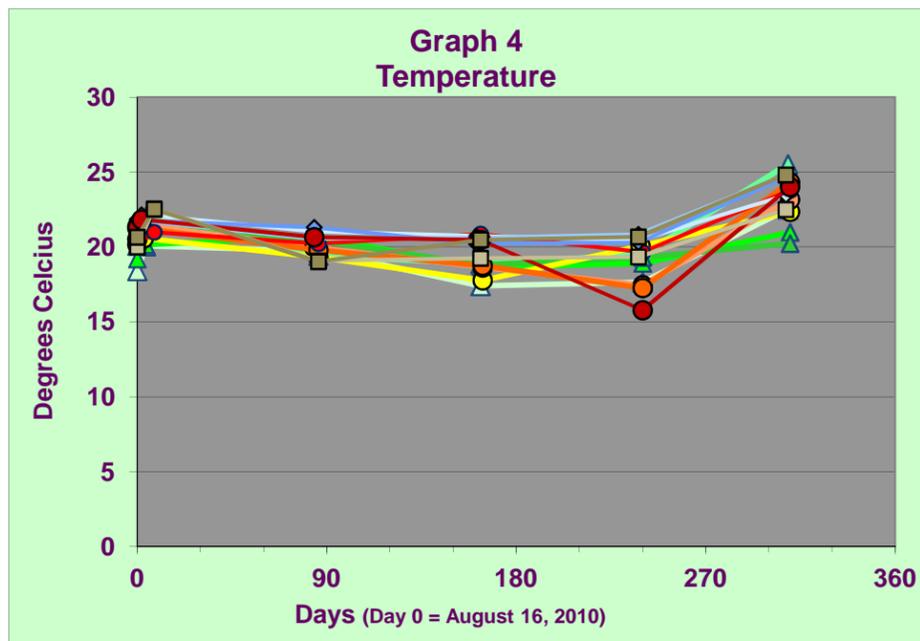
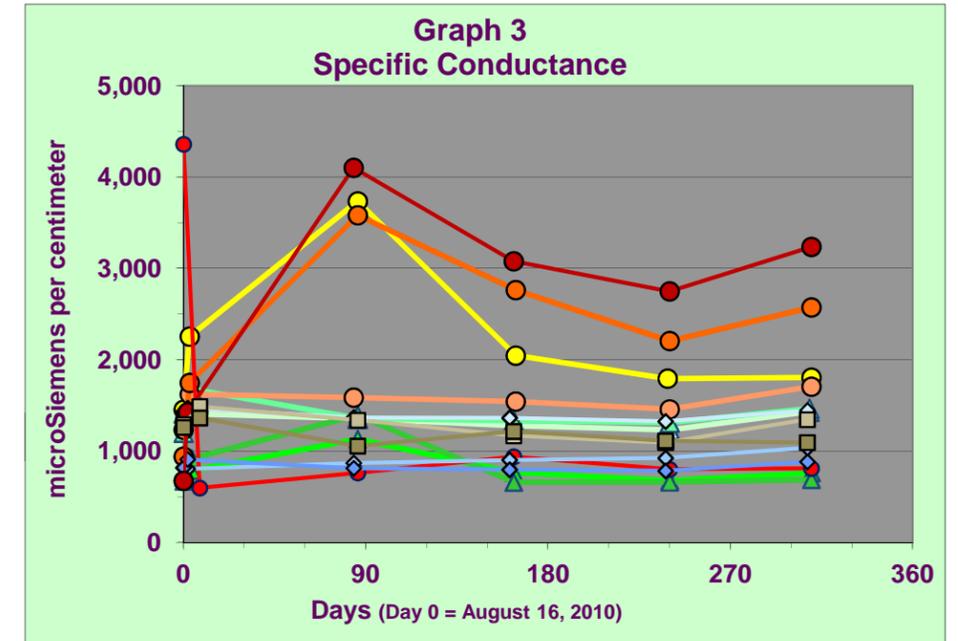
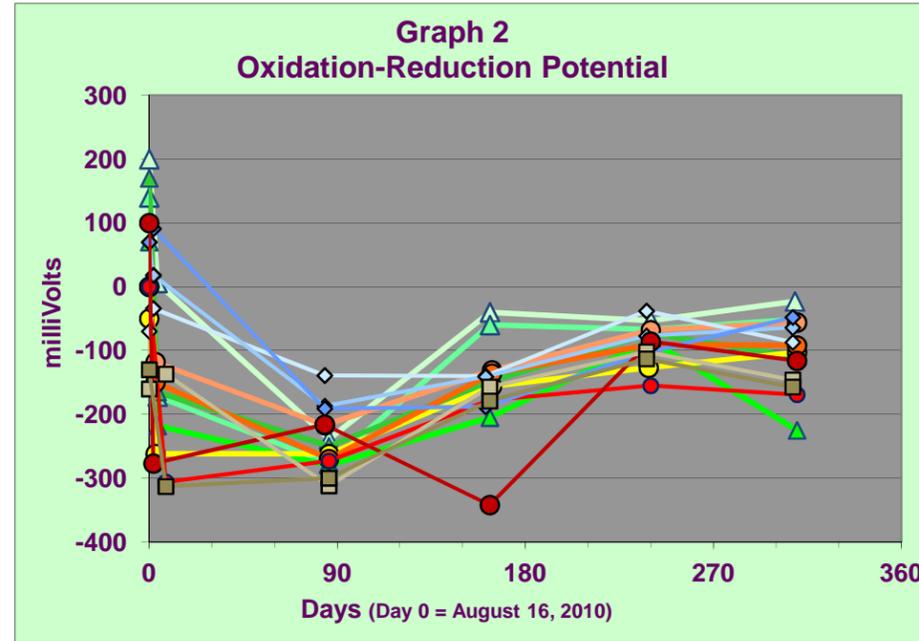
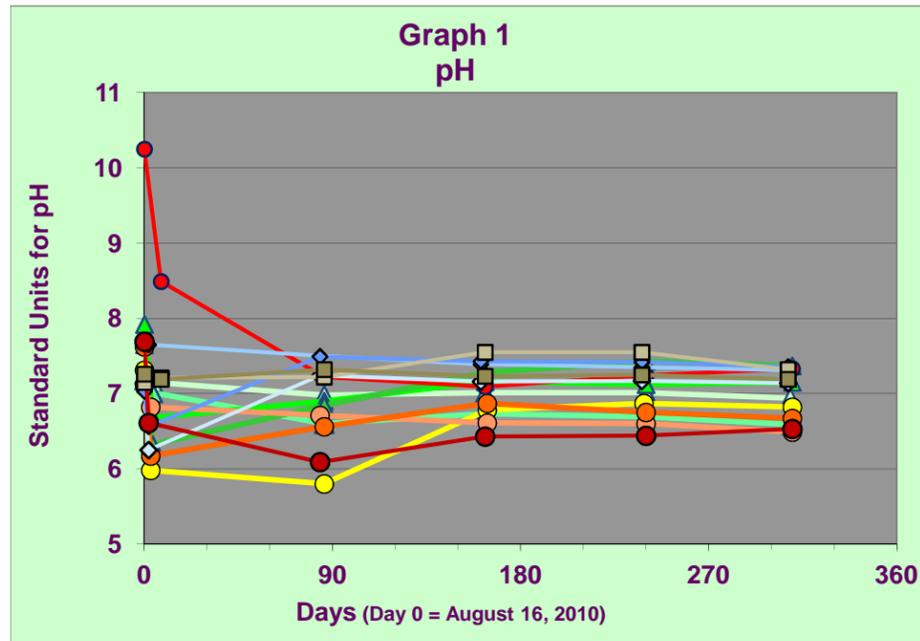
U qualifier indicates that the analyte was not detected at or above the specified practical quantitation limit.

VOC denotes volatile organic compound.

Graphs

Graphs for Physical Parameters of Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field



- ▲ 28OW-01
- ▲ 28OW-02
- ▲ 28OW-03
- ▲ 28OW-04
- 28OW-05
- 28OW-06
- 28OW-07
- 28OW-08
- ◇ 28OW-09
- ◇ 28OW-10
- ◇ 28OW-11
- 28OW-12
- W9-29
- W9-42

▲ Well Downgradient from Treatment Area

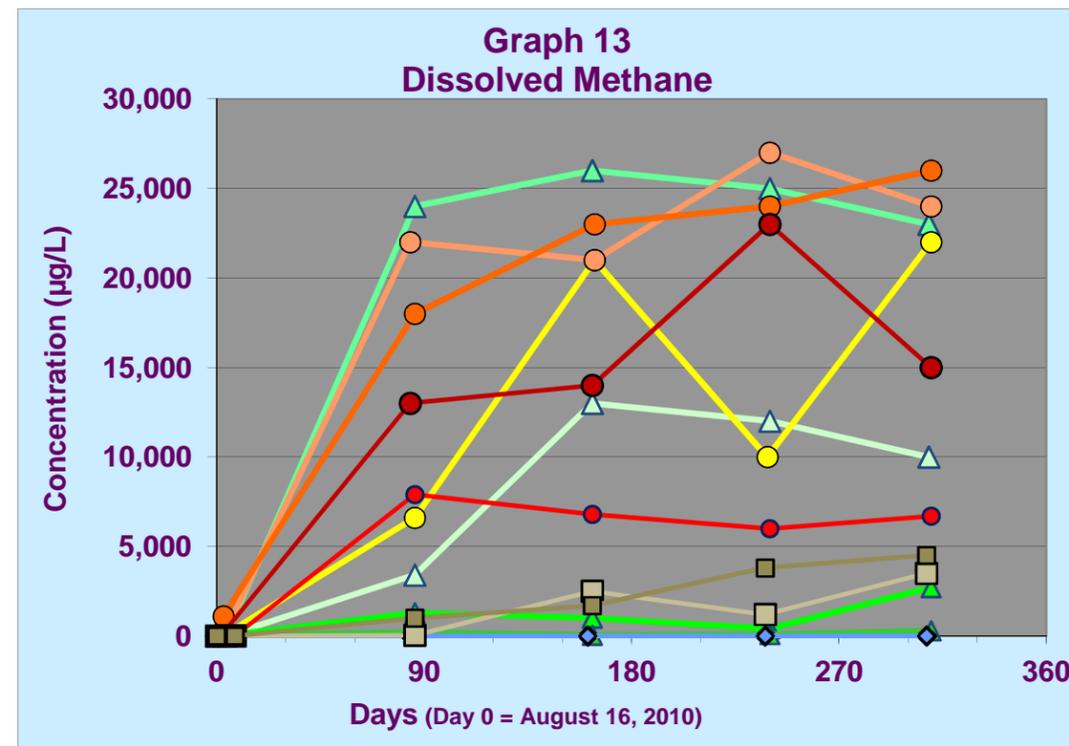
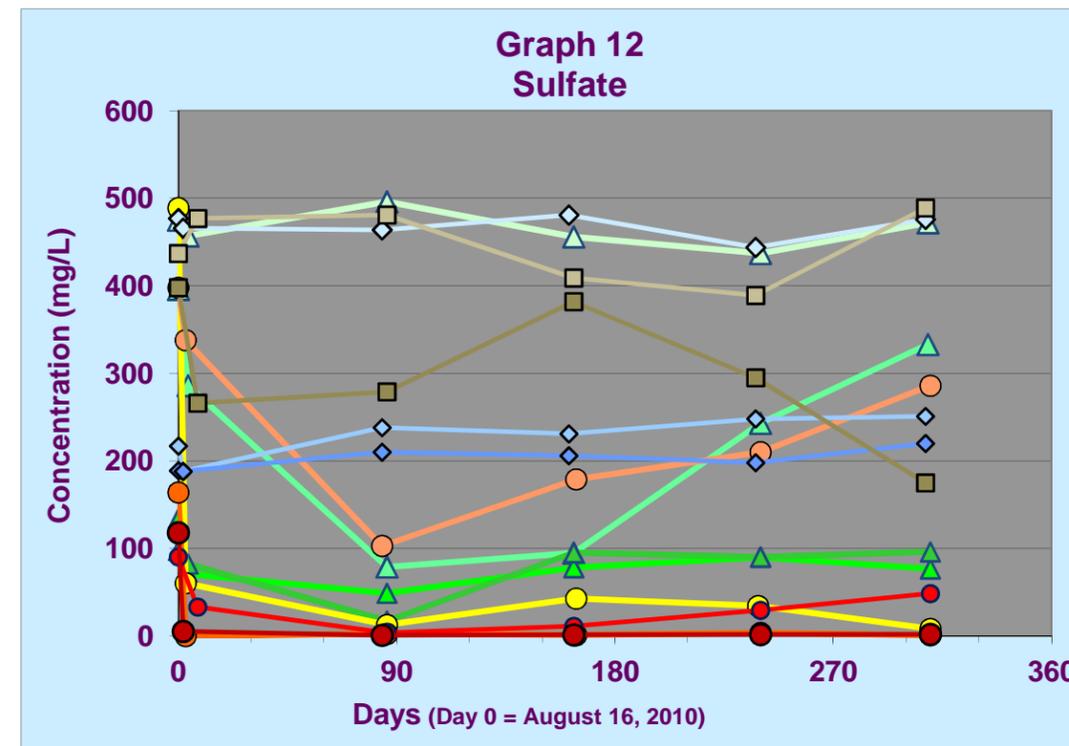
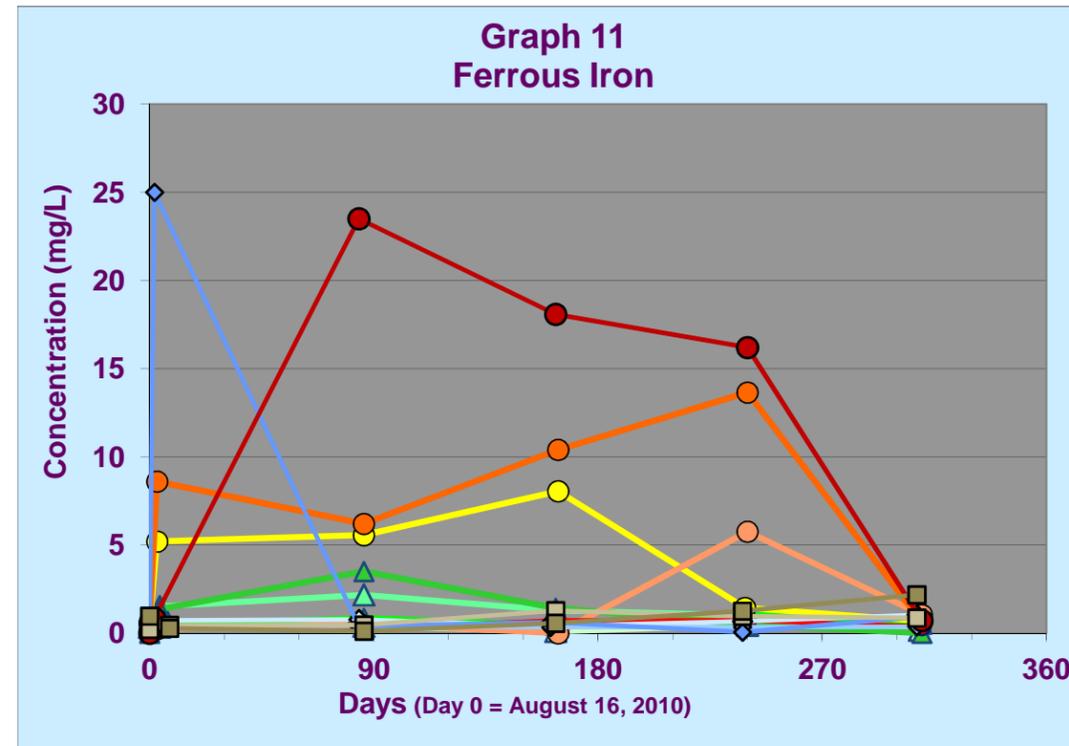
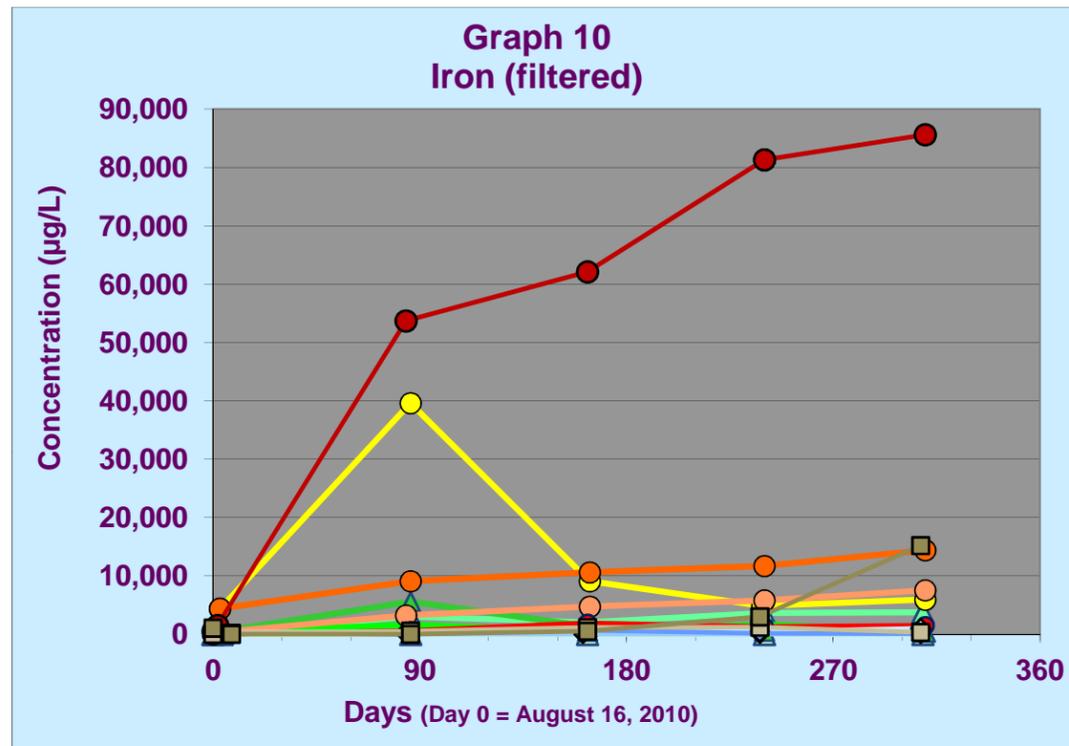
● Well Within Treatment Area

◆ Well Upgradient from Treatment Area

■ Well Crossgradient from Treatment Area

Graphs of Biogeochemical Parameter Concentrations in Groundwater - EVO Pilot Test

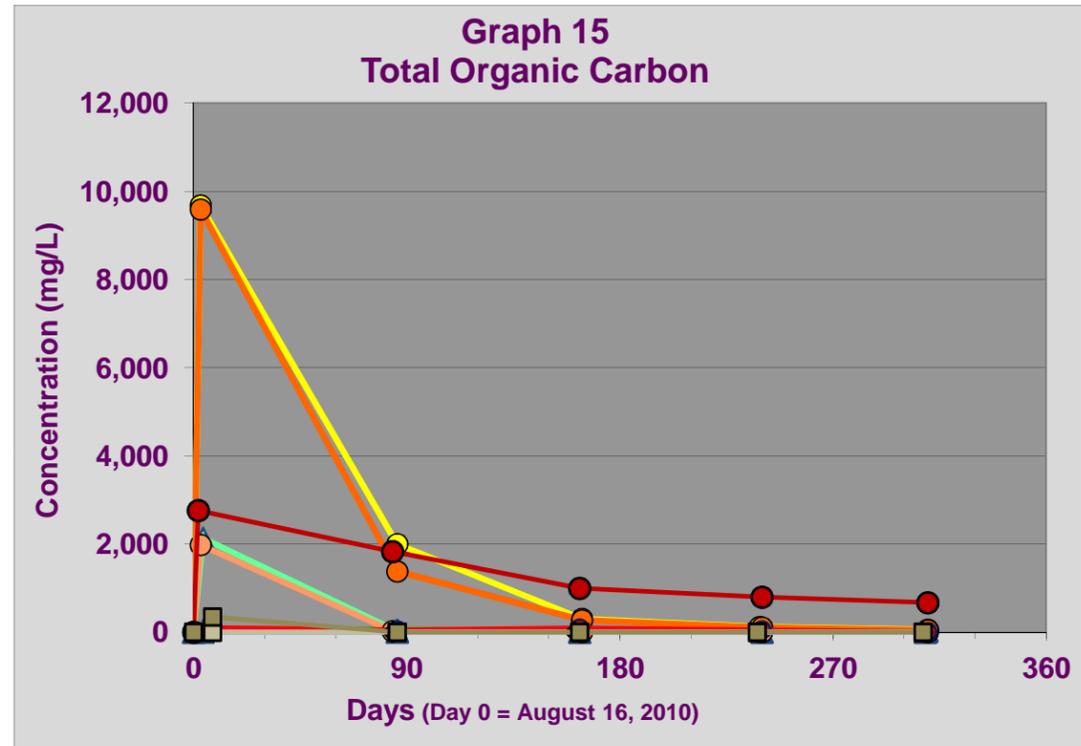
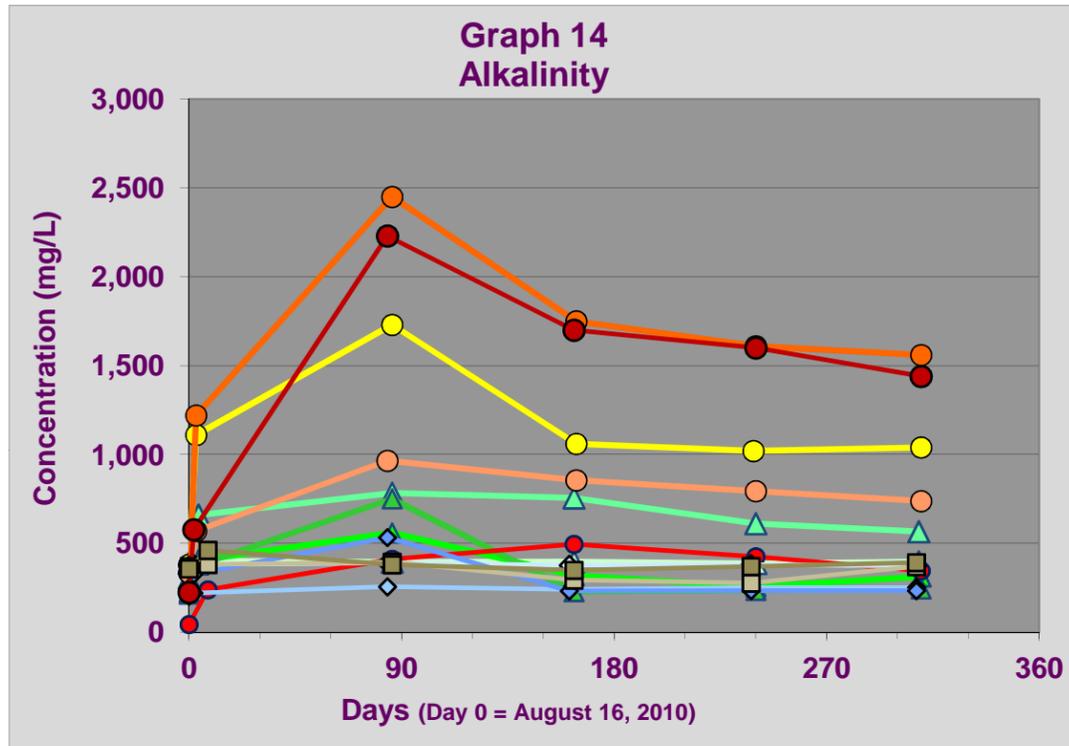
Traffic Island Area, IR Site 28, Former NAS Moffett Field



- △ 28OW-01
- ▲ 28OW-02
- ▲ 28OW-03
- ▲ 28OW-04
- 28OW-05
- 28OW-06
- 28OW-07
- 28OW-08
- ◇ 28OW-09
- ◇ 28OW-10
- ◇ 28OW-11
- 28OW-12
- W9-29
- W9-42

- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◇ Well Upgradient from Treatment Area
- Well Crossgradient from Treatment Area

Graphs of Biogeochemical Parameter Concentrations in Groundwater - EVO Pilot Test Traffic Island Area, IR Site 28, Former NAS Moffett Field

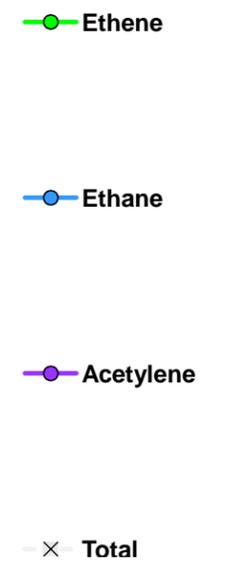
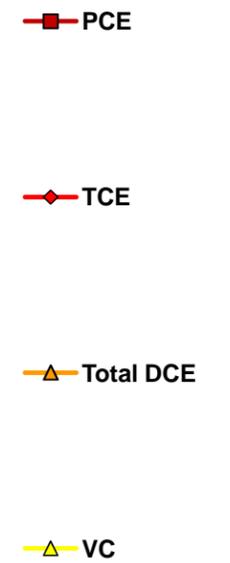
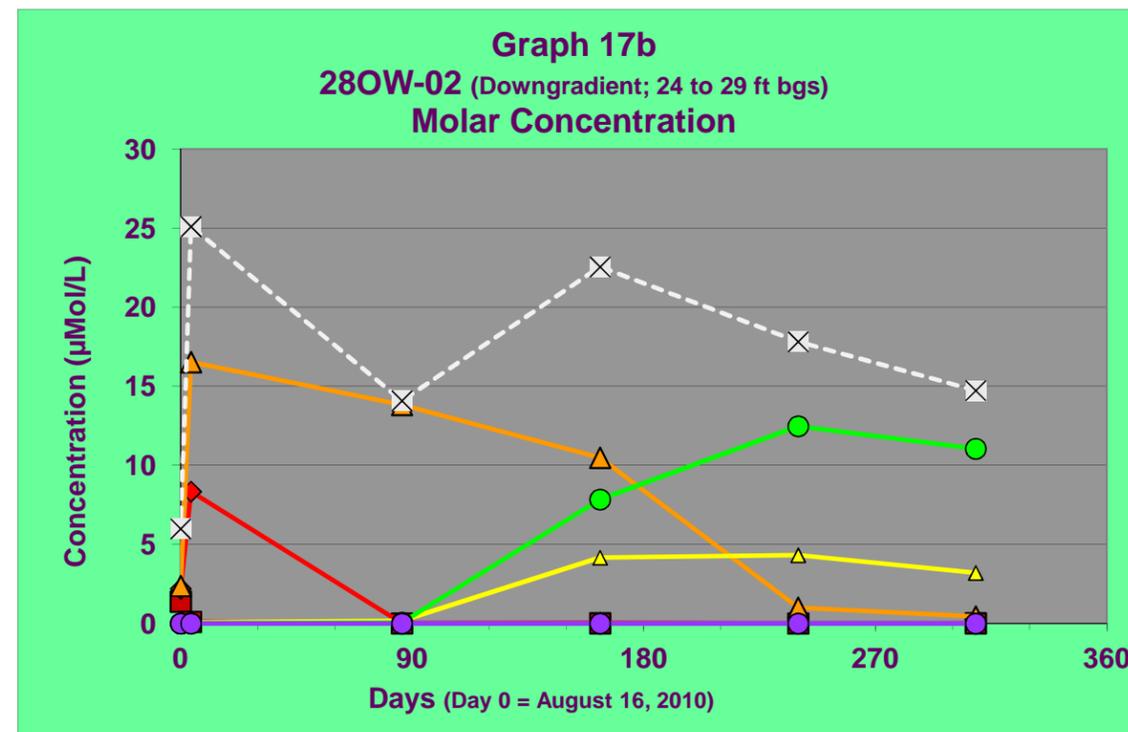
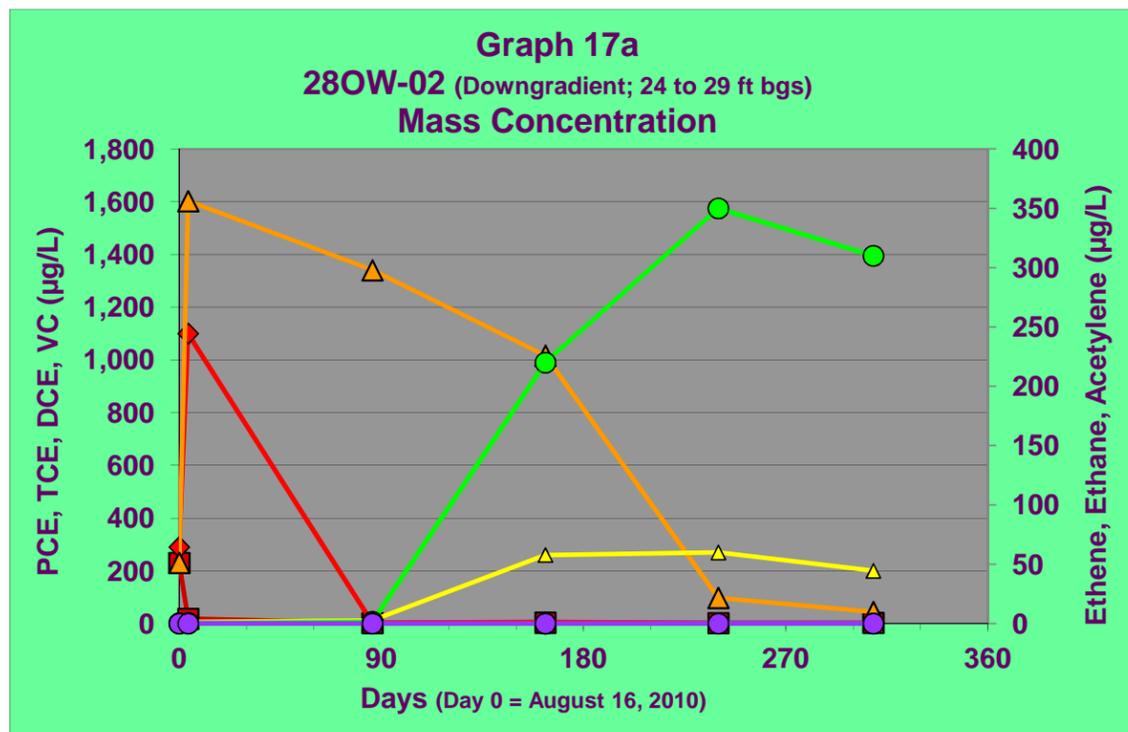
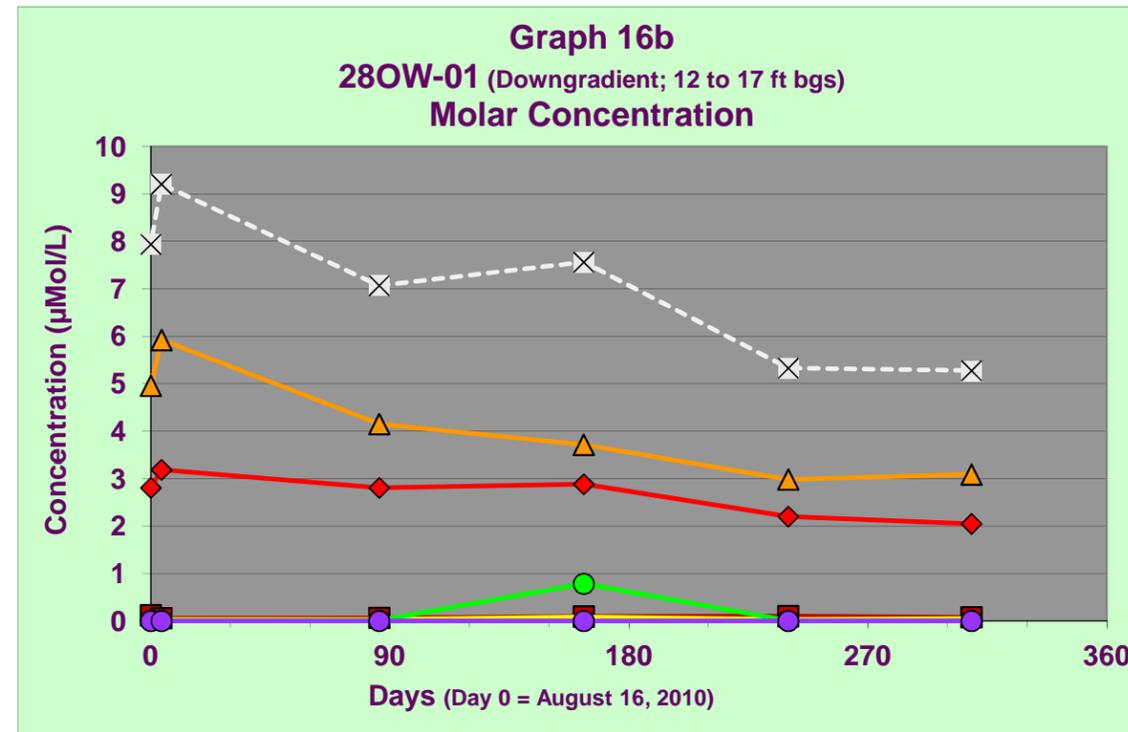
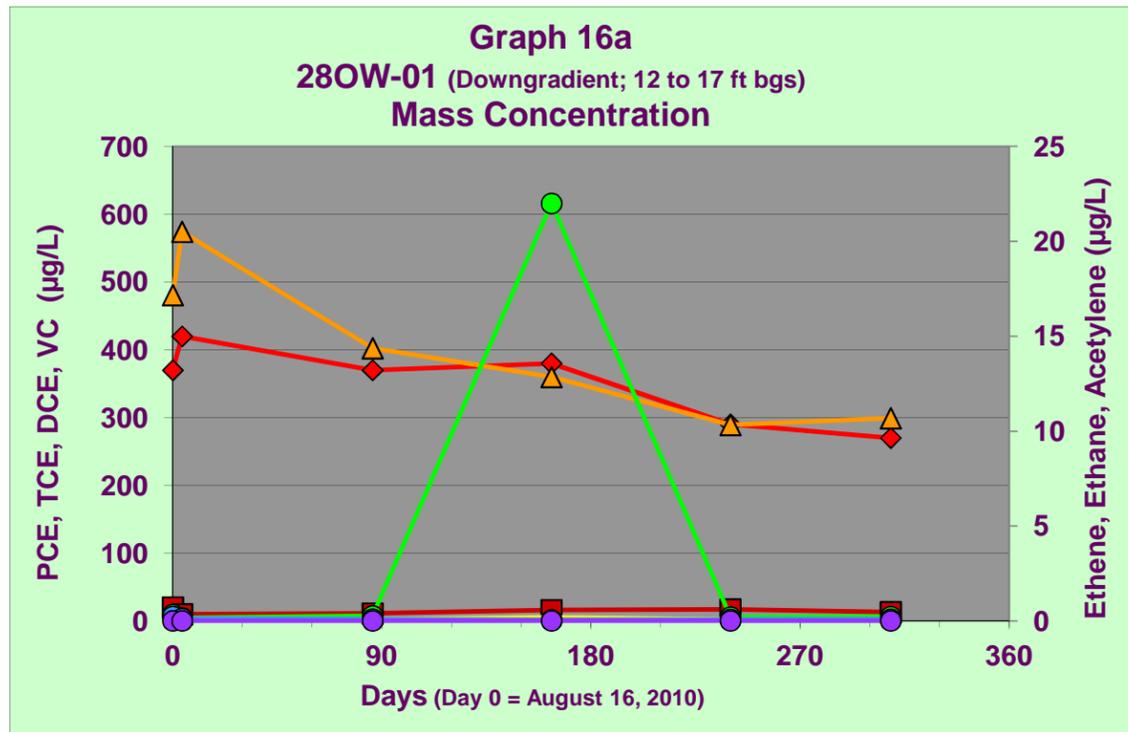


- ▲ 28OW-01
- ▲ 28OW-02
- ▲ 28OW-03
- ▲ 28OW-04
- 28OW-05
- 28OW-06
- 28OW-07
- 28OW-08
- ◆ 28OW-09
- ◆ 28OW-10
- ◆ 28OW-11
- ◆ 28OW-12
- W9-29
- W9-42

▲ Well Downgradient from Treatment Area ● Well Within Treatment Area ◆ Well Upgradient from Treatment Area ■ Well Crossgradient from Treatment Area

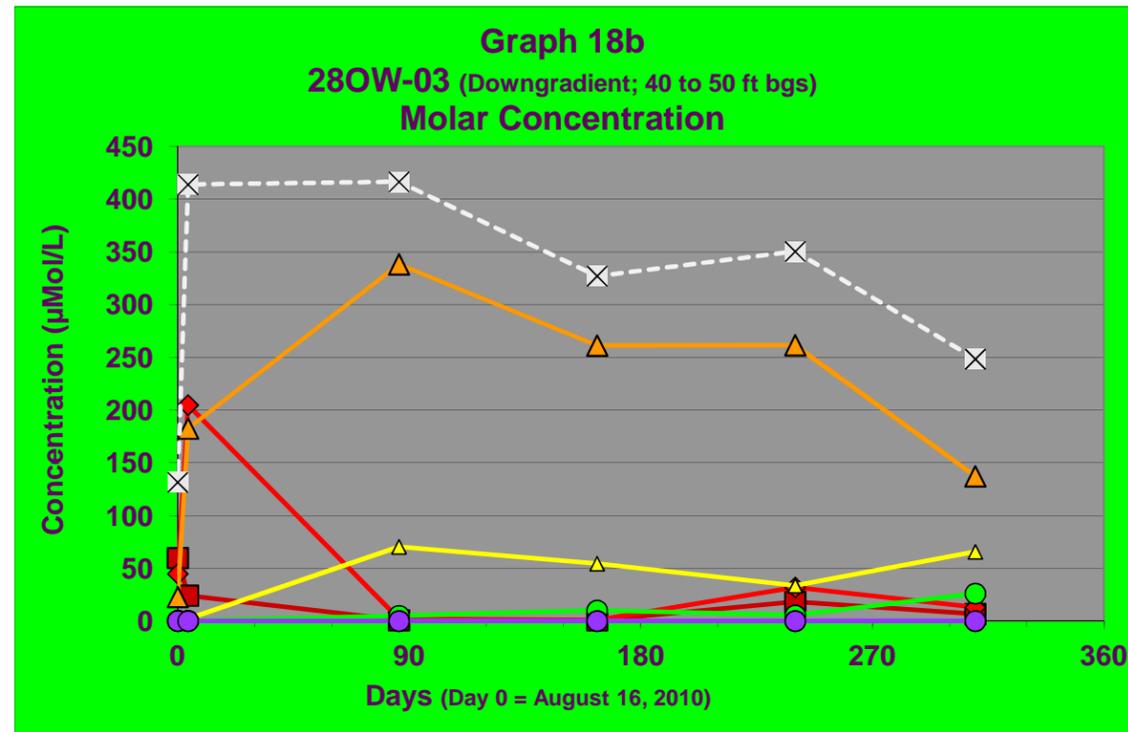
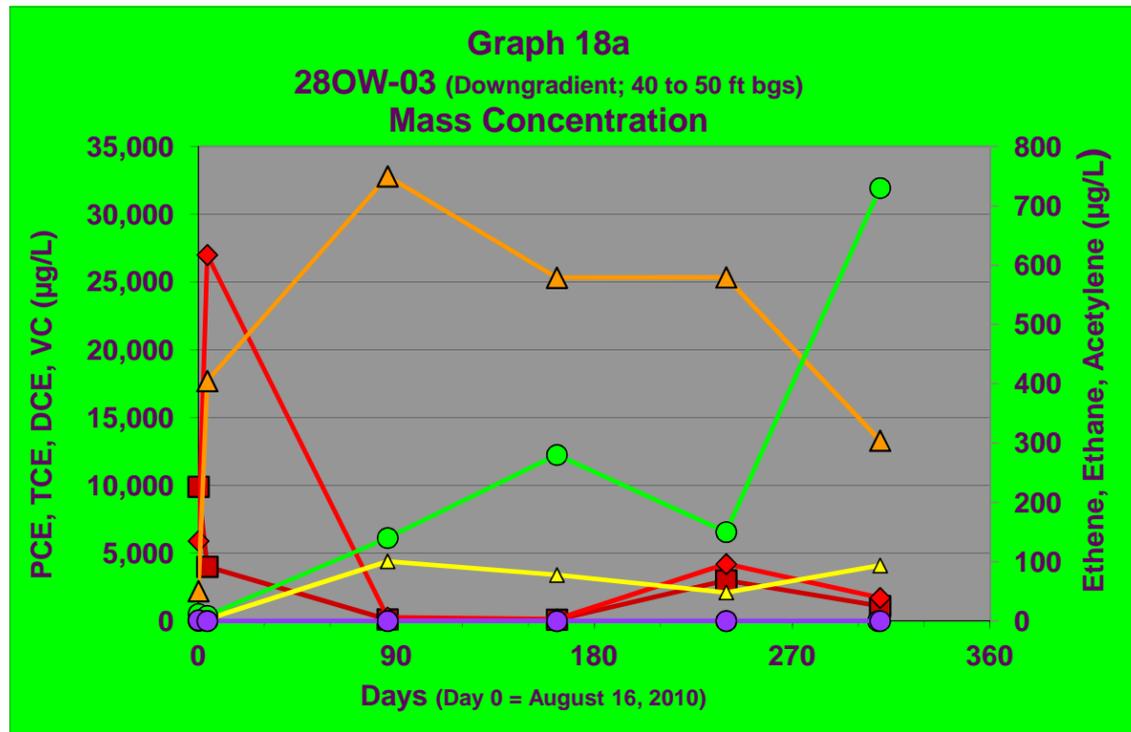
Graphs of Ethenes and Ethane Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field

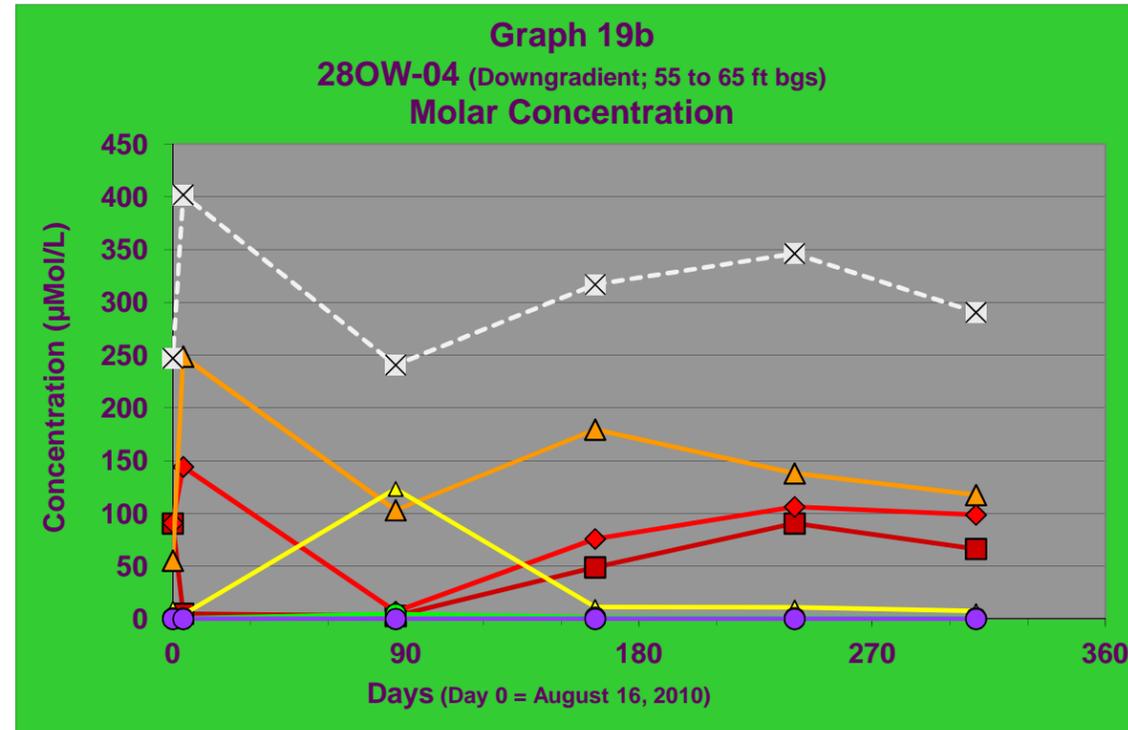
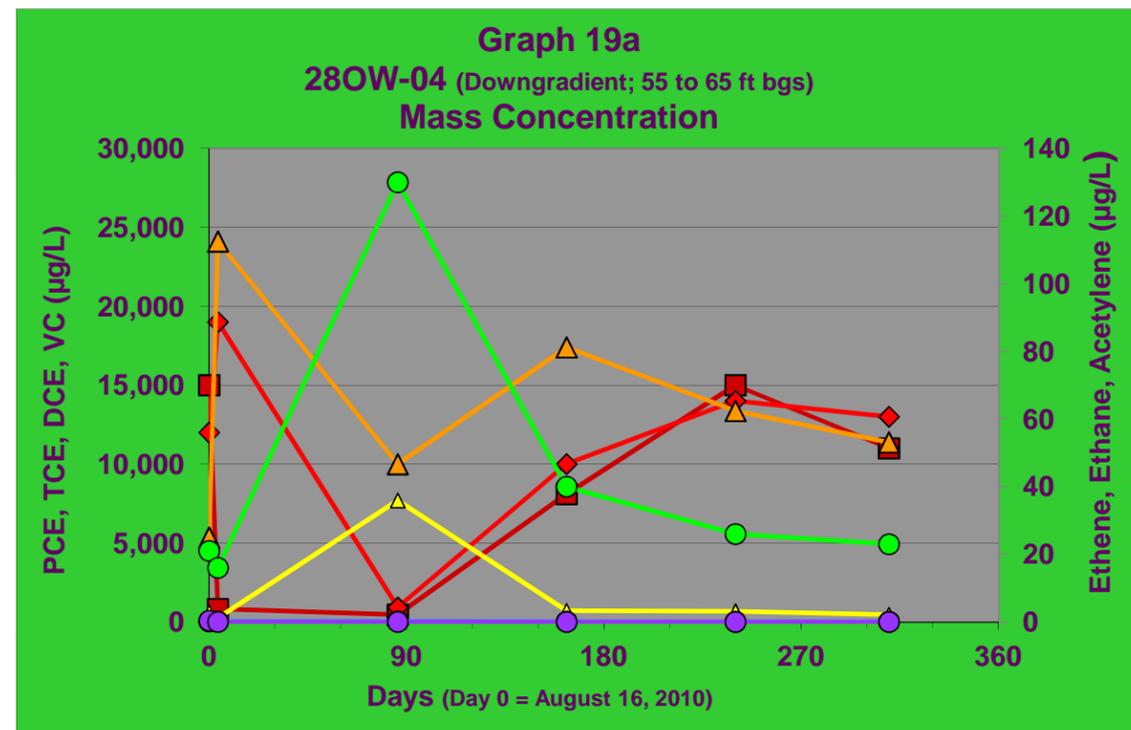


Graphs of Ethenes and Ethane Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field



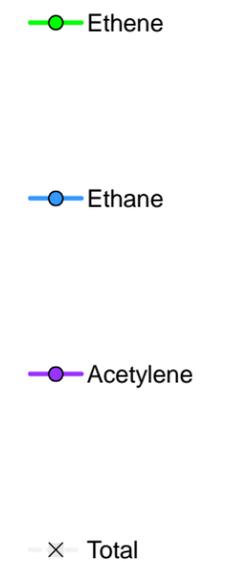
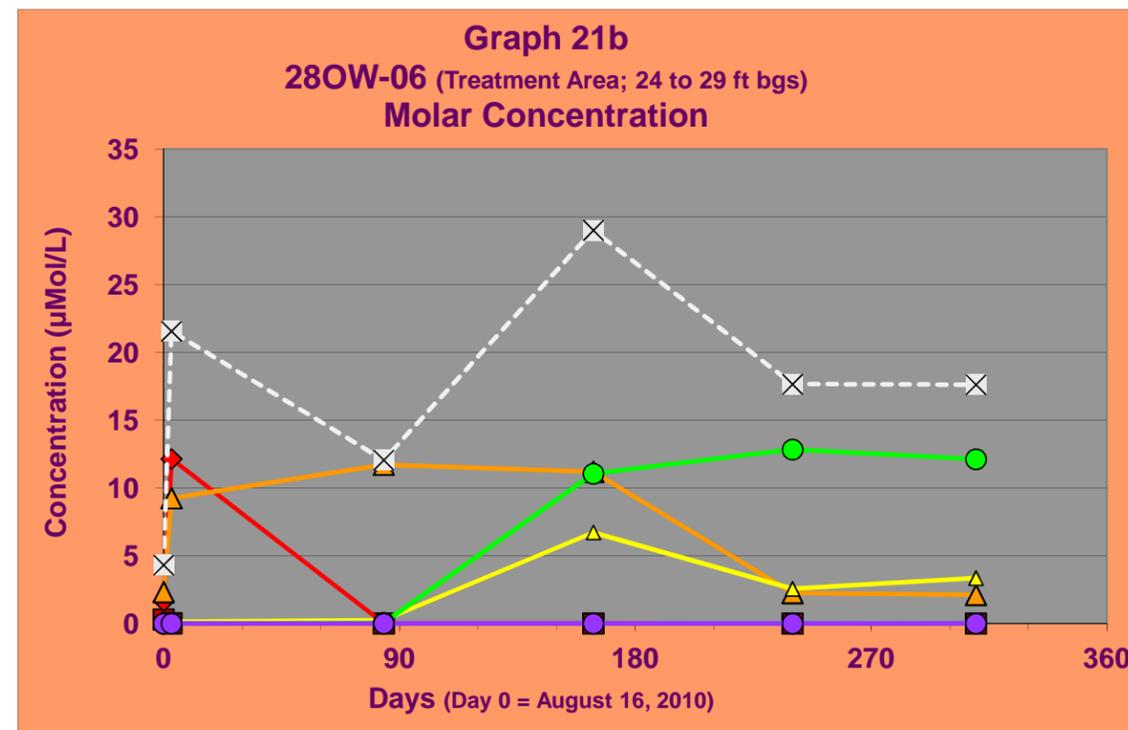
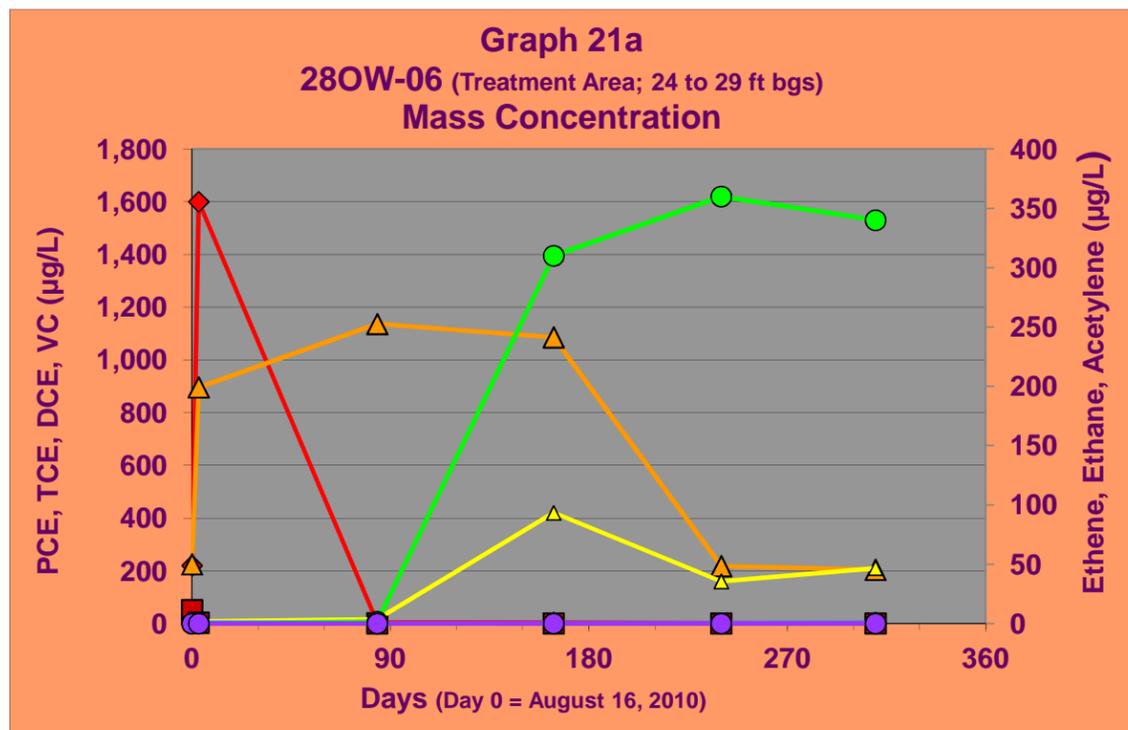
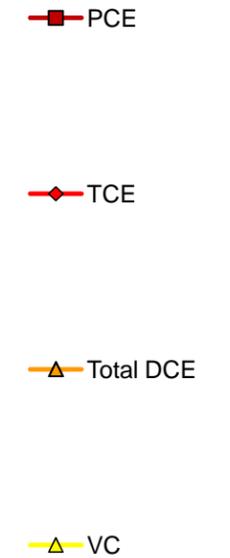
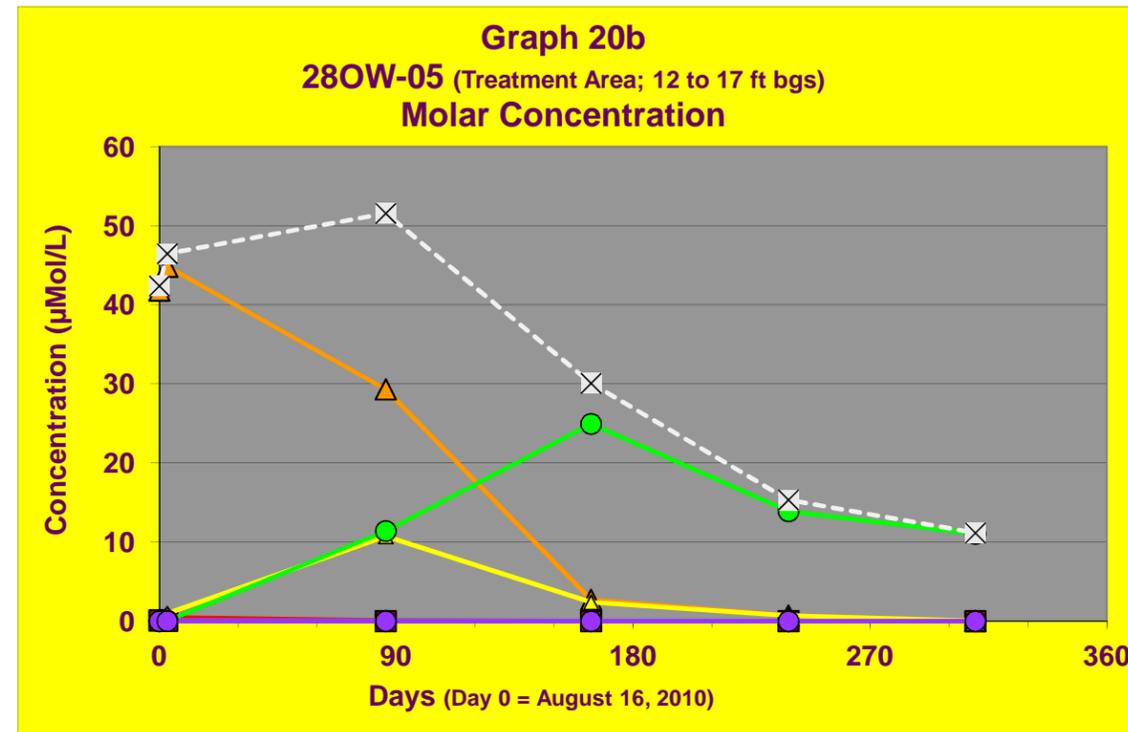
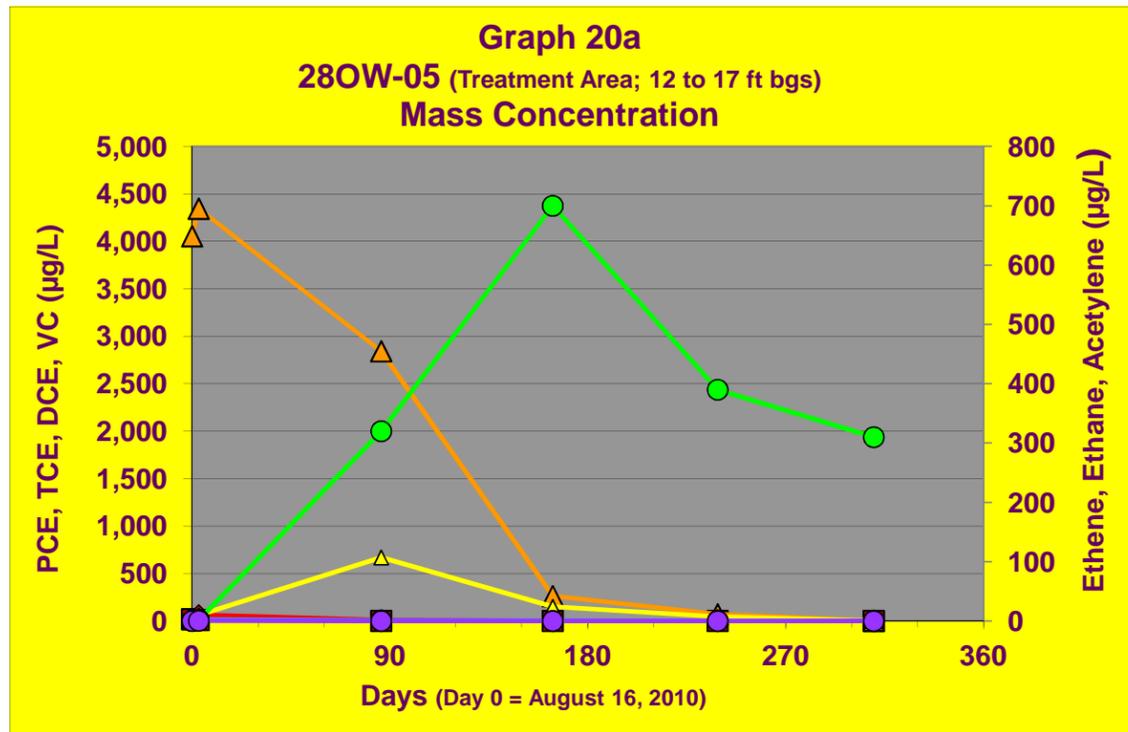
- PCE
- ◆ TCE
- ▲ Total DCE
- ▲ VC



- Ethene
- Ethane
- Acetylene
- × Total

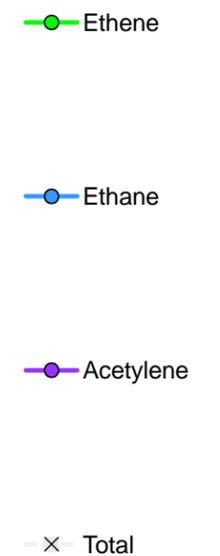
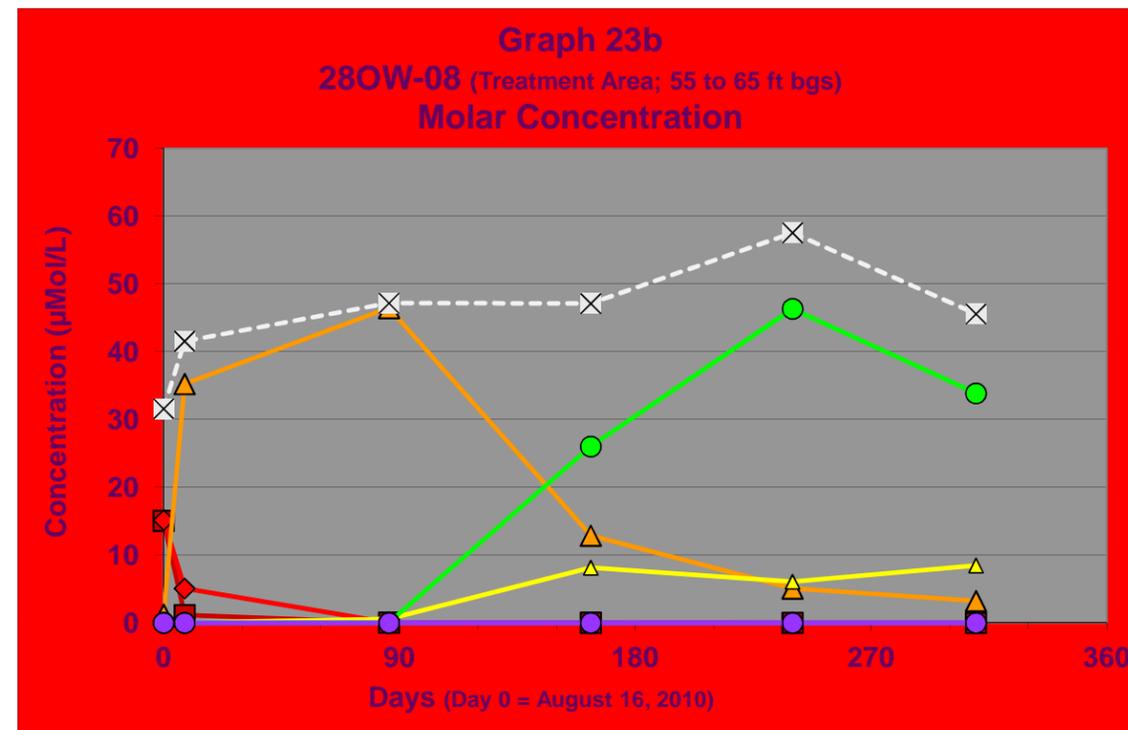
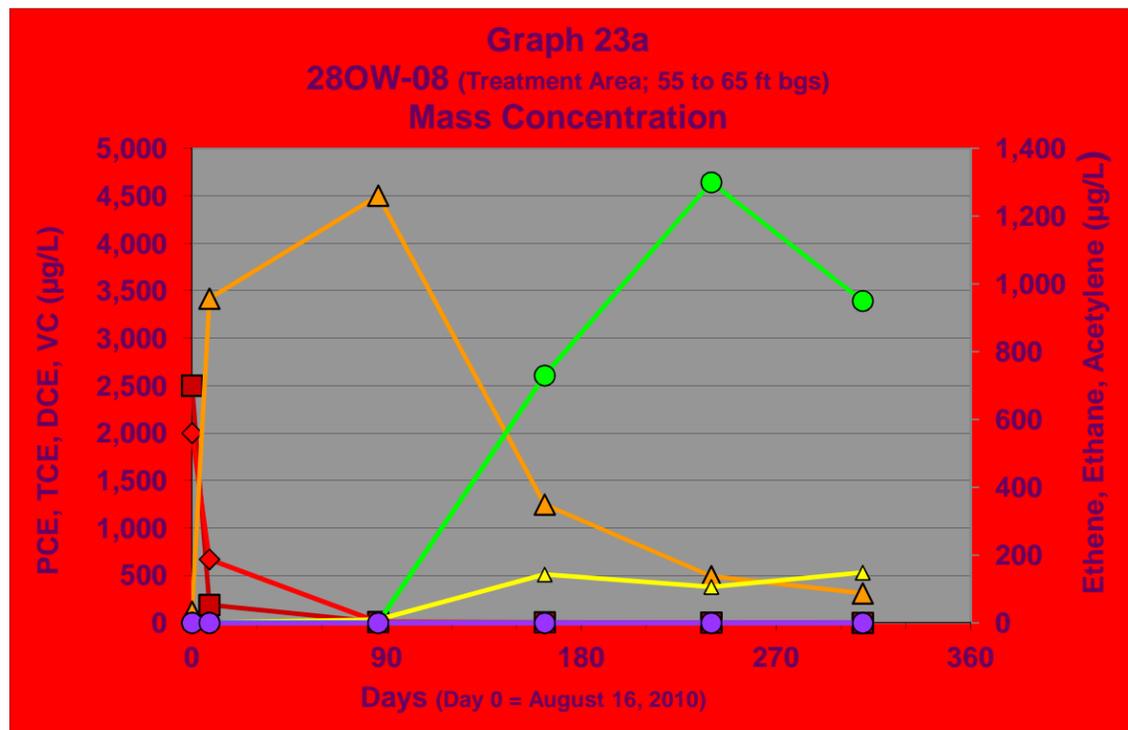
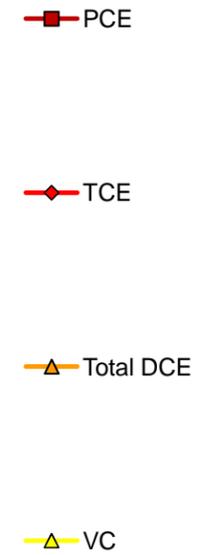
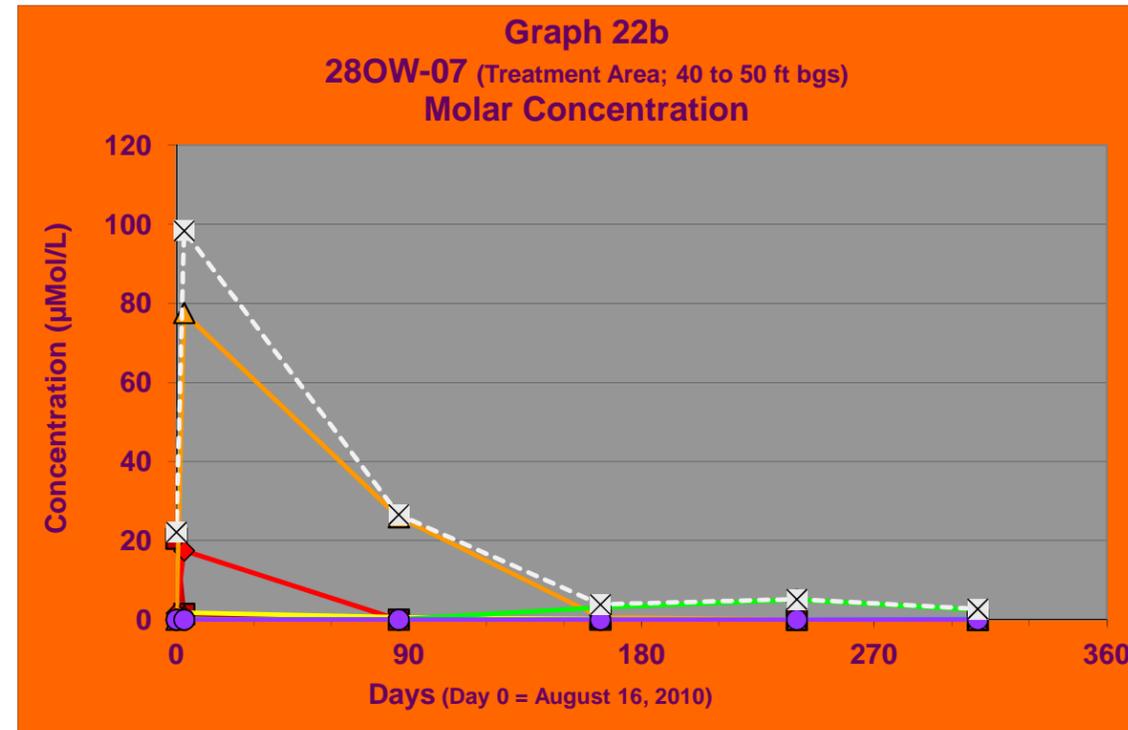
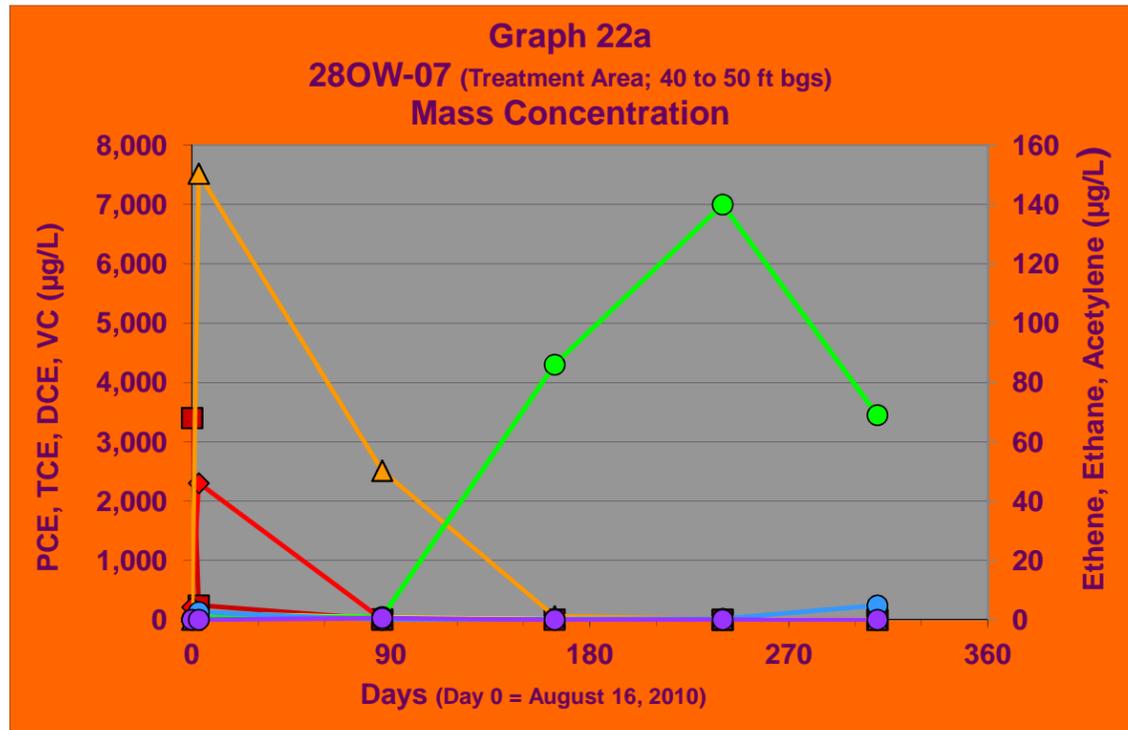
Graphs of Ethenes and Ethane Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field



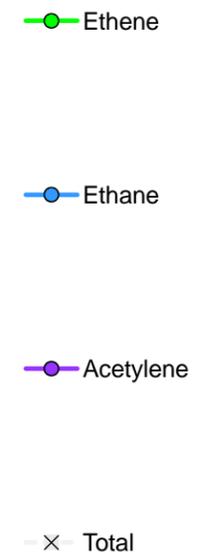
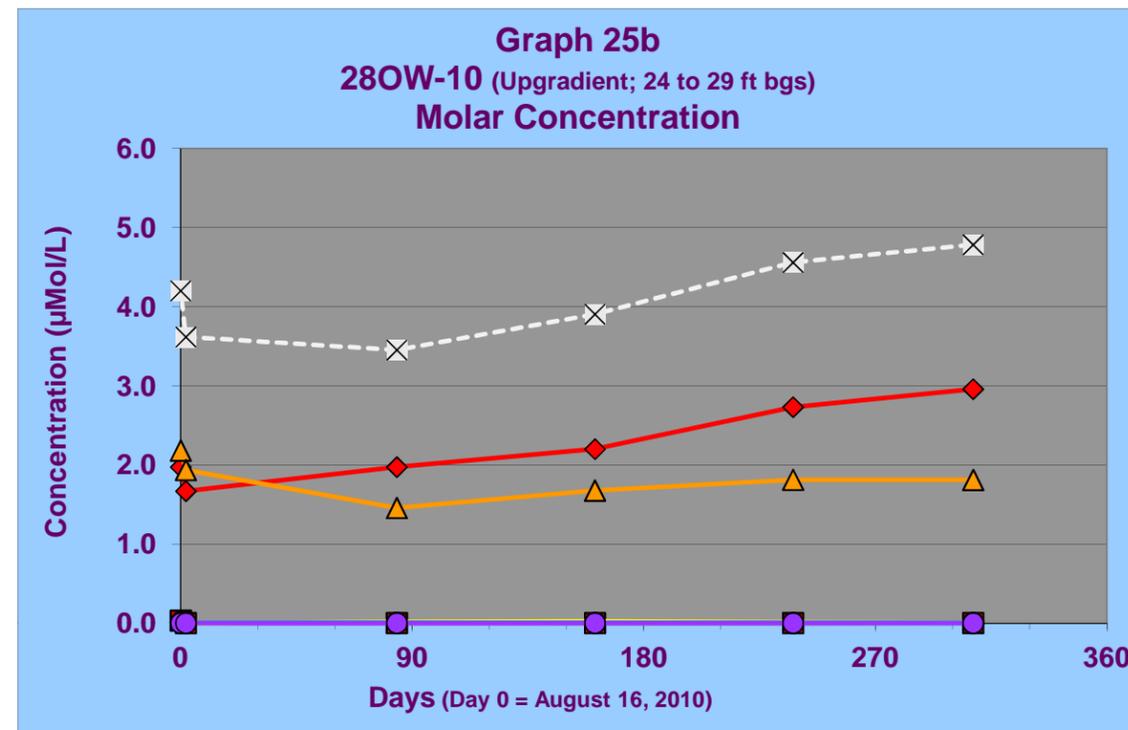
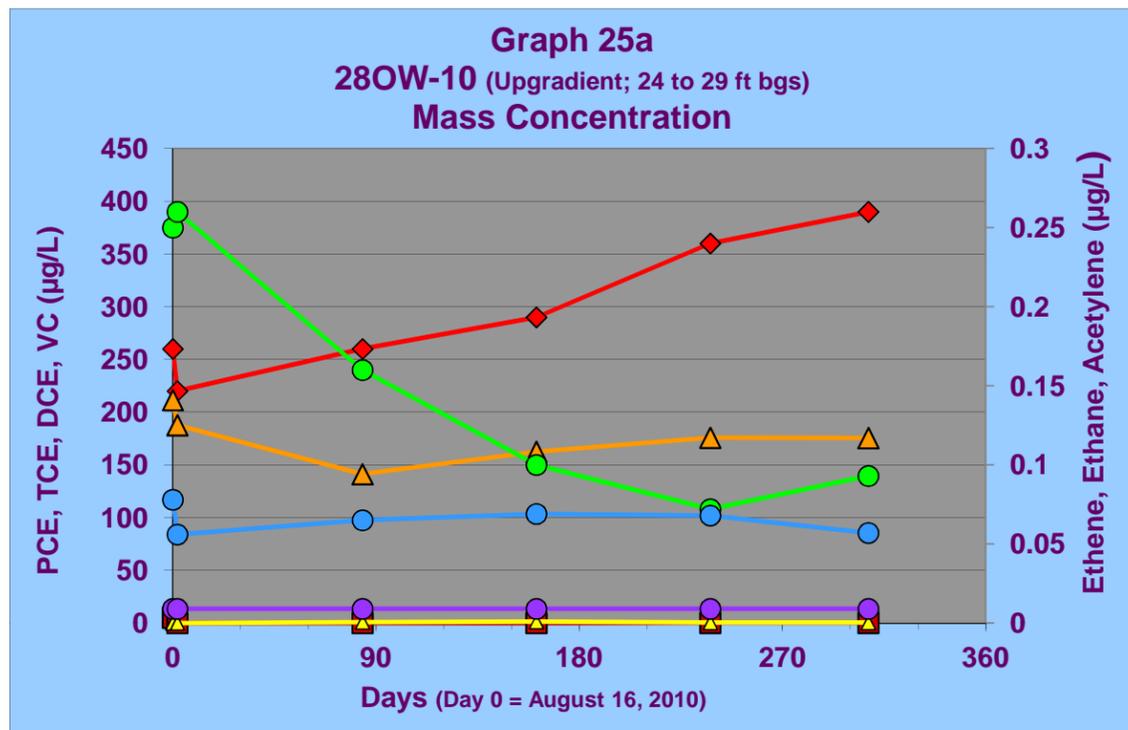
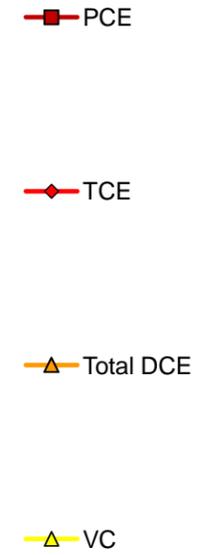
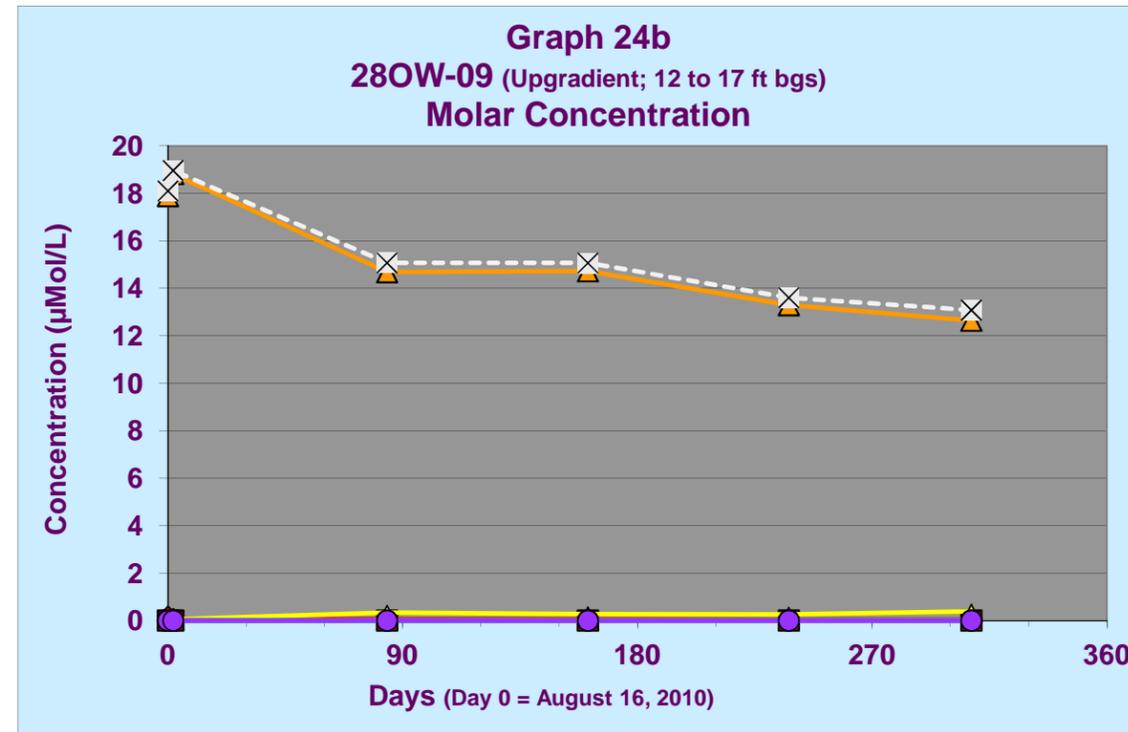
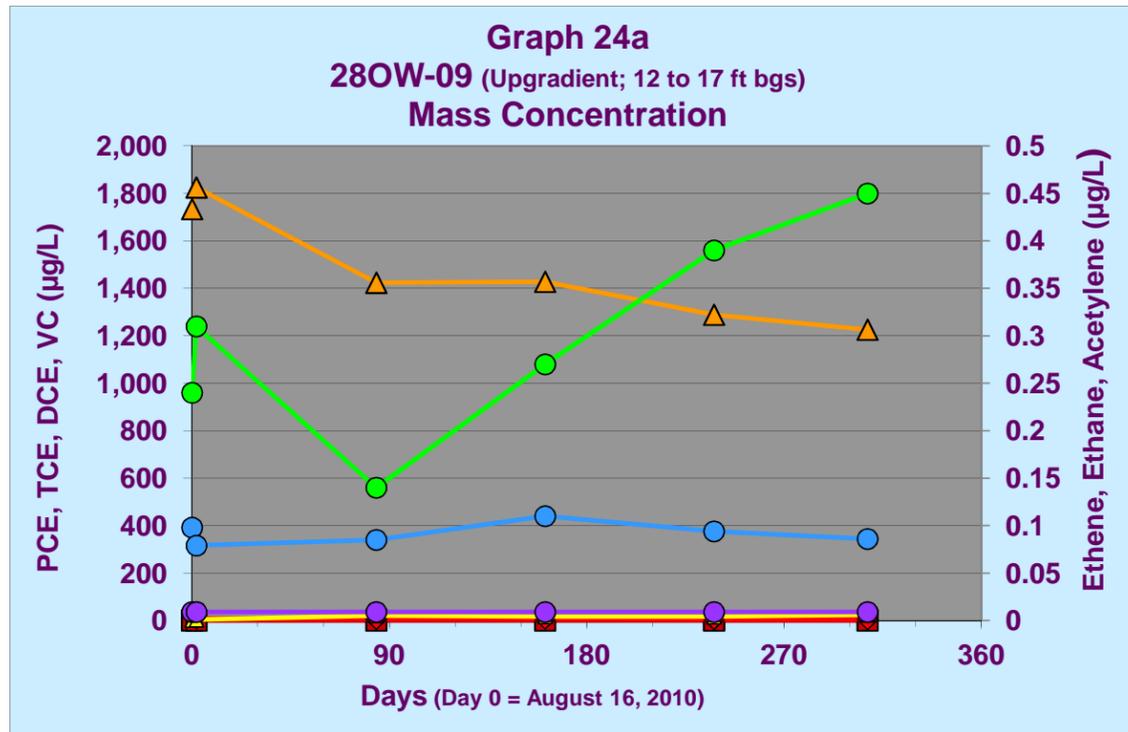
Graphs of Ethenes and Ethane Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field



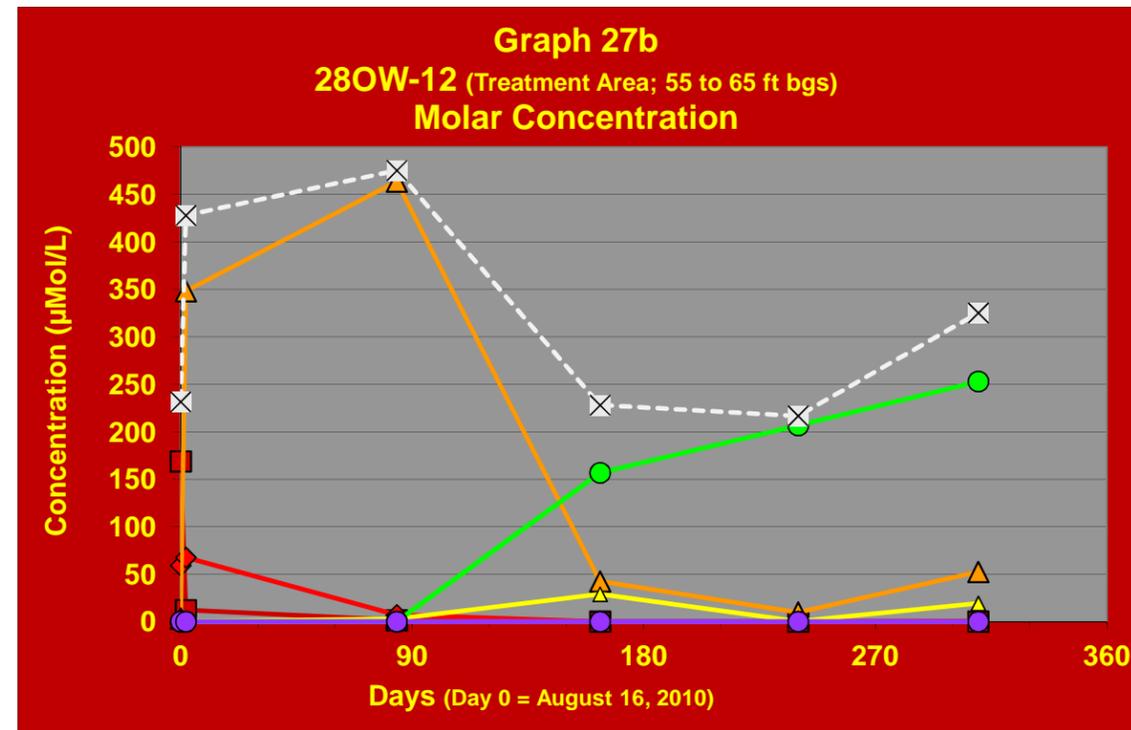
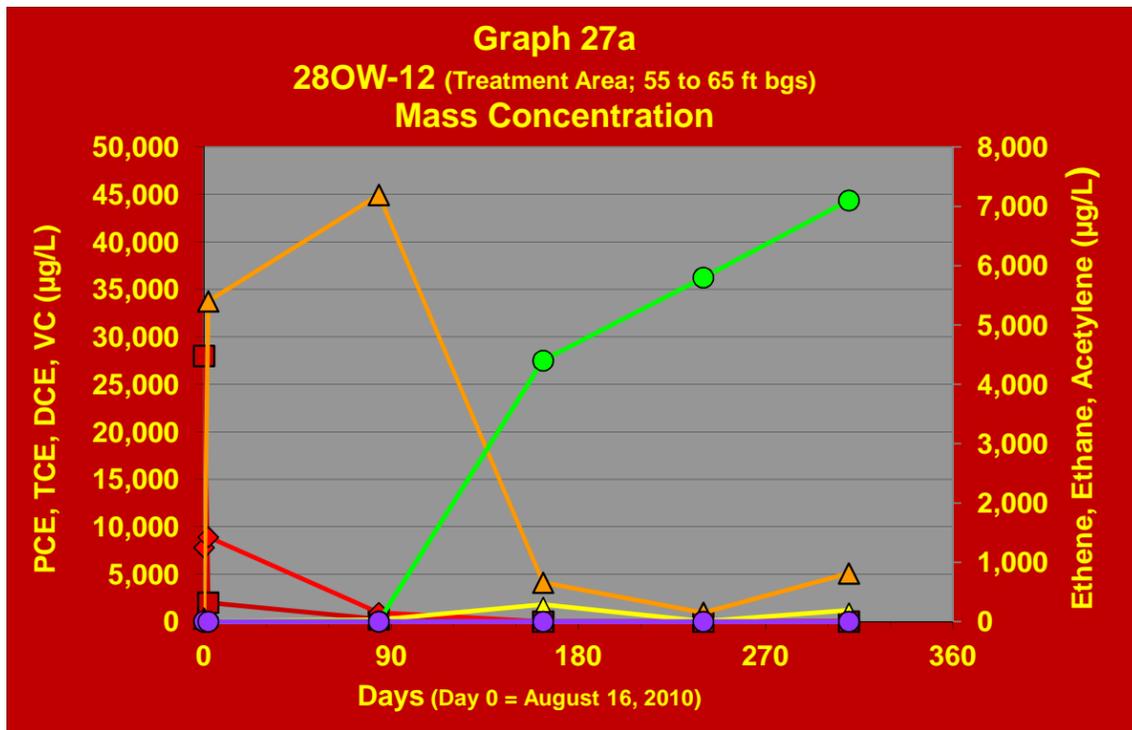
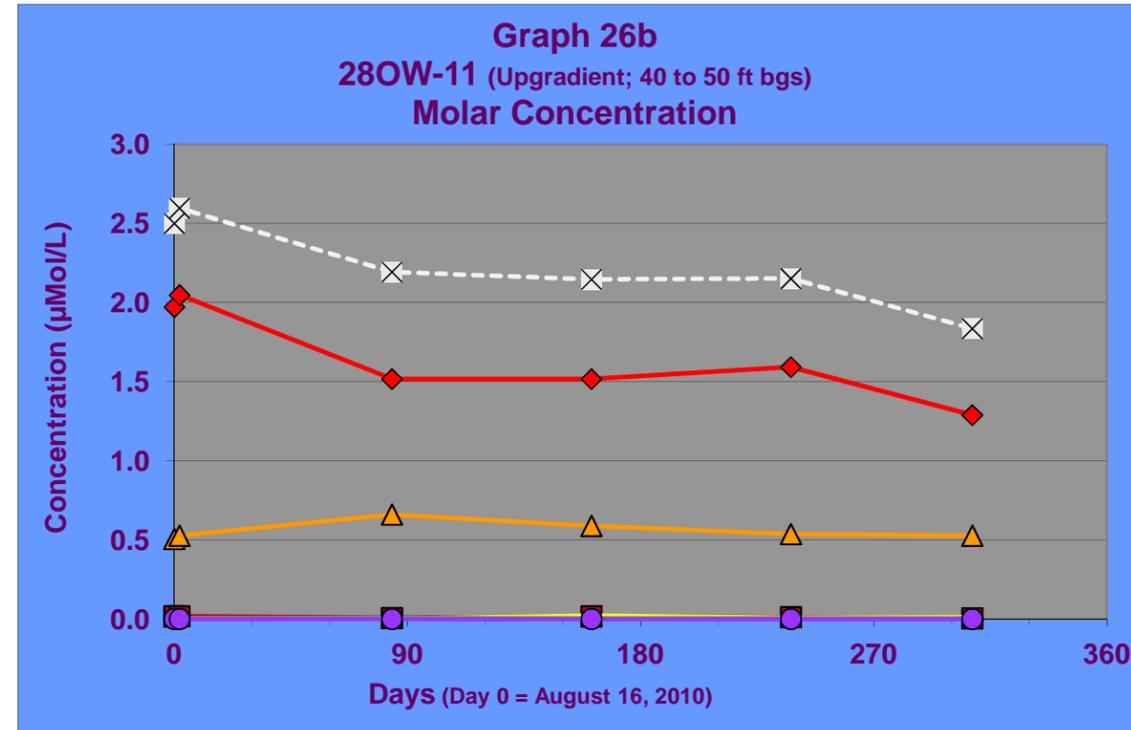
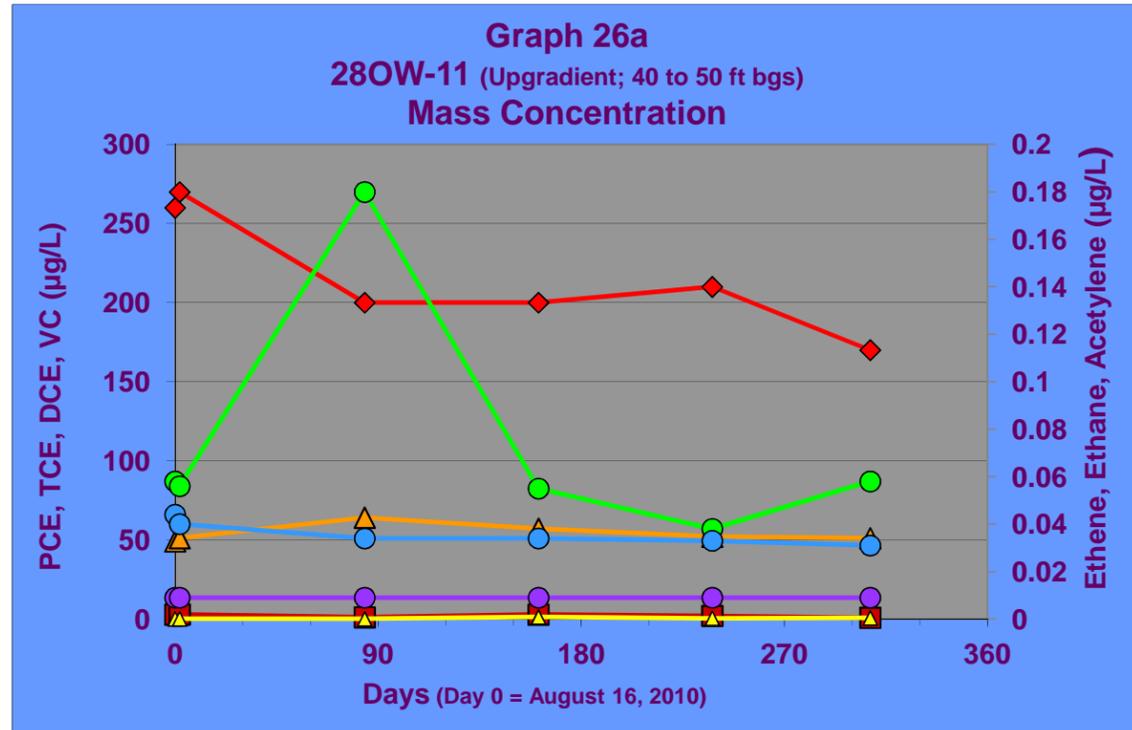
Graphs of Ethenes and Ethane Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field



Graphs of Ethenes and Ethane Concentrations in Groundwater - EVO Pilot Test

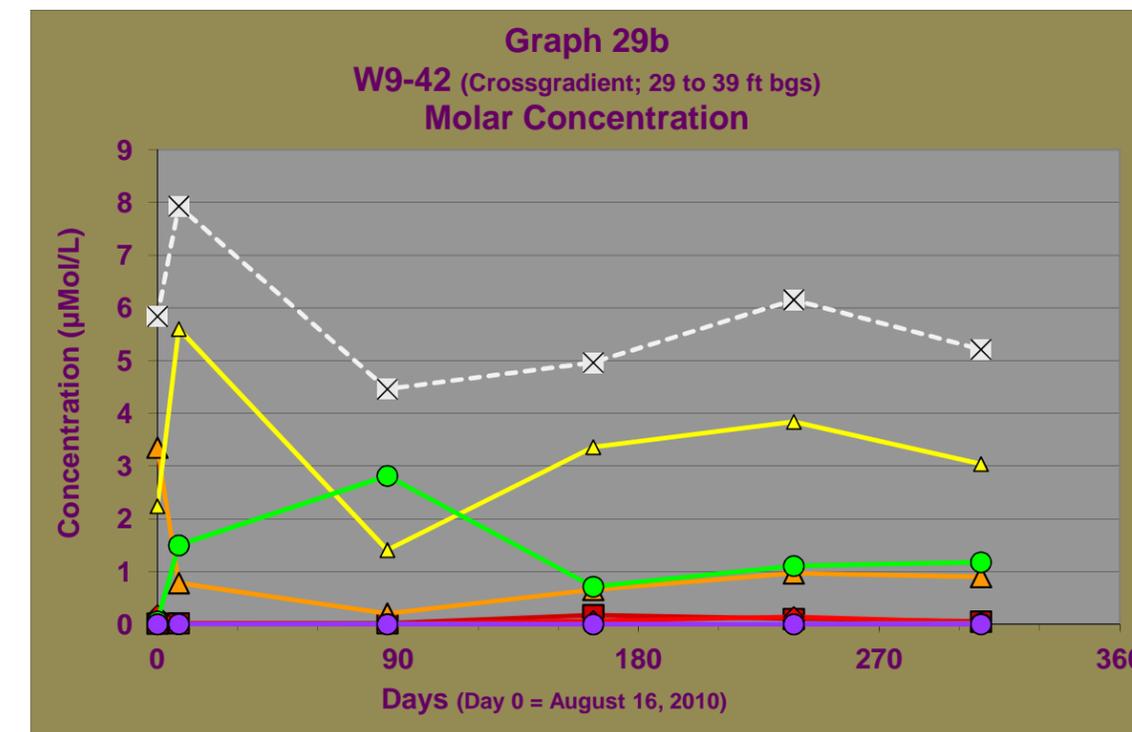
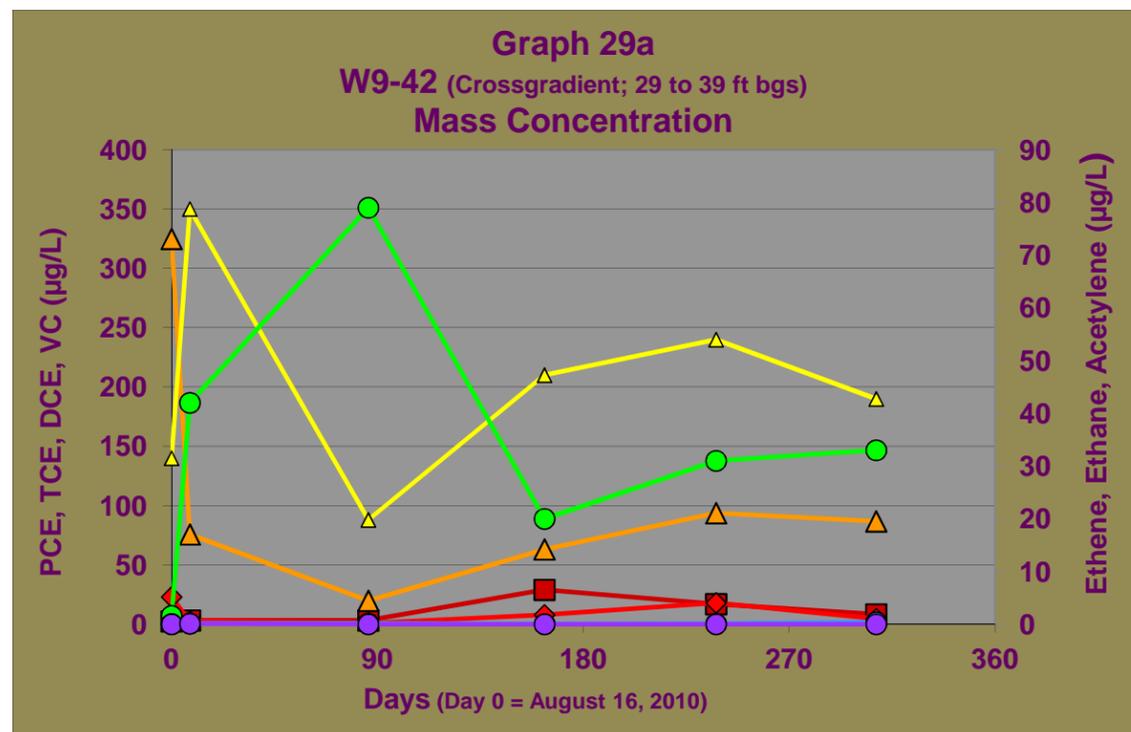
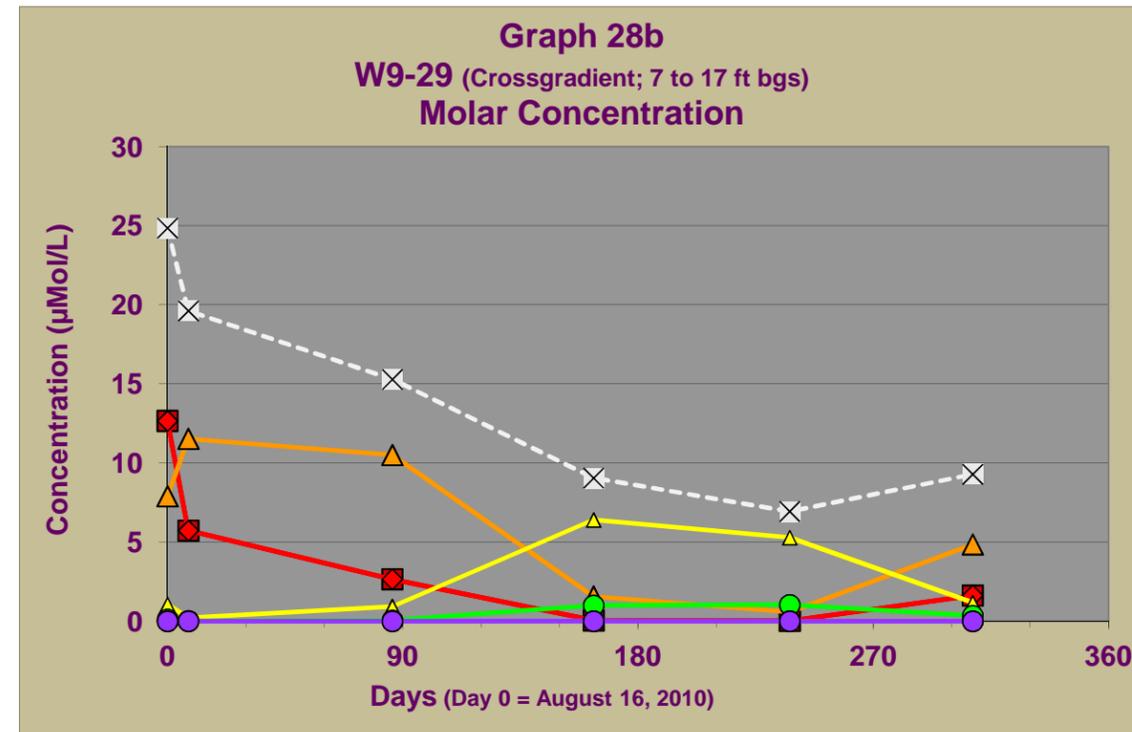
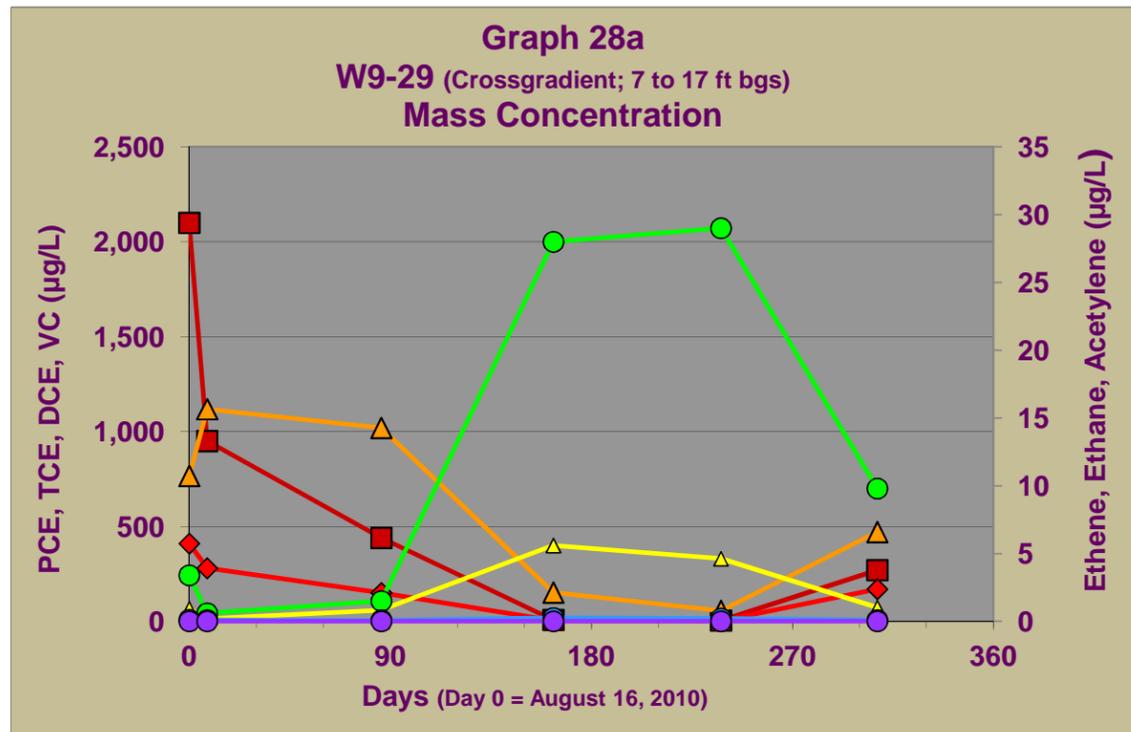
Traffic Island Area, IR Site 28, Former NAS Moffett Field



- PCE
- ◆ TCE
- ▲ Total DCE
- ▲ VC
- Ethene
- Ethane
- Acetylene
- × Total

Graphs of Ethenes and Ethane Concentrations in Groundwater - EVO Pilot Test

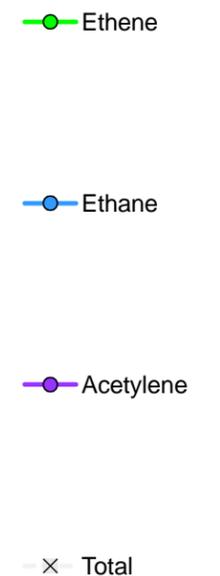
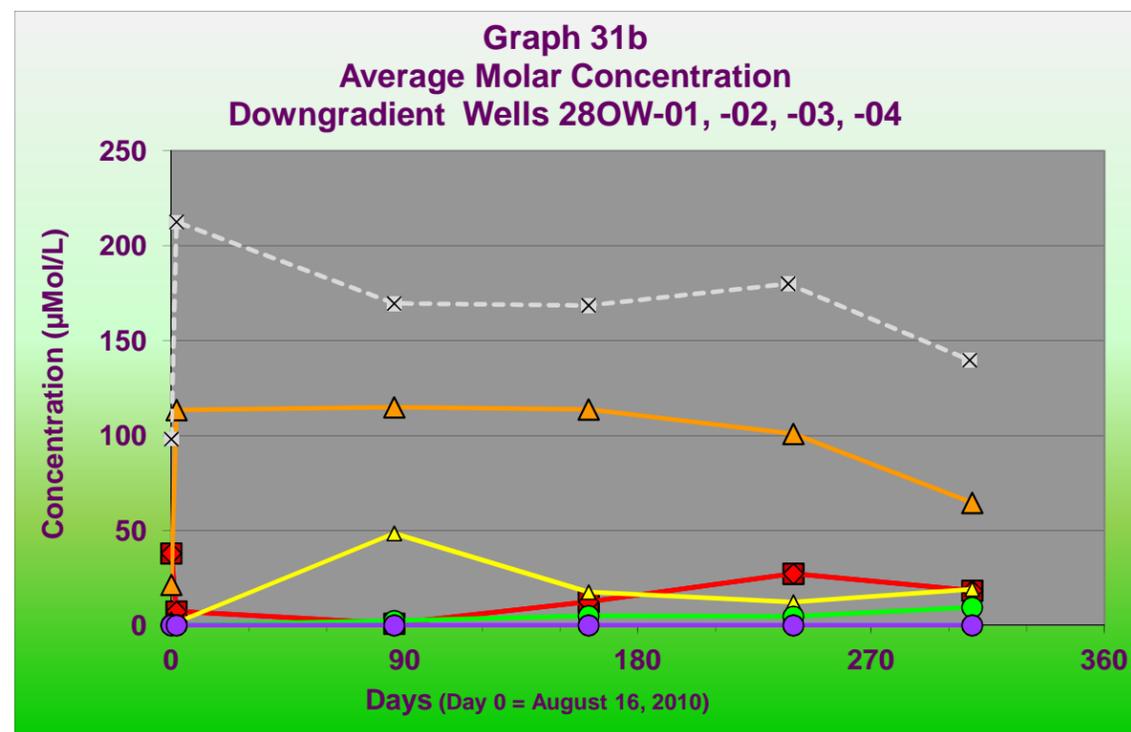
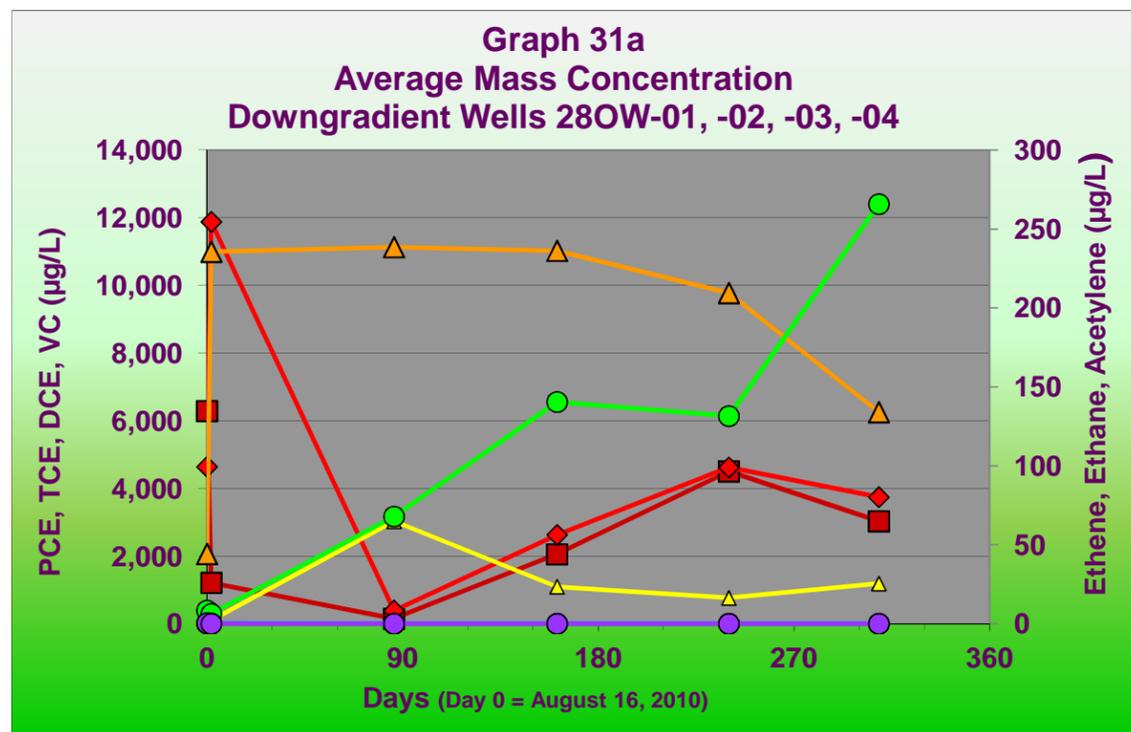
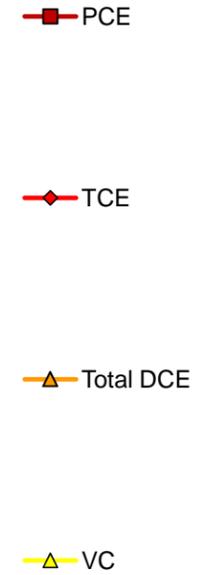
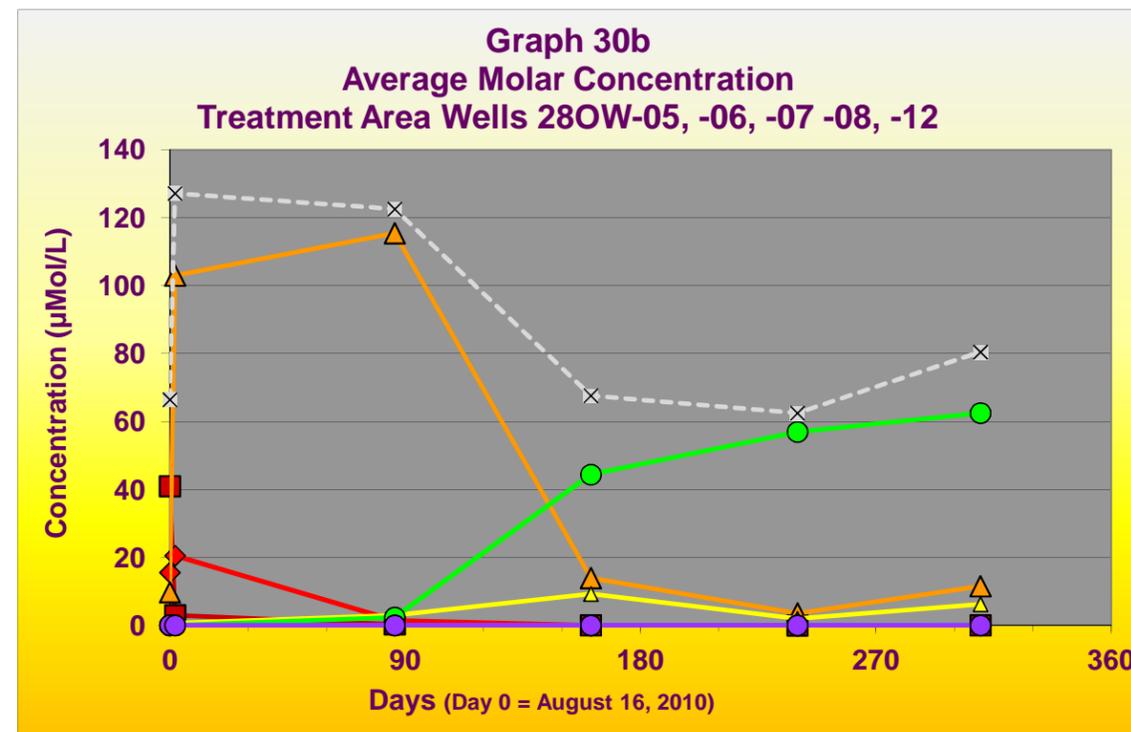
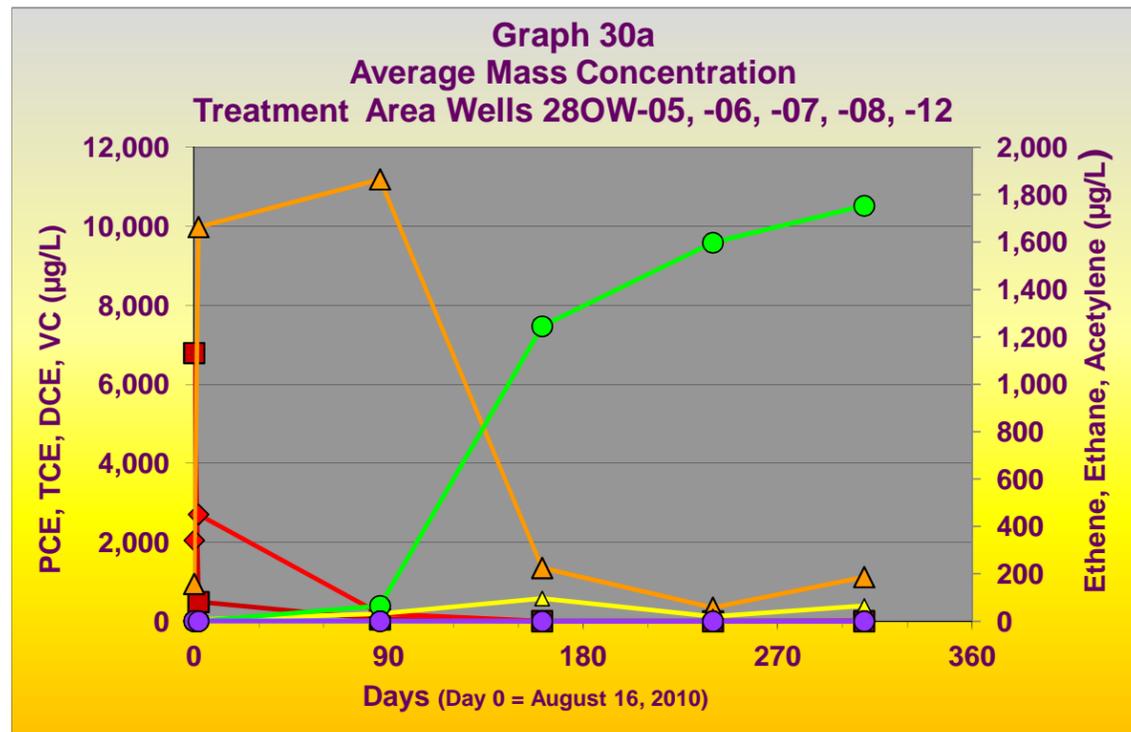
Traffic Island Area, IR Site 28, Former NAS Moffett Field



- PCE
- ◆ TCE
- ▲ Total DCE
- ▲ VC
- Ethene
- Ethane
- Acetylene
- × Total

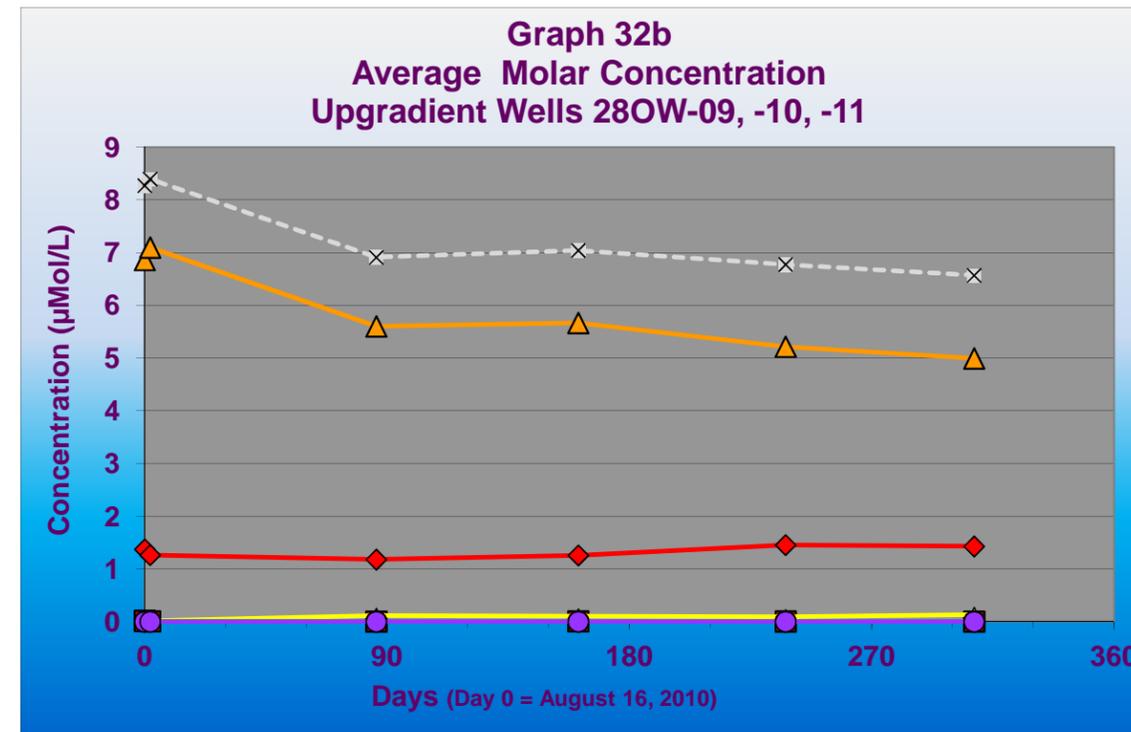
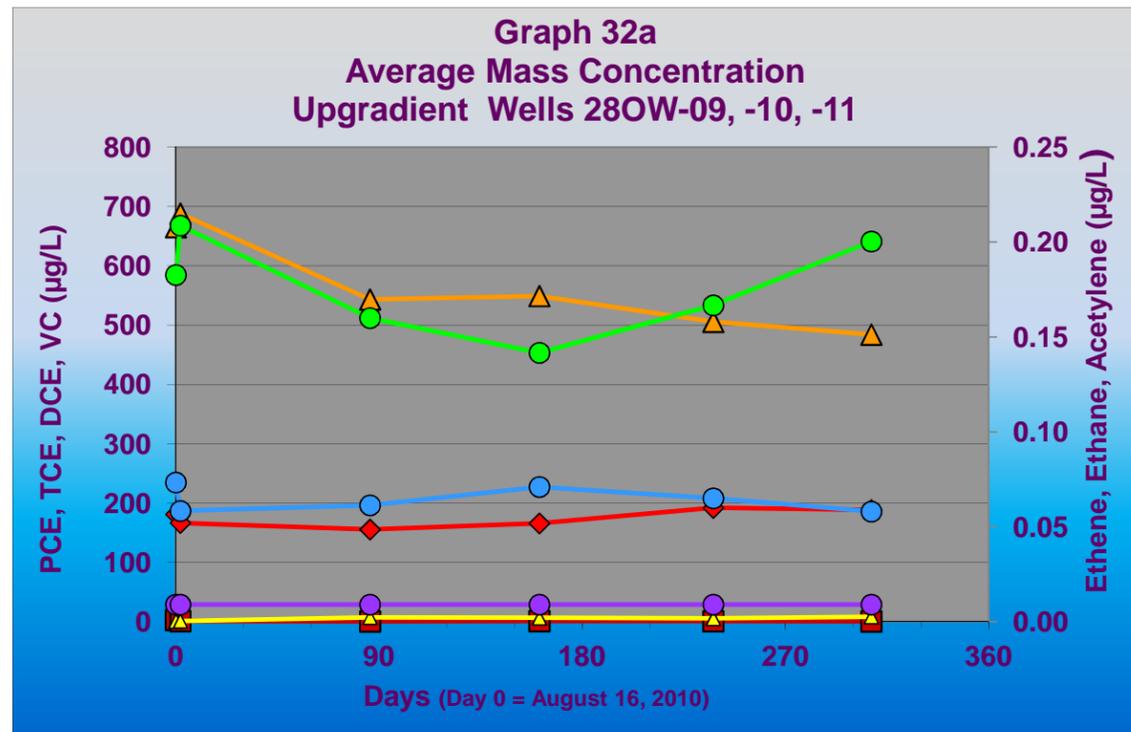
Graphs of Ethenes and Ethane Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field



Graphs of Ethenes and Ethane Concentrations in Groundwater - EVO Pilot Test

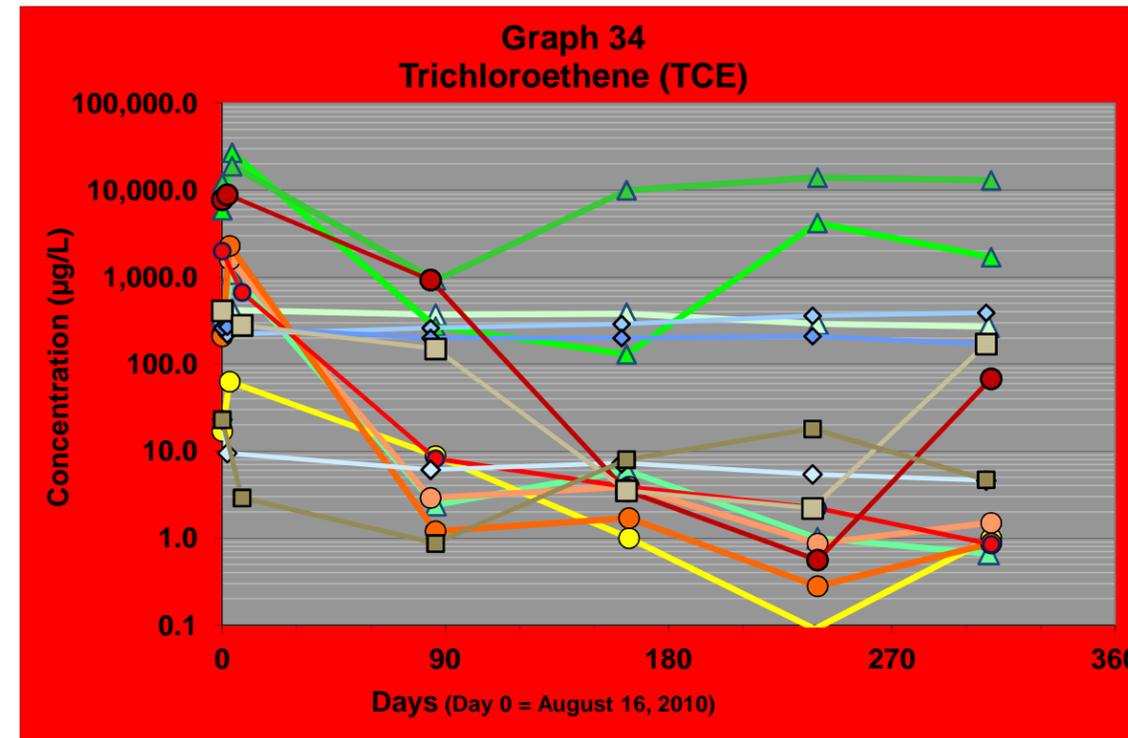
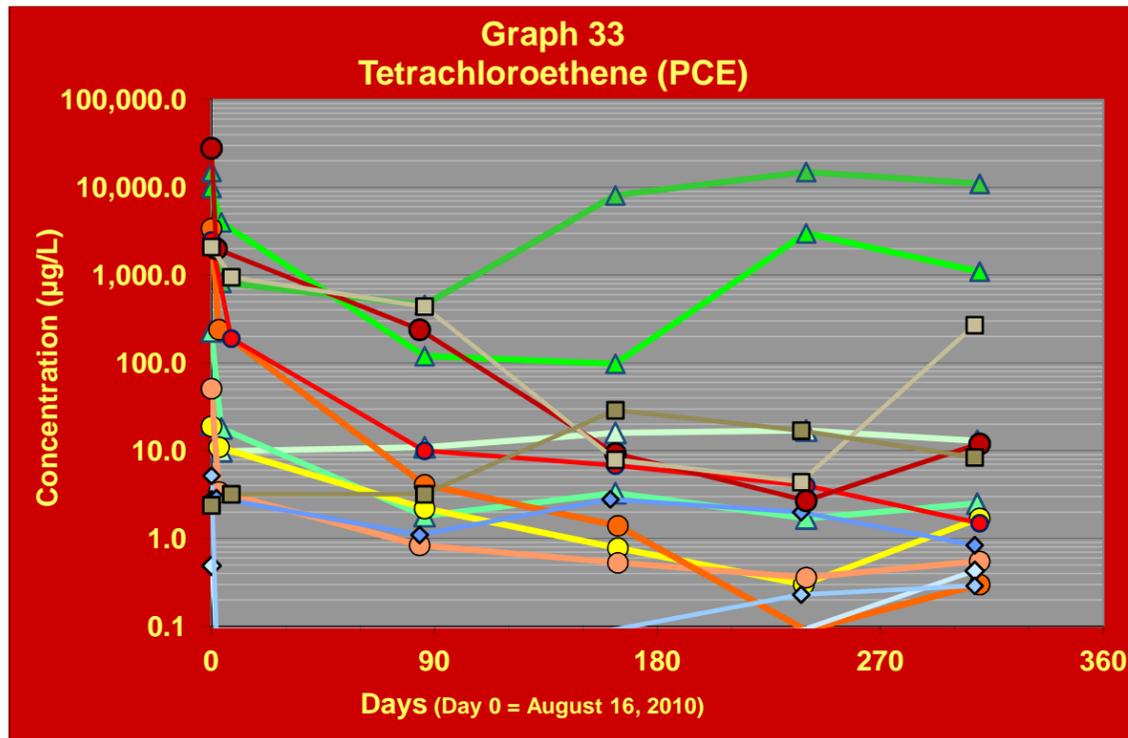
Traffic Island Area, IR Site 28, Former NAS Moffett Field



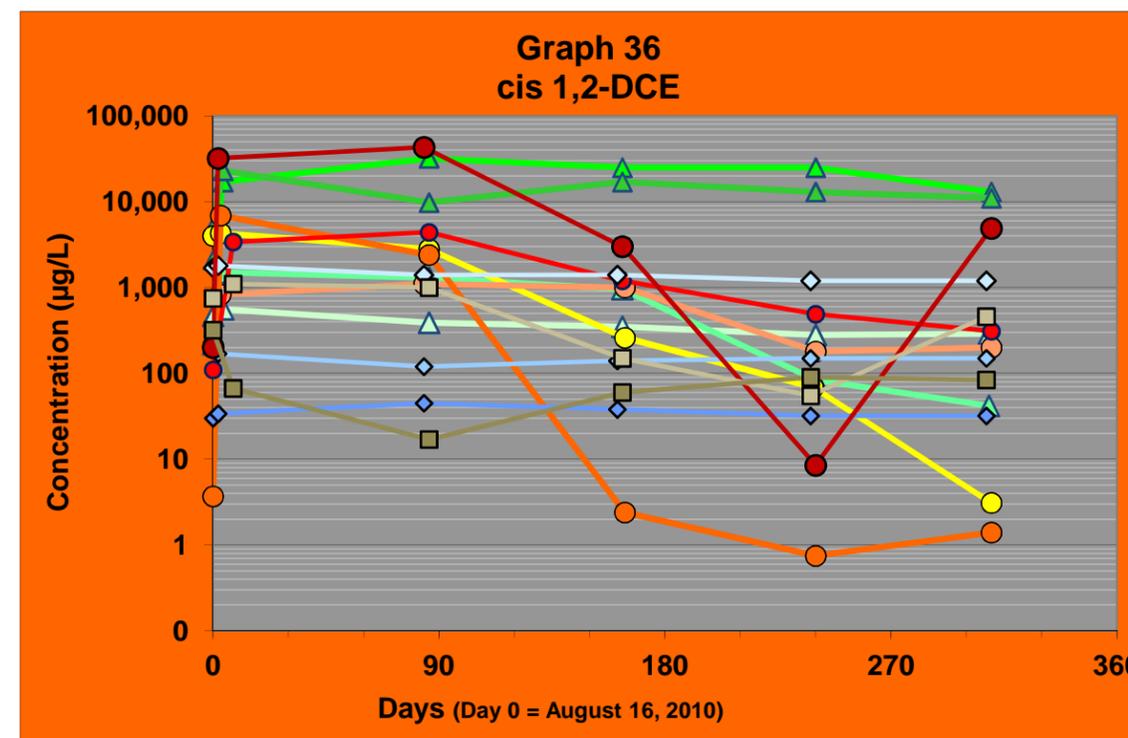
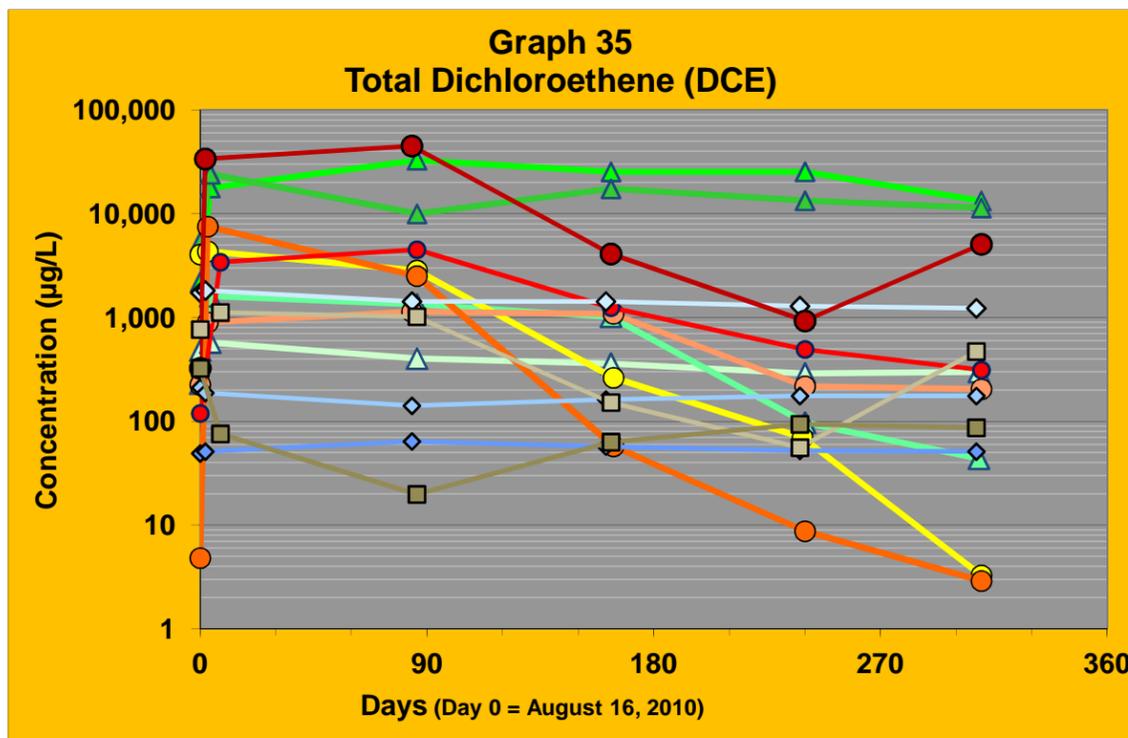
- PCE
- ◆ TCE
- ▲ Total DCE
- ▲ VC
- Ethene
- Ethane
- Acetylene
- × Total

Graphs of VOC Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field



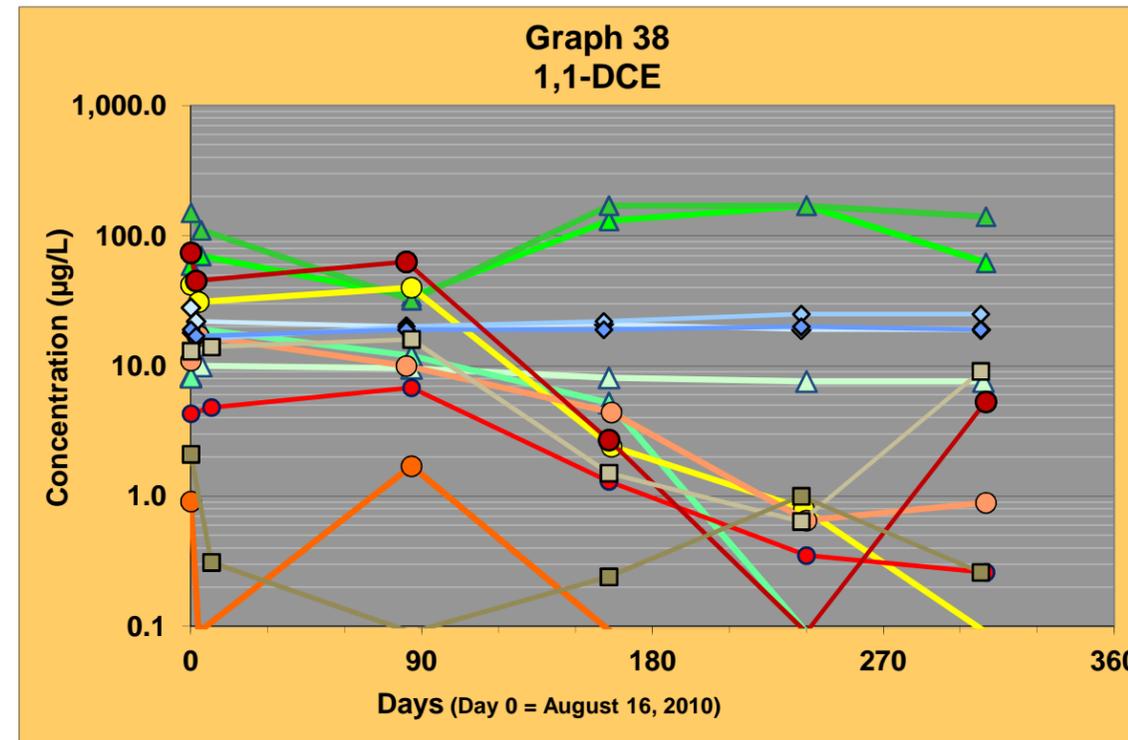
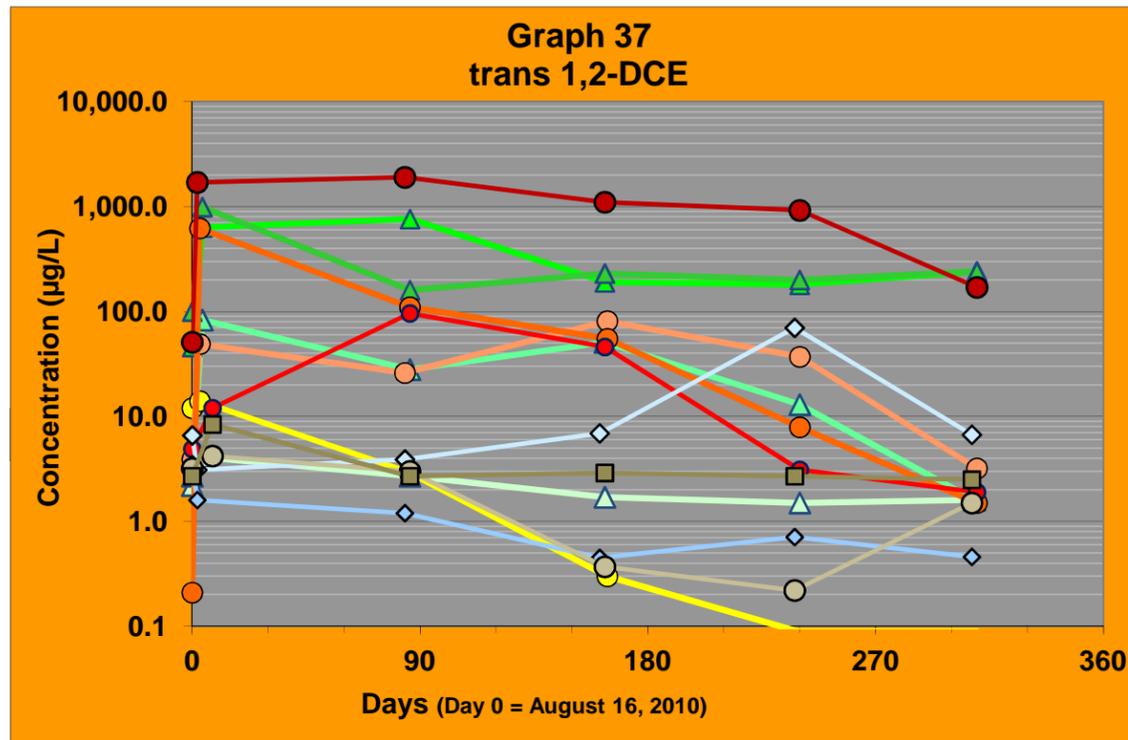
- △ 28OW-01
- ▲ 28OW-02
- ▲ 28OW-03
- ▲ 28OW-04
- 28OW-05
- 28OW-06
- 28OW-07
- 28OW-08
- ◇ 28OW-09
- ◇ 28OW-10
- ◇ 28OW-11
- 28OW-12
- W9-29
- W9-42



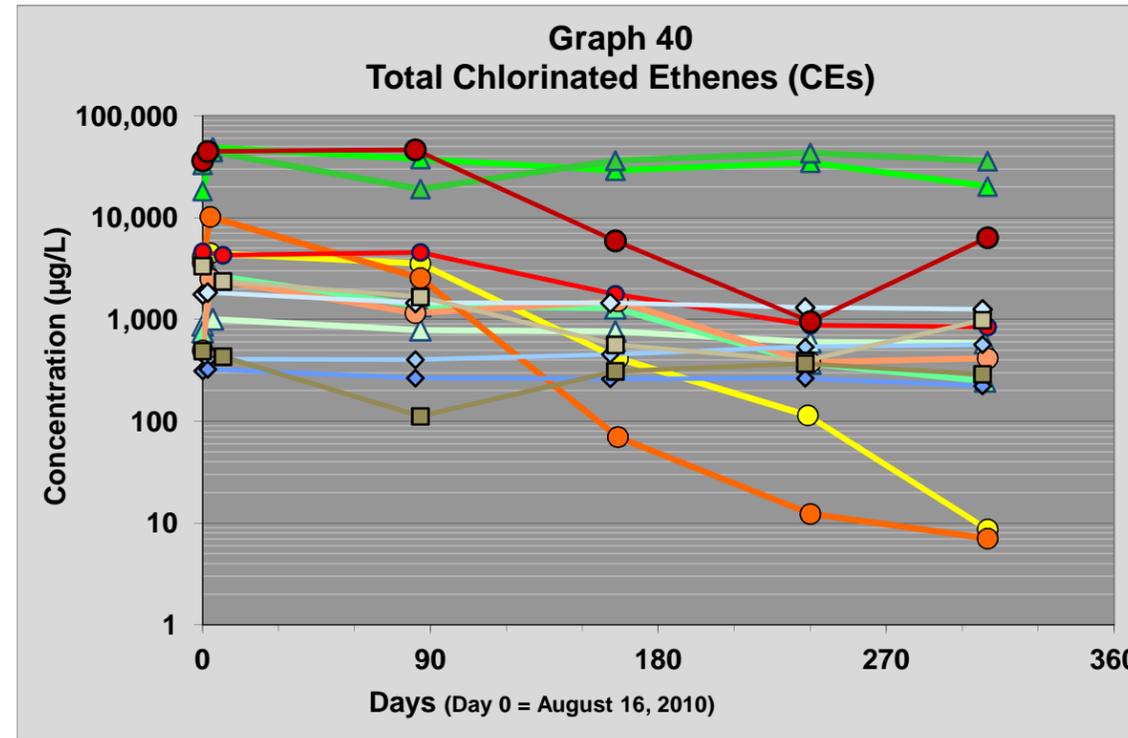
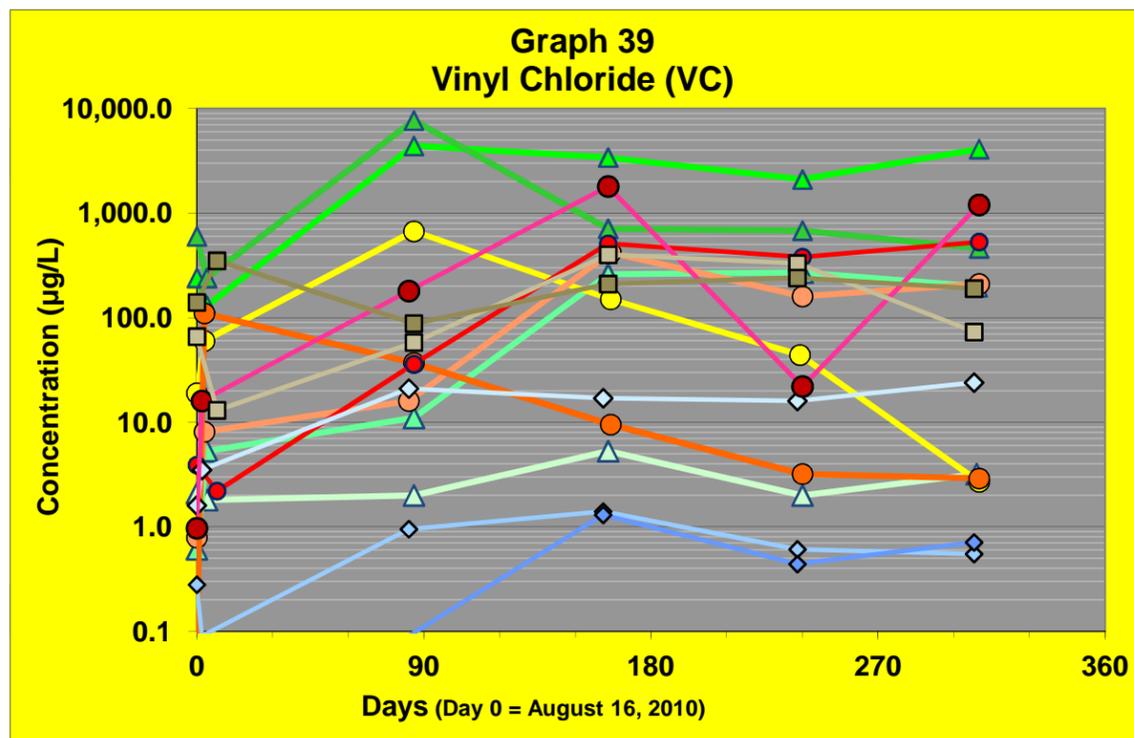
- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◇ Well Upgradient from Treatment Area
- Well Crossgradient from Treatment Area

Graphs of VOC Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field



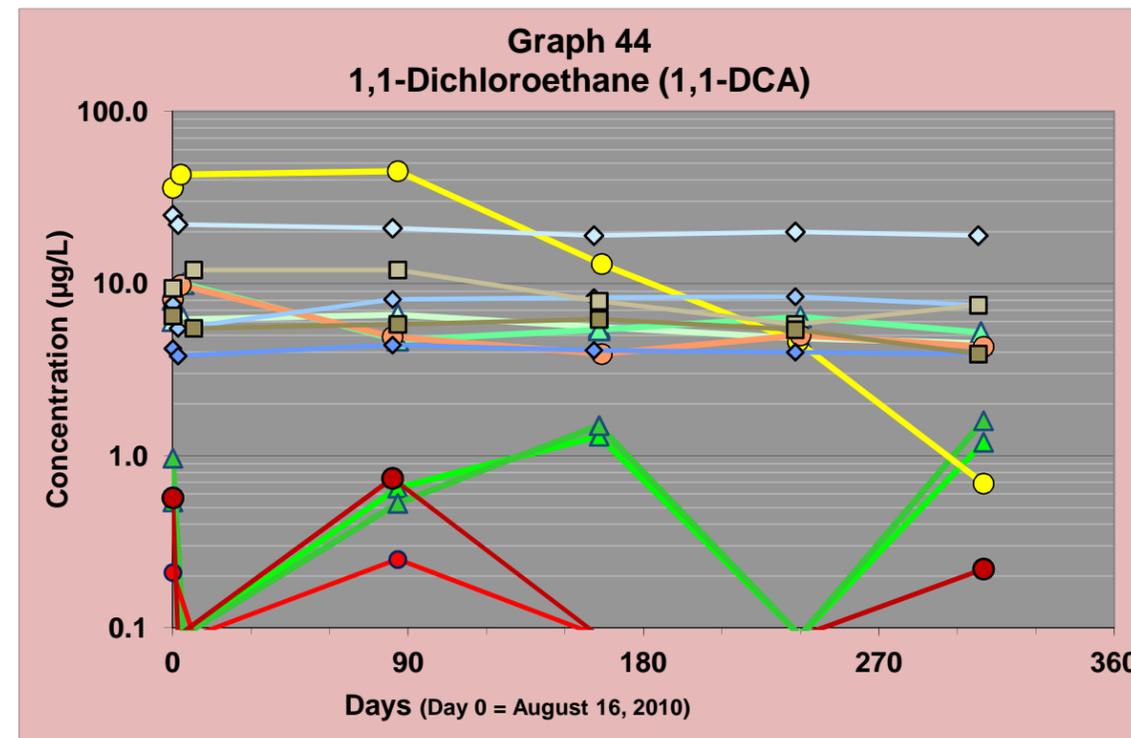
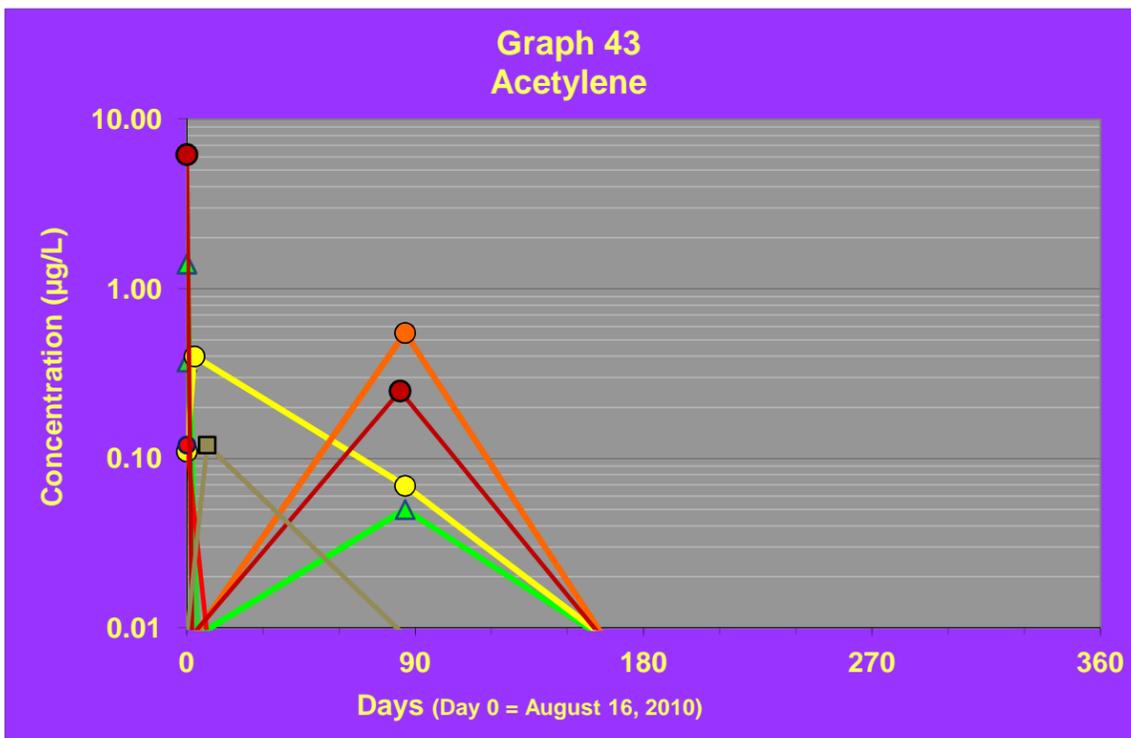
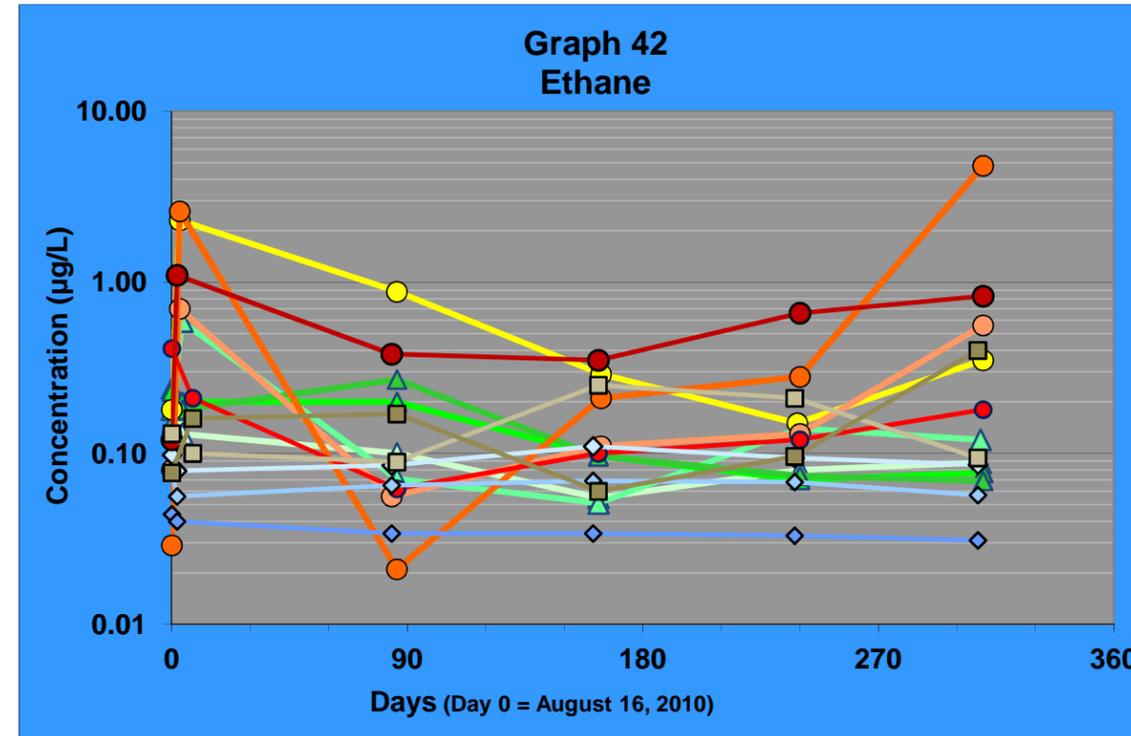
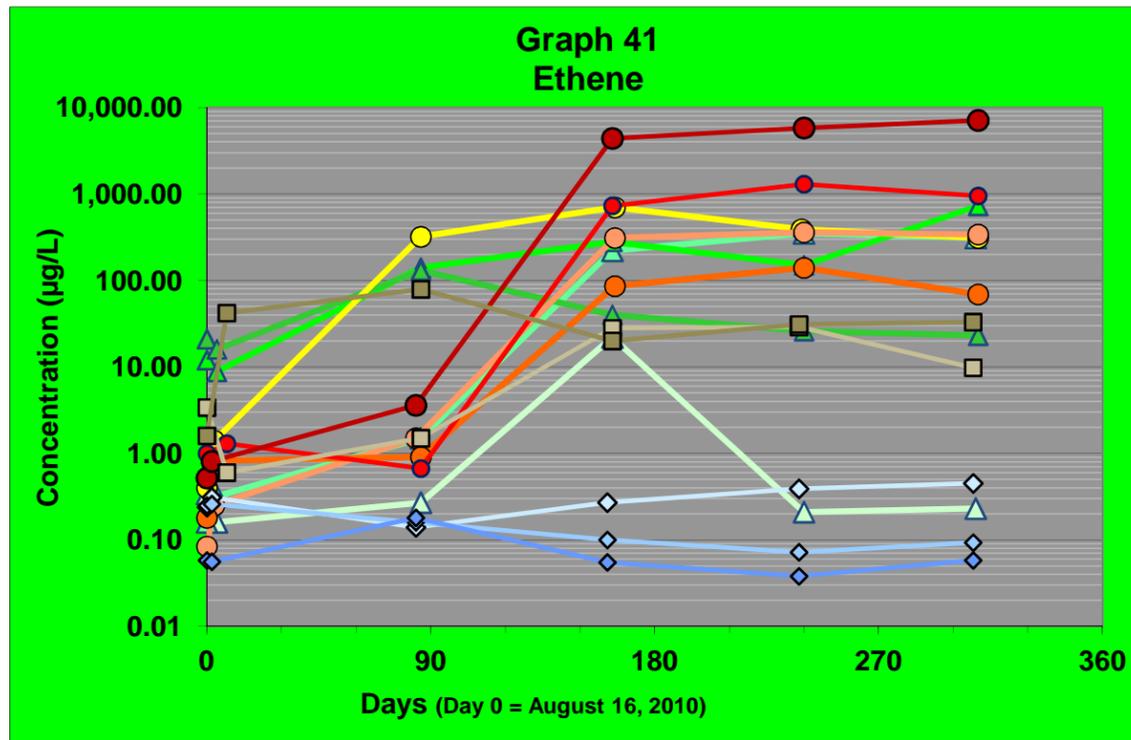
- △ 28OW-01
- ▲ 28OW-02
- ▲ 28OW-03
- ▲ 28OW-04
- 28OW-05
- 28OW-06
- 28OW-07
- 28OW-08
- ◇ 28OW-09
- ◇ 28OW-10
- ◇ 28OW-11
- 28OW-12
- W9-29
- W9-42



- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◇ Well Upgradient from Treatment Area
- Well Crossgradient from Treatment Area

Graphs of VOC Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field

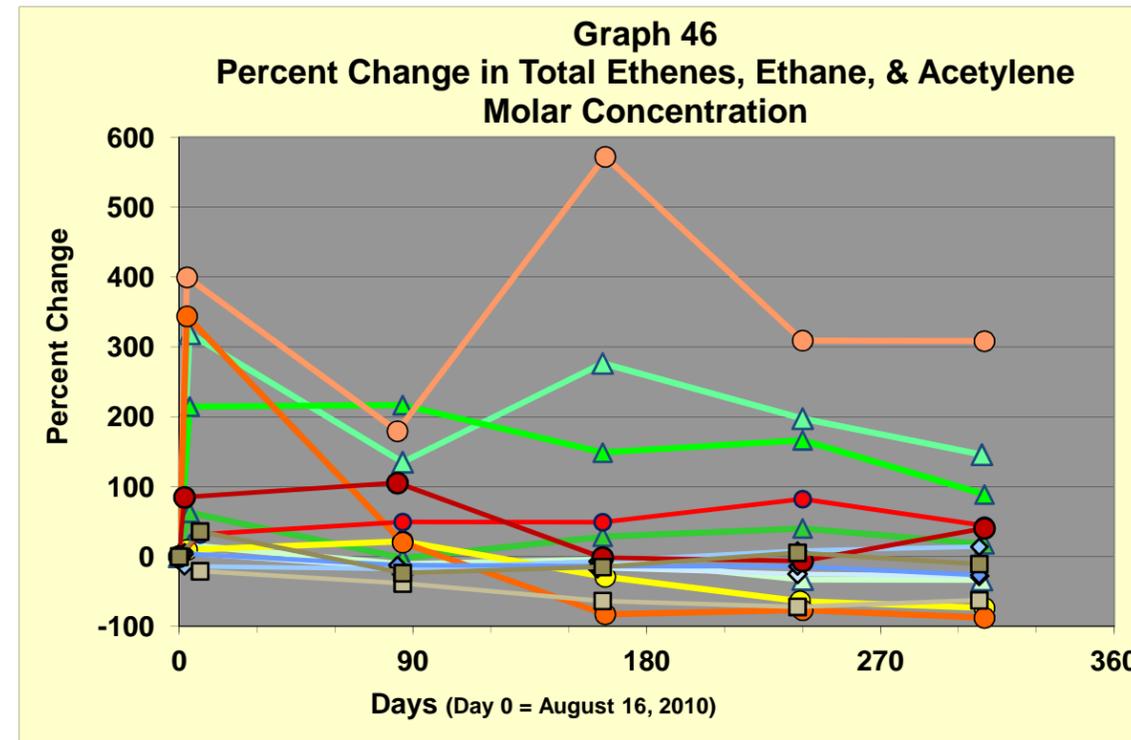
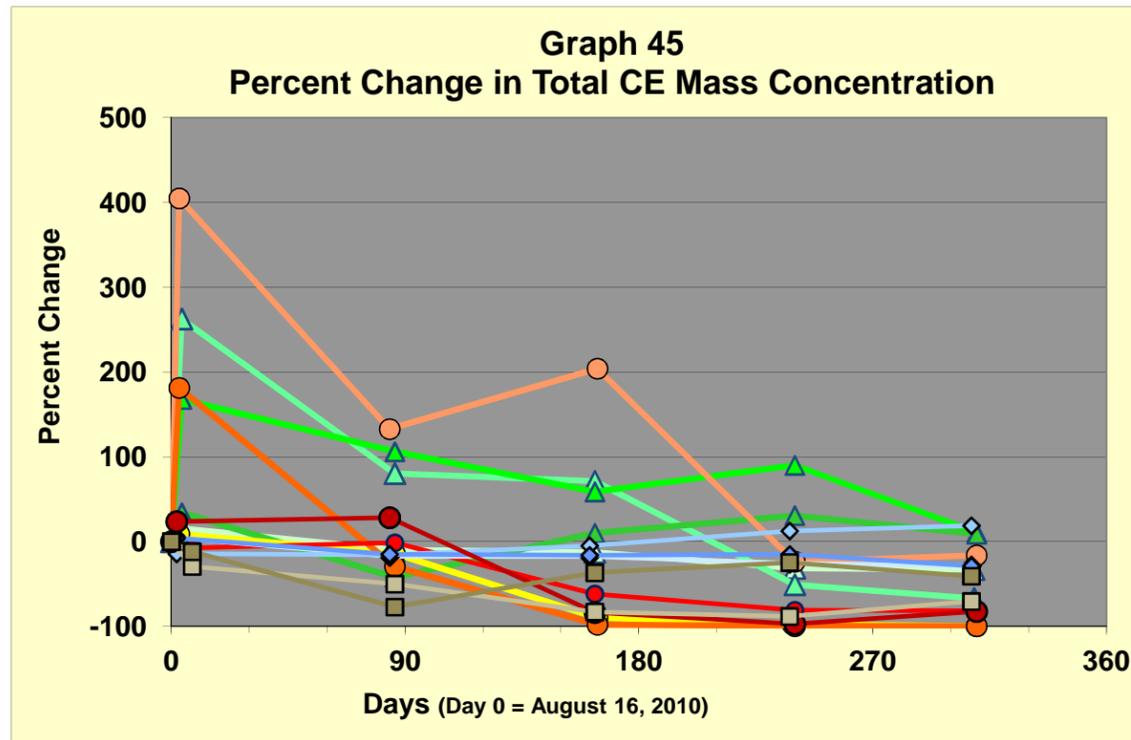


- △ 28OW-01
- ▲ 28OW-02
- ▲ 28OW-03
- ▲ 28OW-04
- 28OW-05
- 28OW-06
- 28OW-07
- 28OW-08
- ◇ 28OW-09
- ◇ 28OW-10
- ◇ 28OW-11
- 28OW-12
- W9-29
- W9-42

- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◇ Well Upgradient from Treatment Area
- Well Crossgradient from Treatment Area

Graphs of VOC Concentrations in Groundwater - EVO Pilot Test

Traffic Island Area, IR Site 28, Former NAS Moffett Field

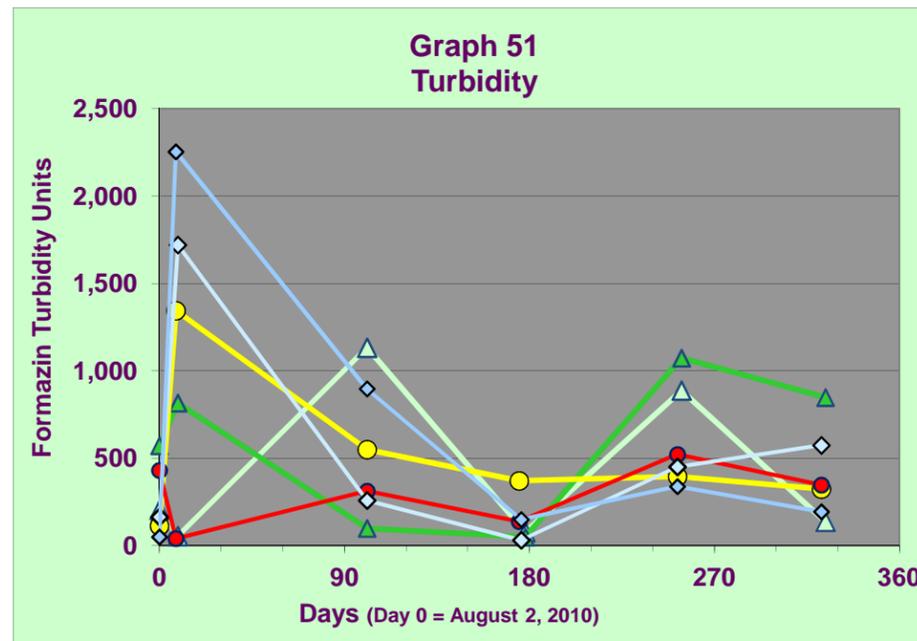
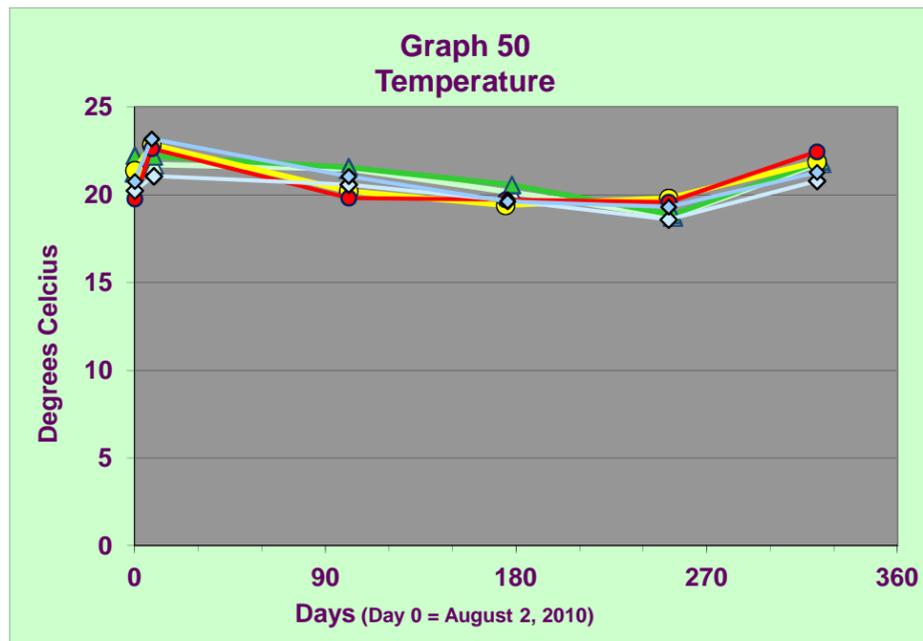
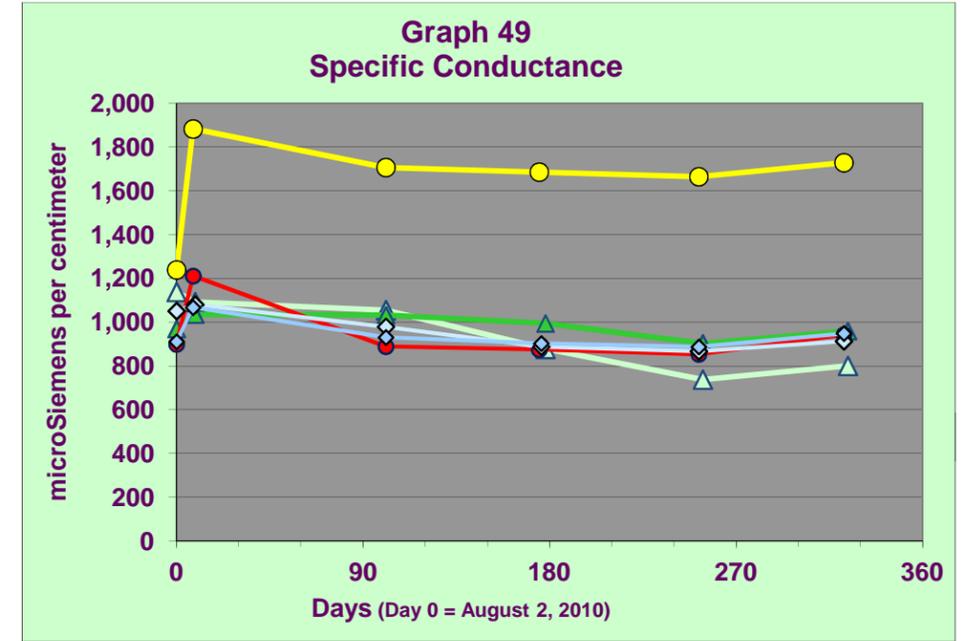
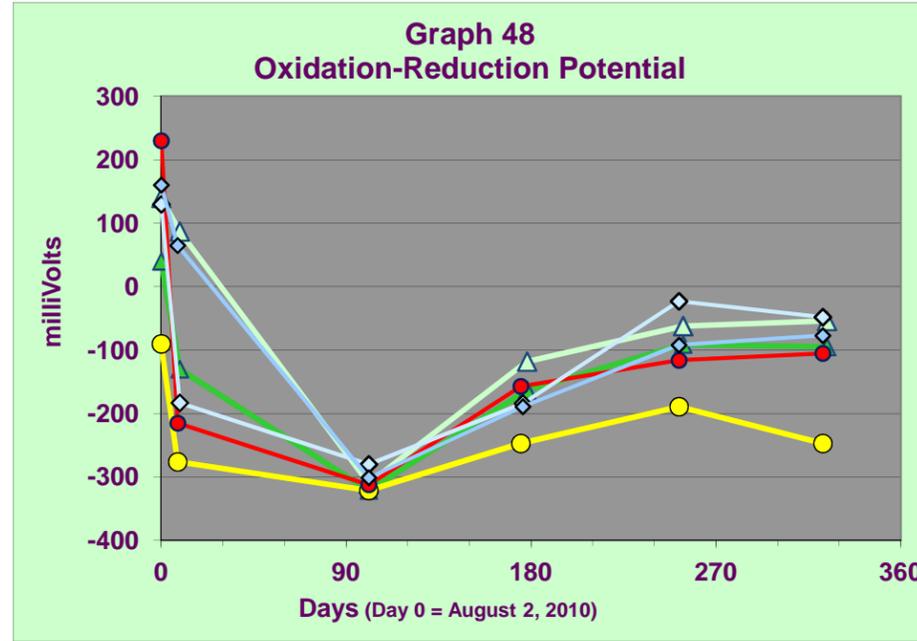
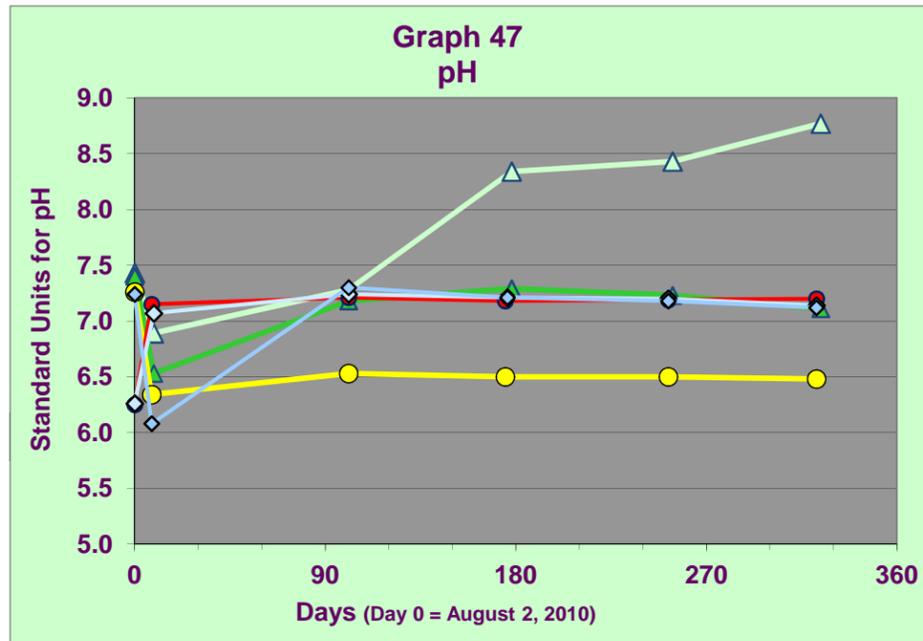


- ▲ 28OW-01
- ▲ 28OW-02
- ▲ 28OW-03
- ▲ 28OW-04
- 28OW-05
- 28OW-06
- 28OW-07
- 28OW-08
- ◇ 28OW-09
- ◇ 28OW-10
- ◇ 28OW-11
- 28OW-12
- W9-29
- W9-42

▲ Well Downgradient from Treatment Area ● Well Within Treatment Area ◆ Well Upgradient from Treatment Area ■ Well Crossgradient from Treatment Area

Graphs for Physical Parameters of Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field



- ▲ 28OW-19
- ▲ 28OW-20
- 28OW-21
- 28OW-22
- ◆ 28OW-23
- ◆ 28OW-24

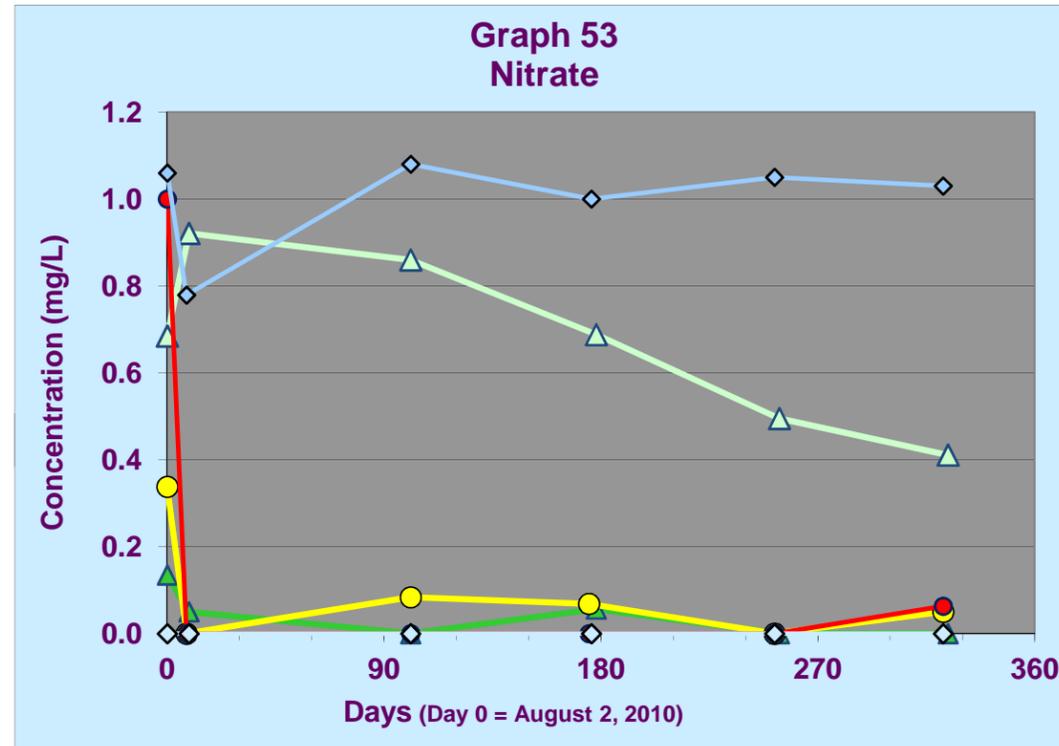
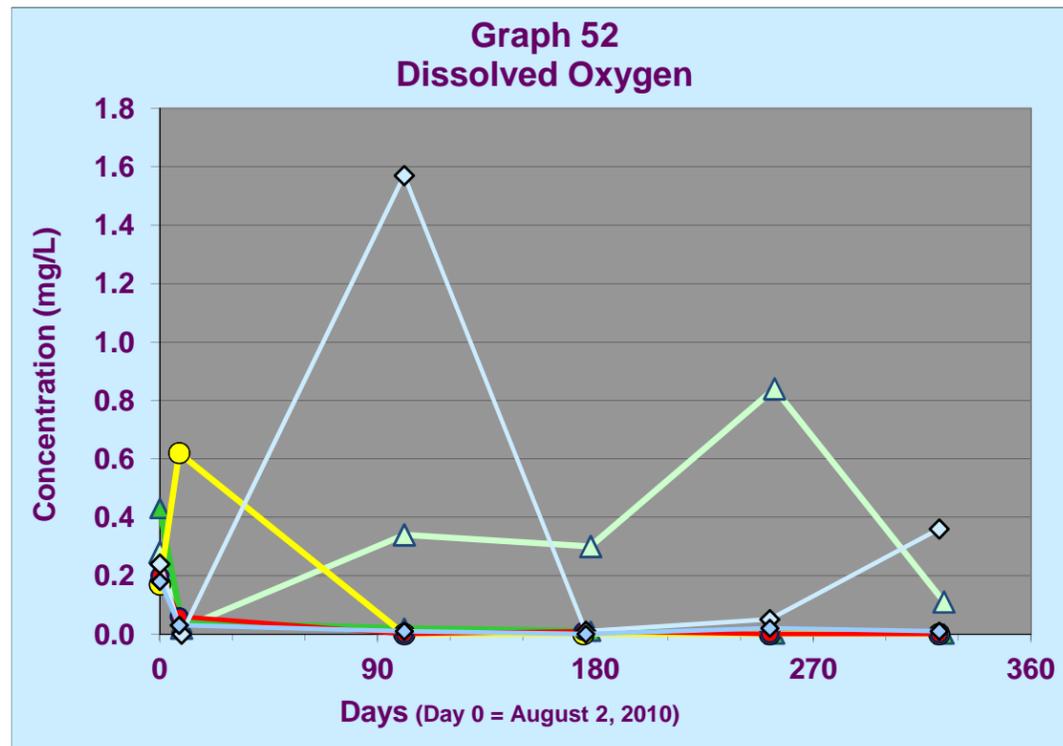
▲ Well Downgradient from Treatment Area

● Well Within Treatment Area

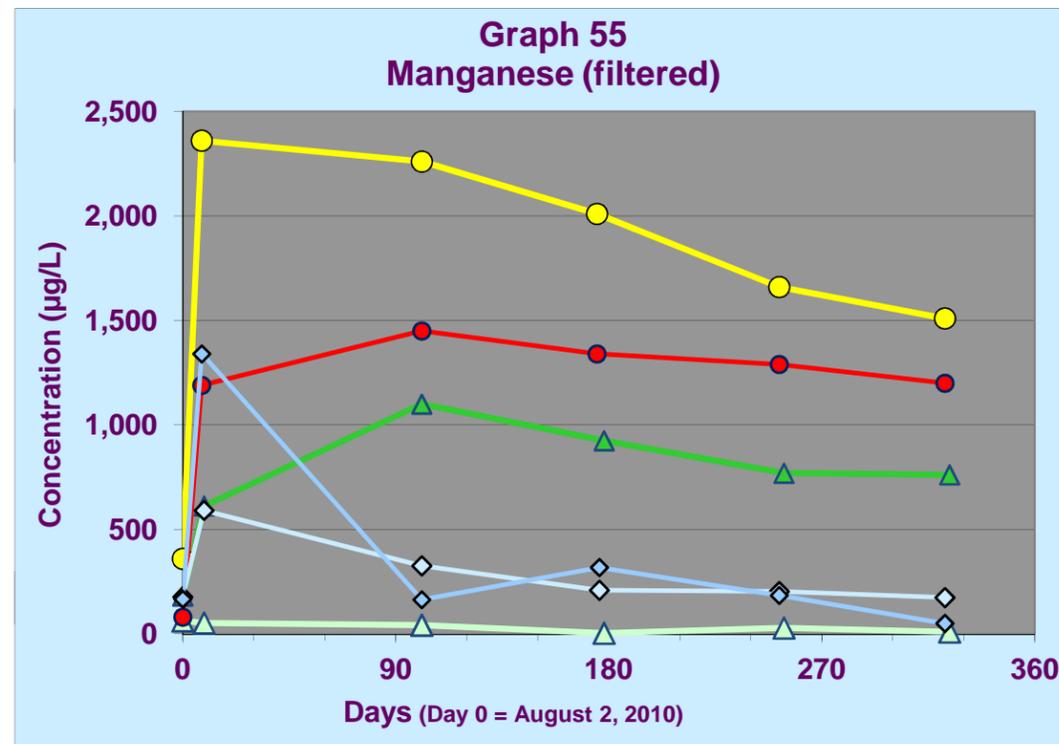
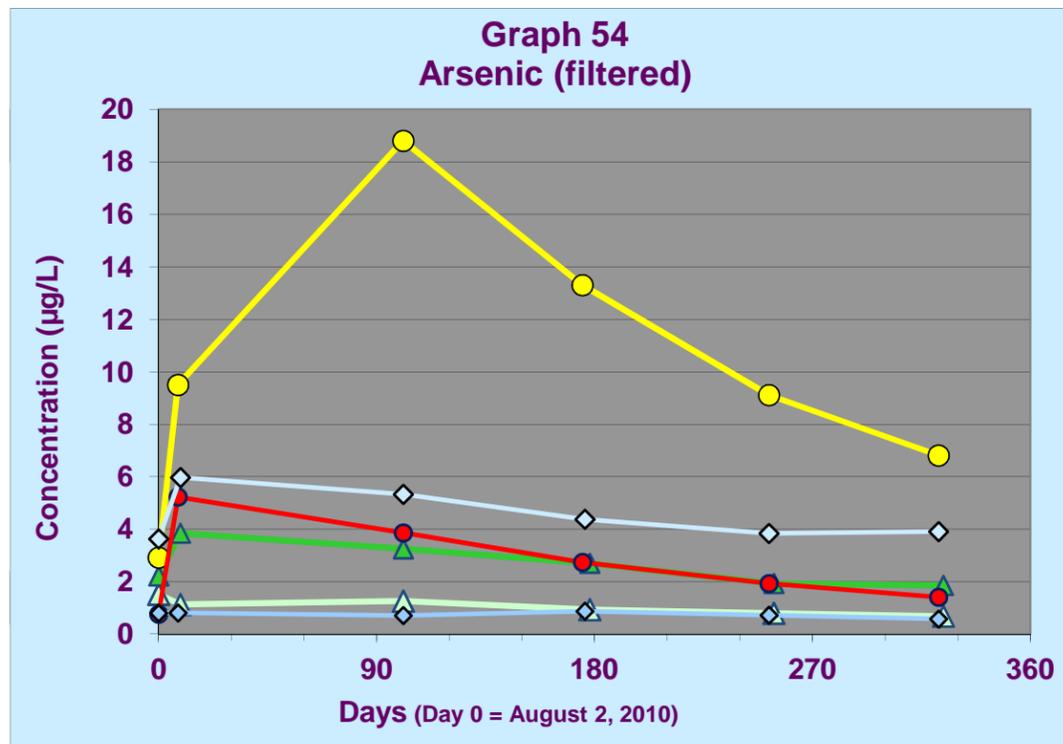
◆ Well Upgradient from Treatment Area

Graphs of Biogeochemical Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field



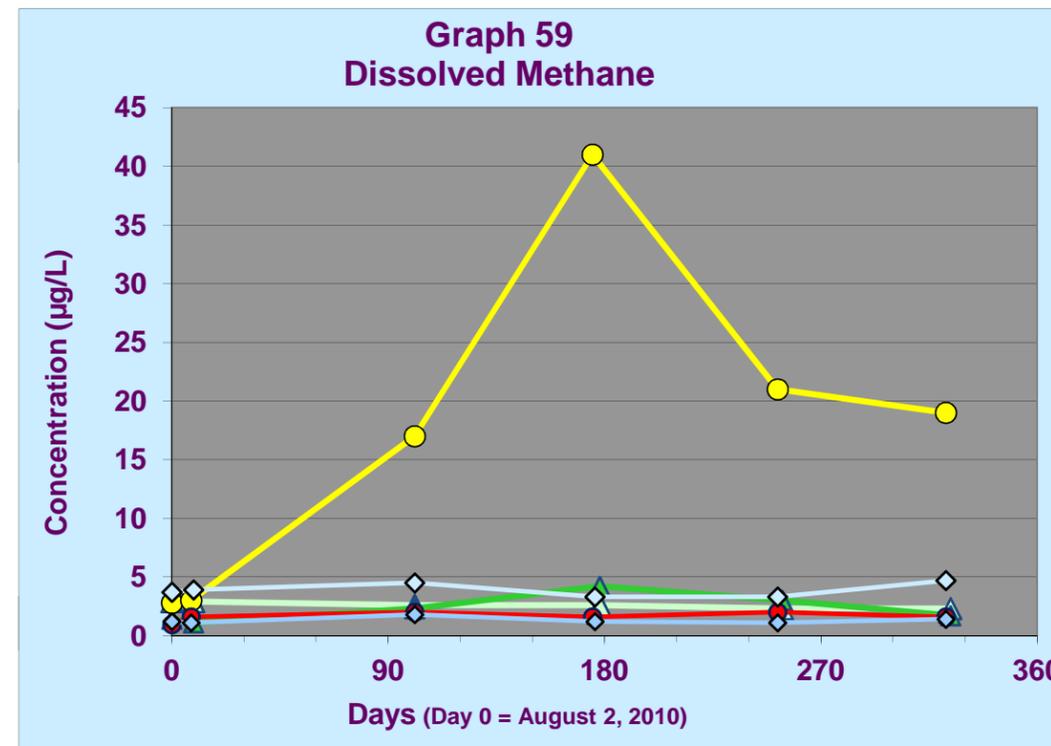
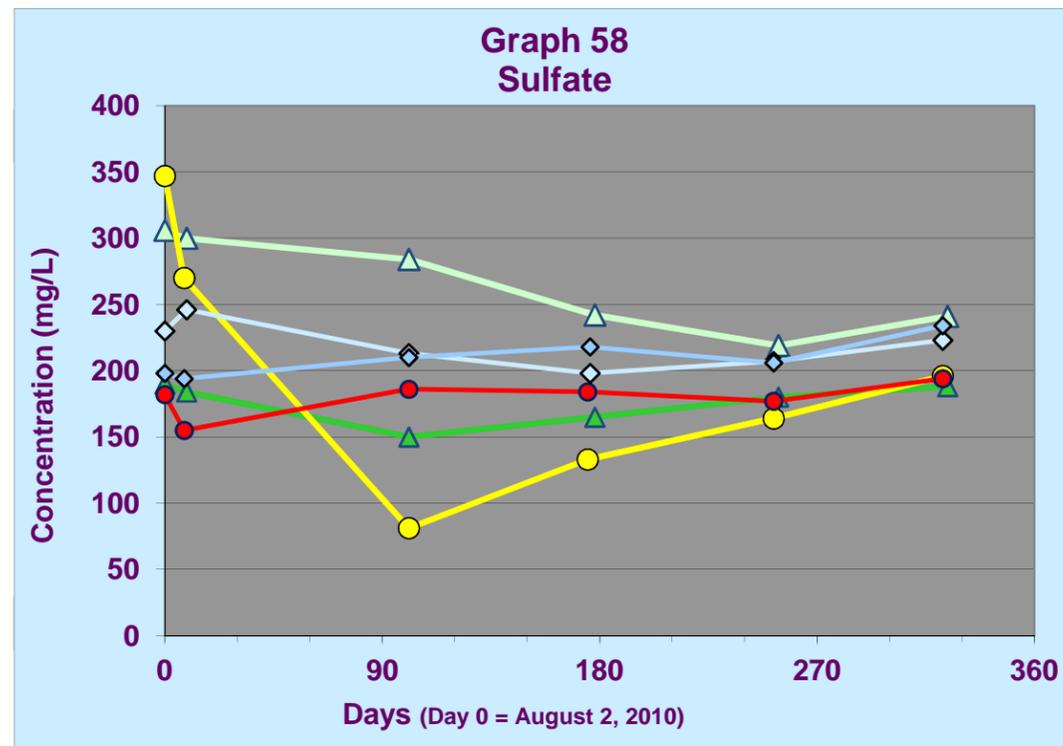
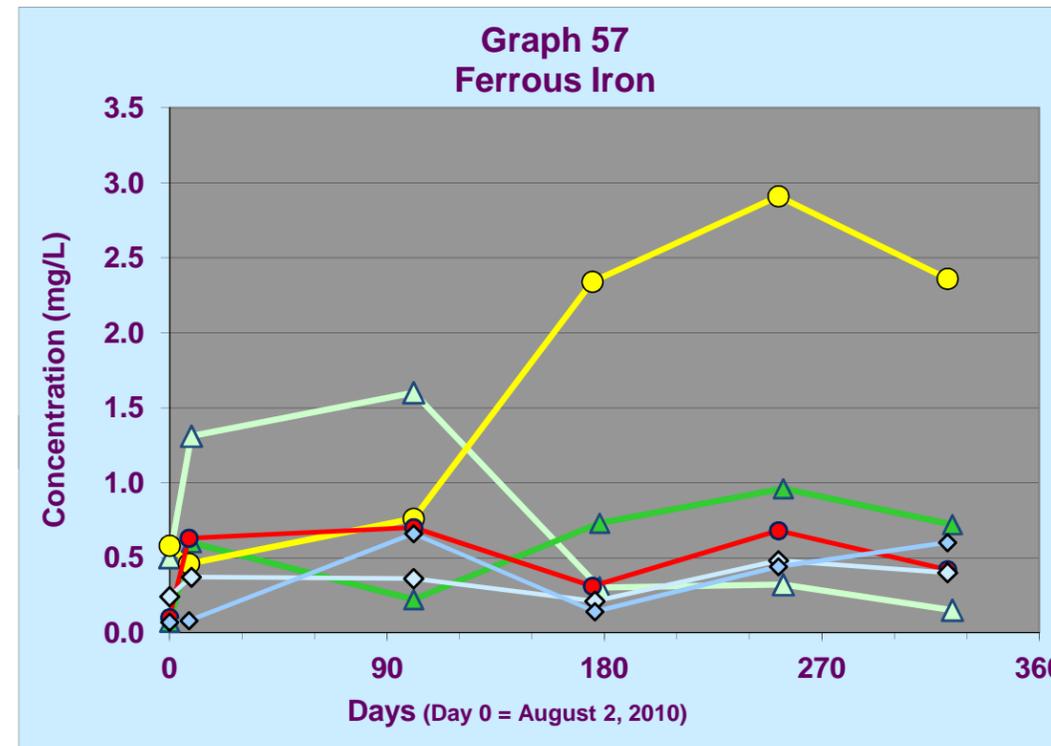
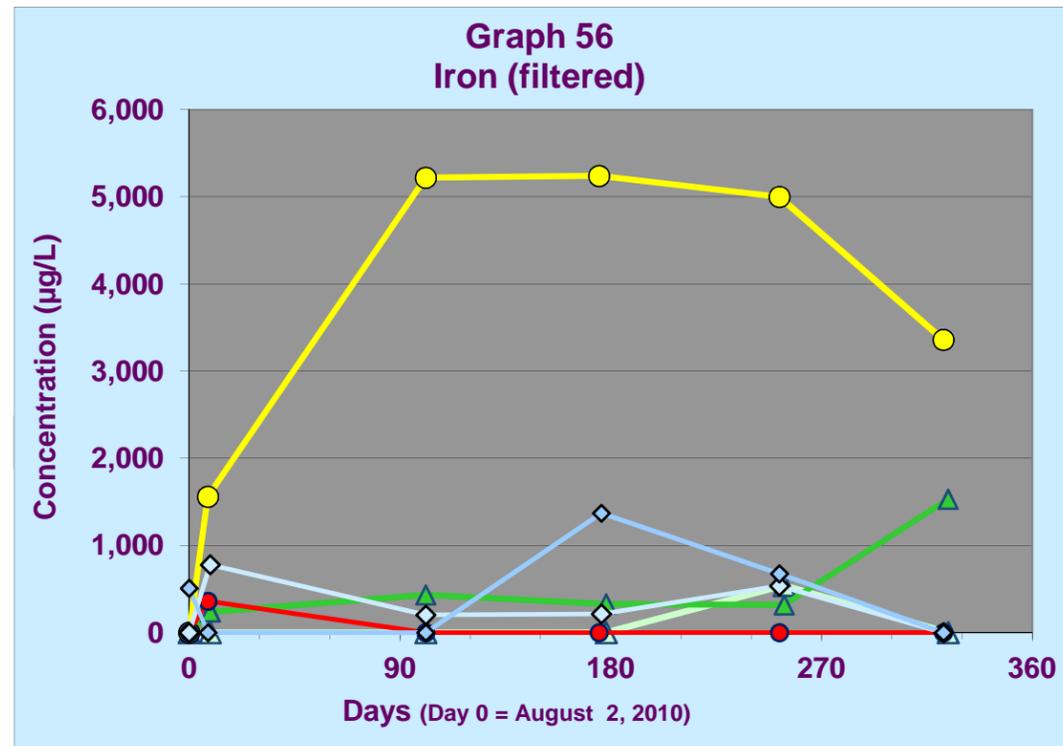
- ▲ 28OW-19
- ▲ 28OW-20
- 28OW-21
- 28OW-22
- ◆ 28OW-23
- ◆ 28OW-24



- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◆ Well Upgradient from Treatment Area

Graphs of Biogeochemical Concentrations in Groundwater - Lactate Pilot Test

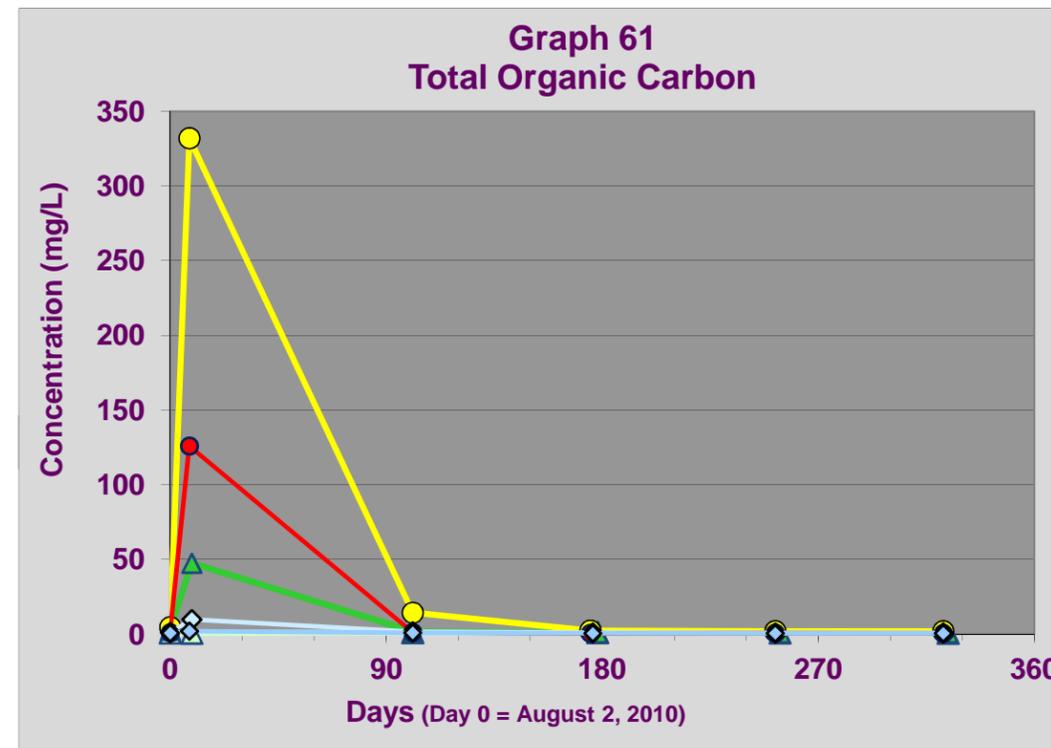
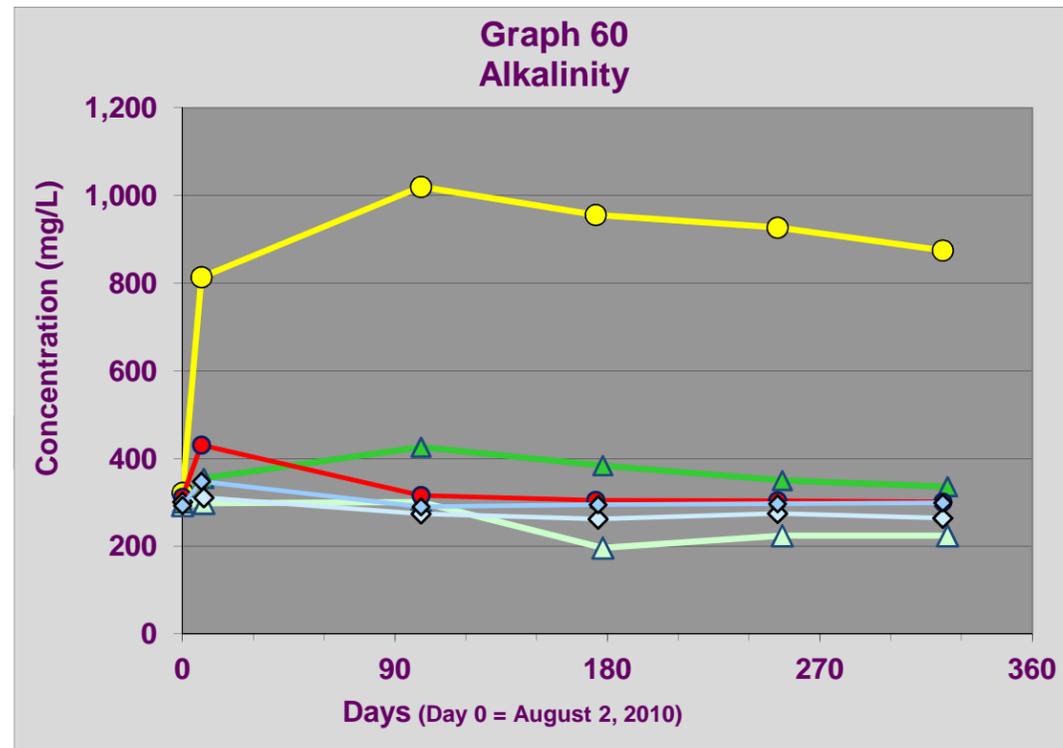
Former Building 88 Area, IR Site 28, Former NAS Moffett Field



- ▲ 28OW-19
 - ▲ 28OW-20
 - 28OW-21
 - 28OW-22
 - ◇ 28OW-23
 - ◇ 28OW-24
-
- ▲ Well Downgradient from Treatment Area
 - Well Within Treatment Area
 - ◇ Well Upgradient from Treatment Area

Graphs of Biogeochemical Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field

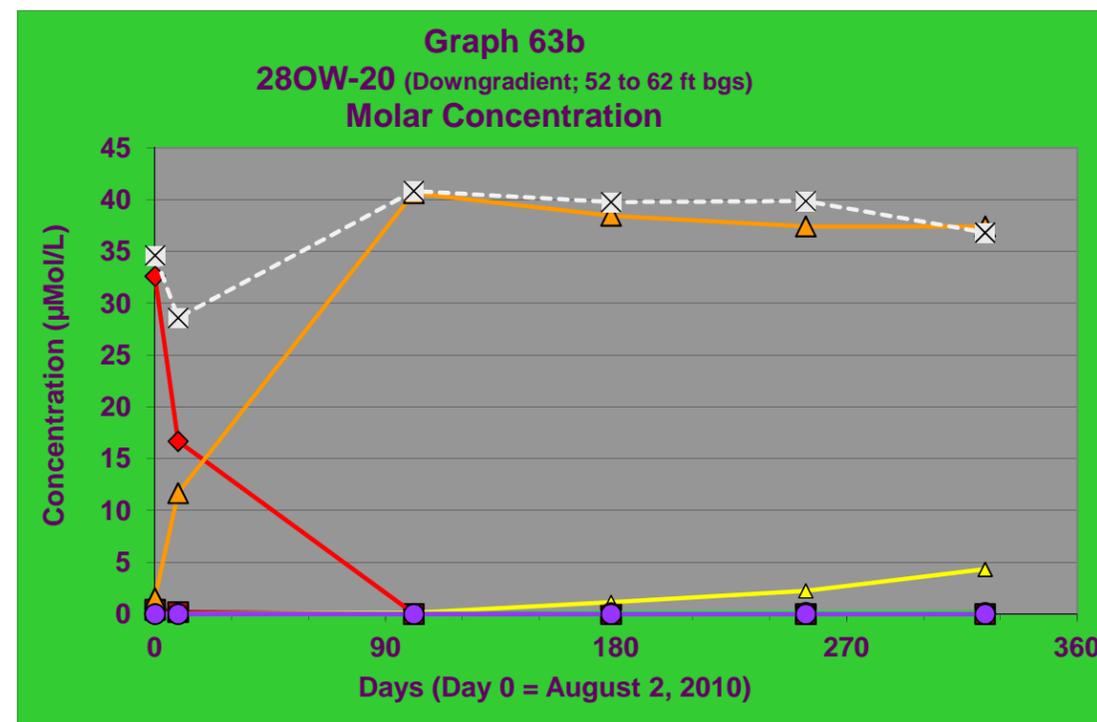
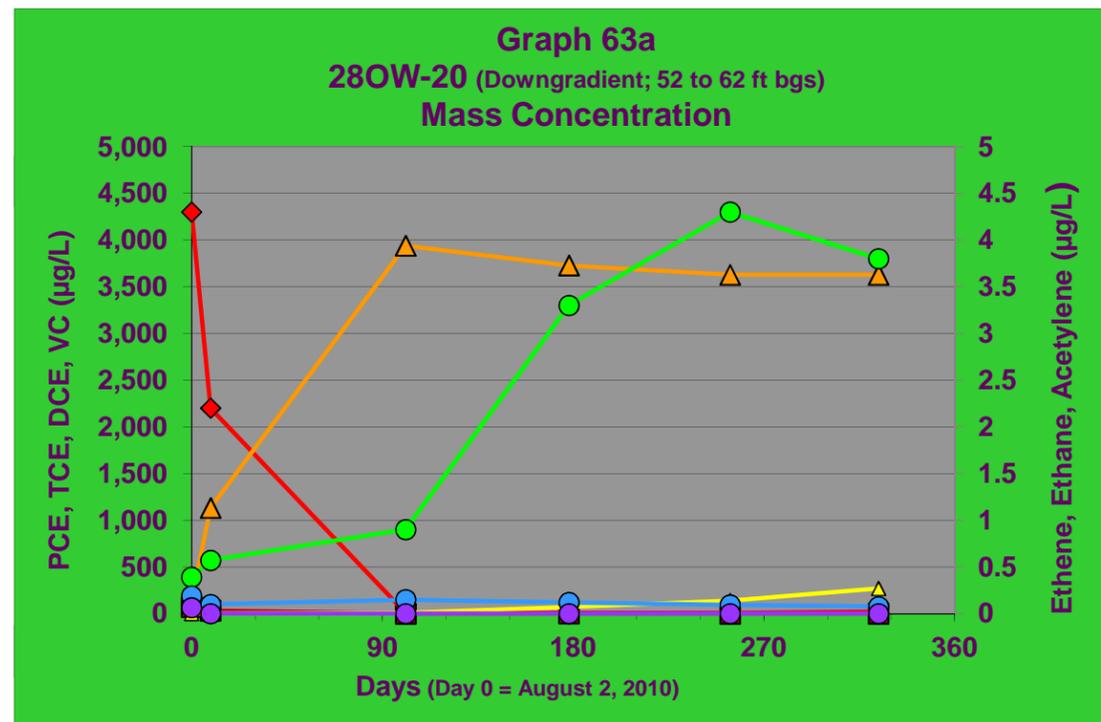
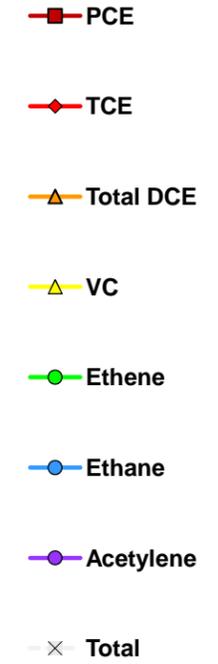
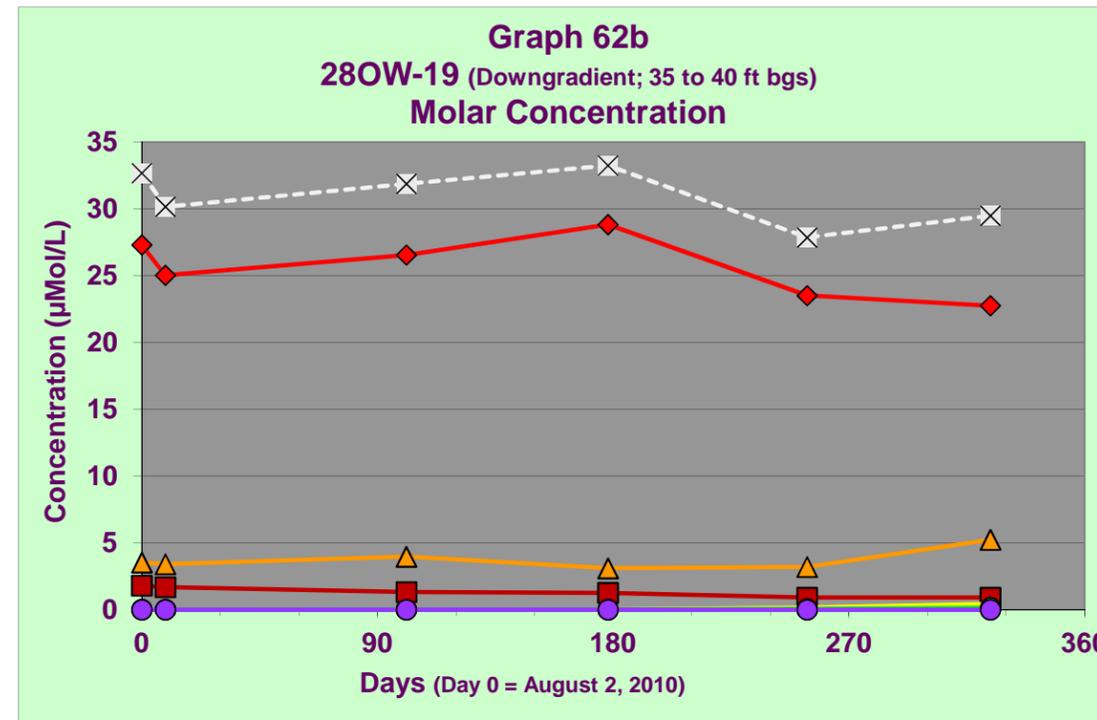
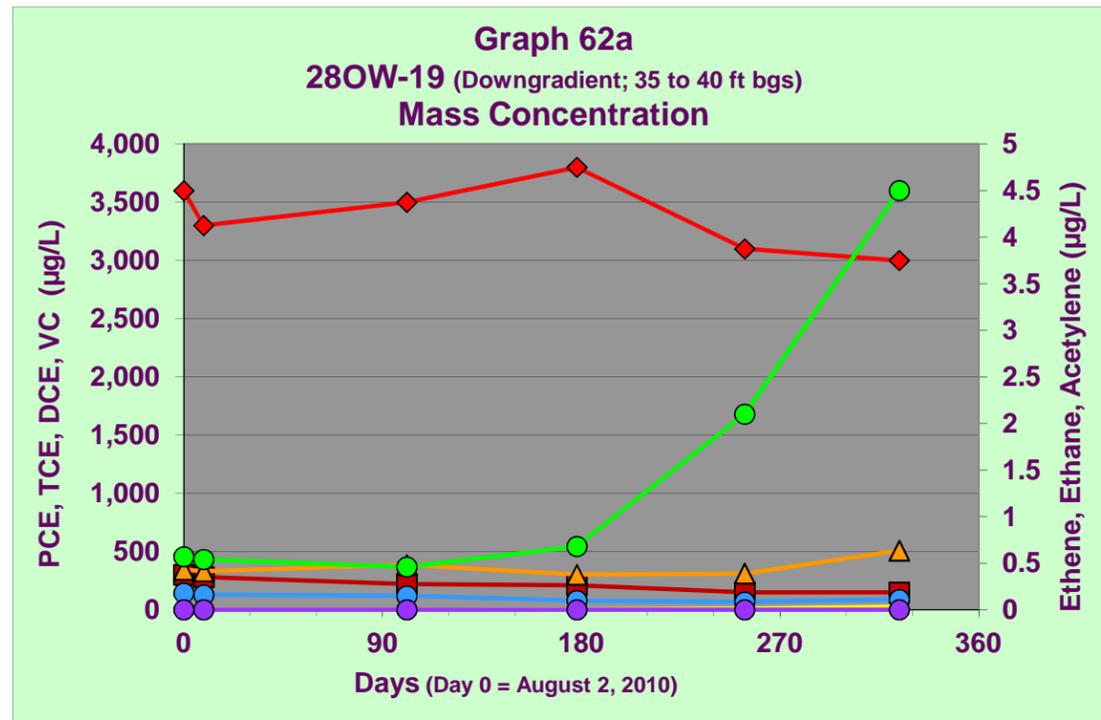


- ▲ 28OW-19
- ▲ 28OW-20
- 28OW-21
- 28OW-22
- ◇ 28OW-23
- ◇ 28OW-24

▲ Well Downgradient from Treatment Area ● Well Within Treatment Area ◆ Well Upgradient from Treatment Area

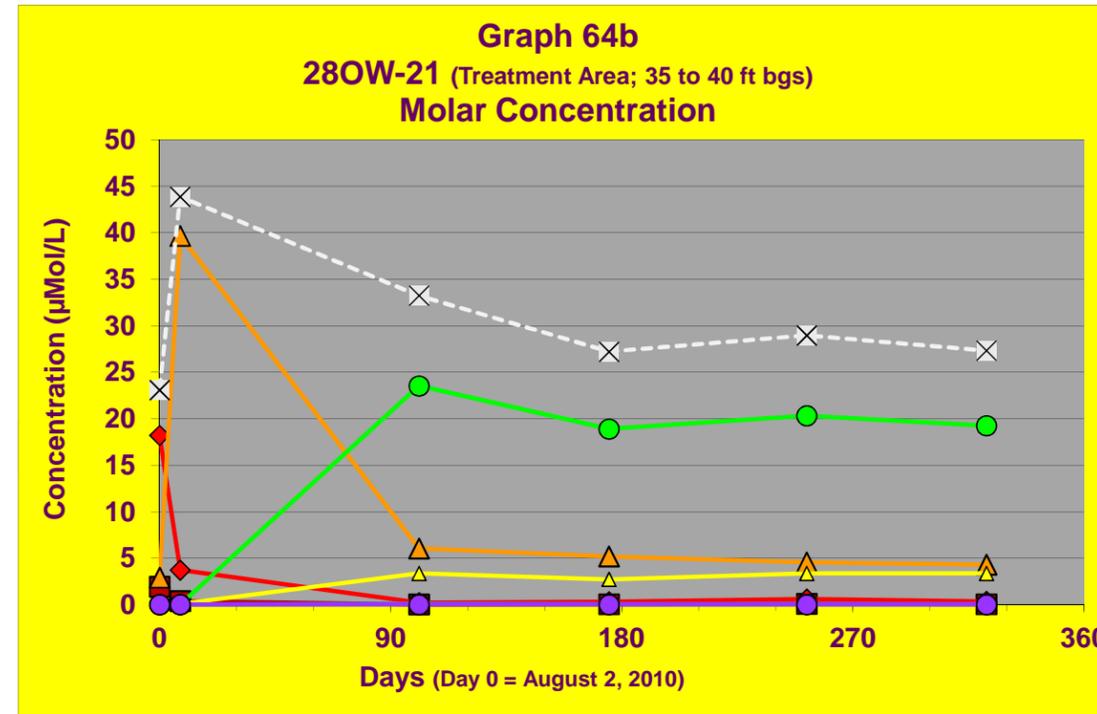
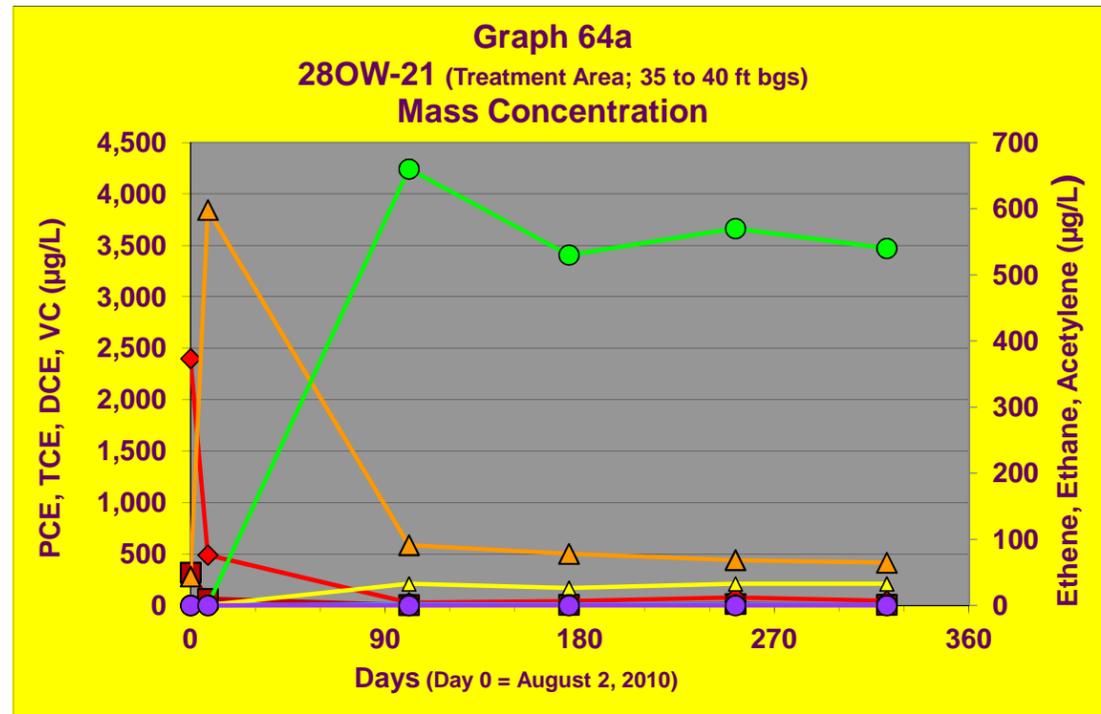
Graphs of Ethenes and Ethane Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field

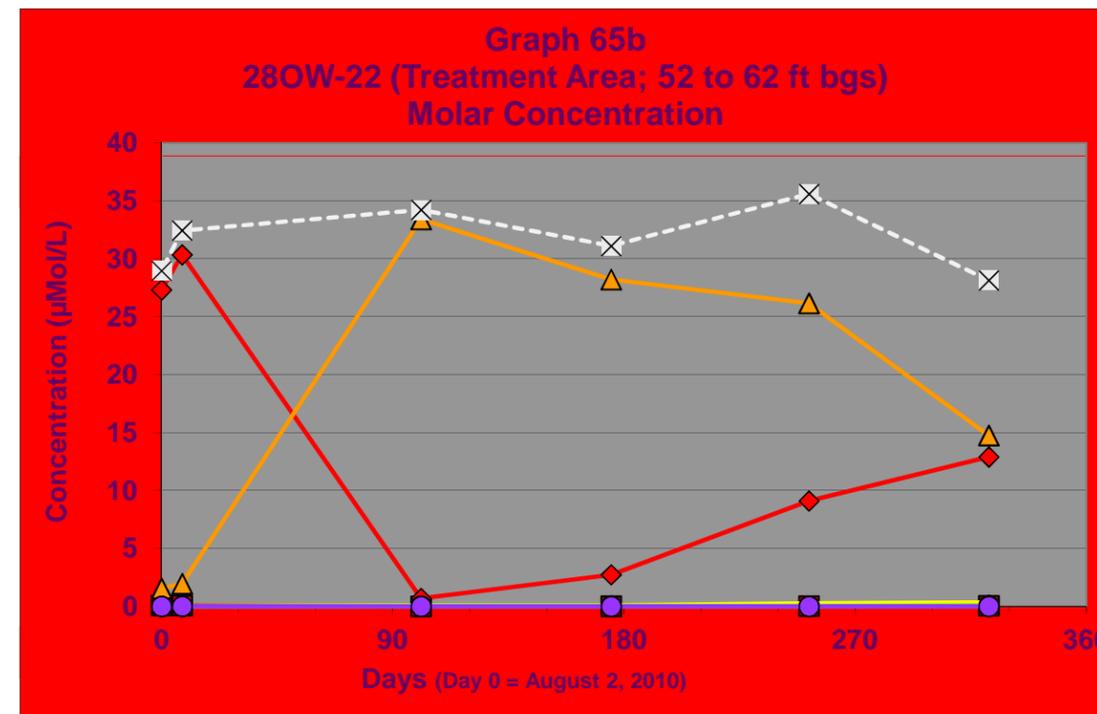
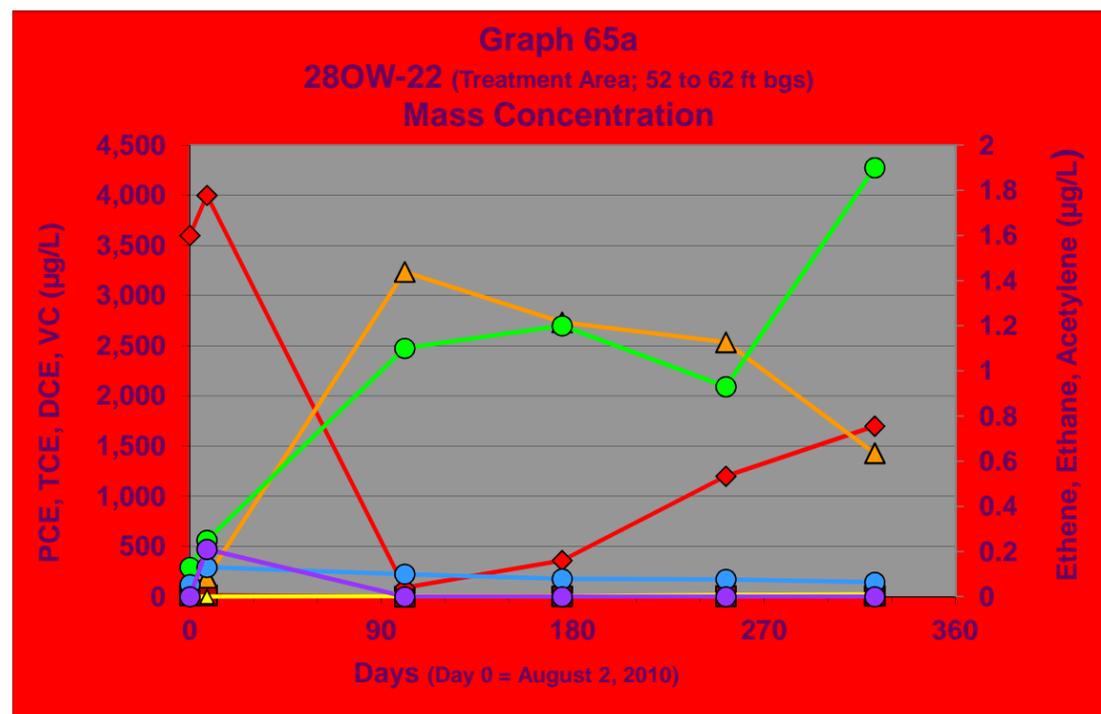


Graphs of Ethenes and Ethane Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field

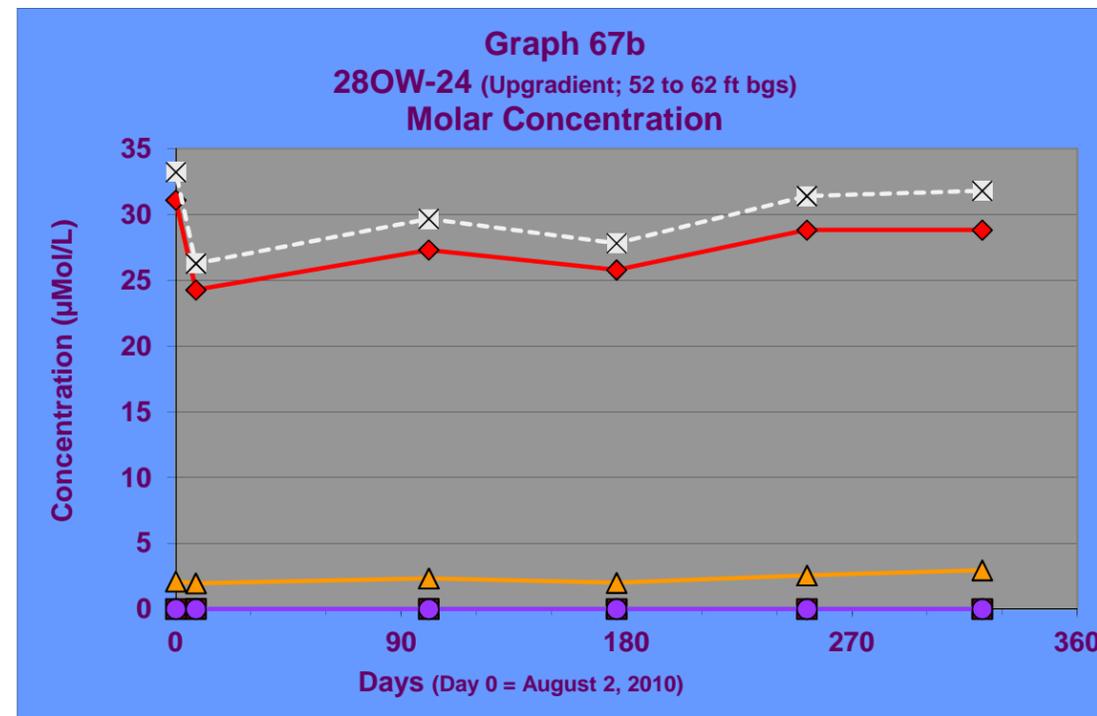
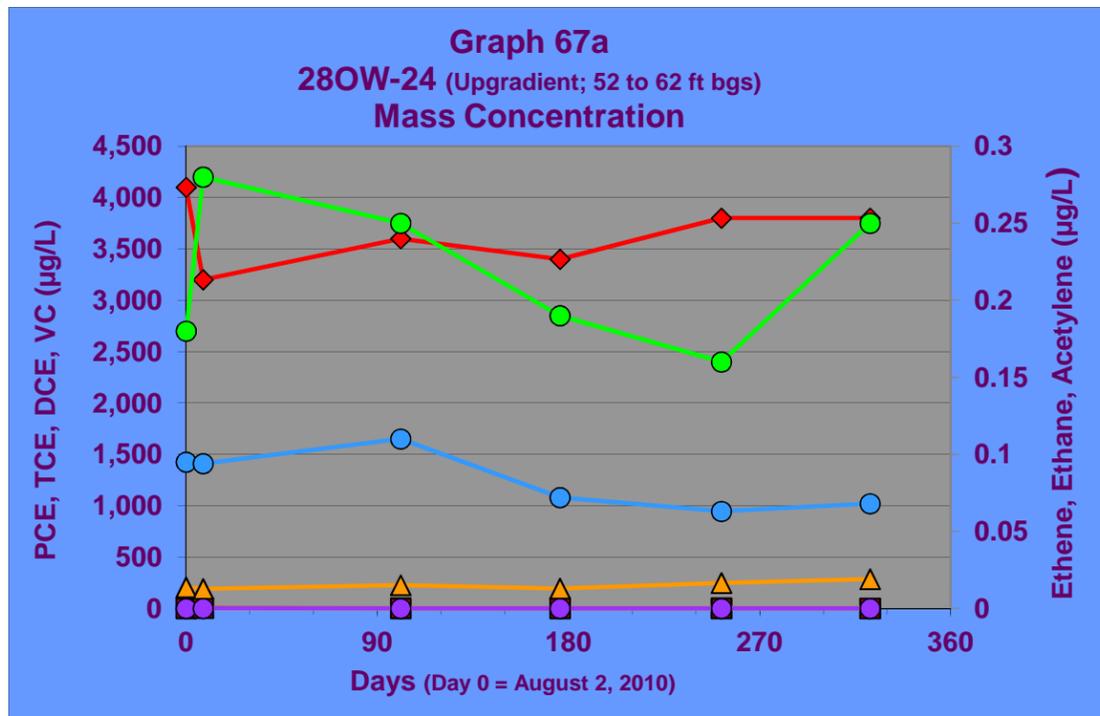
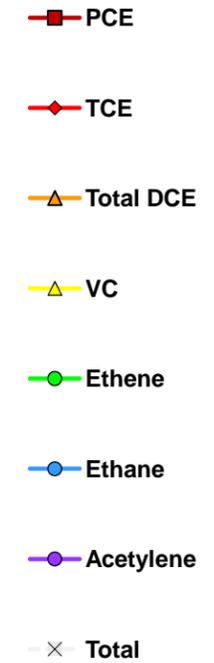
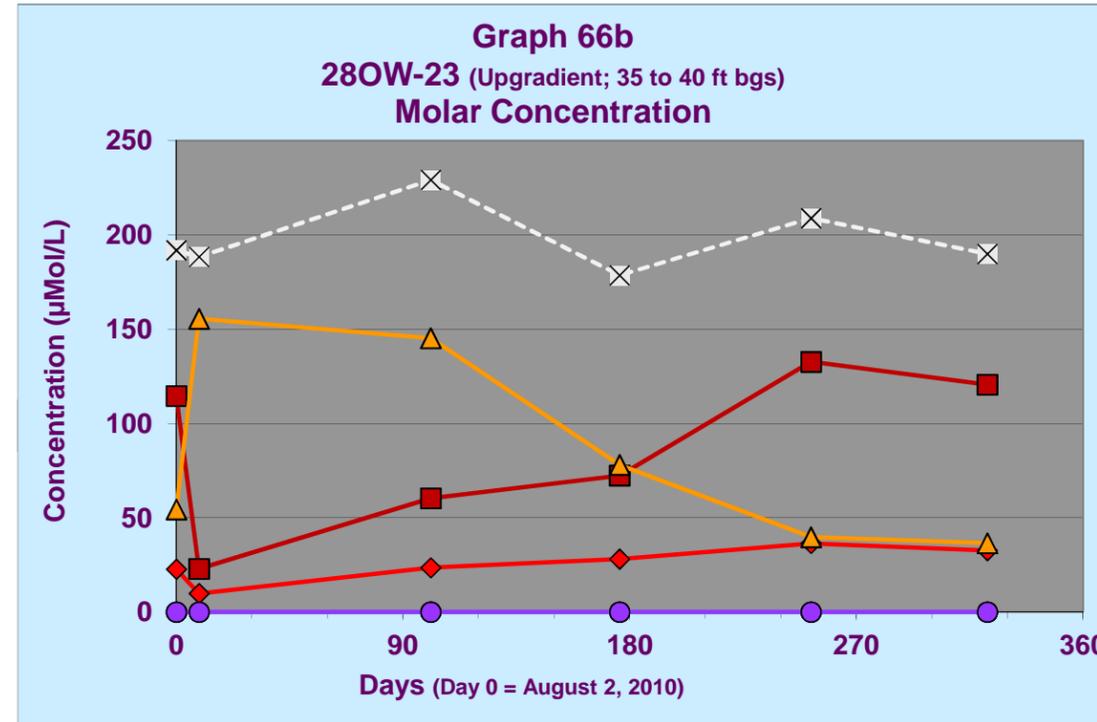
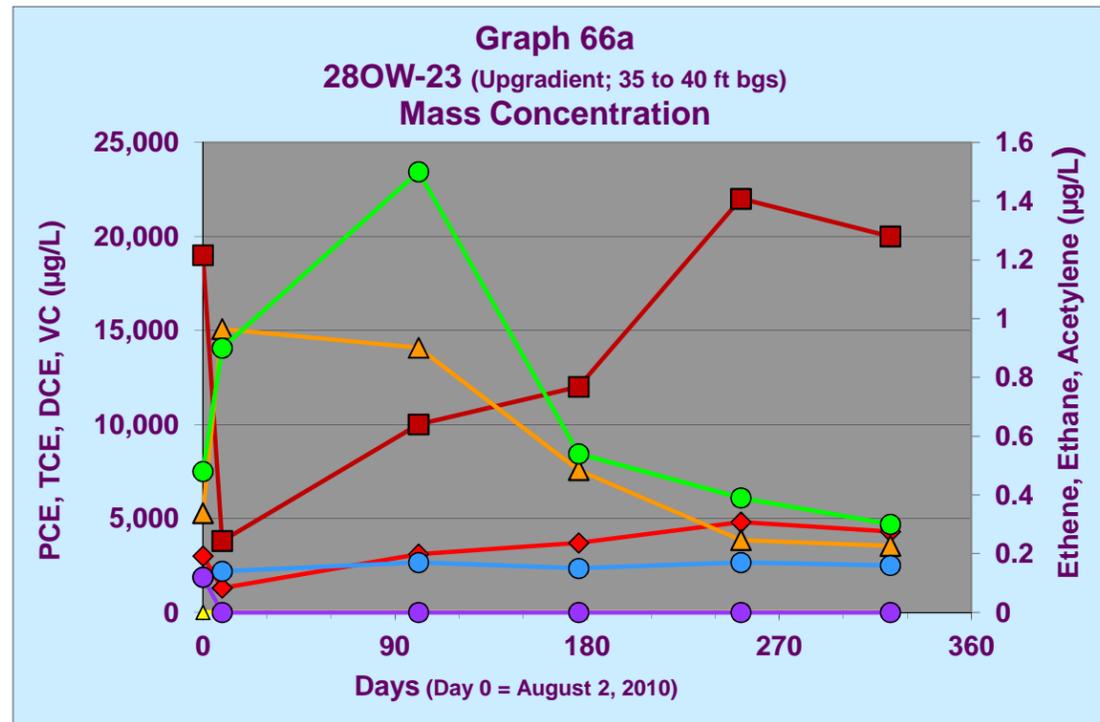


- PCE
- ◆ TCE
- ▲ Total DCE
- ▲ VC
- Ethene
- Ethane
- Acetylene
- × Total



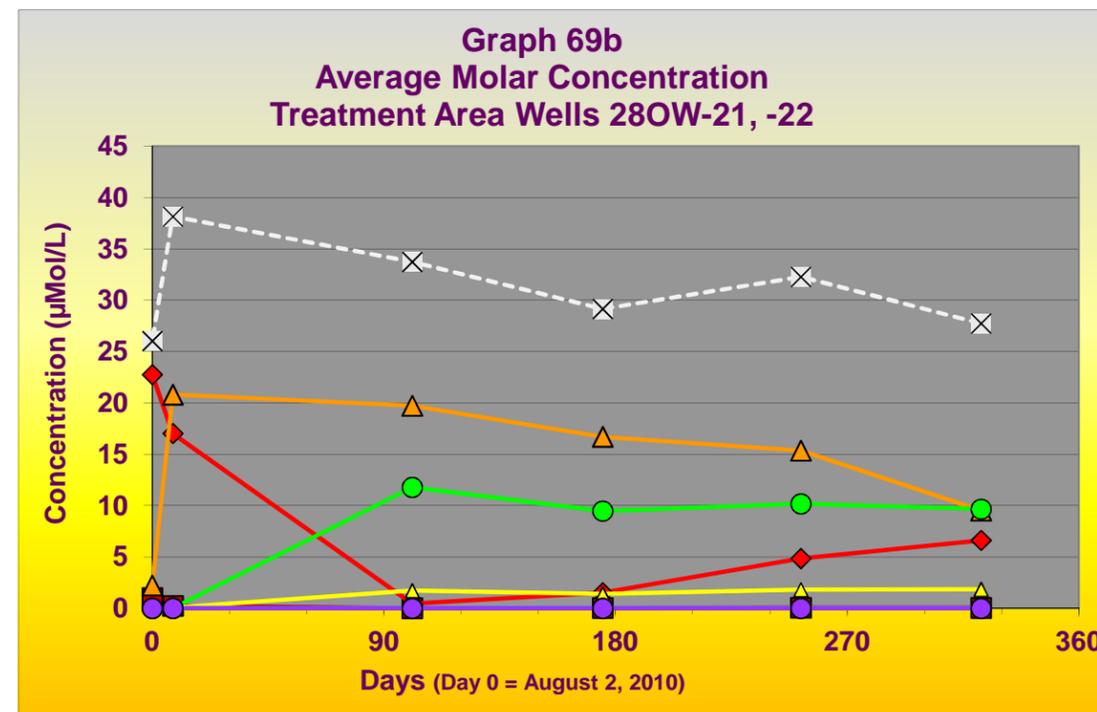
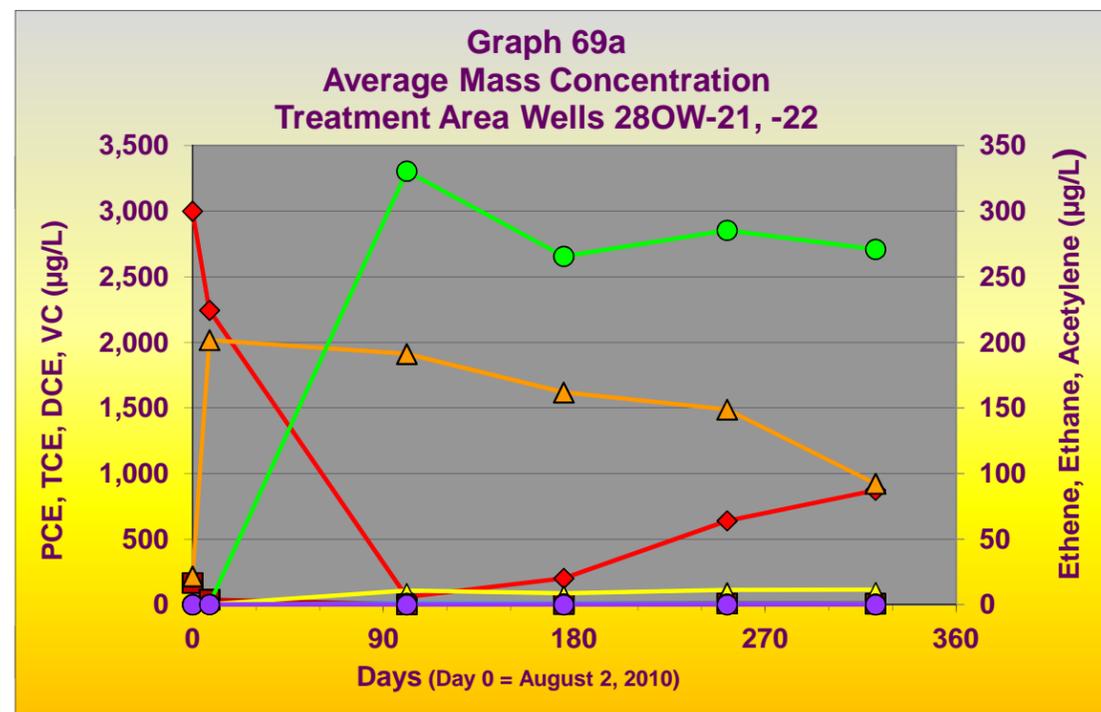
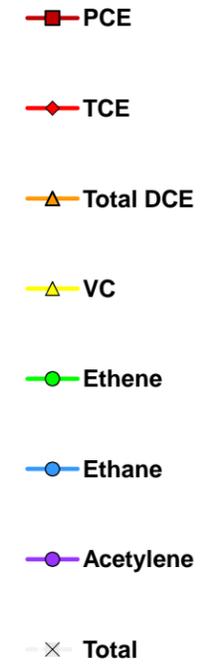
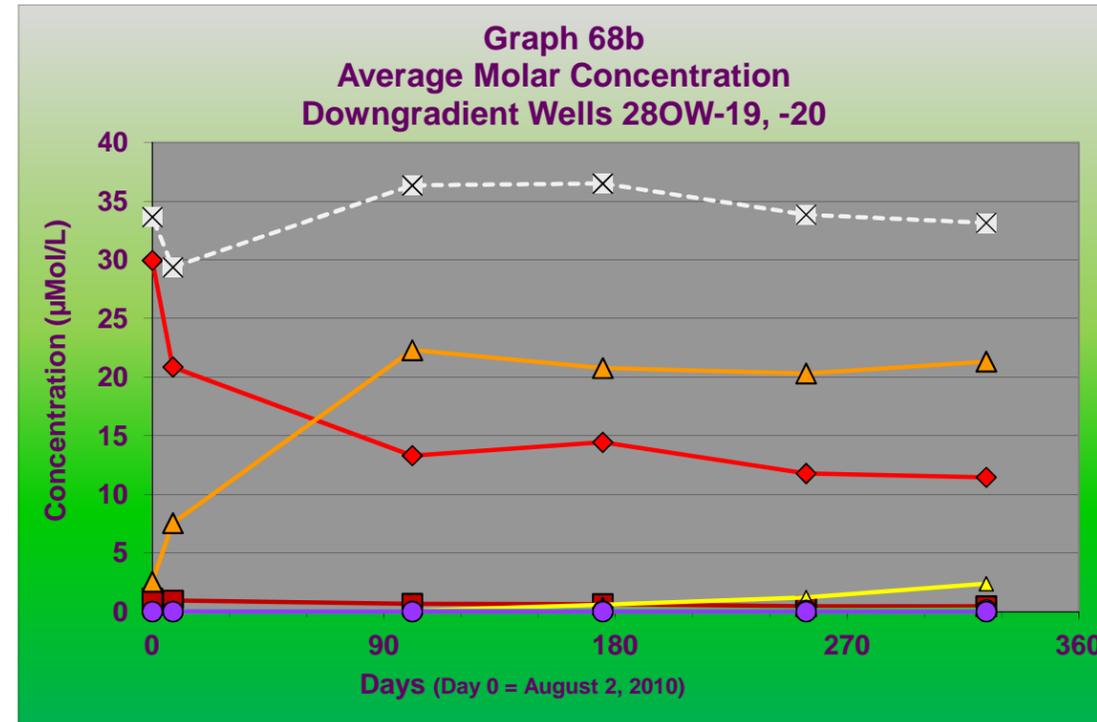
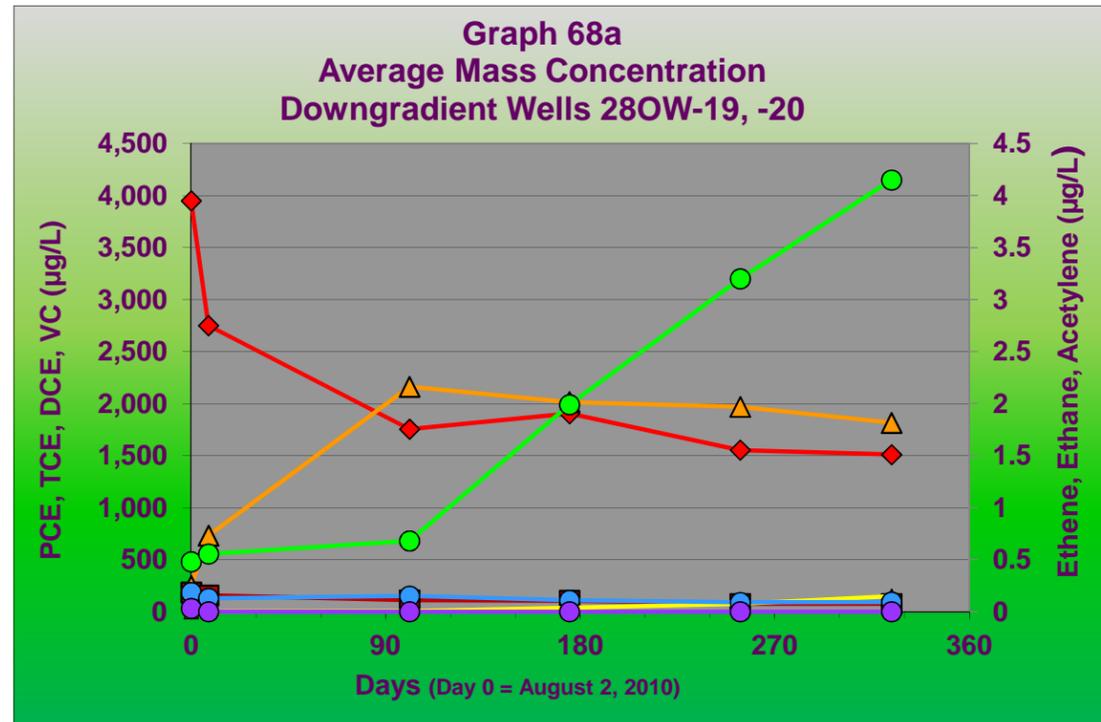
Graphs of Ethenes and Ethane Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field



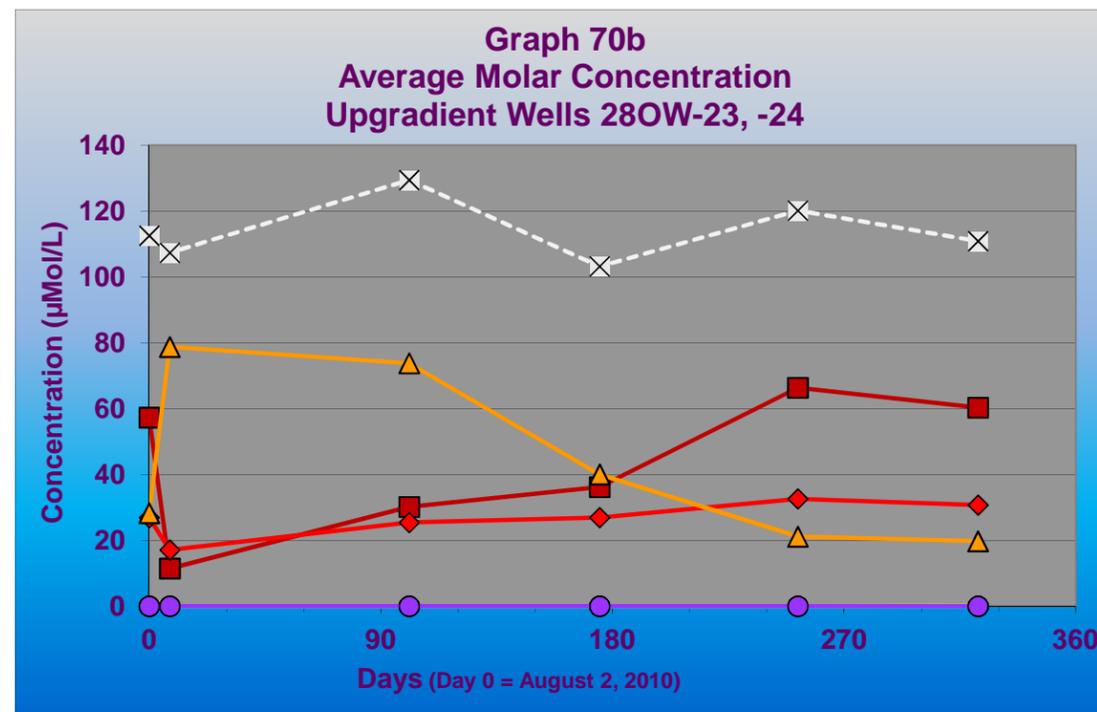
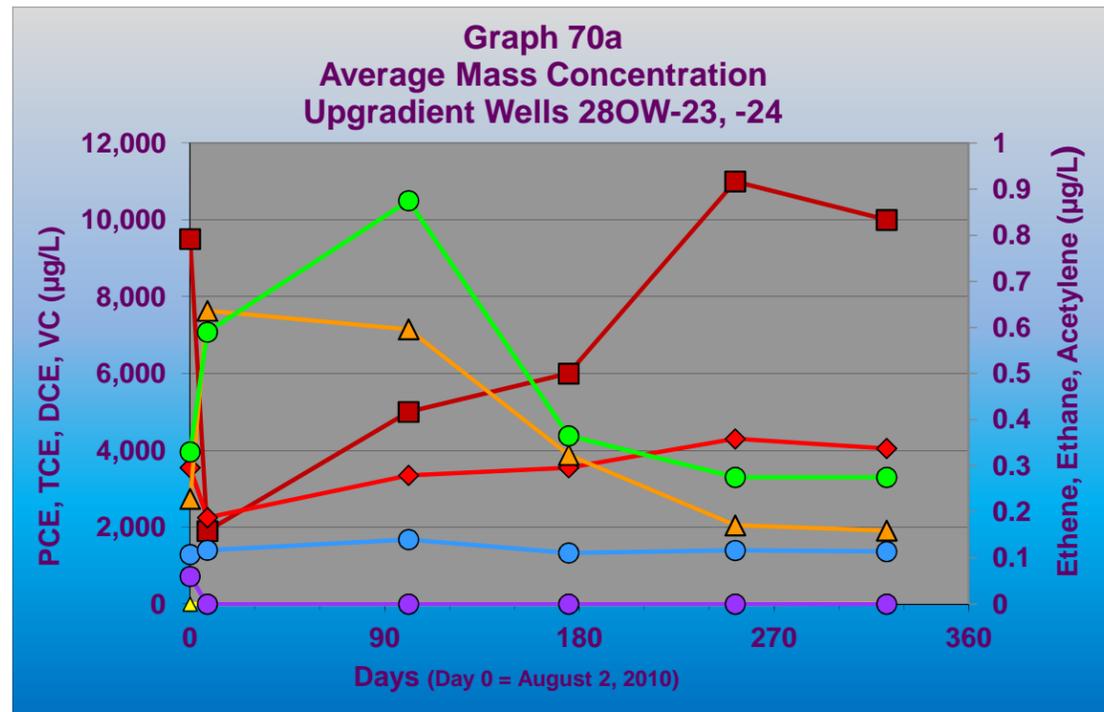
Graphs of Ethenes and Ethane Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field



Graphs of Ethenes and Ethane Concentrations in Groundwater - Lactate Pilot Test

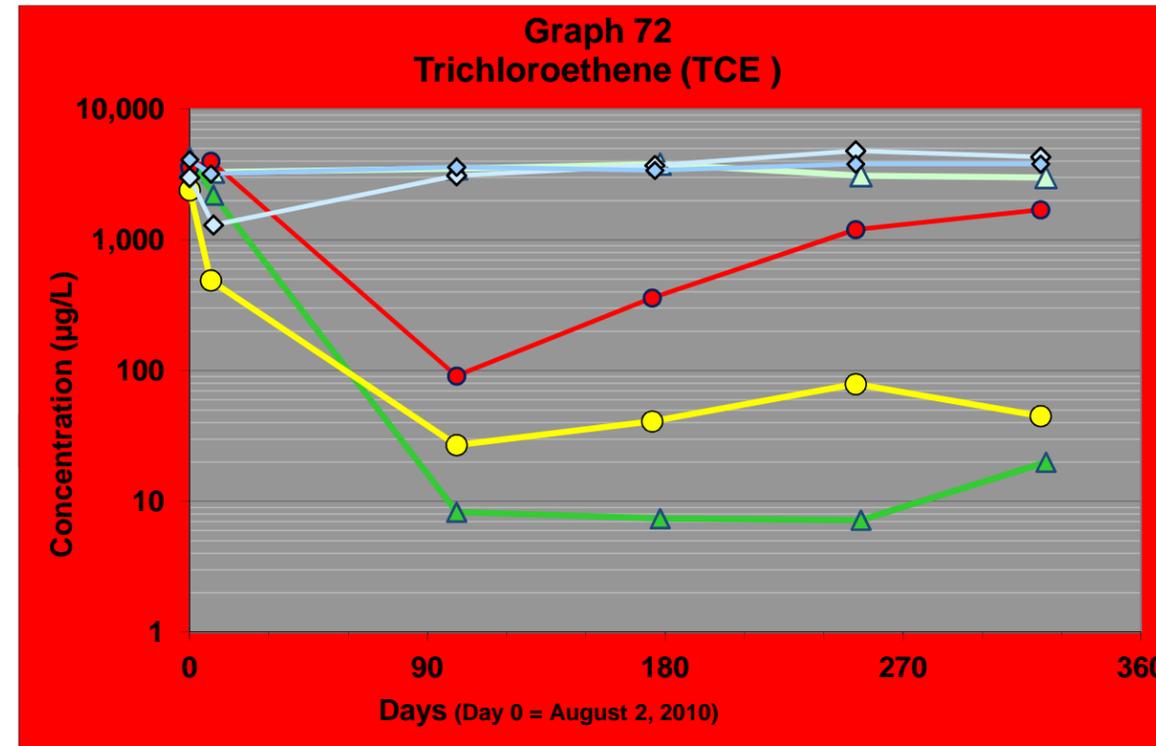
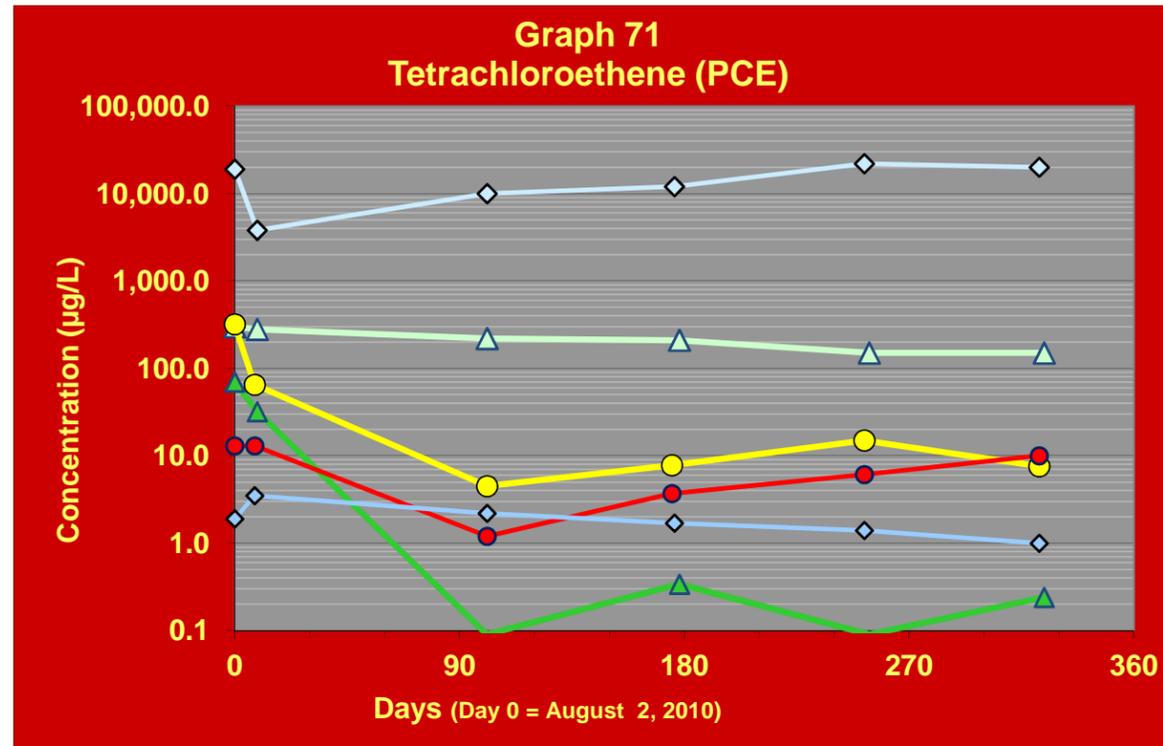
Former Building 88 Area, IR Site 28, Former NAS Moffett Field



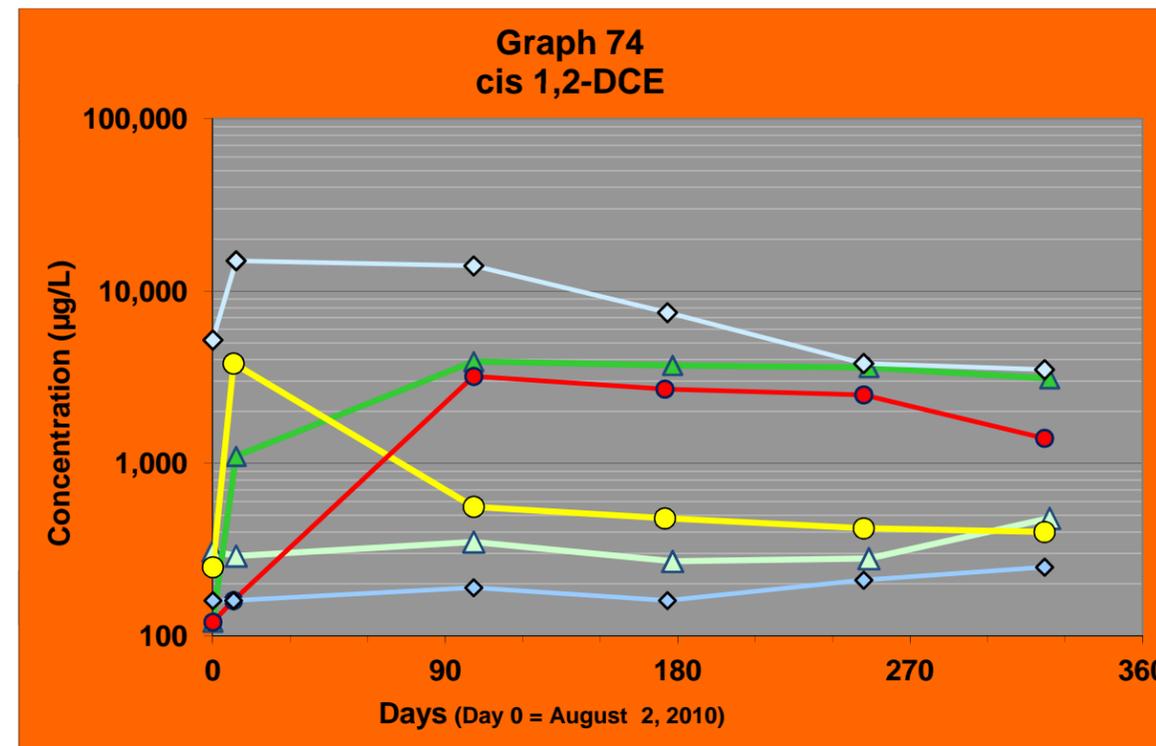
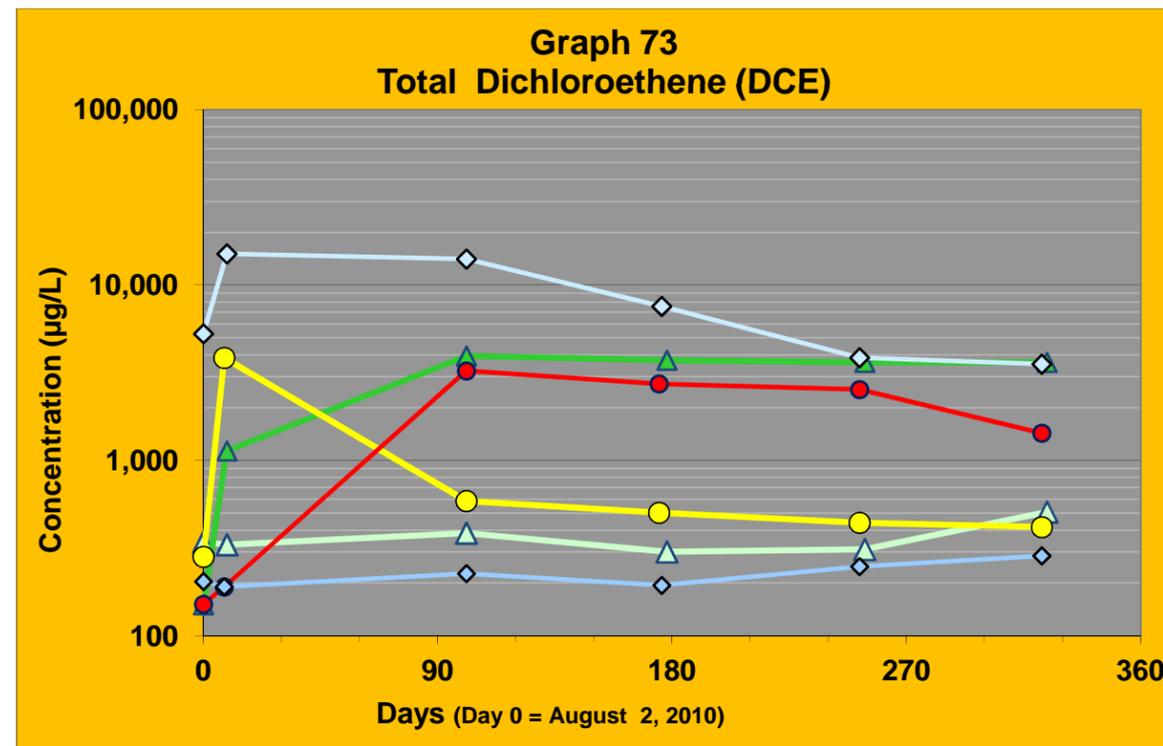
- PCE
- ◆ TCE
- ▲ Total DCE
- ▲ VC
- Ethene
- Ethane
- Acetylene
- × Total

Graphs of VOC Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field



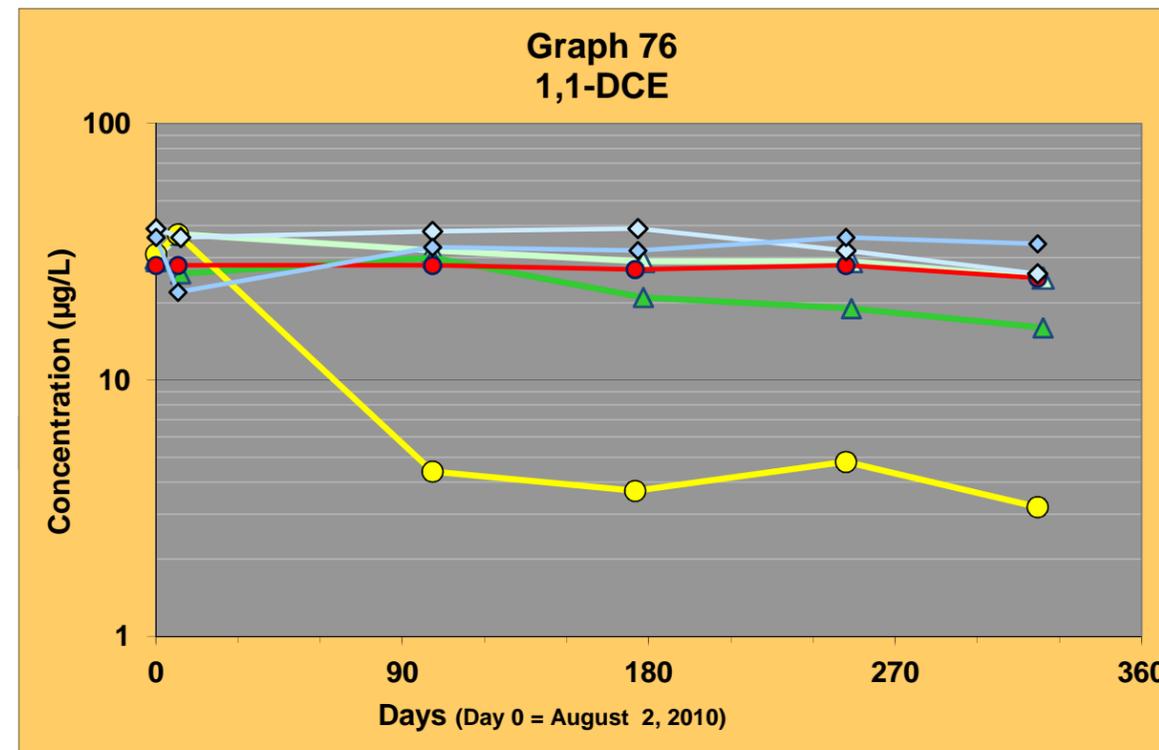
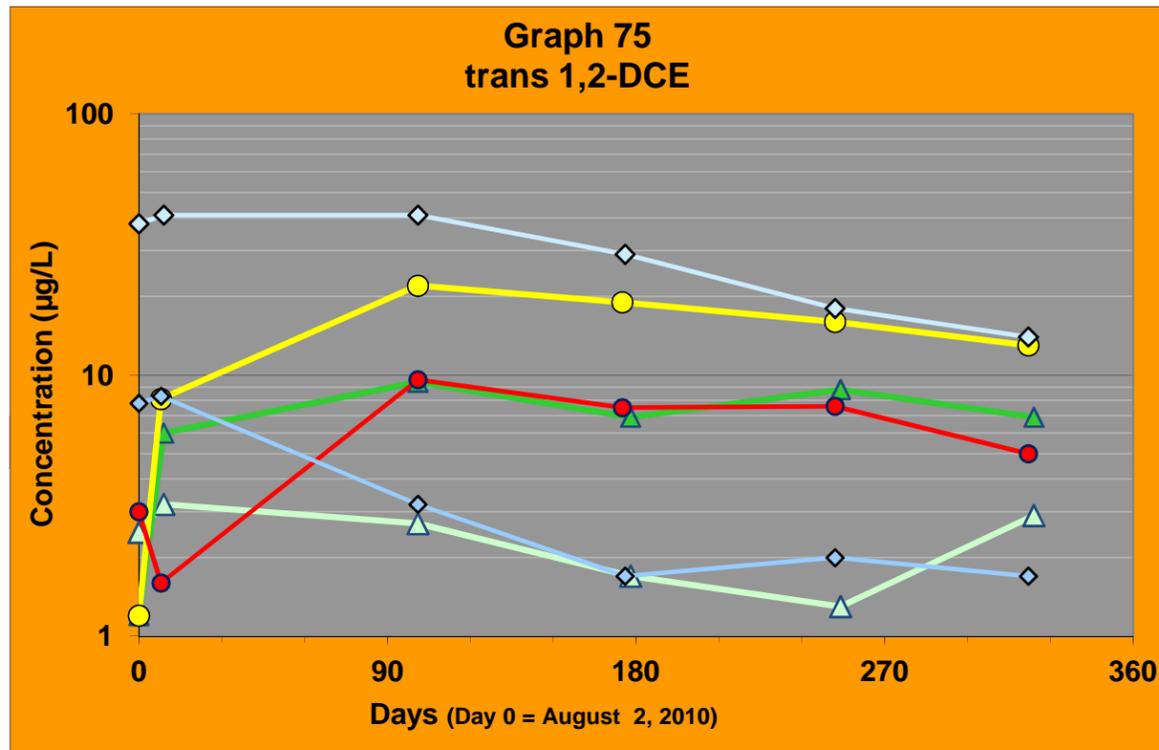
- △ 28OW-19
- ▲ 28OW-20
- 28OW-21
- 28OW-22
- ◇ 28OW-23
- ◇ 28OW-24



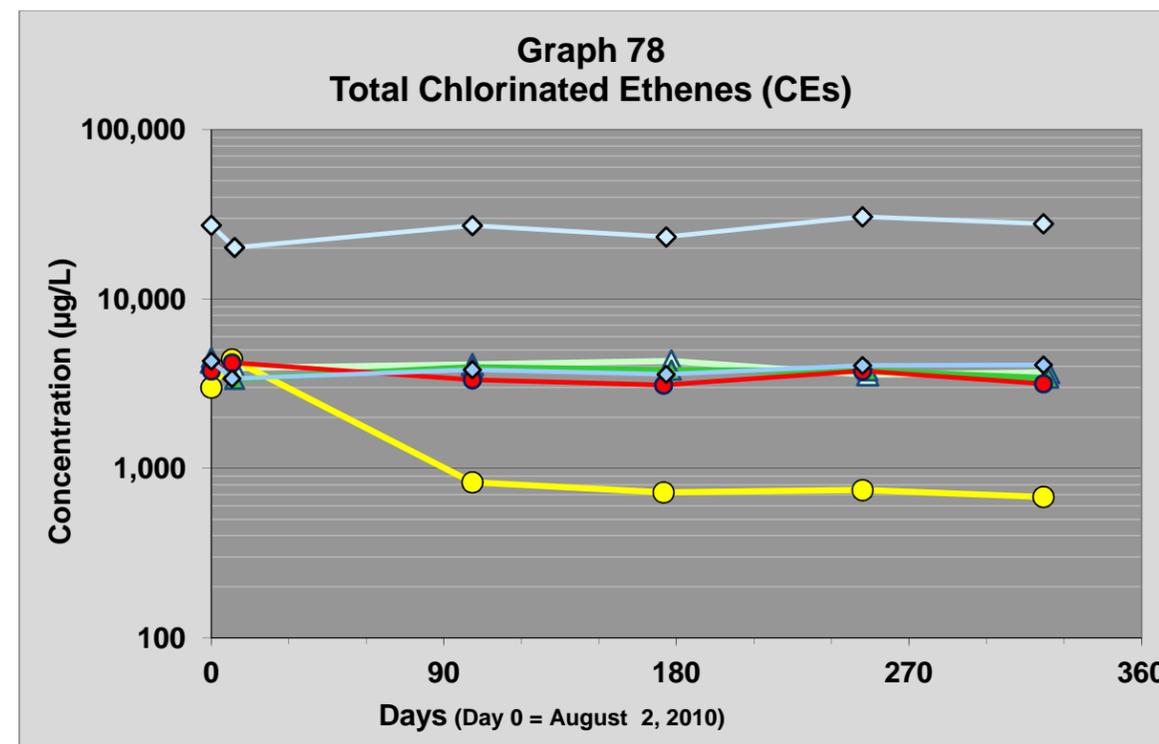
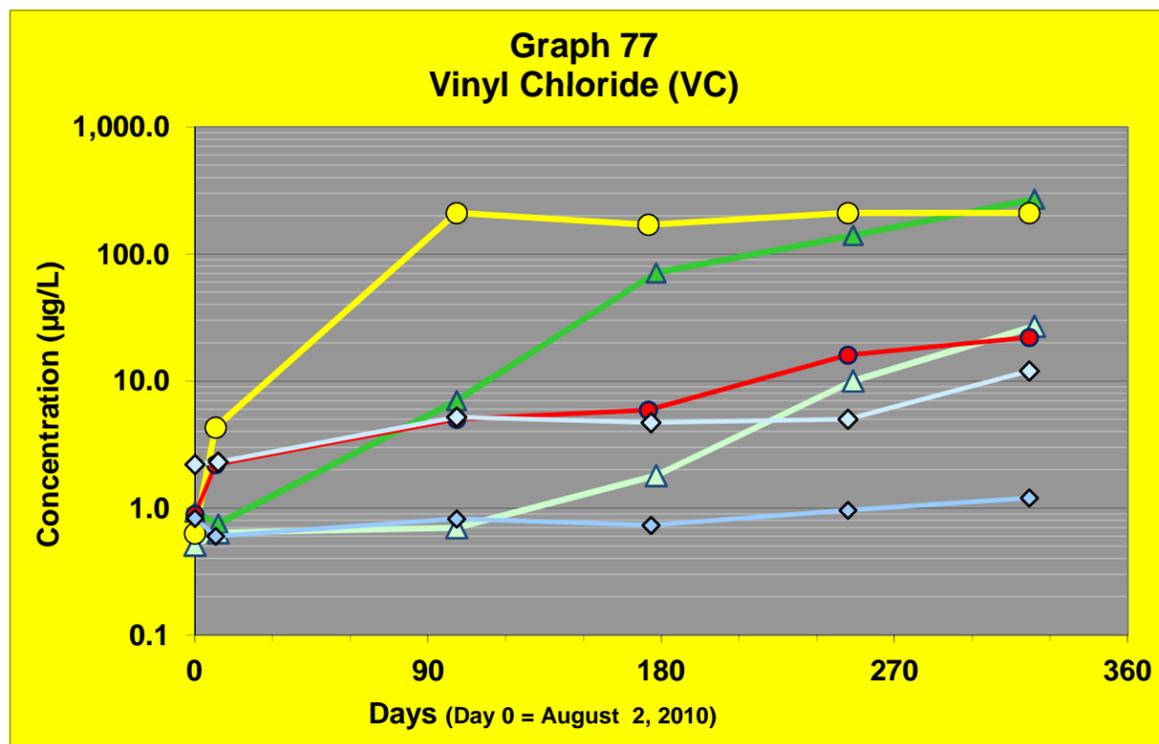
- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◆ Well Upgradient from Treatment Area

Graphs of VOC Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field



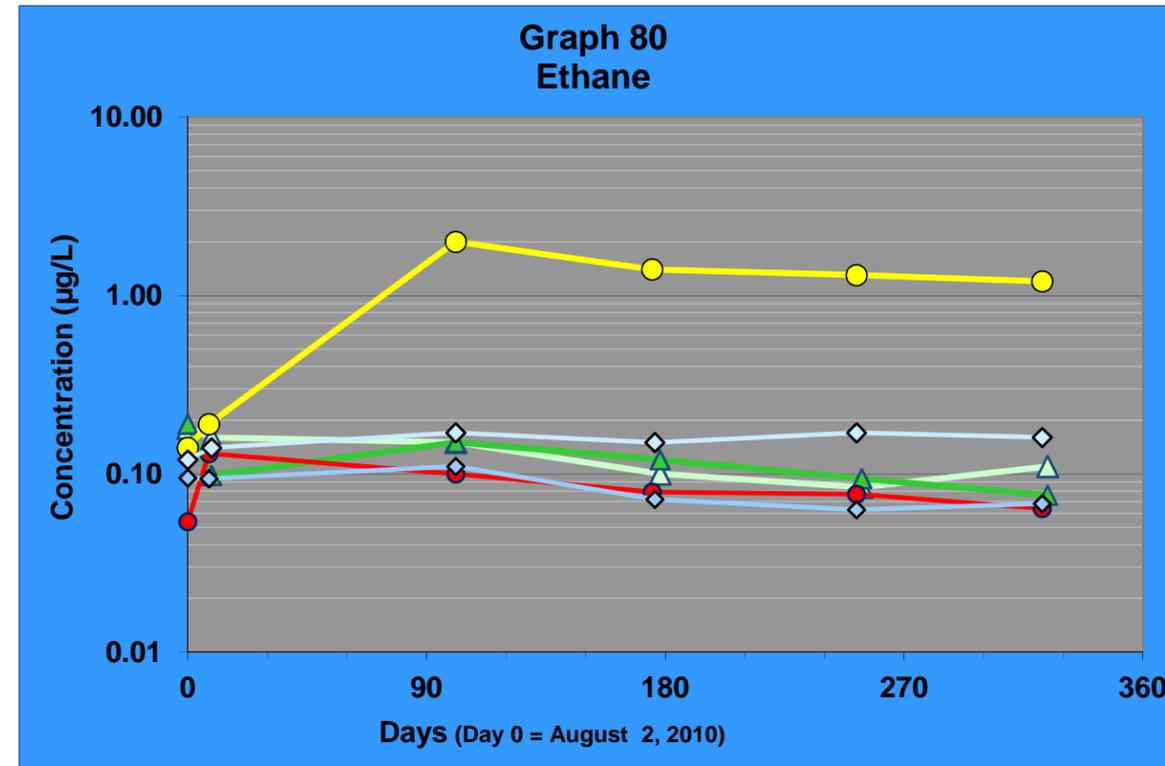
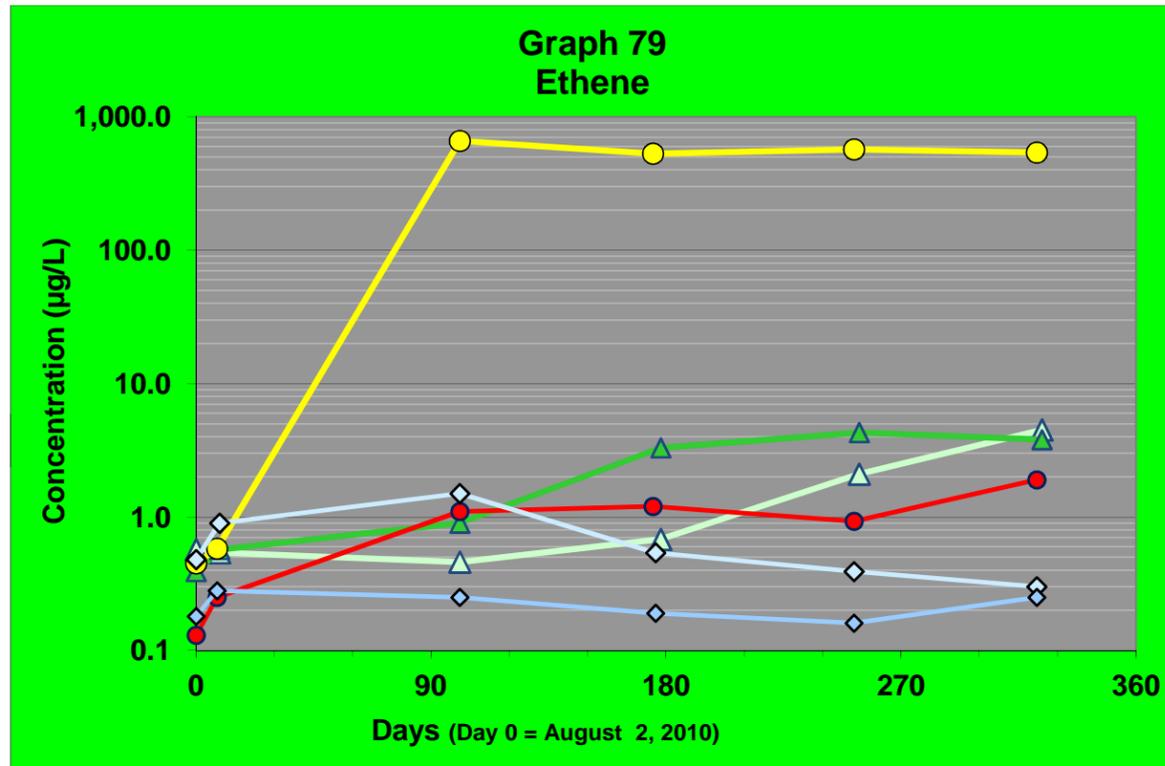
- ▲ 28OW-19
- ▲ 28OW-20
- 28OW-21
- 28OW-22
- ◆ 28OW-23
- ◆ 28OW-24



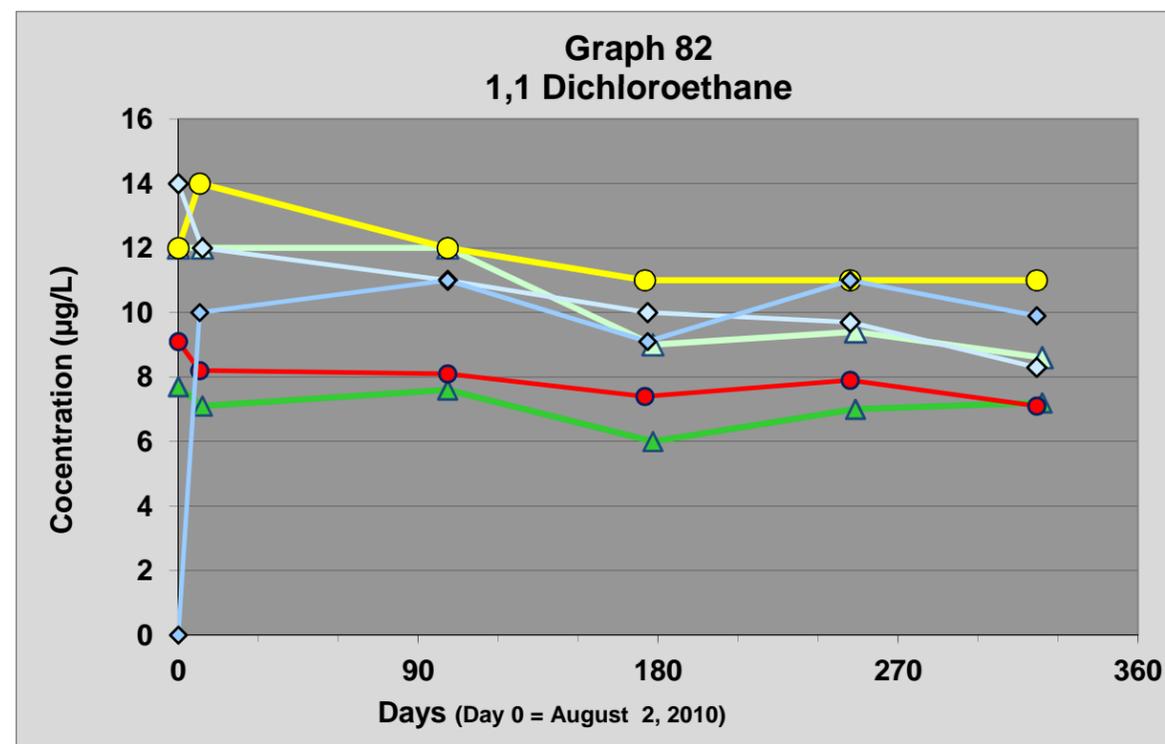
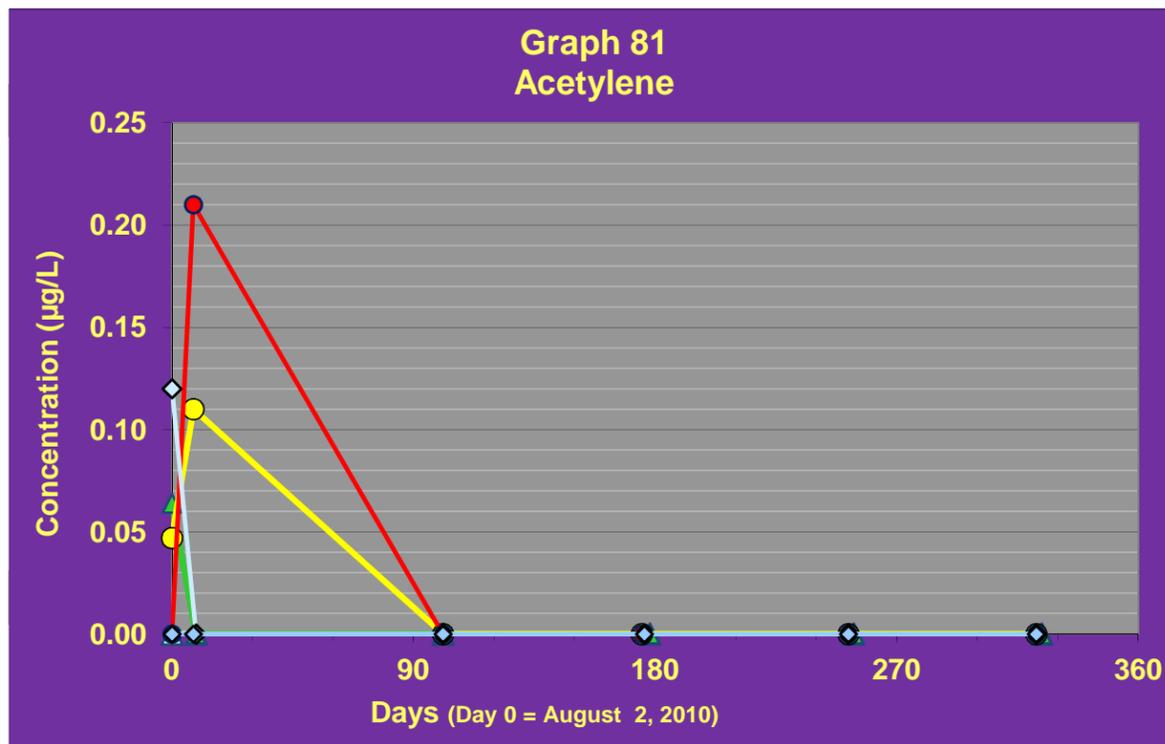
- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◆ Well Upgradient from Treatment Area

Graphs of VOC Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field

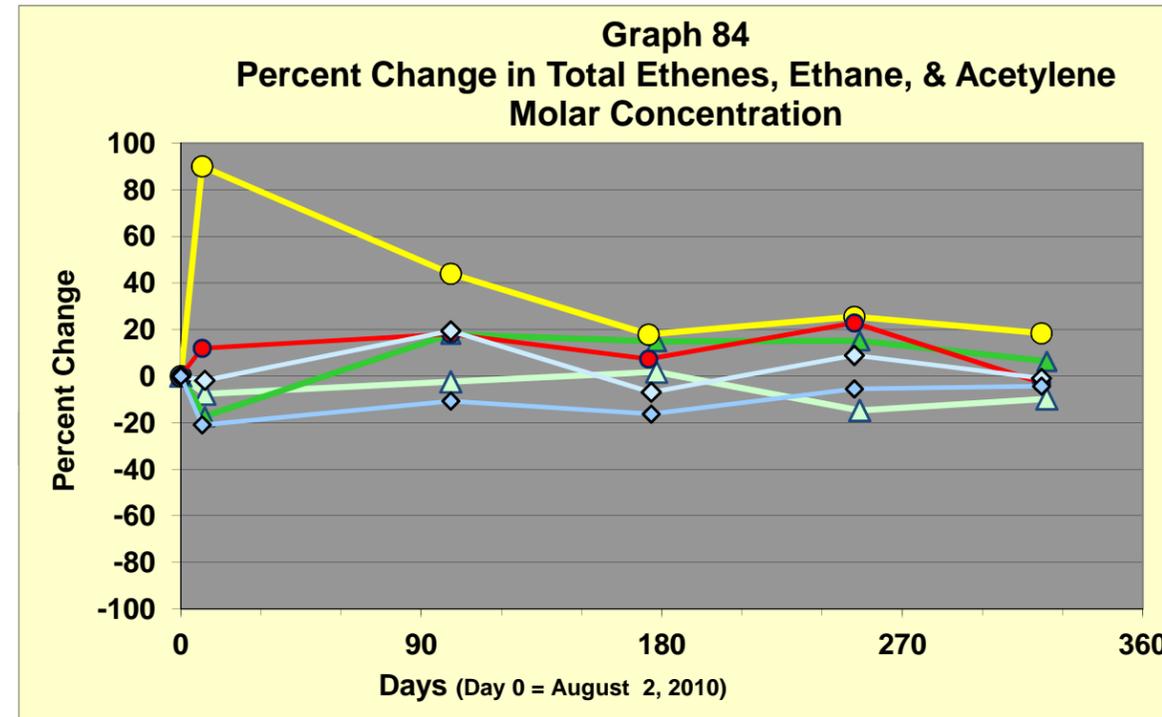
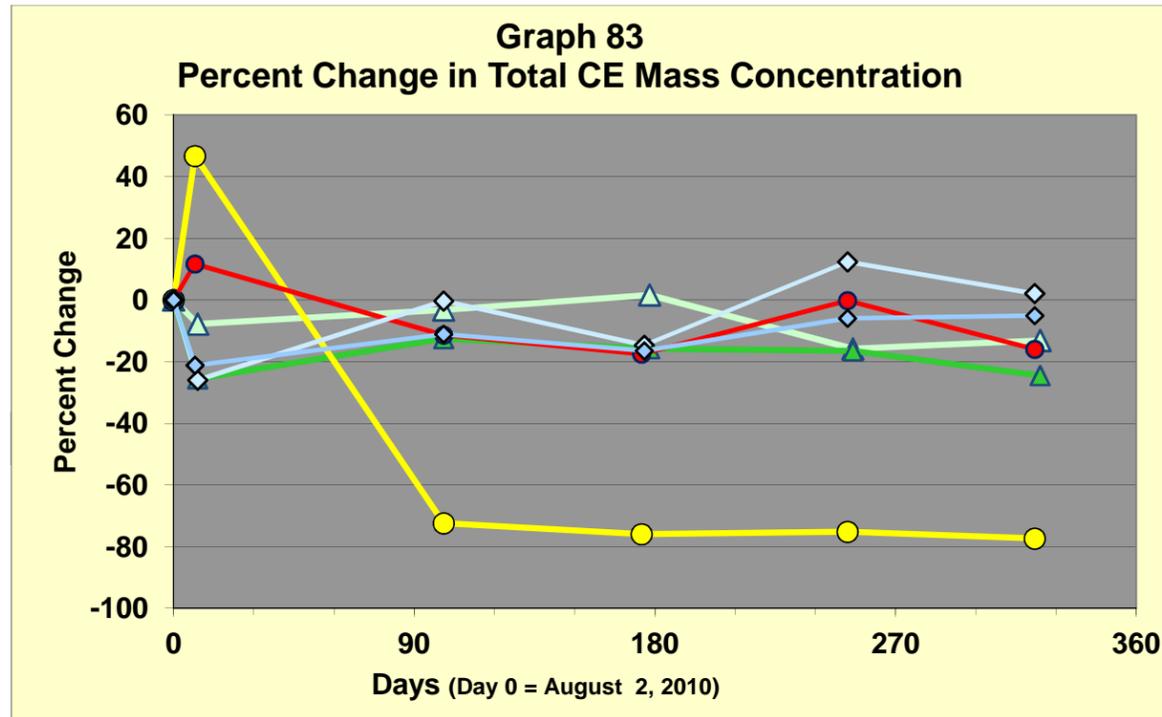


- △ 28OW-19
- ▲ 28OW-20
- 28OW-21
- 28OW-22
- ◇ 28OW-23
- ◇ 28OW-24



Graphs of VOC Concentrations in Groundwater - Lactate Pilot Test

Former Building 88 Area, IR Site 28, Former NAS Moffett Field



- △ 28OW-19
- ▲ 28OW-20
- 28OW-21
- 28OW-22
- ◇ 28OW-23
- ◇ 28OW-24
- + Avg Treatment
- * Avg Downgradient
- × Avg Upgradient

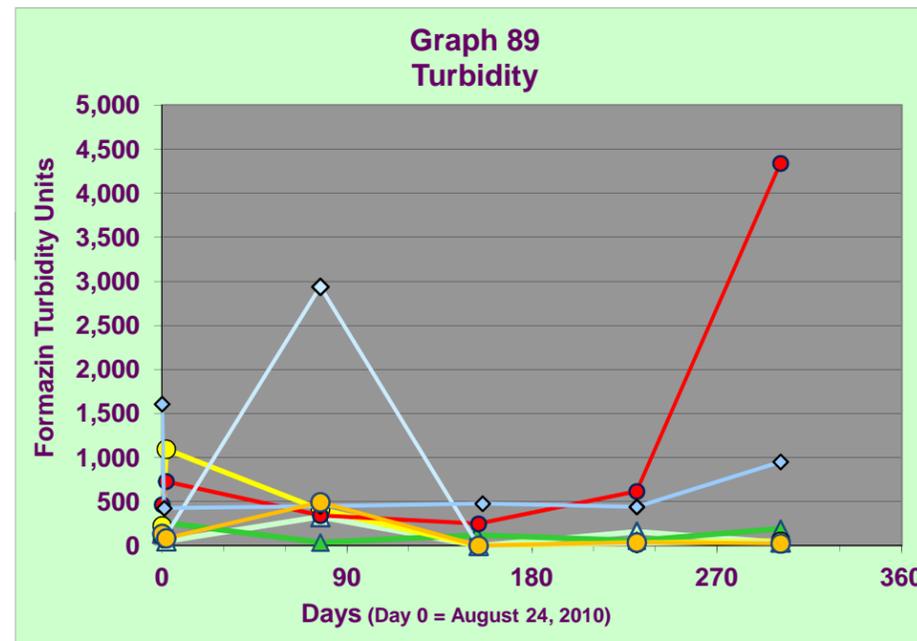
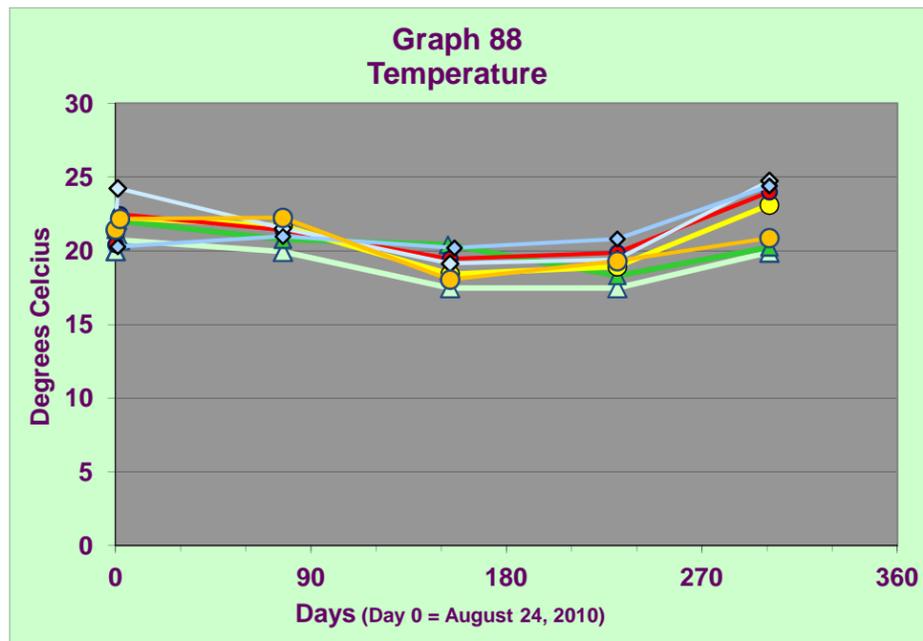
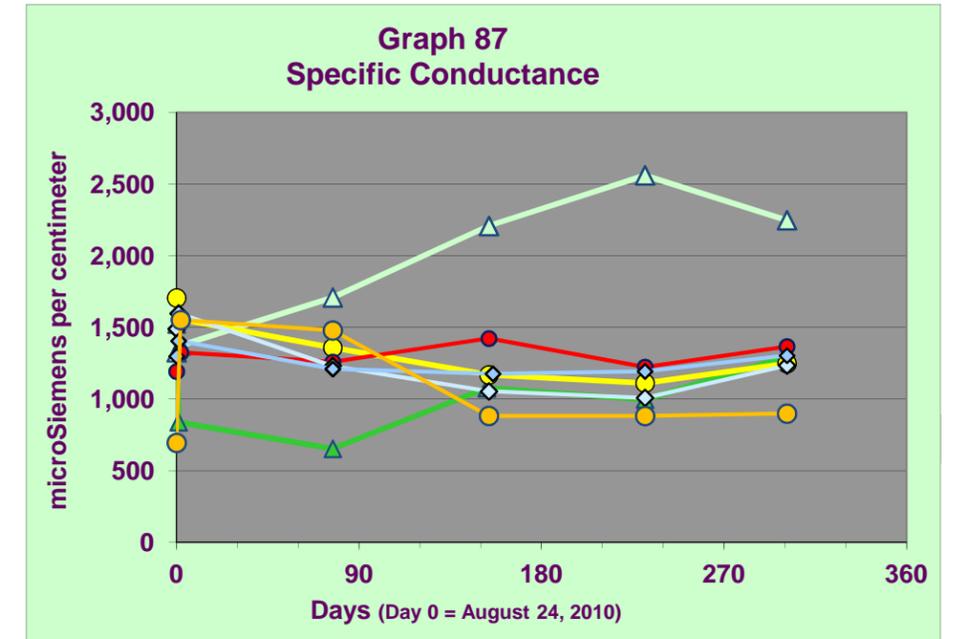
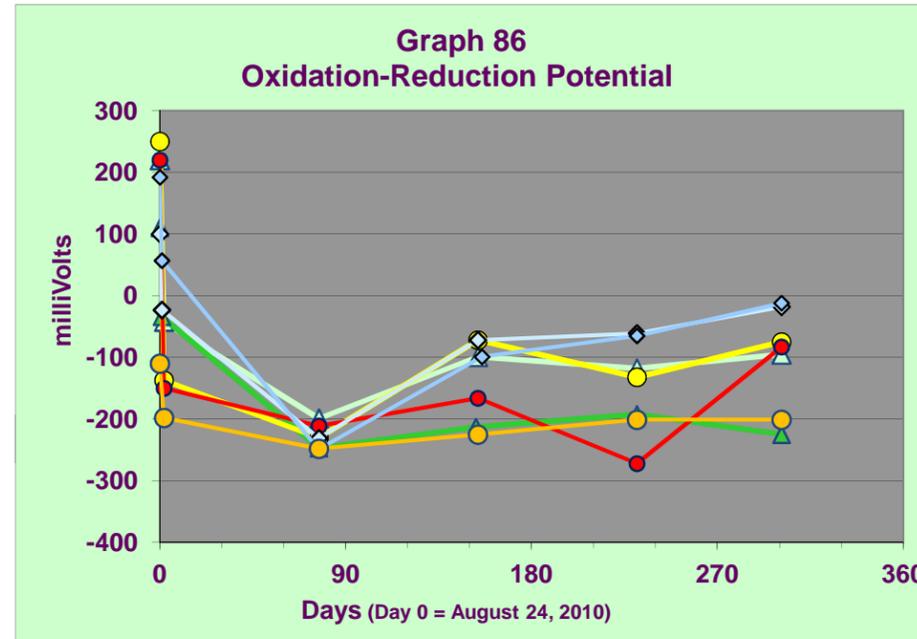
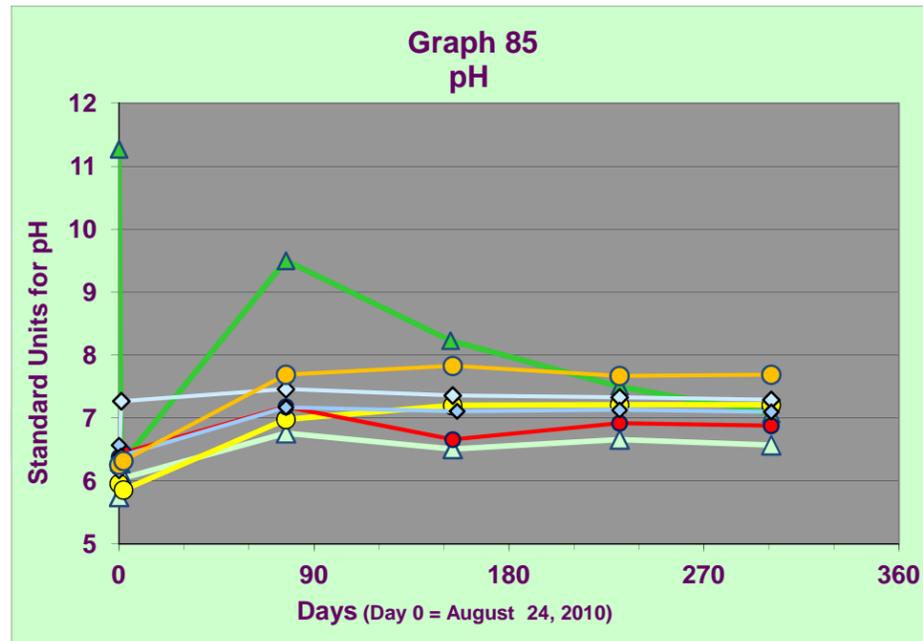
▲ Well Downgradient from Treatment Area

● Well Within Treatment Area

◆ Well Upgradient from Treatment Area

Graphs for Physical Parameters of Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field



- ▲ 28OW-13
- ▲ 28OW-14
- 28OW-15
- 28OW-16
- ◆ 28OW-17
- ◆ 28OW-18
- W9-18

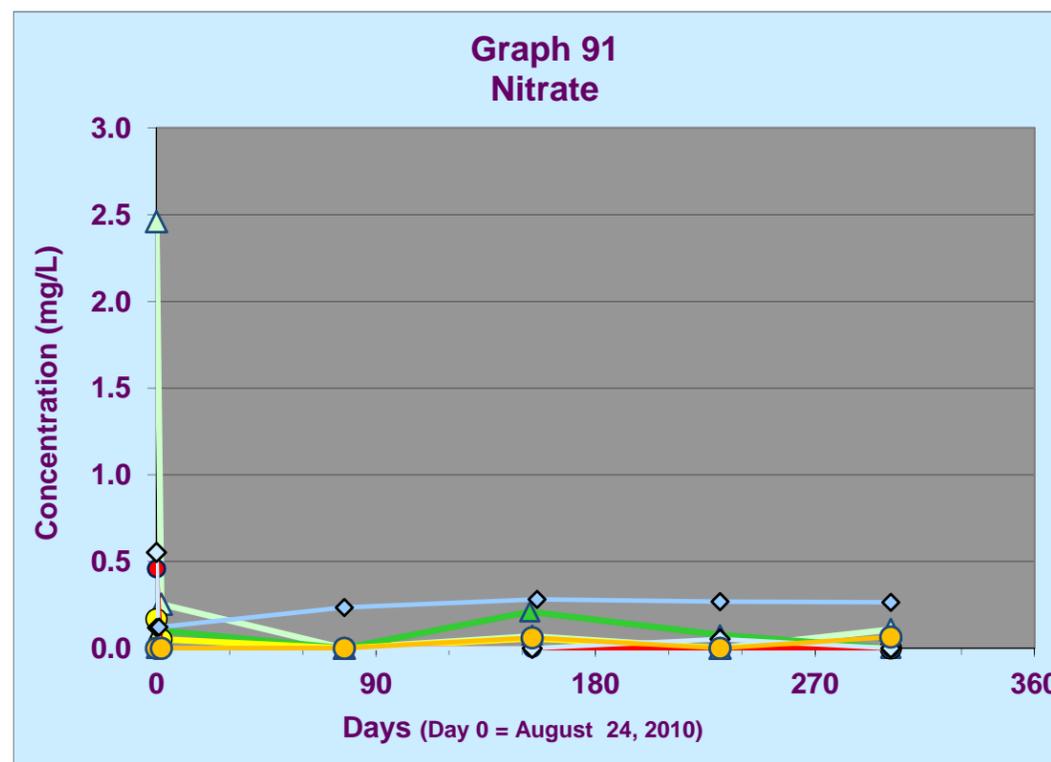
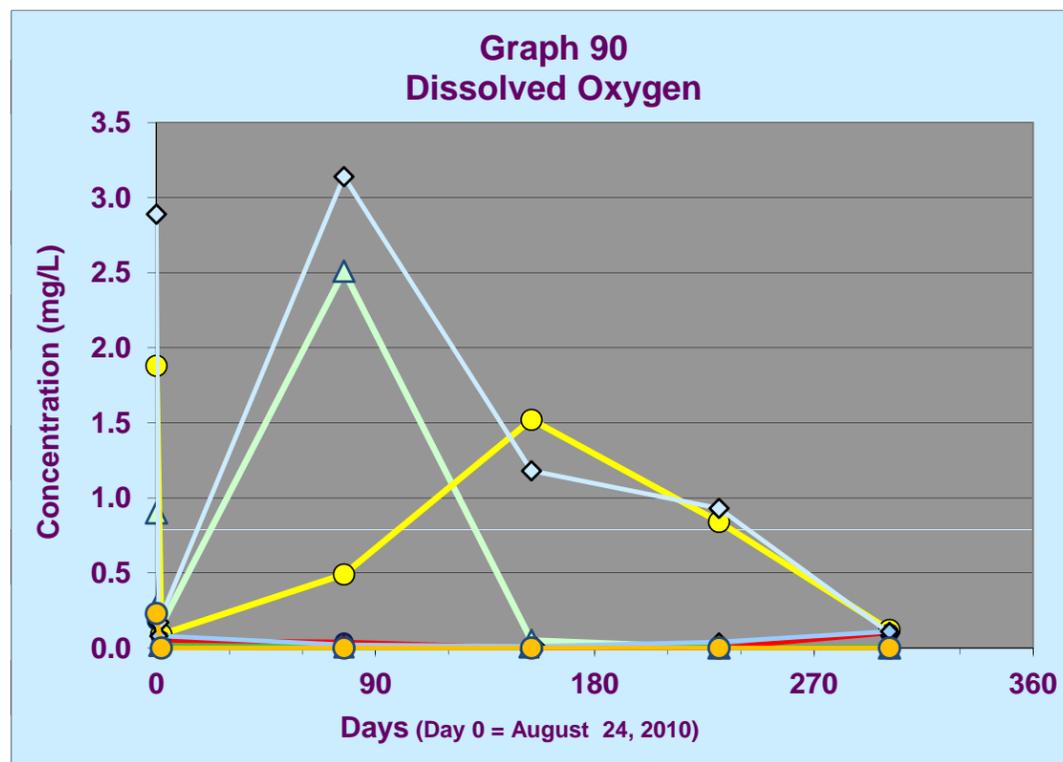
▲ Well Downgradient from Treatment Area

● Well Within Treatment Area

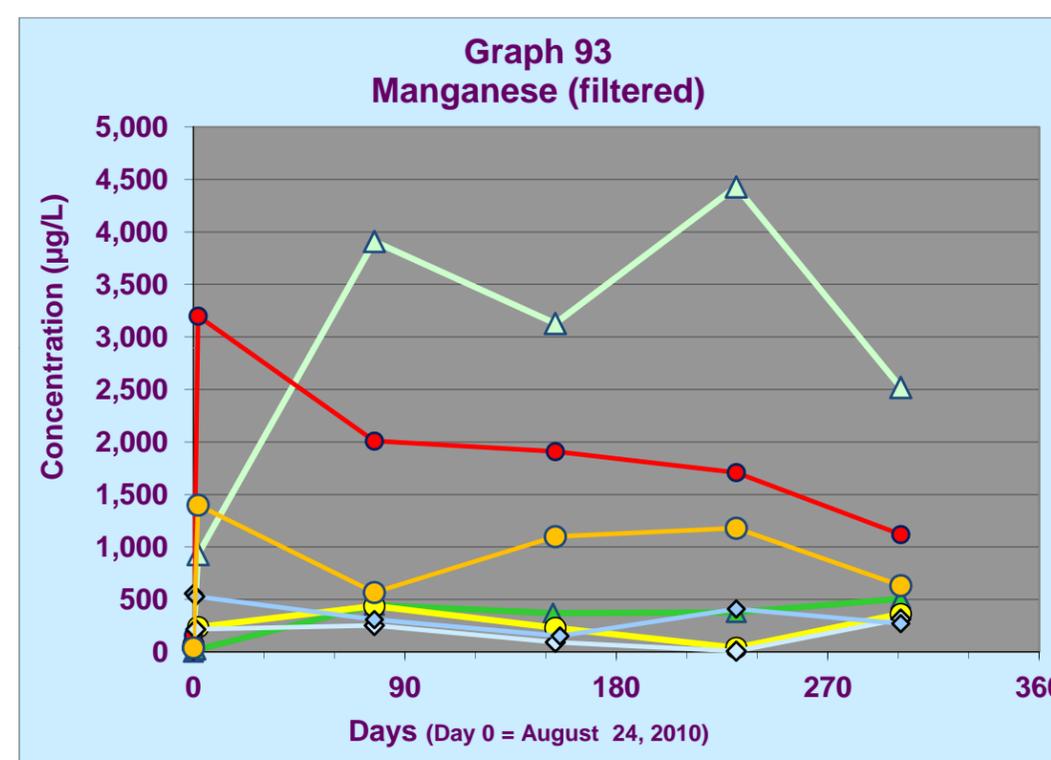
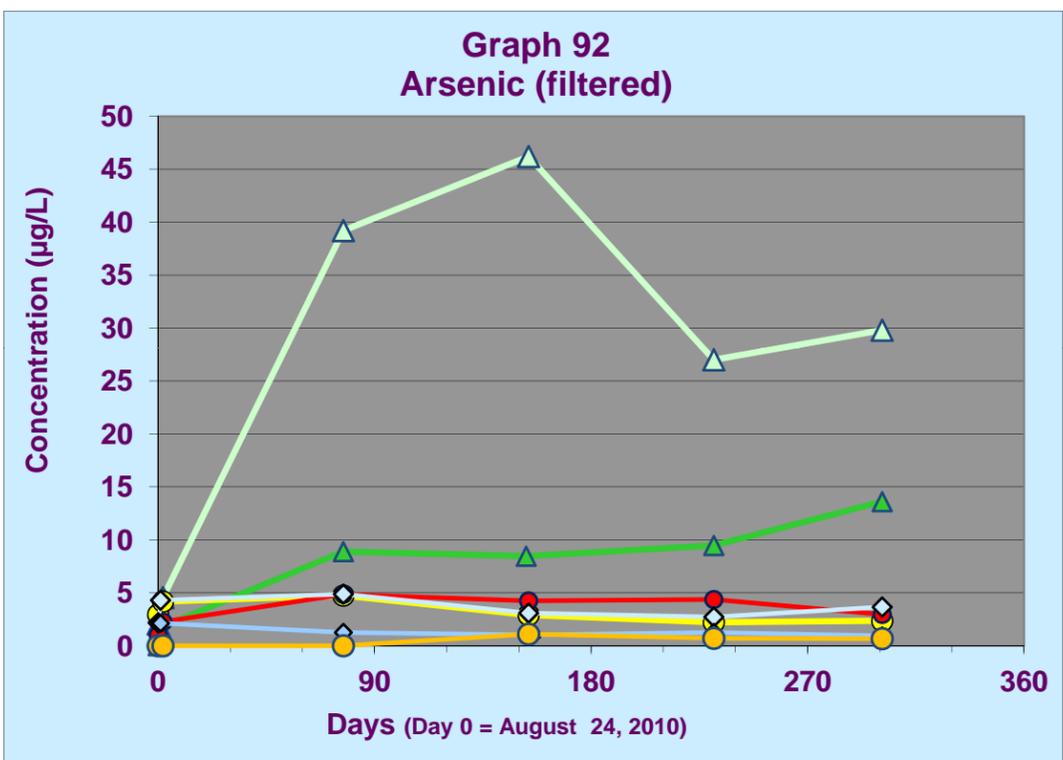
◆ Well Upgradient from Treatment Area

Graphs of Biogeochemical Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field



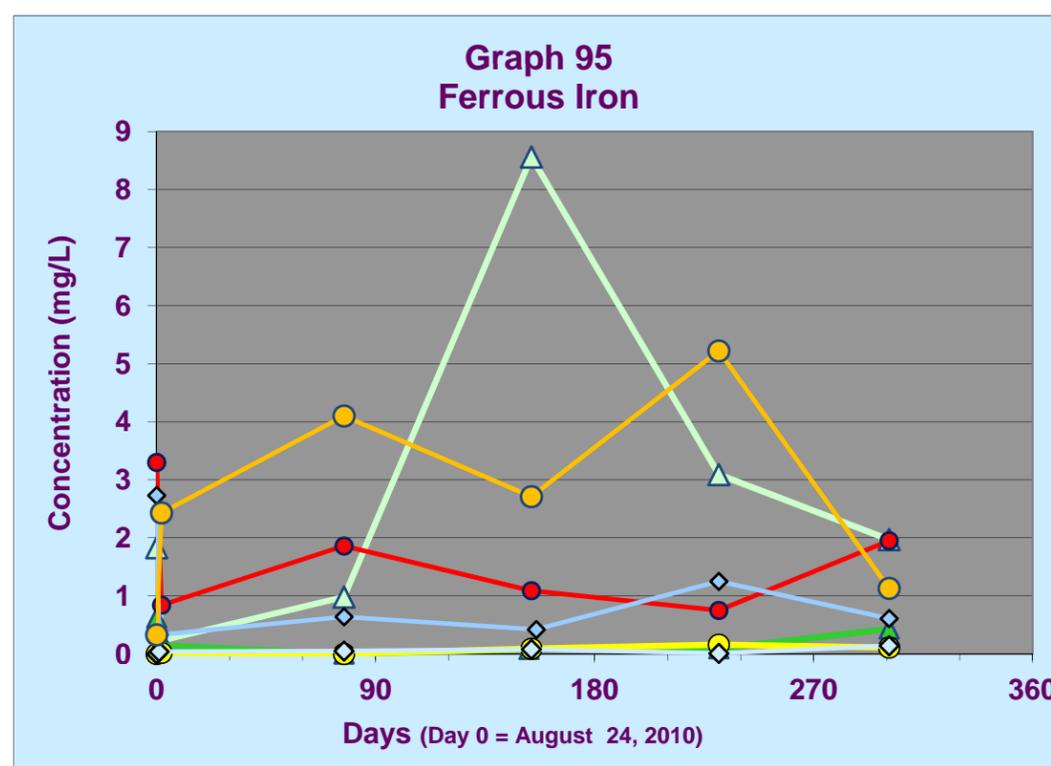
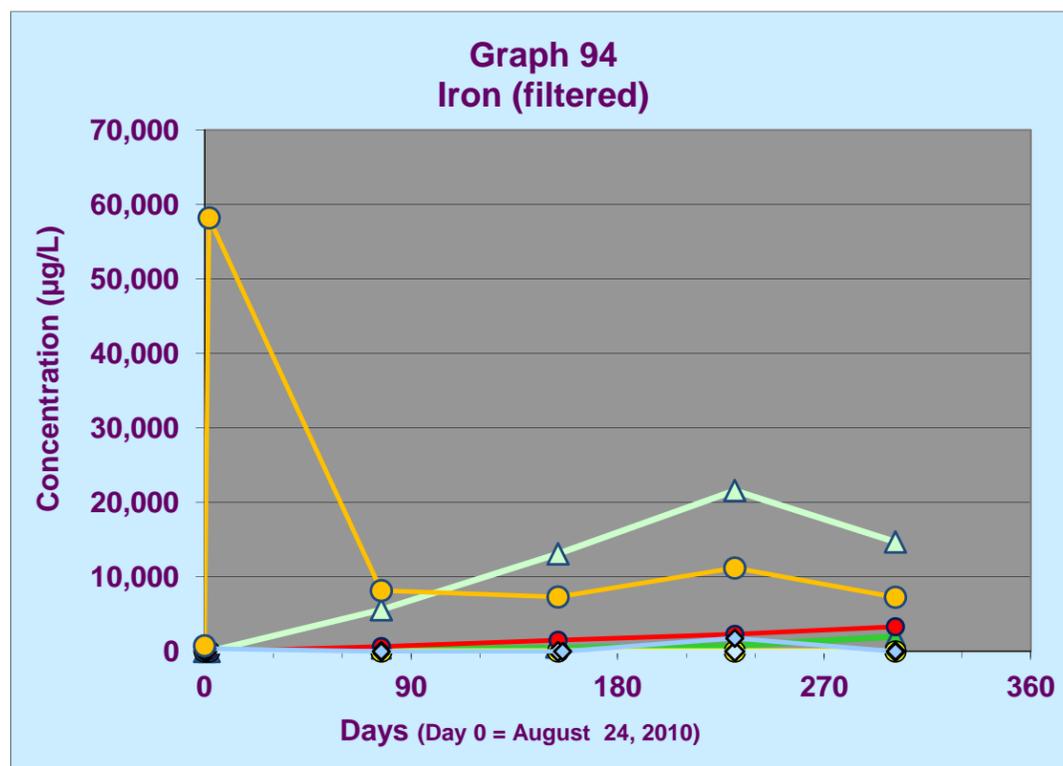
- ▲ 28OW-13
- ▲ 28OW-14
- 28OW-15
- 28OW-16
- ◇ 28OW-17
- ◇ 28OW-18
- W9-18



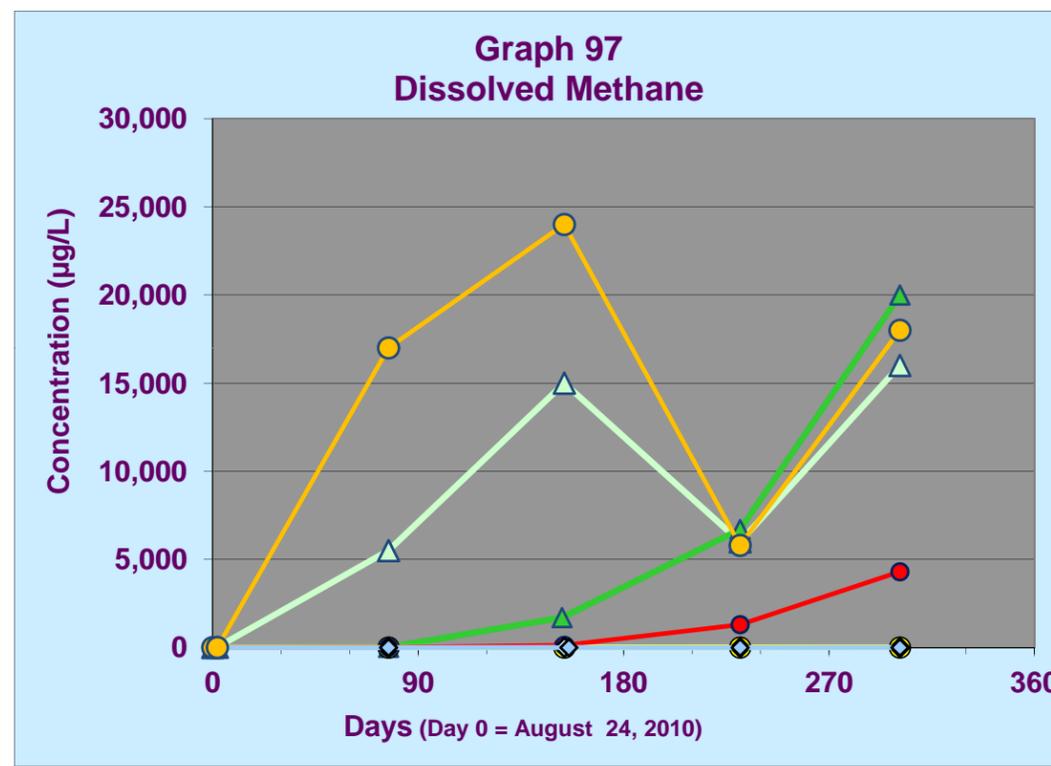
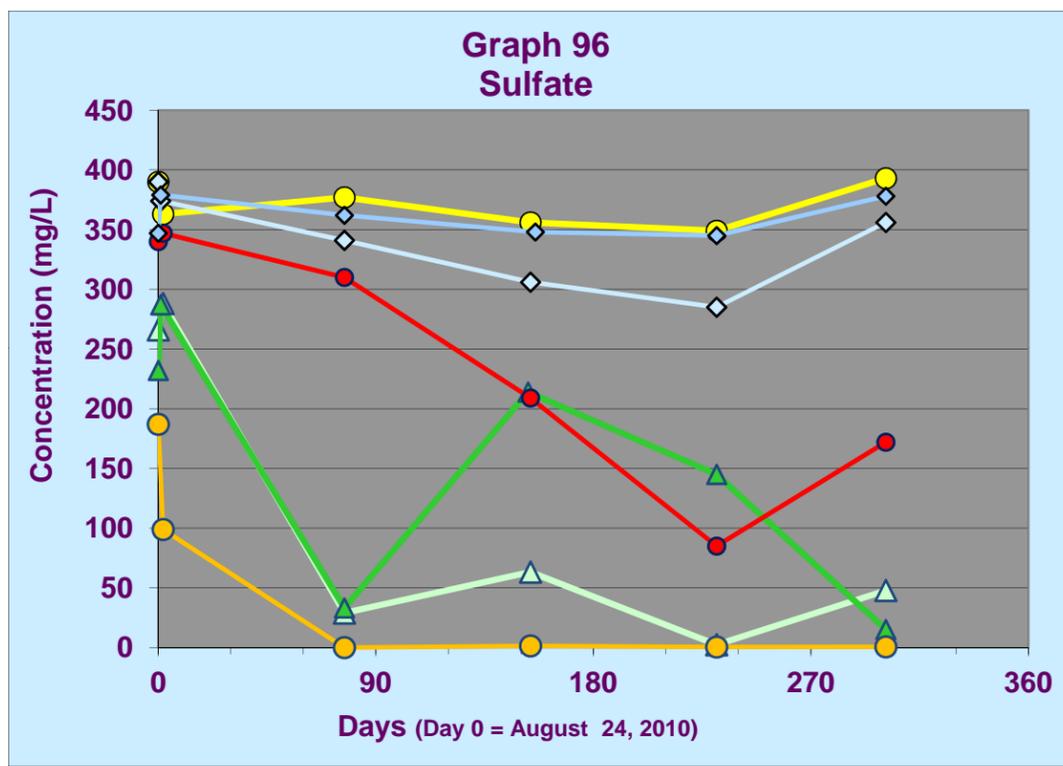
- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◇ Well Upgradient from Treatment Area

Graphs of Biogeochemical Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field



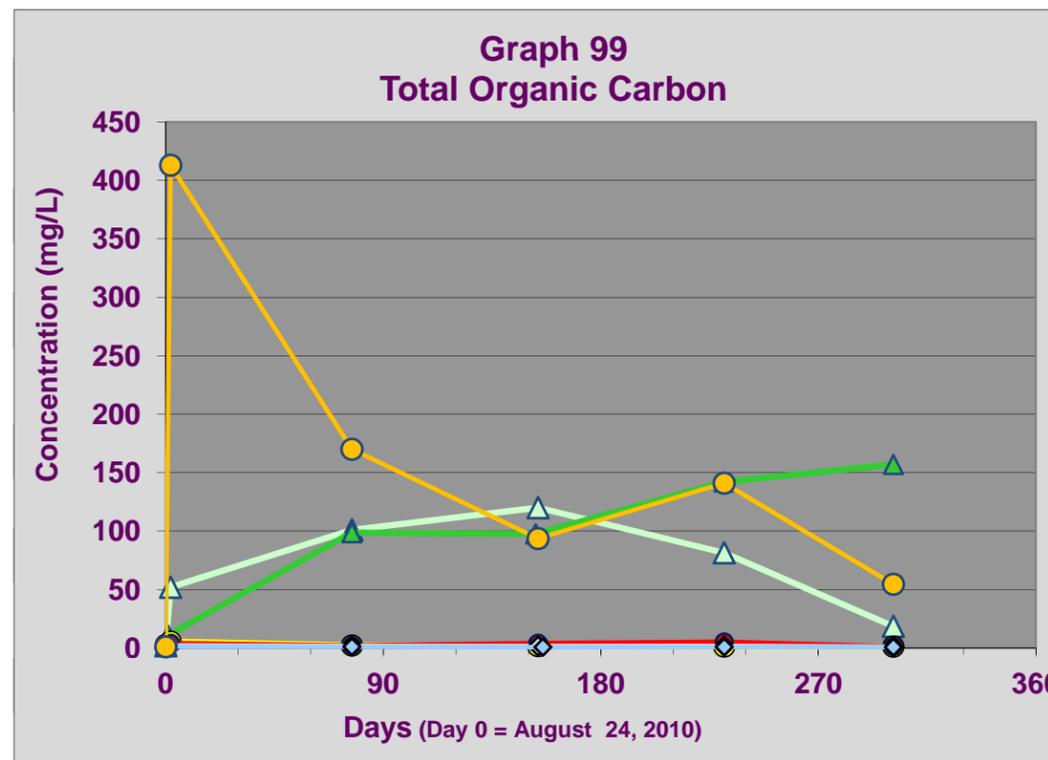
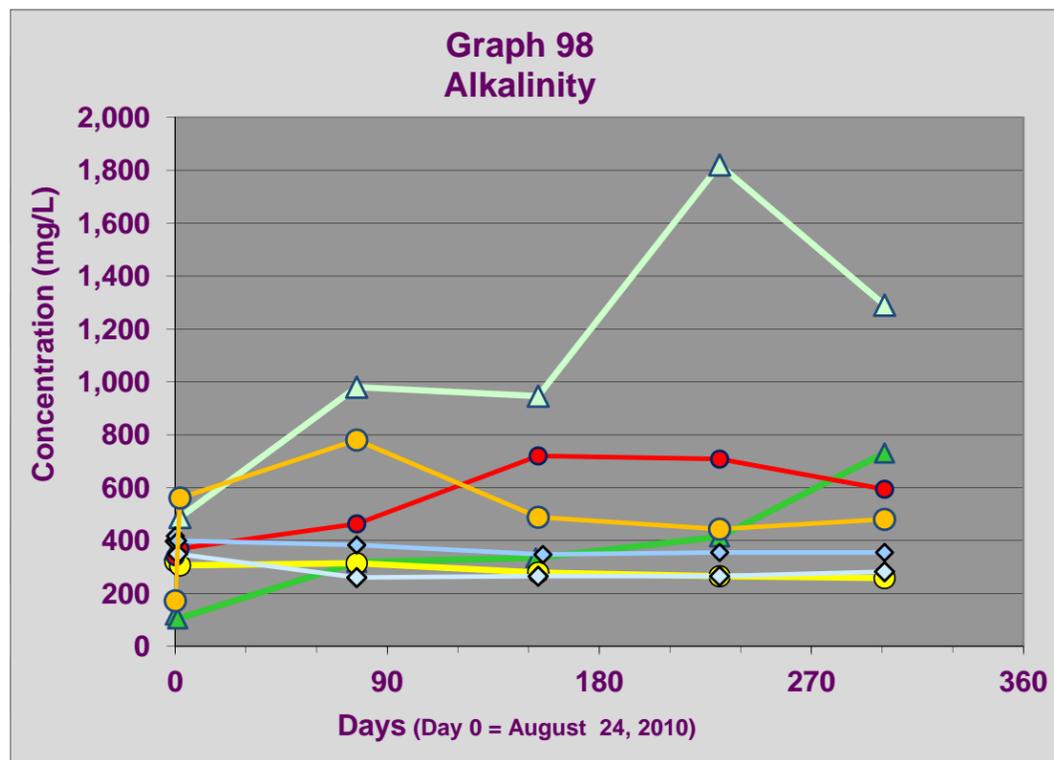
- ▲ 28OW-13
- ▲ 28OW-14
- 28OW-15
- 28OW-16
- ◆ 28OW-17
- ◆ 28OW-18
- W9-18



- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◆ Well Upgradient from Treatment Area

Graphs of Biogeochemical Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field



- ▲ 28OW-13
- ▲ 28OW-14
- 28OW-15
- 28OW-16
- ◇ 28OW-17
- ◇ 28OW-18
- W9-18

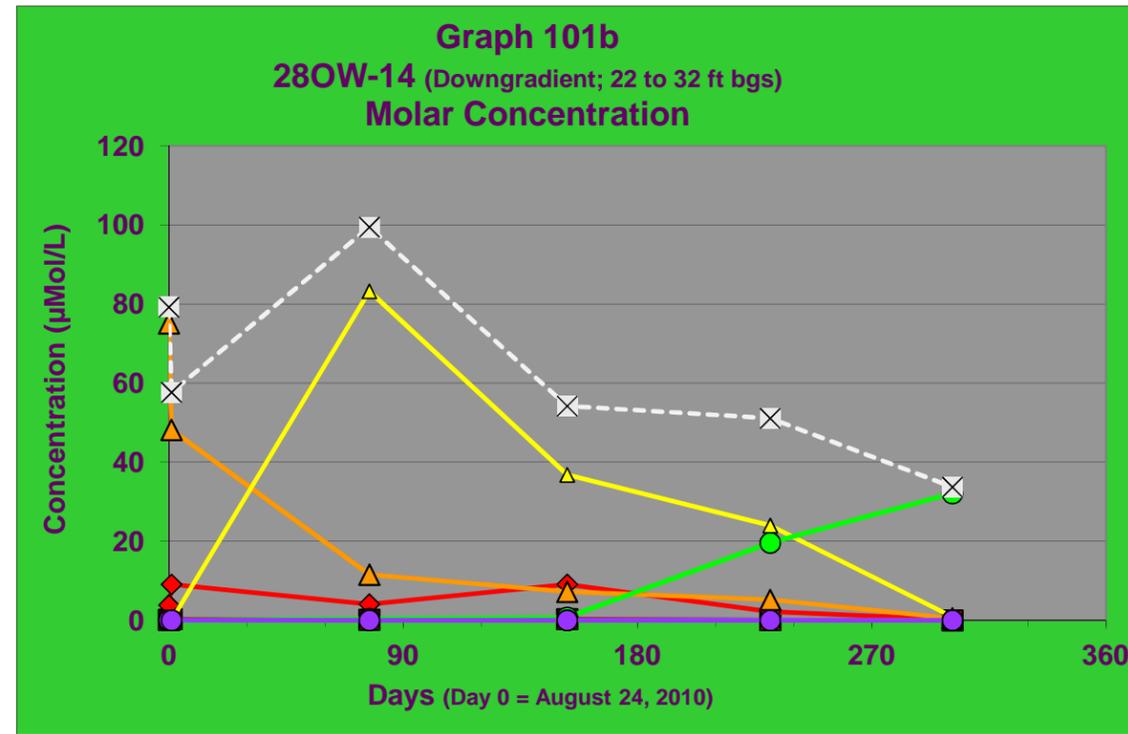
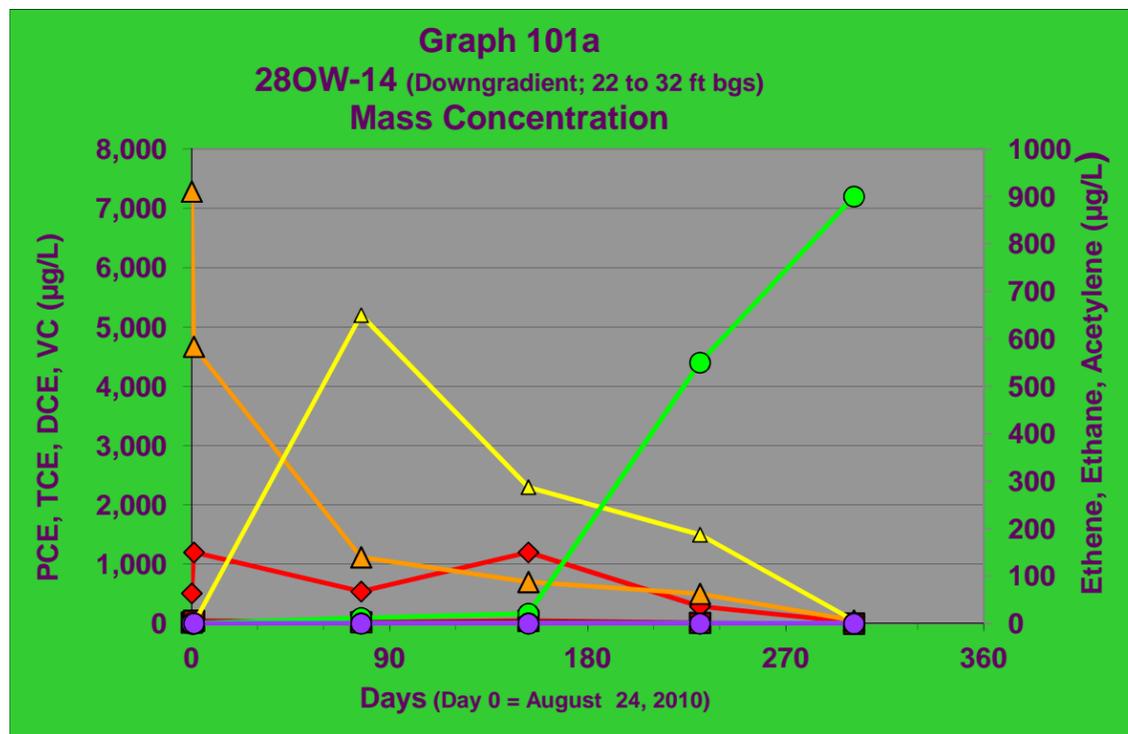
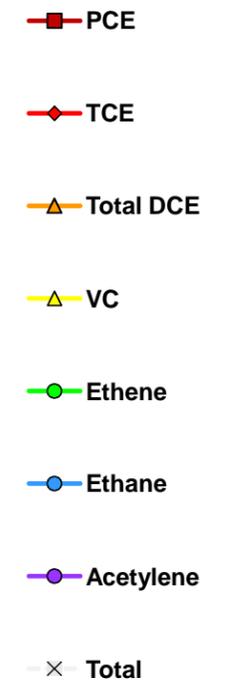
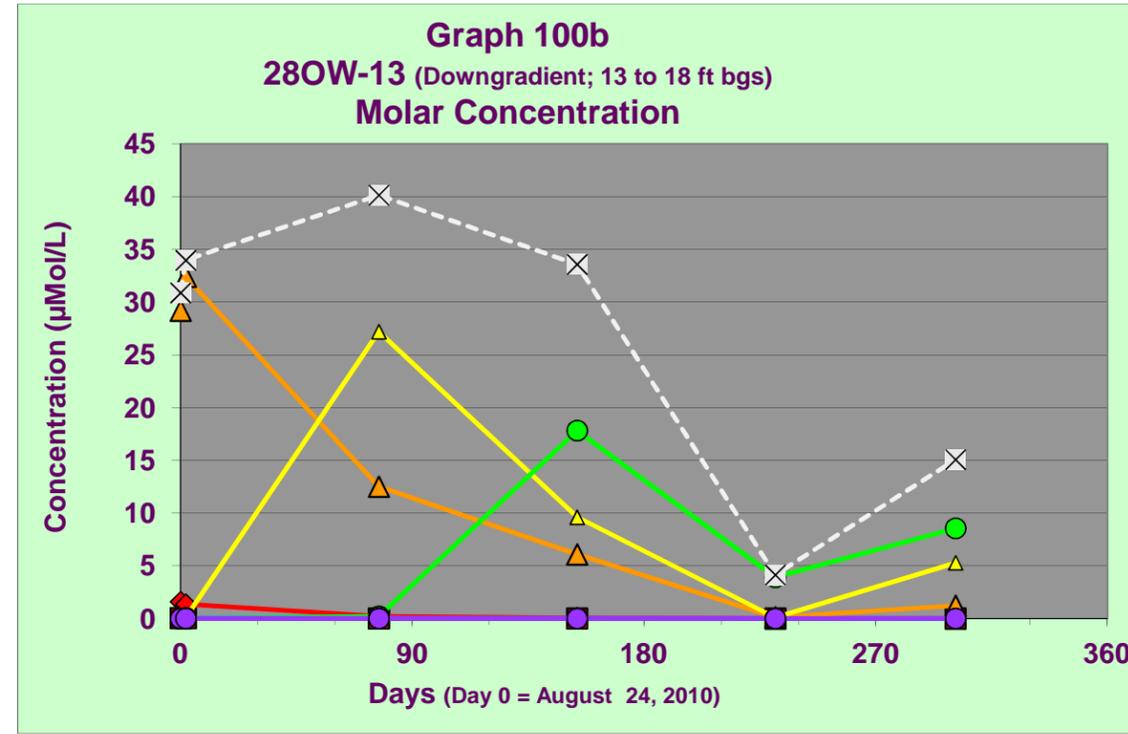
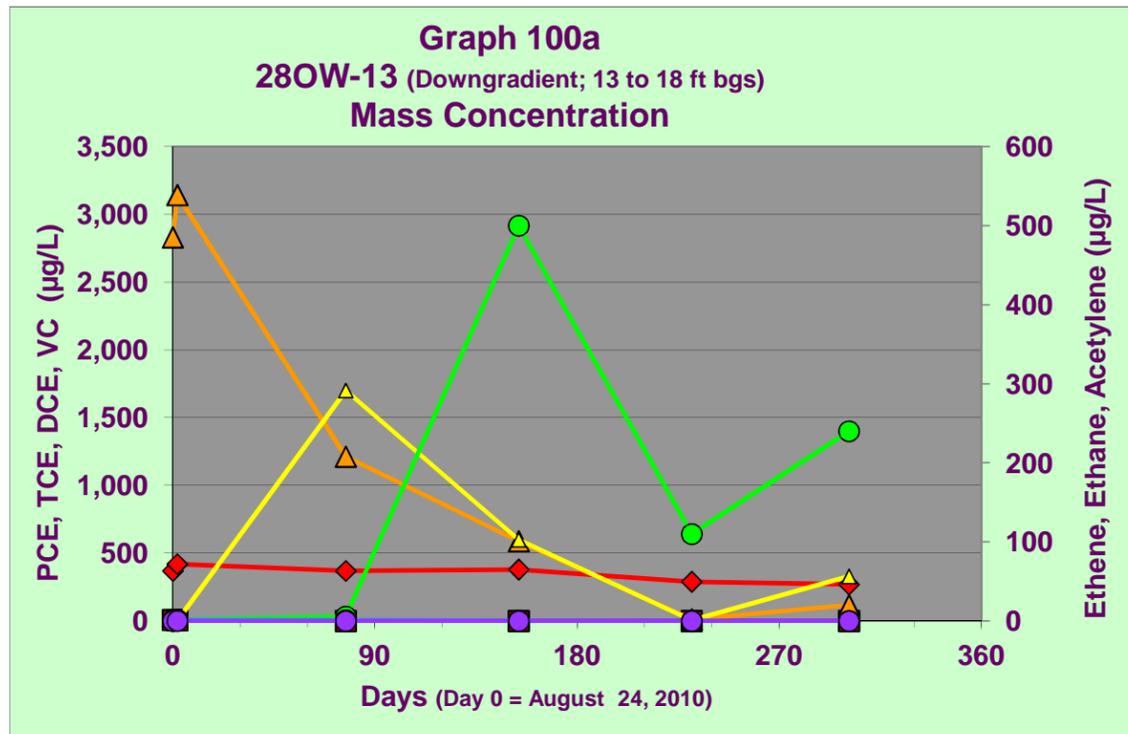
▲ Well Downgradient from Treatment Area

● Well Within Treatment Area

◆ Well Upgradient from Treatment Area

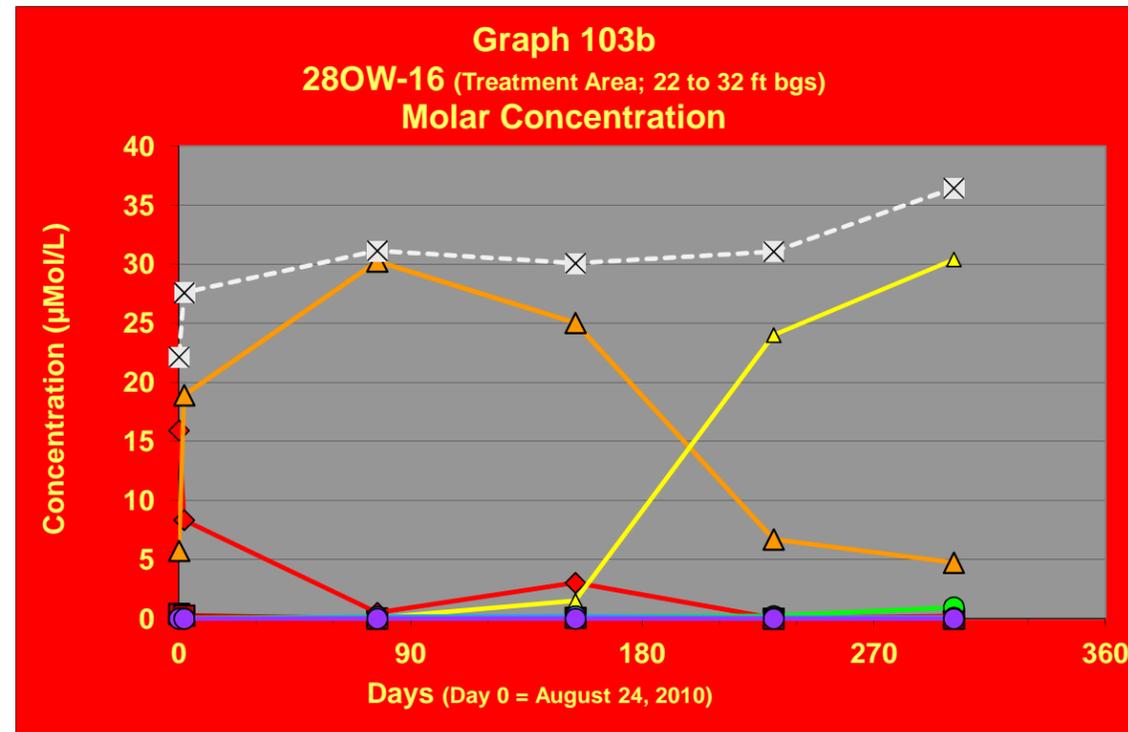
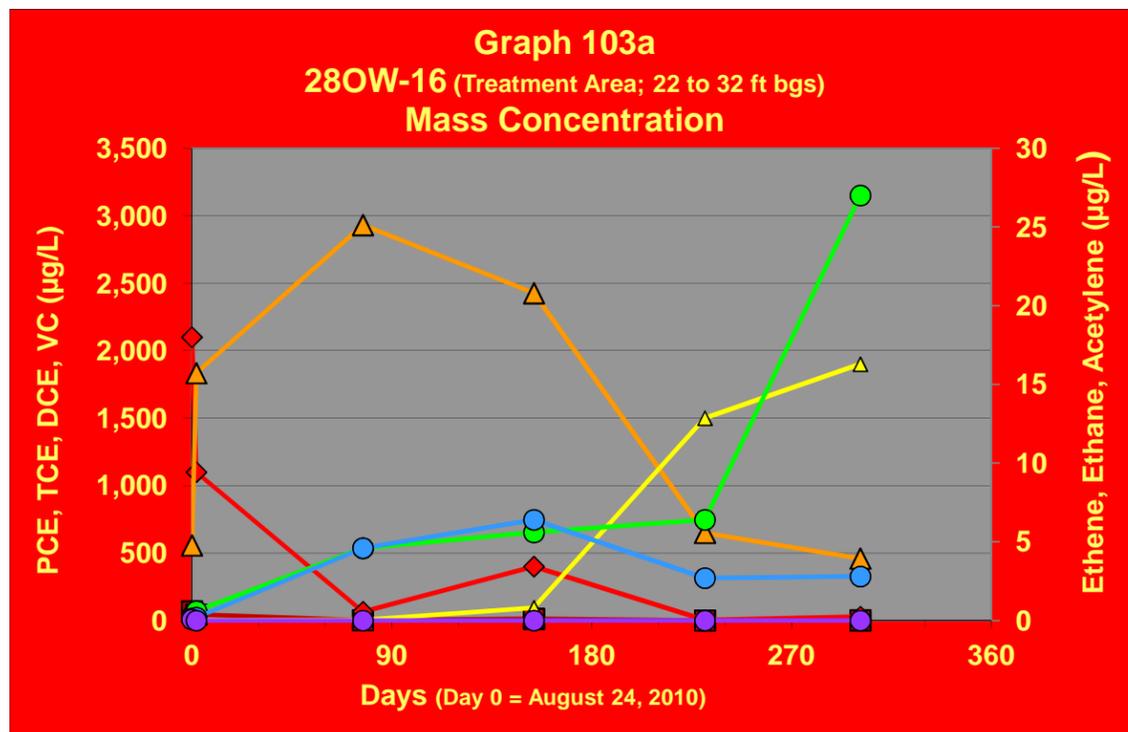
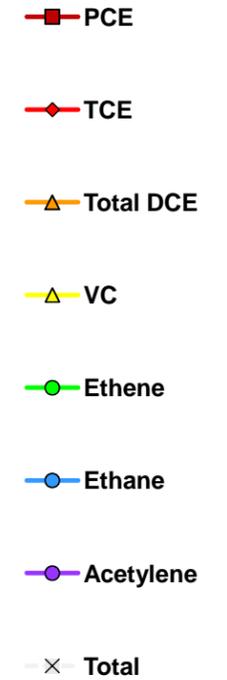
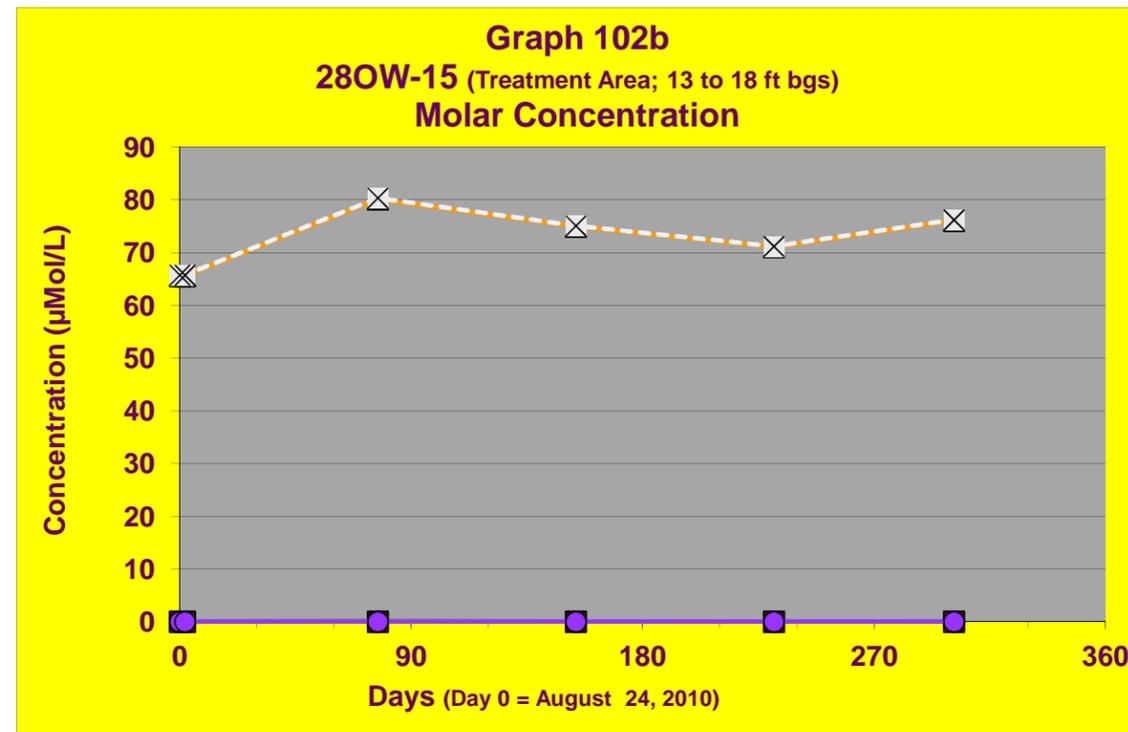
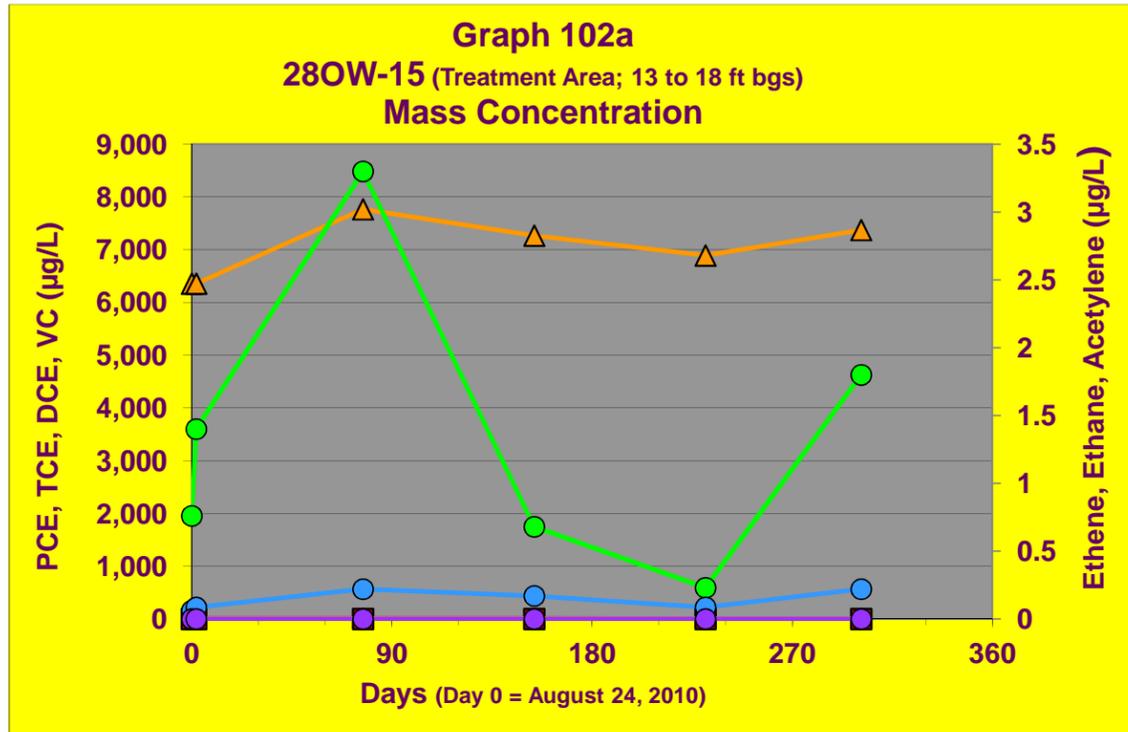
Graphs of Ethenes and Ethane Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field



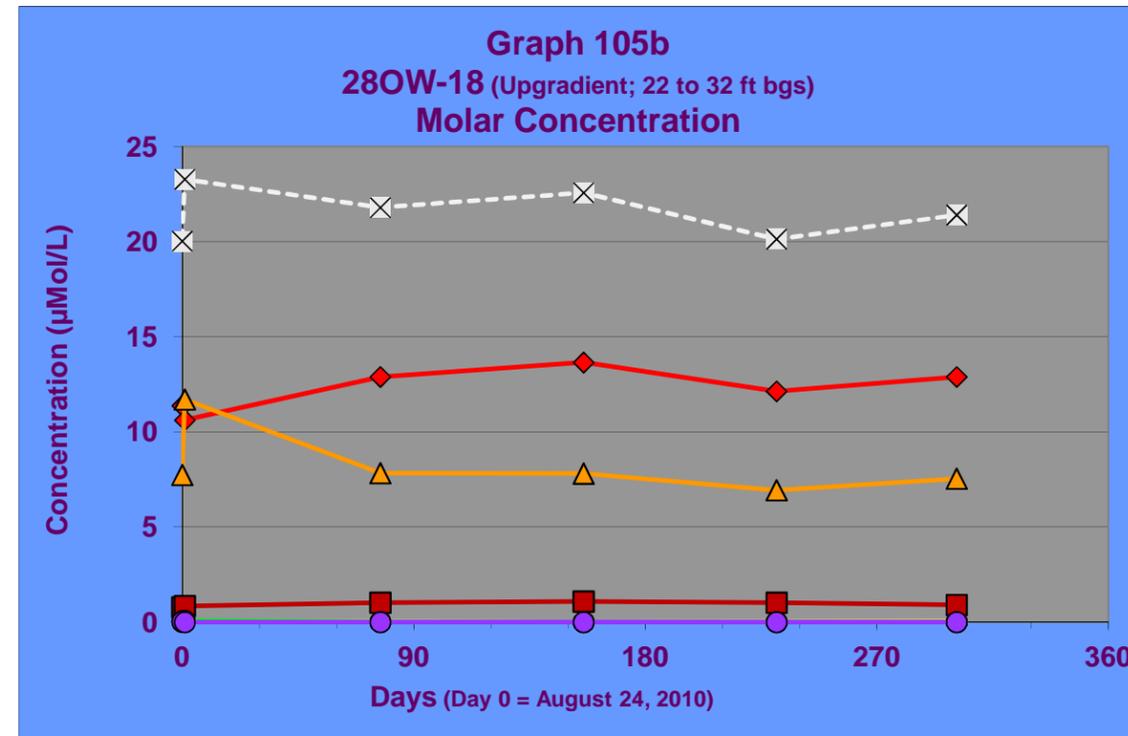
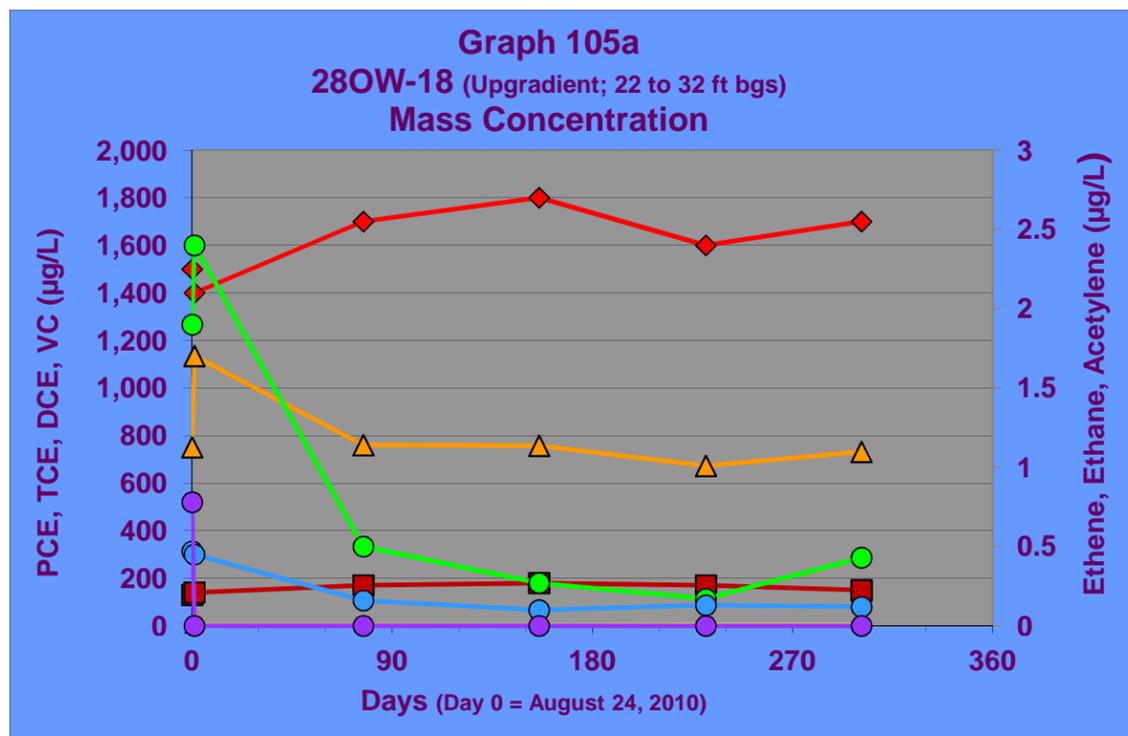
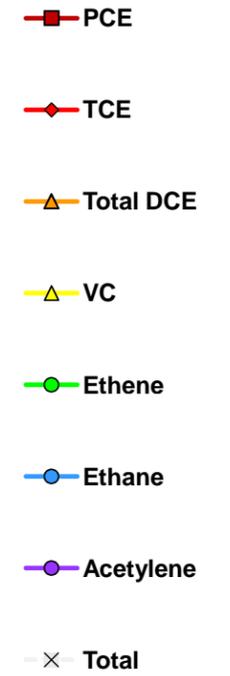
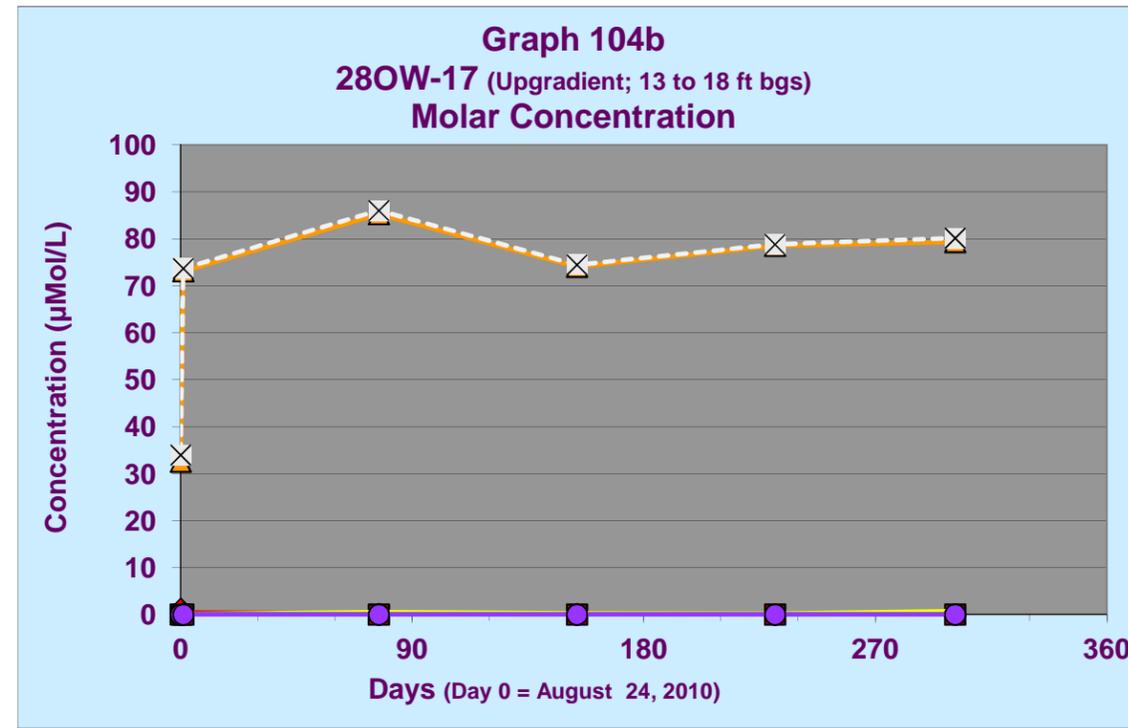
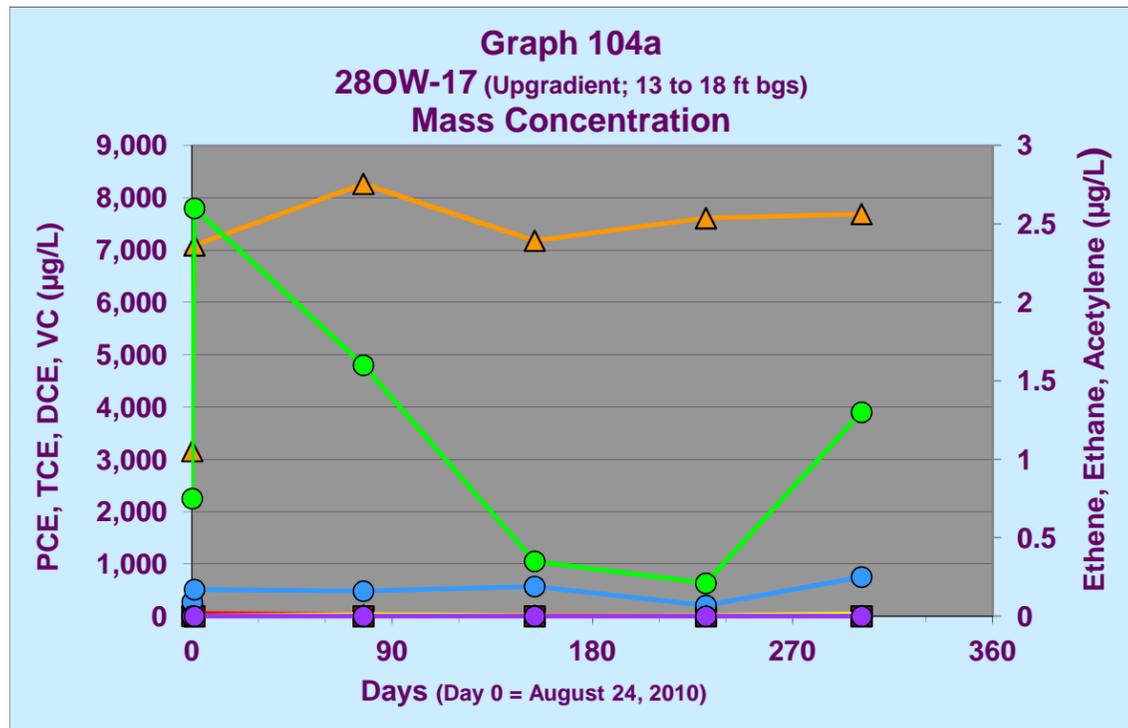
Graphs of Ethenes and Ethane Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field



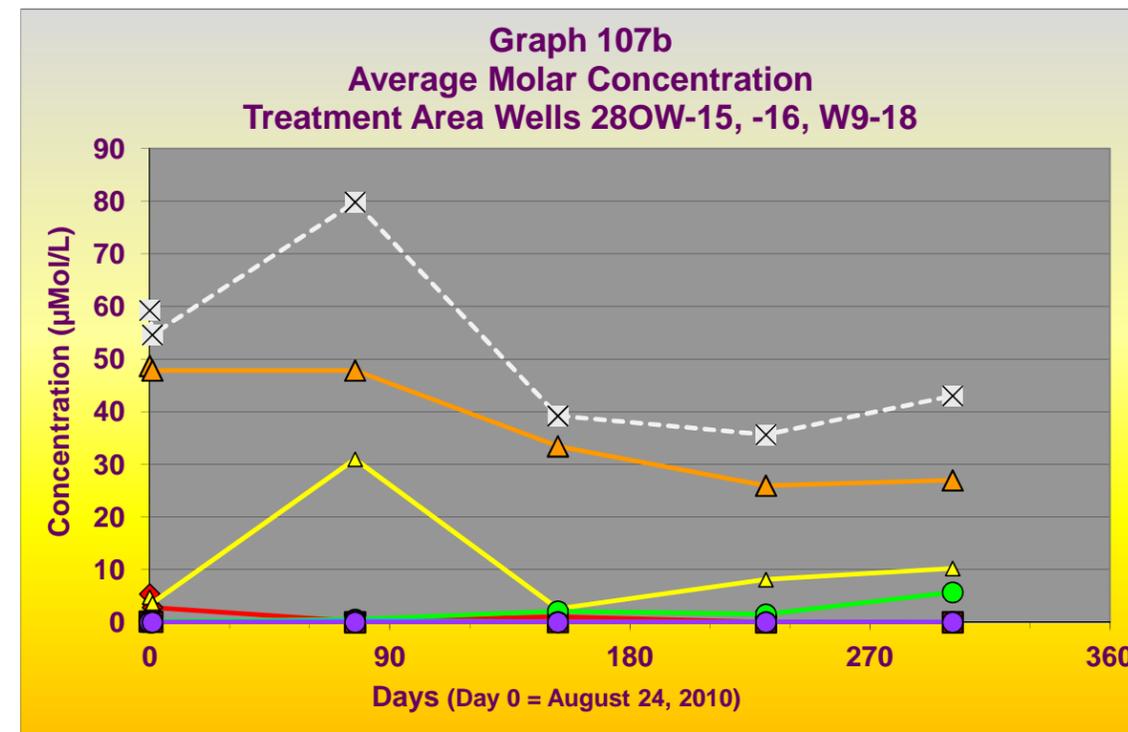
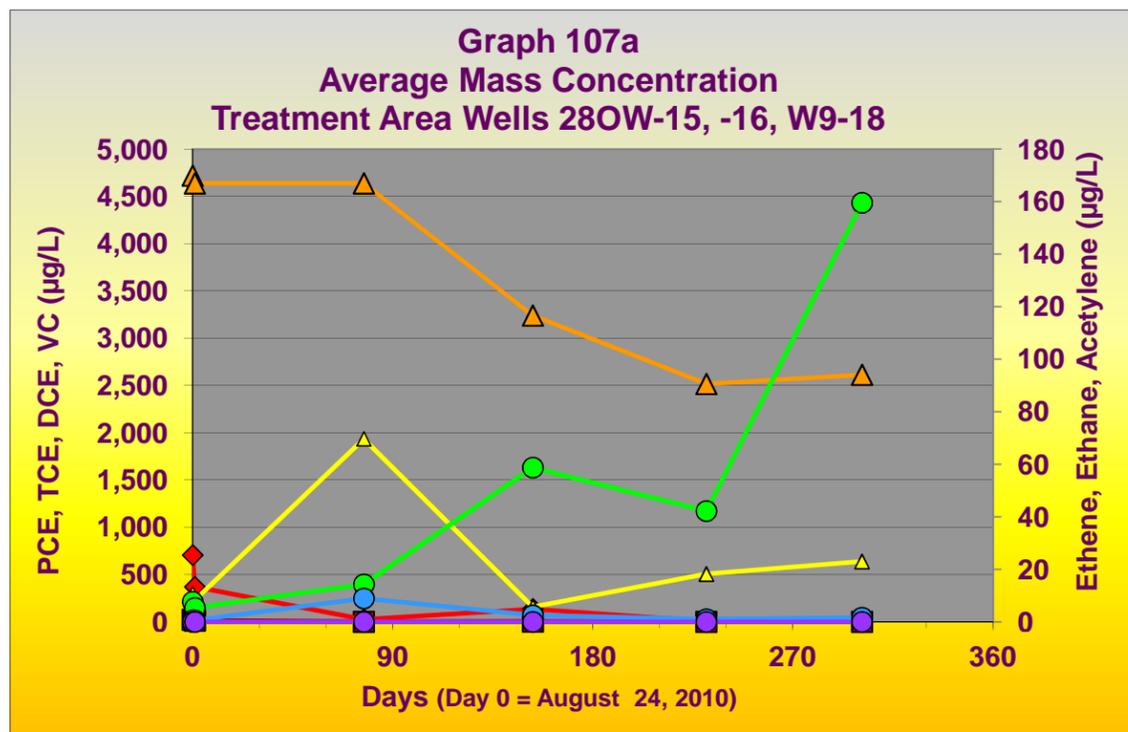
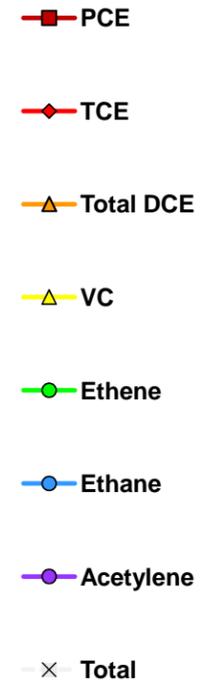
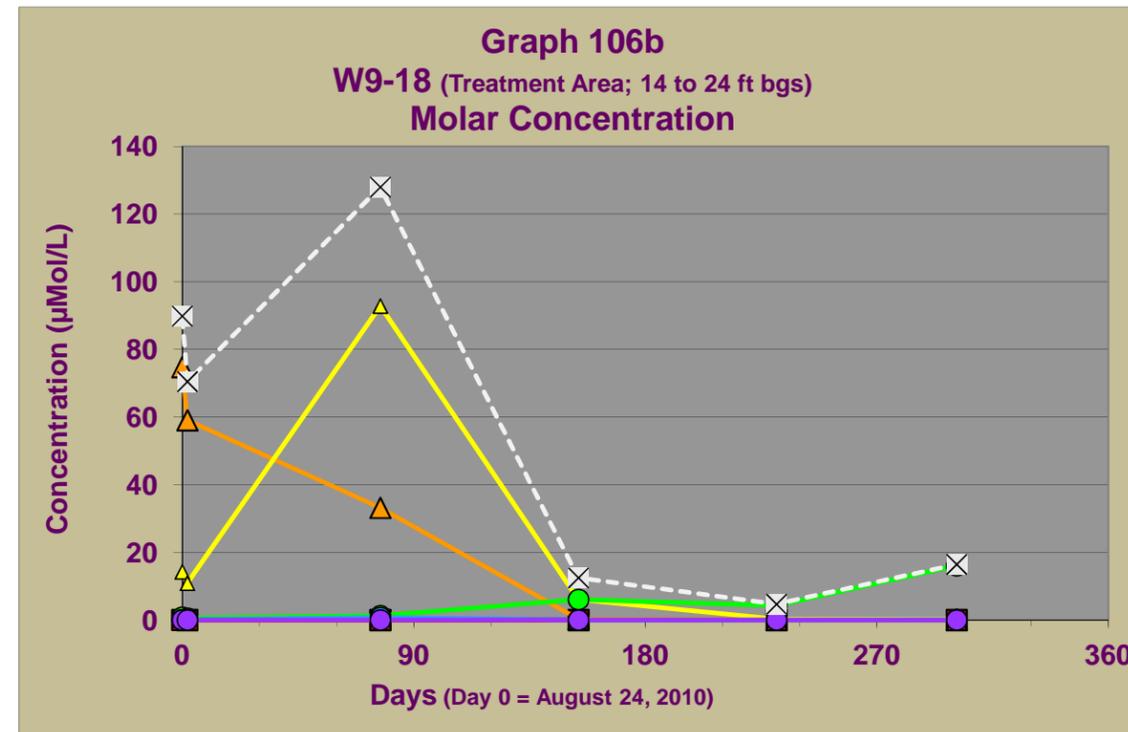
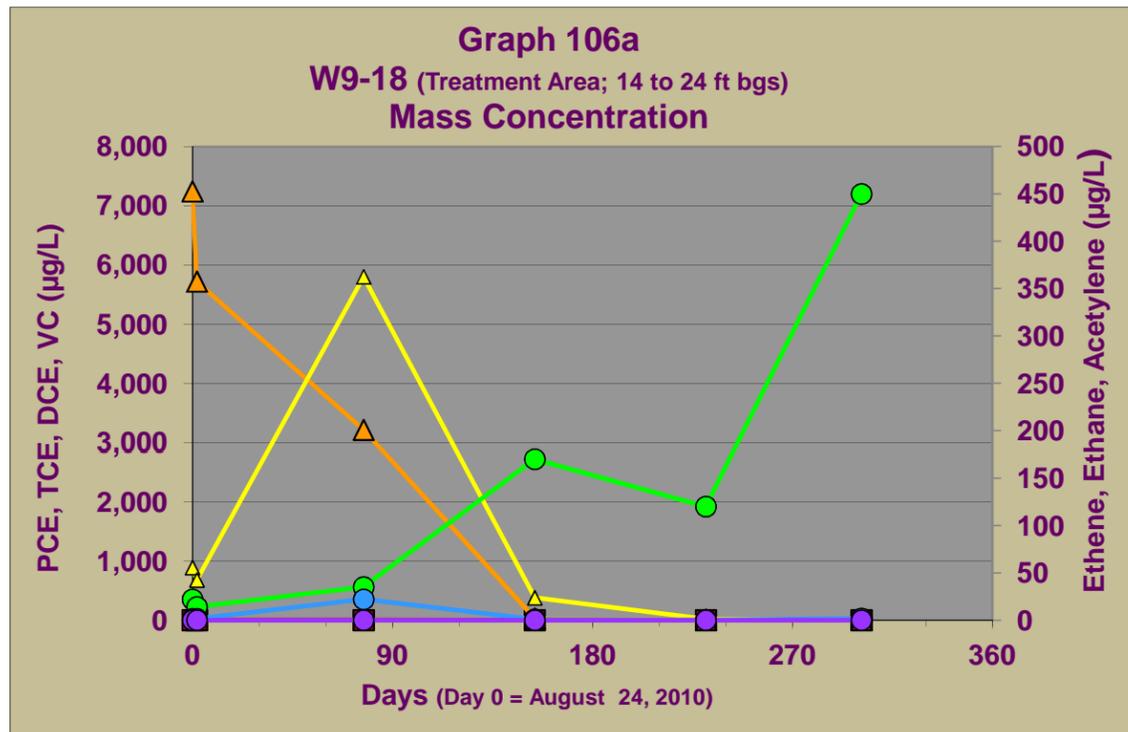
Graphs of Ethenes and Ethane Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field



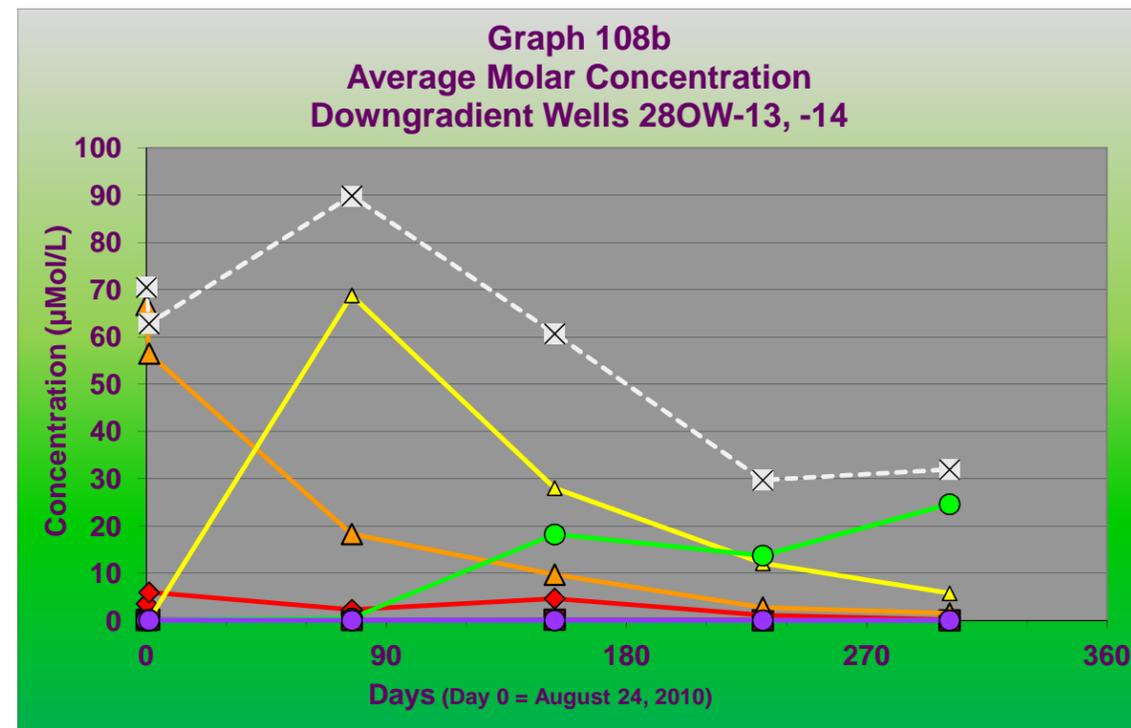
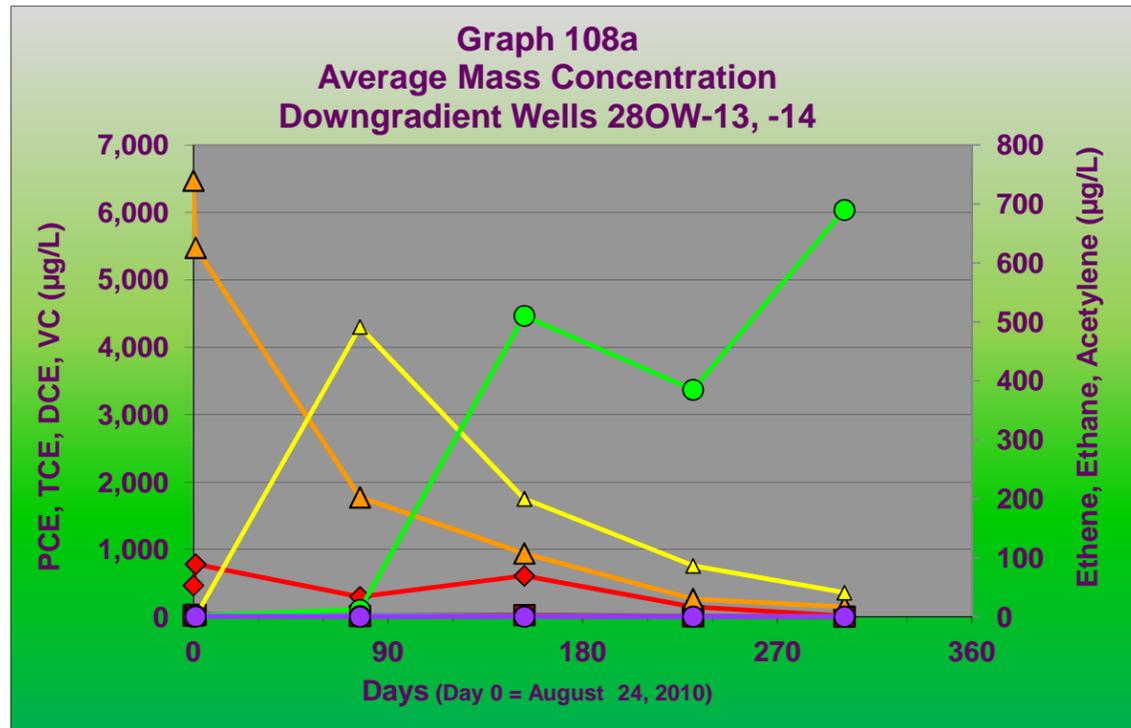
Graphs of Ethenes and Ethane Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field

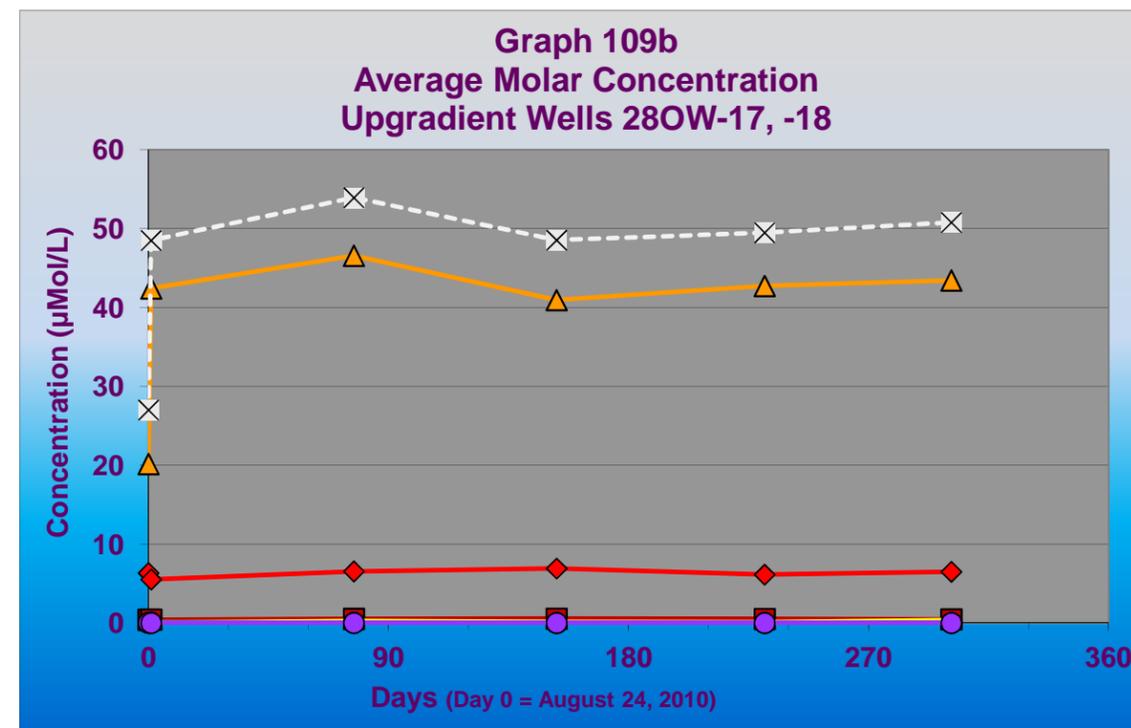
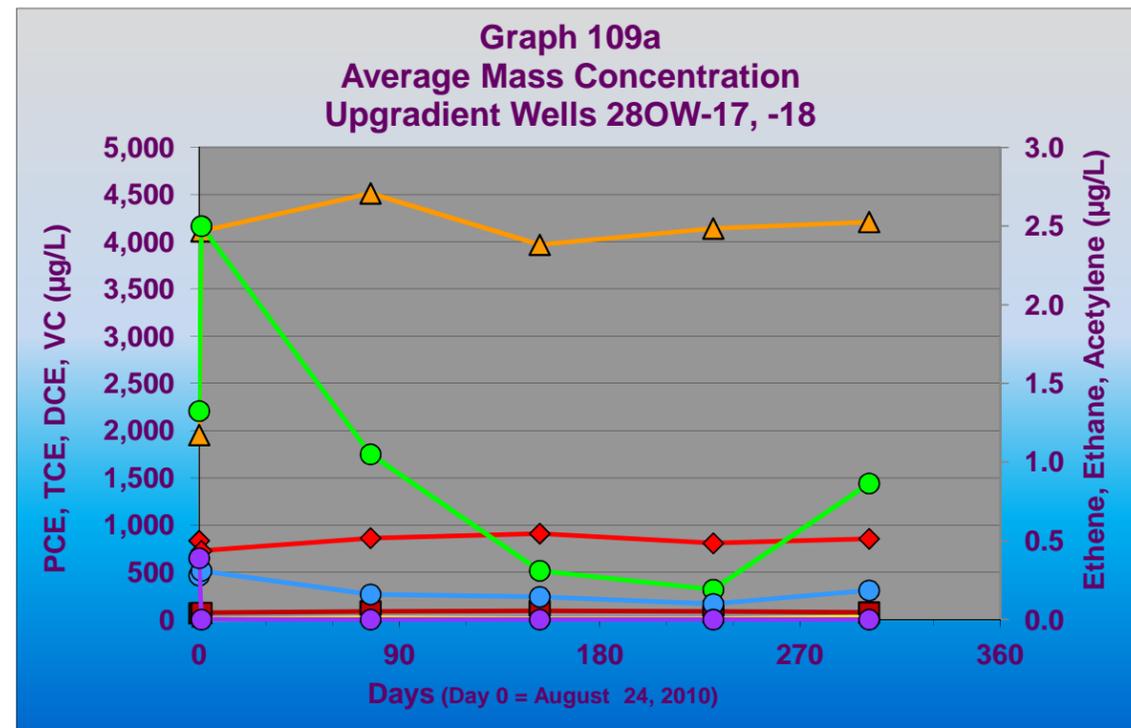


Graphs of Ethenes and Ethane Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field

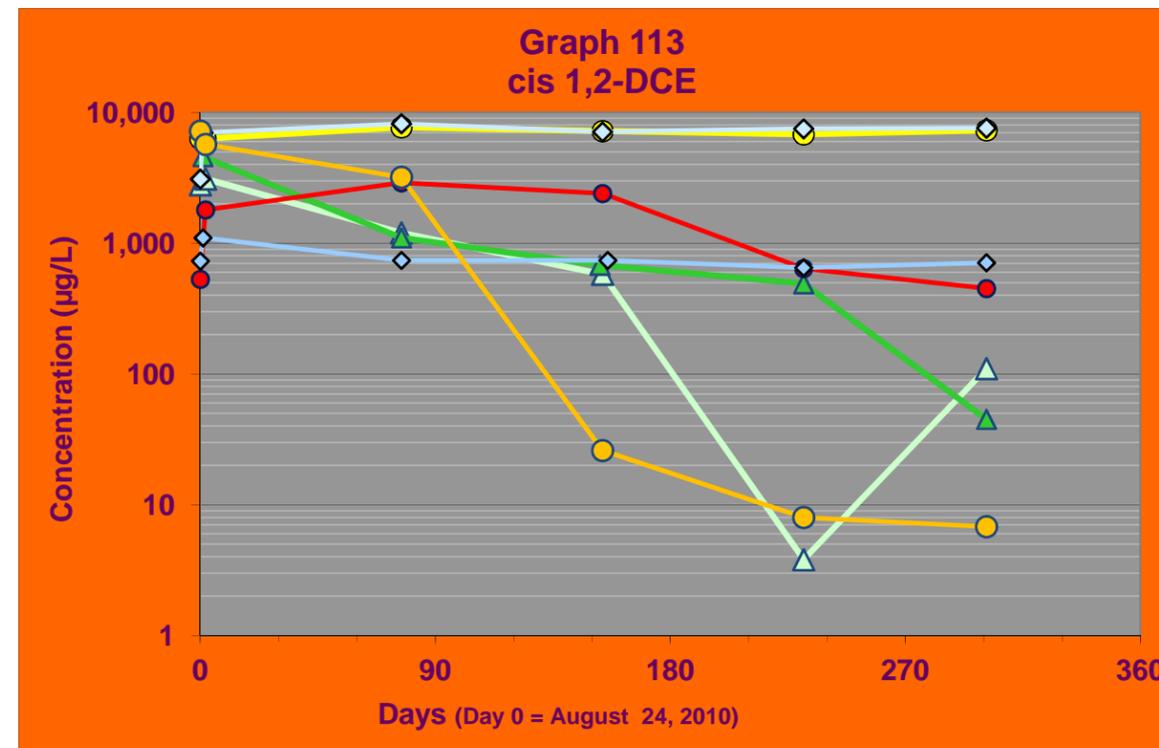
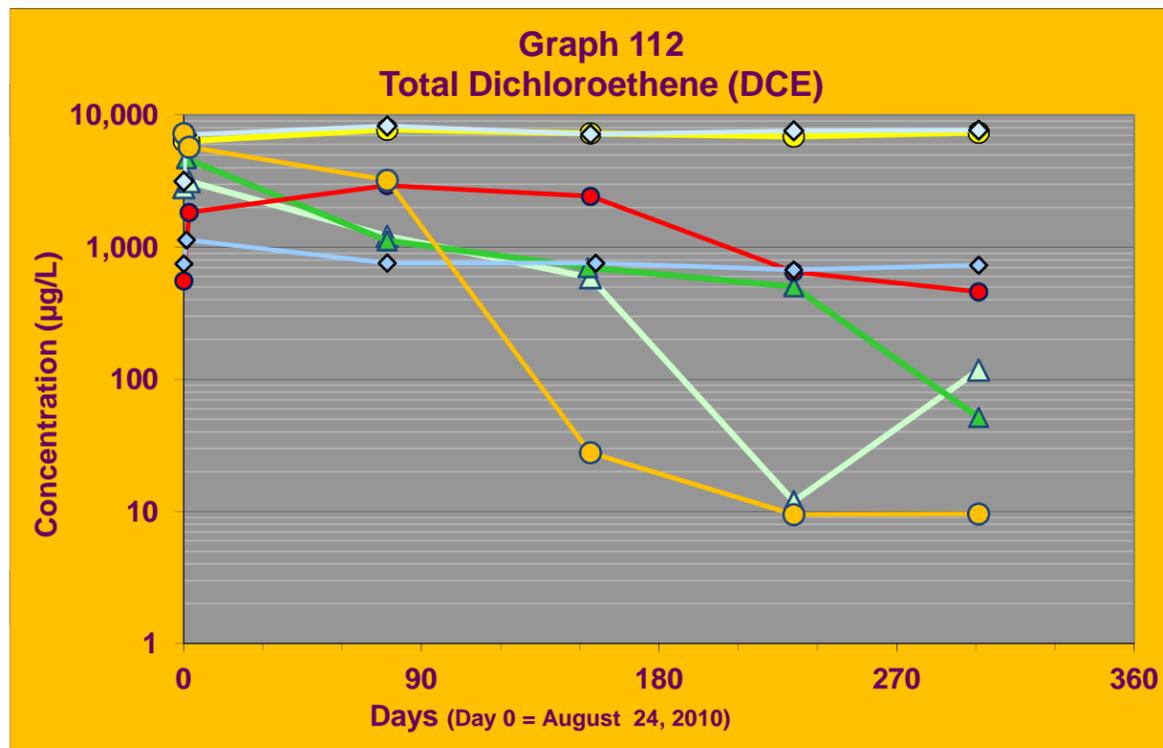
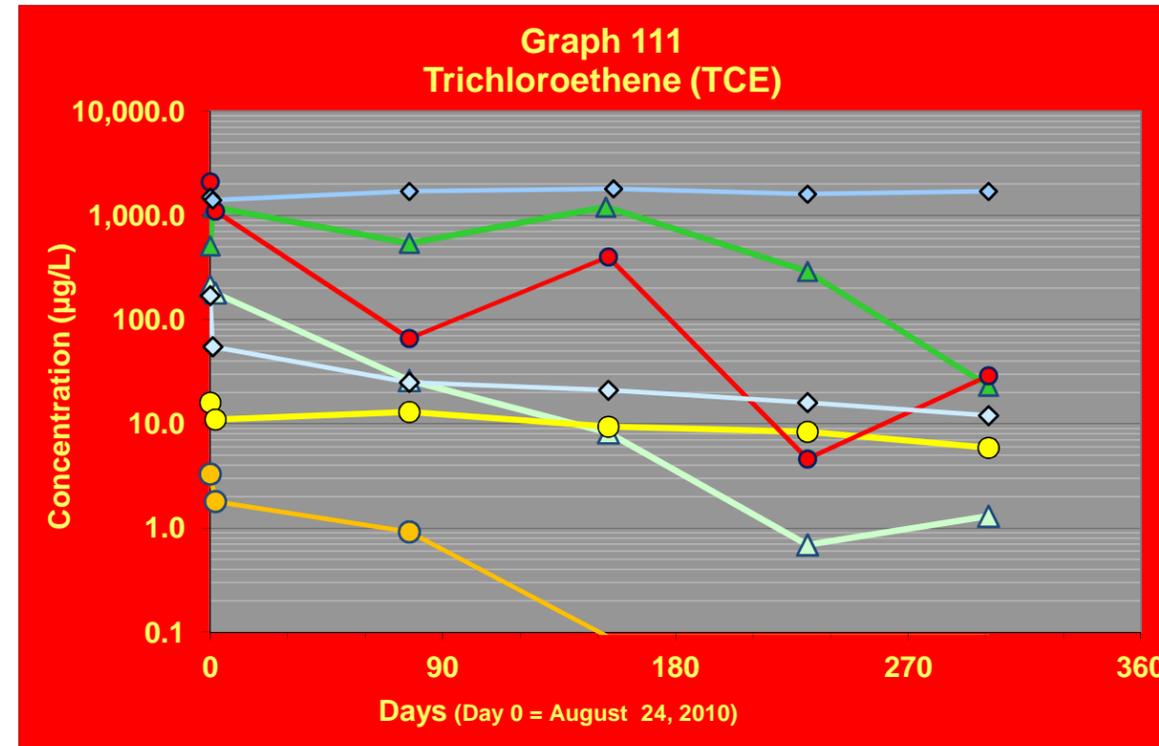
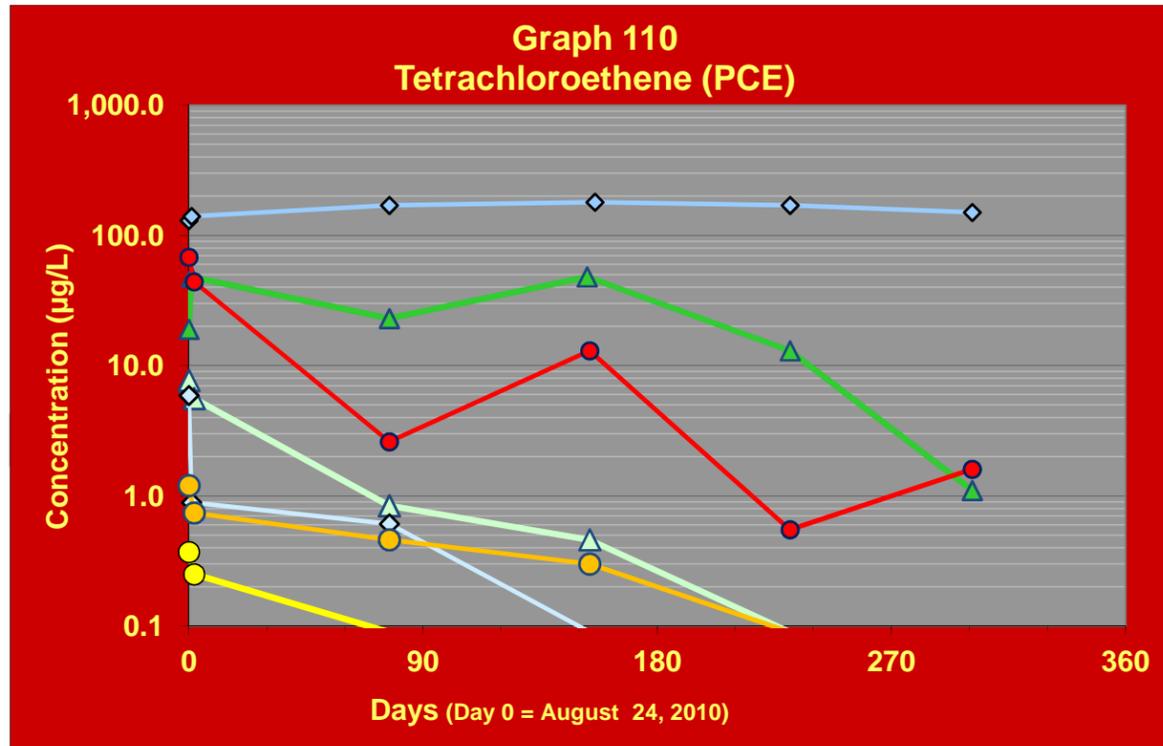


- PCE
- ◆ TCE
- ▲ Total DCE
- ▲ VC
- Ethene
- Ethane
- Acetylene
- × Total



Graphs of VOC Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field

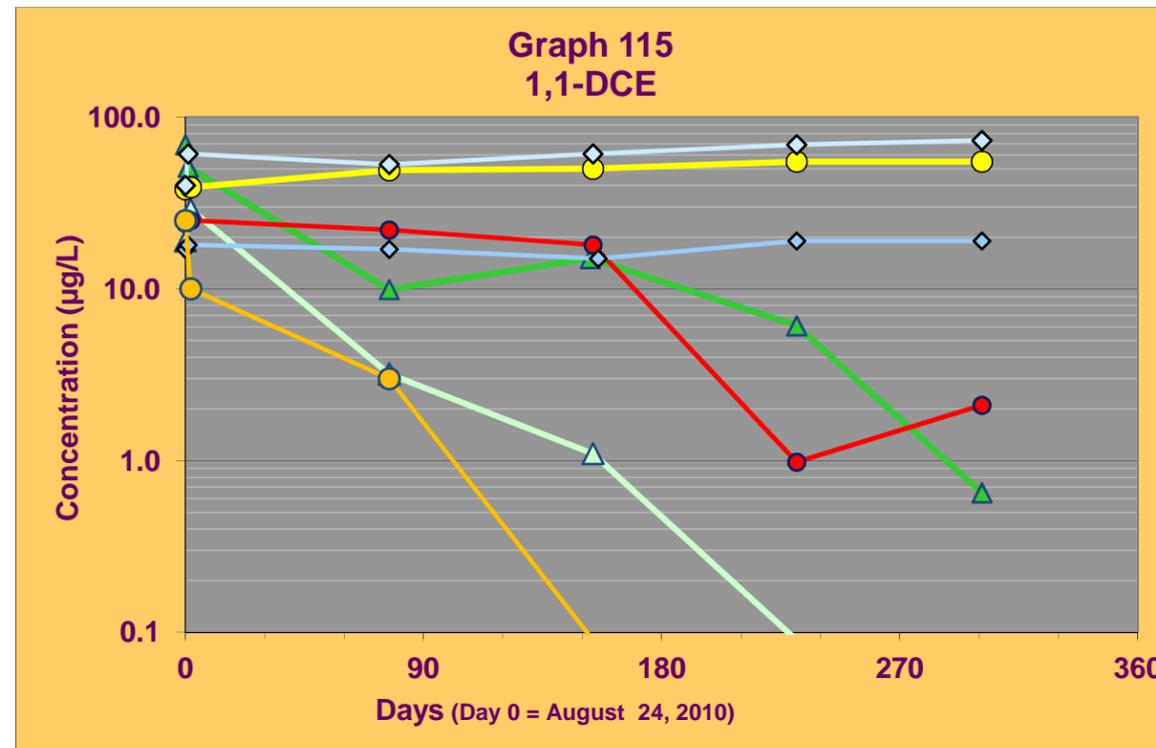
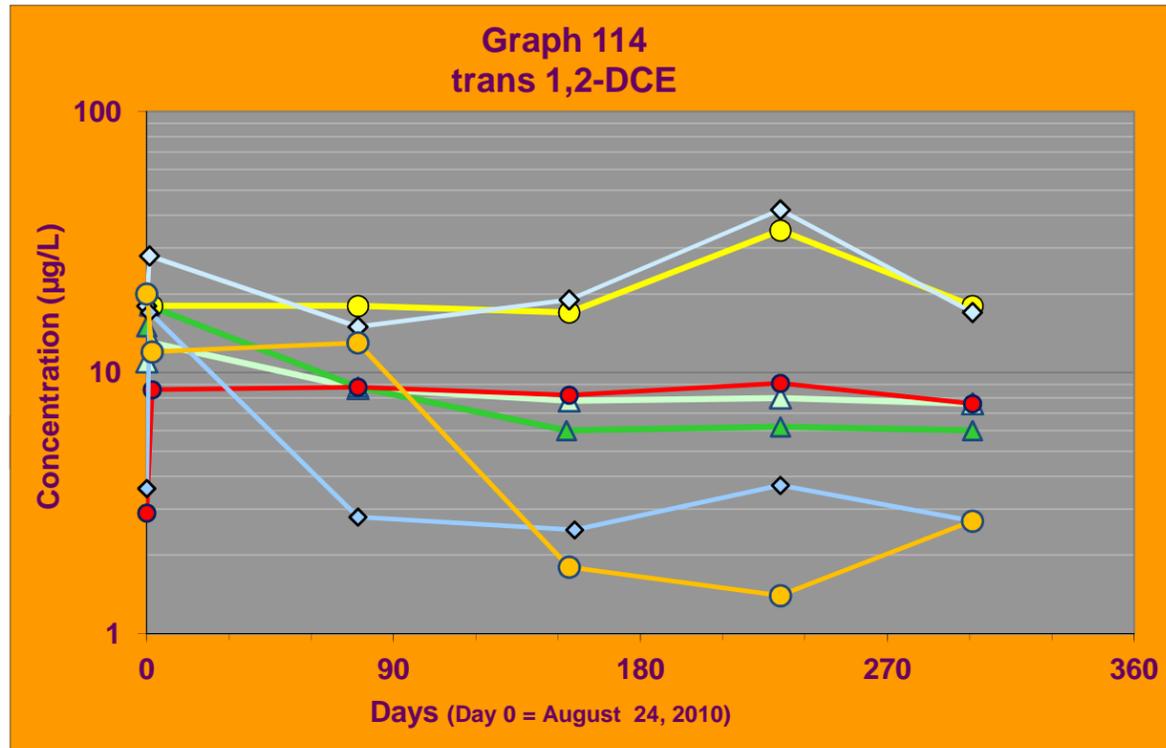


- ▲ 28OW-13
- ▲ 28OW-14
- 28OW-15
- 28OW-16
- ◇ 28OW-17
- ◇ 28OW-18
- W9-18

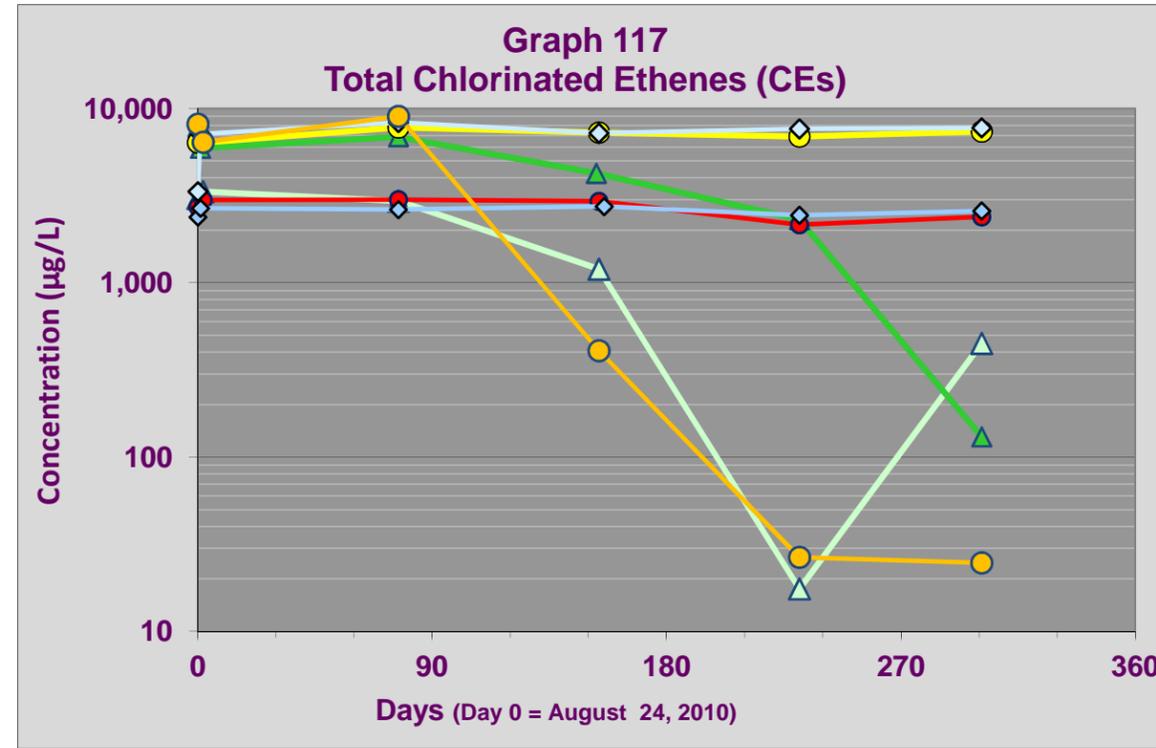
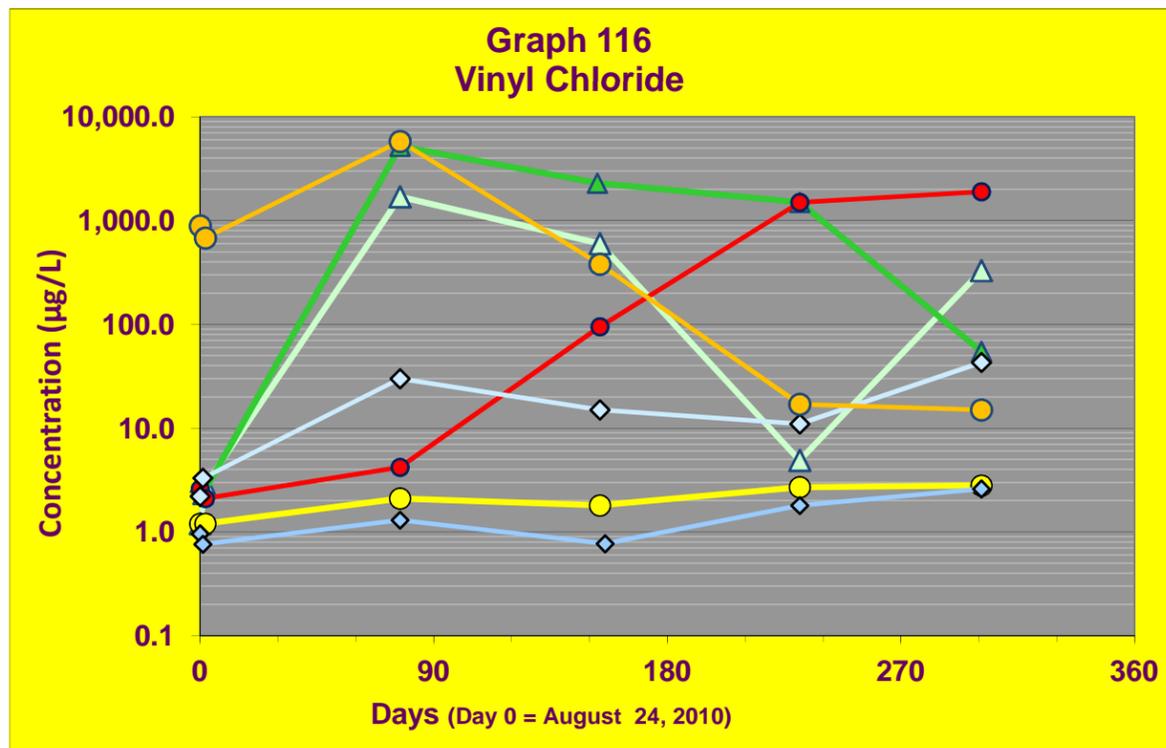
- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◇ Well Upgradient from Treatment Area

Graphs of VOC Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field



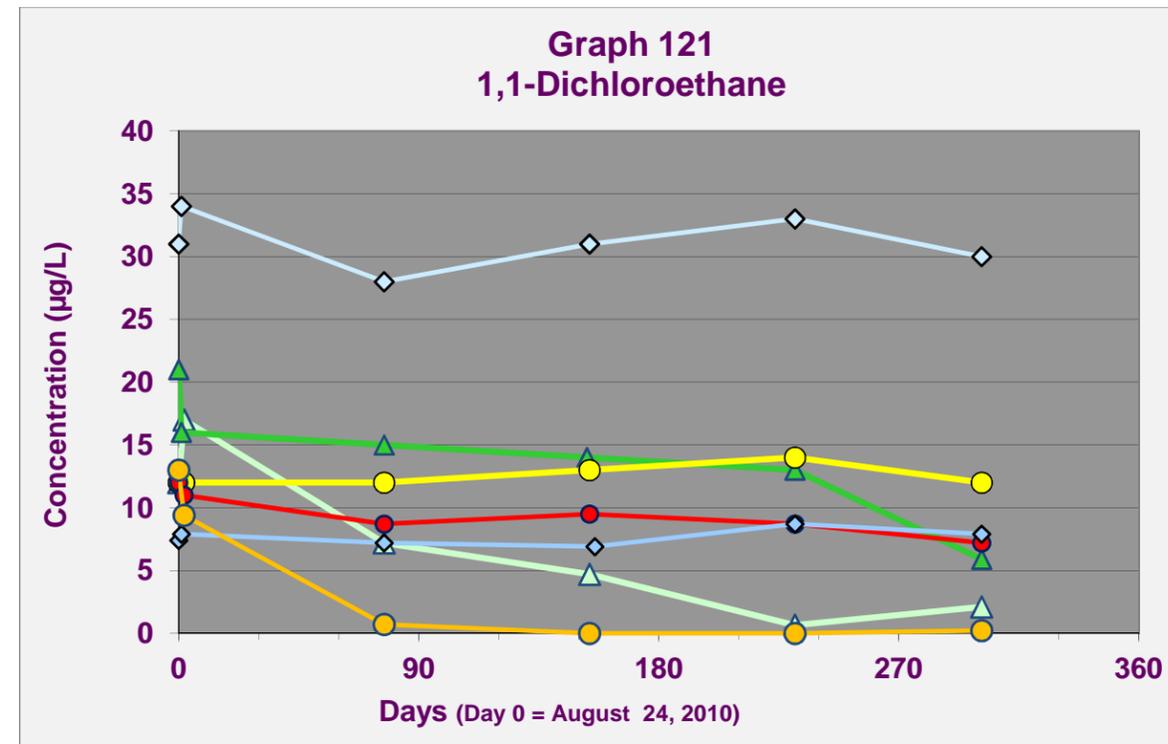
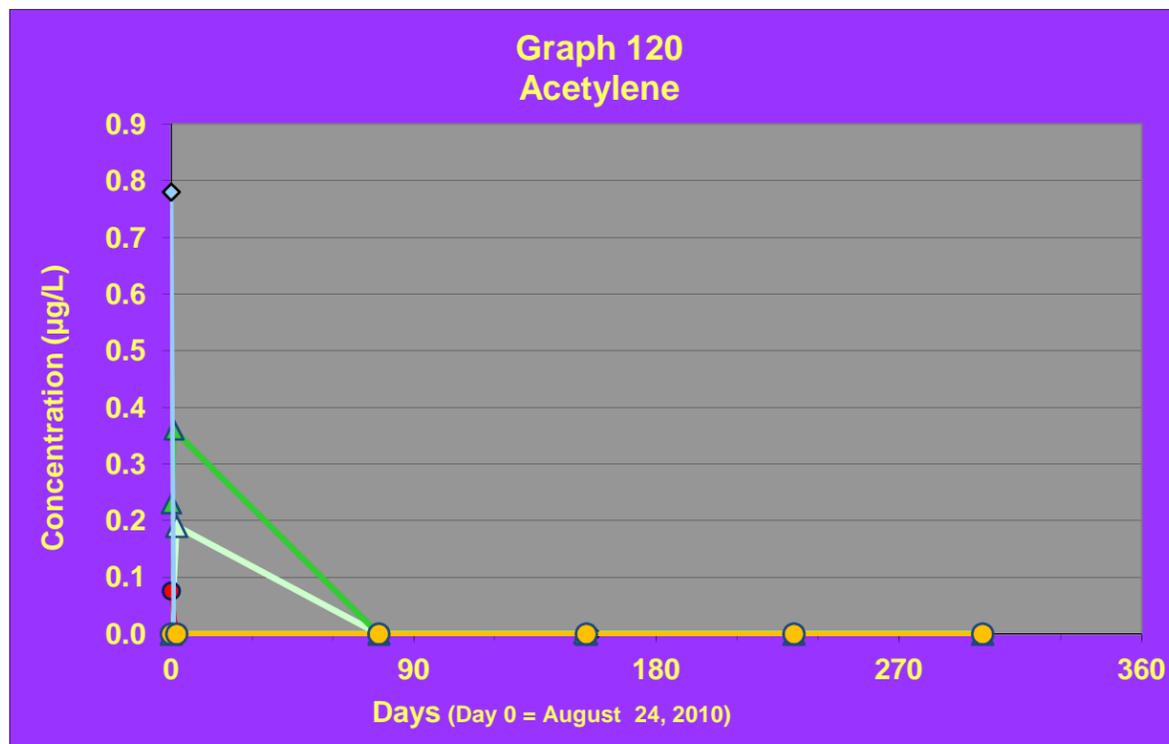
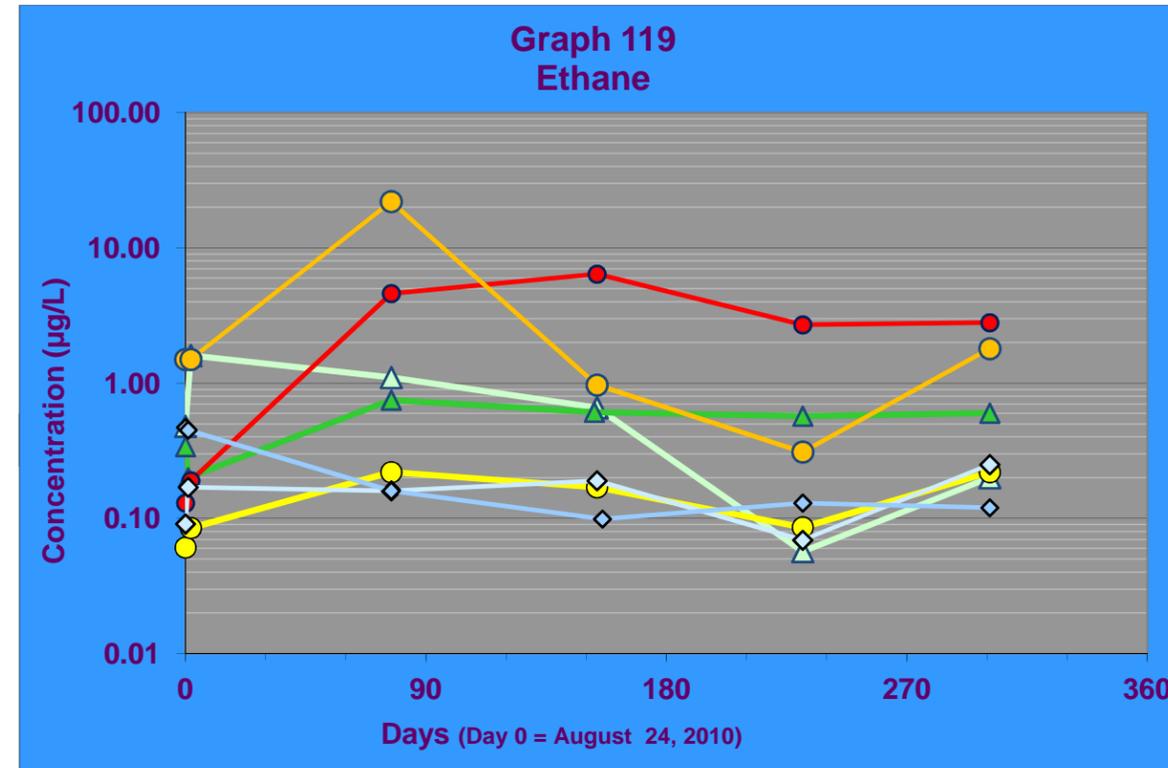
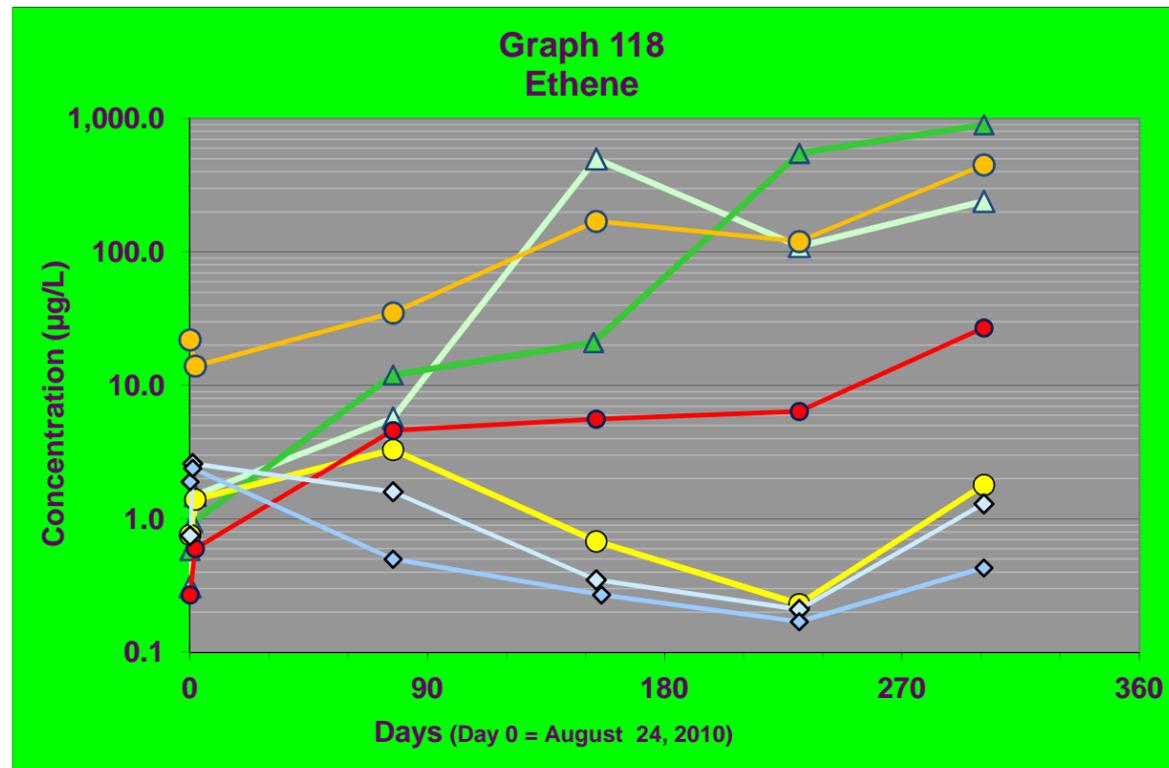
- ▲ 28OW-13
- ▲ 28OW-14
- 28OW-15
- 28OW-16
- ◆ 28OW-17
- ◆ 28OW-18
- W9-18



- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◆ Well Upgradient from Treatment Area

Graphs of VOC Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field

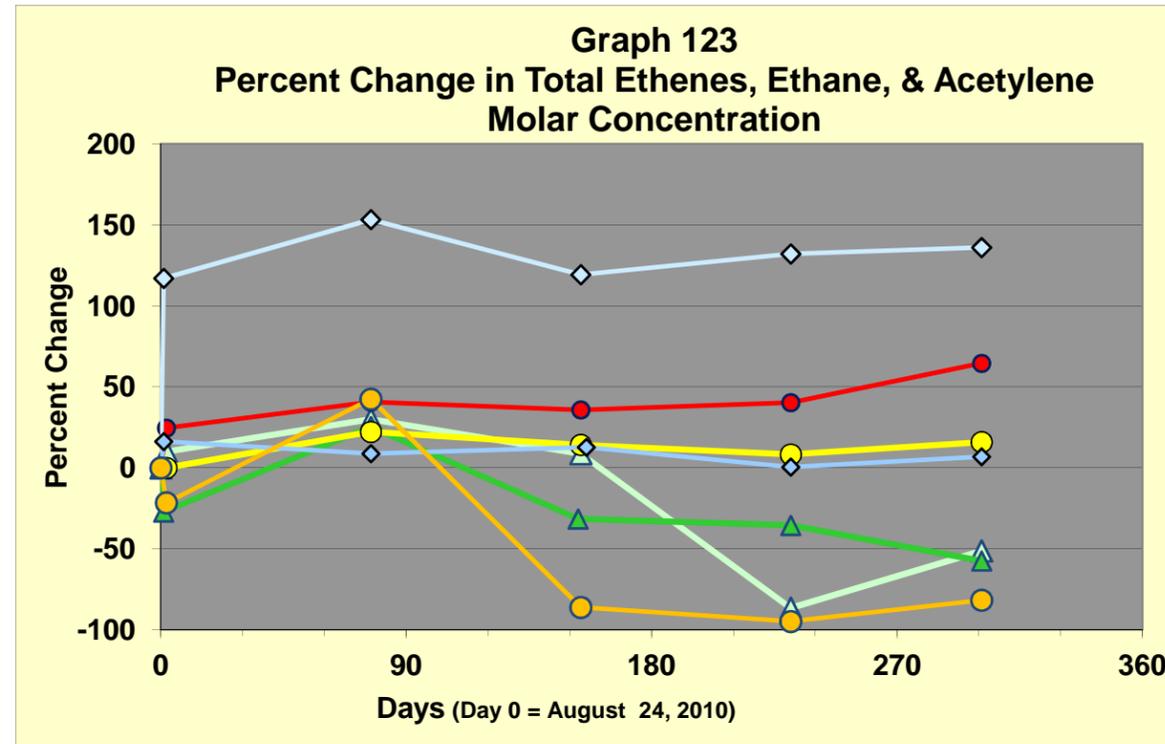
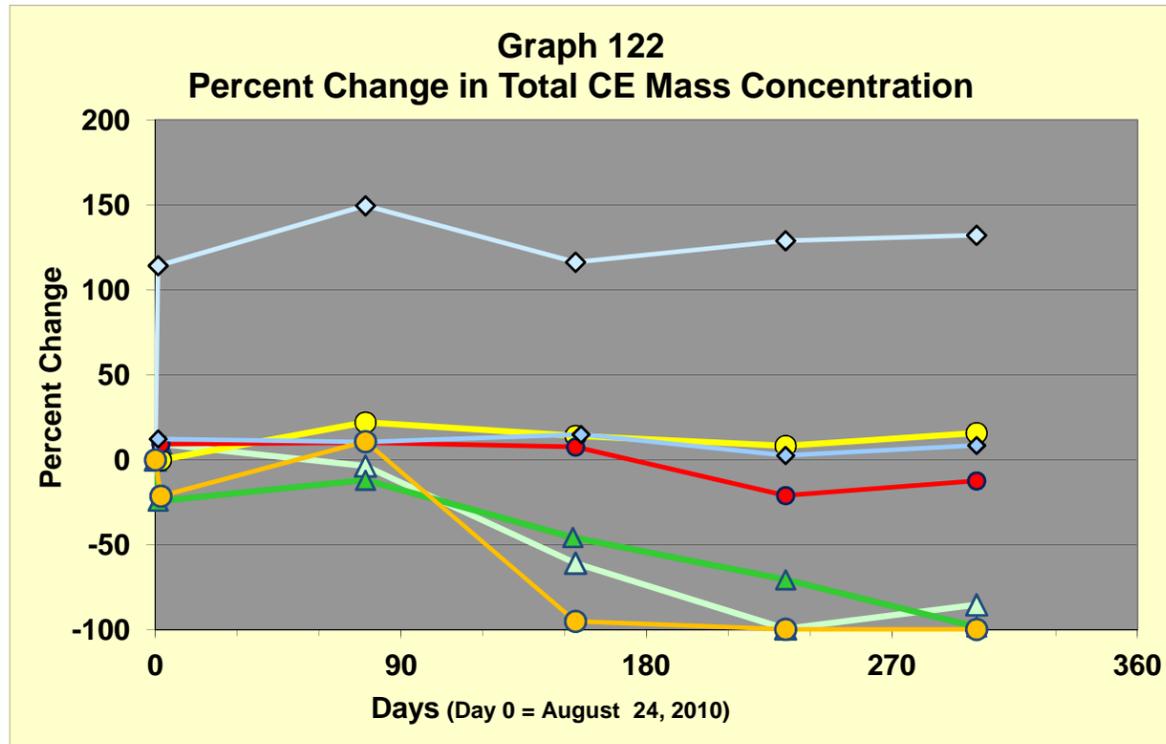


- △ 28OW-13
- ▲ 28OW-14
- 28OW-15
- 28OW-16
- ◇ 28OW-17
- ◇ 28OW-18
- W9-18

- ▲ Well Downgradient from Treatment Area
- Well Within Treatment Area
- ◇ Well Upgradient from Treatment Area

Graphs of VOC Concentrations in Groundwater - EHC Pilot Test

Well W9-18 Area, IR Site 28, Former NAS Moffett Field



- ▲ 28OW-13
- ▲ 28OW-14
- 28OW-15
- 28OW-16
- ◆ 28OW-17
- ◆ 28OW-18
- W9-18

▲ Well Downgradient from Treatment Area ● Well Within Treatment Area ◆ Well Upgradient from Treatment Area