

FINAL REPORT

In Situ Bioremediation of Chlorinated Solvent Source Areas with Enhanced Mass Transfer

ESTCP Project ER-0218

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Acronyms

AFB	Air Force Base
ARD	anaerobic reductive dechlorination
ATSDR	Agency for Toxic Substances and Disease Registry
B.E.T. TM	Bioavailability Enhancement Technology TM
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CMT	Continuous Multichannel Tubing
COD	chemical oxygen demand
DCE	trichloroethene
DNAPL	dense non-aqueous phase liquid
do	dissolved oxygen
DoD	Department of Defense
DOE	Department of Energy
DQO	data quality objective
dr	Decision Rule
EGDY	East Gate Disposal Yard
ERH	electrical resistance heating
ESTCP	Environmental Security Technology Certification Program
gpm	gallons per minute
HDC	high donor concentration
IDC	intermediate donor concentration
IFT	interfacial tension
INL	Idaho National Laboratory
ISB	in situ bioremediation
LDC	low donor concentration
MROD	Mount Rainier Ordnance Depot
MS/MSD	matrix spike/matrix spike duplicate
msl	mean sea level
MW	monitoring well
NAPL	non-aqueous phase liquid
NPL	National Priorities List
ORP	oxidation reduction potential
OSHA	Occupational Safety and Health Act
PCE	tetrachloroethene
PCR	polymerase chain reaction
PID	photoionization detector
POL	petroleum, oils, and lubricants
ppb	parts per billion
PPE	personal protective equipment
PVC	polyvinyl chloride

QA	quality assurance
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
RPD	relative percent difference
SERDP	Strategic Environmental Research and Development Program
TAN	Test Area North
TCA	1,1,1-trichloroethane
TCE	trichloroethene
TDP	Technology Demonstration Plan
T-RFLP	terminal restriction fragment length polymorphism
UIC	underground injection control
USACE	United States Army Corps of Engineers
UWRL	Utah Water Research Laboratory
VC	vinyl chloride
VFA	volatile fatty acid
VOA	volatile organic analysis
VOC	volatile organic compound
WAC	Waste Acceptance Criteria
WDOE	Washington Department of Ecology

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Executive Summary

Cleanup of chlorinated solvent sources in groundwater is often considered technically (or economically) impracticable because of their density and hydrophobicity, often compounded by subsurface heterogeneity. As a result, many sites have resorted to pump and treat or other containment technologies. Operations and maintenance costs of such systems become very large over time, however, because of the longevity of the subsurface sources, and these costs have become a large proportion of Department of Defense (DoD) environmental budgets.

While significant progress has been made in addressing solvent source areas, parties responsible for cleaning up sites with chlorinated solvent residual source areas in ground water are still faced with several technologies with significant capital costs, secondary waste streams, the involvement of hazardous materials or energy, and the potential for additional worker or environmental exposure. A more ideal technology would involve lower capital costs, would not generate secondary waste streams, would be non-hazardous to workers and the environment, would destroy contaminants in situ, would be low maintenance, and would minimize disturbance of the site.

While bioremediation satisfies all of the characteristics of an ideal technology listed above, it has traditionally been viewed as very passive with respect to source area remediation. That is, conventional wisdom suggests that bioremediation is limited by the rate at which nonaqueous contaminants dissolve or diffuse to where bacteria can degrade them. If that were true, bioremediation would still have all the benefits of an in situ technology regarding low capital cost, lack of secondary waste streams, low maintenance, minimal site disturbance, etc., but would not be much different than pump-and-treat in terms of cleanup times. Recent advances have shown however, that mass transfer rates of chlorinated solvents from the nonaqueous phase to the aqueous phase (where they are bioavailable) can be substantially increased during bioremediation.

This report provides the demonstration results for enhanced mass transfer of chloroethenes from dense non-aqueous phase liquid (DNAPL) to groundwater during in situ bioremediation (ISB) at the Fort Lewis Logistics Center East Gate Disposal Yard (EGDY). Enhanced mass transfer can occur as a direct result of biological anaerobic reductive dechlorination (ARD), or simply due to the physicochemical interaction of the electron donor itself and the nonaqueous contaminant(s). Increased mass transfer from DNAPL to groundwater through the latter mechanism by addition of certain electron donors, such as sodium lactate or whey powder, has been demonstrated to increase contaminant bioavailability and thereby rates and extents of biological degradation via ARD in both laboratory and field-scale studies (U.S. patents 6,783,678; 7,045,339; and 7,141,170). This technology is referred to as Bioavailability Enhancement Technology™, or B.E.T.™. This demonstration provided rigorous documentation of the electron donor (whey) concentration-dependence of enhanced mass transfer of chlorinated solvents in a source area for the first time in a field study. It was also observed that ARD occurred concurrently with the enhanced mass transfer and resulted in rapid source strength reduction.

Two hydraulically isolated treatment cells, each consisting of a network of monitoring wells, an injection well, and an extraction well, were installed at the EGDY. One treatment cell was located on the fringe of the DNAPL source area (Treatment Cell 1) and the other was located within the DNAPL source area (Treatment Cell 2). Two injection strategies were applied to each treatment cell. For Treatment Cell 1, the first injection strategy was high concentration (10%) whey powder injections and the second strategy was low concentration (1%) whey powder injections. For Treatment Cell 2, the first injection strategy was the low concentration (1%) injections and the second strategy was the high concentration (10%) injections. The results of the two injection strategies were compared for each treatment cell.

Previous laboratory studies demonstrated that abiotic whey solutions increase effective solubility (i.e., enhance mass transfer) of trichloroethane (TCE) as a linear function of the dissolved organic matter concentration in the range of 0% to 6% (by weight) whey powder concentration (Macbeth et al., 2006; Macbeth, 2008). From 6% to 10% whey powder concentrations, the solubility increases at a slower rate. Based on these studies, it was expected that at lower concentrations, enhanced mass transfer would be achieved primarily due to mechanisms related to the biological anaerobic reductive dechlorination stimulated by the electron donor. At high concentrations, however, it was anticipated that mass transfer would be enhanced to a greater extent due to physicochemical interactions between the electron donor solution and nonaqueous contaminant mass that exists in the source area either as a nonaqueous liquid, or as sorbed mass. Comparison of the demonstration results in each treatment cell during injection of low and high whey concentrations facilitated quantification of the relative difference of the enhanced mass transfer mechanisms both within and downgradient of the DNAPL source area.

Three statistical comparisons were made based on the demonstration results in order to understand whether enhanced mass transfer occurred during bioremediation of the DNAPL source area at Ft. Lewis, and the relative importance of the reductive dechlorination-based mechanisms versus the electron donor solution-based mechanisms. The first statistical comparison was the aqueous concentrations observed under low concentration whey injection conditions and baseline. This was used to determine the extent to which the reductive dechlorination-based mechanisms enhanced mass transfer. The second comparison was high concentration whey injections relative to baseline. This evaluated the extent of mass transfer due to all mechanisms. The third comparison was the high whey concentrations relative to the low concentrations. This allowed determination of the extent of enhanced mass transfer due solely to the electron donor solution-based mechanisms.

A series of four tracer tests was performed in the treatment cells to ensure that both the horizontal and vertical distribution of electron donor solution would be adequate. New injection and extraction wells were installed based on the early tests in order to improve the ability to distribute injected fluids. This was successful, facilitating excellent tracer distribution in the final test throughout both cells.

During baseline sampling of the treatment cells, it was found that Treatment Cell 2 had significantly higher concentrations of trichloroethene (TCE) and dichloroethene (DCE) than Treatment Cell 1, which was determined to be on the fringe of the source area. For this reason, the statistical comparisons discussed above were focused on Treatment Cell 2. Once whey injections began, iron- and sulfate-reducing conditions were established very quickly, and reductive dechlorination of TCE to DCE was rapid and complete. An initial drop in pH due to the whey injections delayed the onset of methanogenic conditions and further dechlorination of the DCE to vinyl chloride (VC) and ethene. This turned out to be beneficial for purposes of the demonstration, however, because once VC and ethene production became significant as pH increased near the end of the test, the mass balance was lost (likely due primarily to volatilization) and enhanced mass transfer would have been difficult to quantify.

The three statistical comparisons demonstrated that volatile organic compound (VOC) molar concentrations were increased at the 95% confidence level for two of the three scenarios evaluated. Specifically, VOC molar concentration increases were statistically significant from 10% electron donor injections relative to baseline conditions, and from 10% relative to 1% electron donor injection conditions. In other words, the Treatment Cell 2 results conclusively demonstrated that at 10% whey injection concentrations, the B.E.T.[™] process significantly enhanced mass transfer. While some increases appeared to occur for 1% electron donor injections relative to baseline conditions, these increases could not be considered statistically consistent based on the analysis.

The results in Treatment Cell 2 allowed quantification of the potential for enhanced mass transfer for a high-concentration whey solution, and facilitated comparison to that for the lower concentration. The factor of increase in aqueous chloroethene concentrations from baseline to 10% whey injections ranged from 1.8 to 4.2, with only one sampling location showing an increase less than a factor of 2.4, and four locations were 3.0 or greater. These increases greatly exceeded those observed during the 1% injections, even though the extent of dechlorination was constant for the data used in the analysis (i.e., dechlorination was complete to cis-DCE, but little VC or ethene production had begun yet). In fact aqueous concentrations during 10% injections increased by factors ranging from 1.8 to 2.5 in Treatment Cell 2 as compared to those during 1% injections.

Further demonstrating the importance of whey concentration for enhanced mass transfer was the strong correlation between chemical oxygen demand (which was used as a surrogate for the total electron donor concentration) and enhanced mass transfer factors (increases of aqueous VOC concentrations). This correlation was evident not only for the 10% whey injections, but also for the 1% injections. These results clearly confirmed not only that chloroethene mass transfer to the aqueous phase was enhanced during biostimulation in the Treatment Cell 2 source area, but also that the extent of enhanced mass transfer was a strong function of electron donor concentration. That is, the enhanced mass transfer that occurred due to abiotic interactions of the high concentration electron donor solution with the source material was significantly greater (a factor of 1.8 to 2.5 greater) than that due to the biological reductive dechlorination process alone.

The demonstration was greatly aided by the addition of a row of flux monitoring wells installed by the Army downgradient of the treatment cells. Monitoring of chloroethenes in these wells revealed the impact of B.E.T.TM implementation on downgradient contaminant flux. Baseline concentrations in these wells were measured in July 2005, immediately after the initial whey injections in the treatment cells. A dramatic change occurred in the data collected in November 2005, 3 months after 10% whey injections began in Treatment Cell 1. Concentrations downgradient of Treatment Cell 1 increased by a factor of 3 to 8, while total chloroethene concentrations downgradient of Treatment Cell 2 changed only by a factor of 0.8 to 1.3. In other words little or no change in aqueous concentrations was observed downgradient of the 1% whey injections in Treatment Cell 2, although previously the highest concentrations were observed there. These results suggested that while little residual source was present in Treatment Cell 1, the high concentration whey solution encountered source material as it migrated beyond Treatment Cell 1 to the downgradient wells. The increased aqueous concentrations resulting from the 10% whey solution were consistent with the increase of solubility by a factor of 6 measured by Macbeth et al. (2006) in abiotic column studies apparently due to the dissolved organic matter in the whey solution.

The injection concentrations in the two treatment cells were reversed in November 2005. When the downgradient wells were sampled again in January 2006, the distribution of chloroethenes in downgradient wells had undergone a complete reversal from the November 2005 data. The highest concentrations were measured downgradient from Treatment Cell 2, and the lowest concentrations were measured downgradient from Treatment Cell 1, including wells FX3-02 and FX3-03, which only 1 month earlier had the highest concentrations in the transect. In fact, chloroethenes concentrations at one well downgradient from Treatment Cell 2 were a factor of 16 higher than baseline and a factor of more than 8 relative to December. Concentrations in two other wells increased in January by factors of 2.8 and 2.5 compared to December. This change in concentrations downgradient from Treatment Cell 2 of a factor almost 3 to greater than 8 from December to January is nearly identical to the change observed downgradient from Treatment Cell 1 in November 2005 compared to the baseline. All of these results are again remarkably similar to the column study results of Macbeth et al. (2006) for abiotic 10% whey solutions.

The enhanced mass transfer due to high concentration whey solution injections can be summarized both for observation points within the treatment cells and as an overall effect based on downgradient observation points. Within the treatment cells, mass transfer appeared to increase somewhat for 1% whey injections relative to baseline, but the increase was not found to be statistically significant at the 95% confidence level. For 10% whey injections, mass transfer was observed to increase within Treatment Cell 2 by a factor ranging from 1.8 to 4.2, and was statistically significant. Although these data are based on point measurements within the cell, this increase is consistent with mass transfer enhancements observed in the ER-0008 project at Dover Air Force Base (AFB), where increases of total mass discharge from the treatment cell following bioaugmentation in a tetrachloroethene (PCE) source zone ranged from about 2 to 4.5 (NAVFAC 2007). In the downgradient observation points (perhaps more consistent with a total mass discharge measurement), mass transfer was enhanced by a factor ranging from 3 to greater than 8 due to 10% whey injections, while increases due to 1% whey injections were less than a factor of

2. When evaluating the potential mechanisms enhancing mass transfer in the demonstration, at least three points should be considered. First, the pattern of enhanced mass transfer observed following whey injections can be accounted for entirely by the previously documented enhanced solubilization of TCE by abiotic whey solutions over a range of concentrations due to its dissolved organic matter. Second, the extent of reductive dechlorination (complete conversion of TCE to DCE with little vinyl chloride or ethene) was the same for both 1% and 10% whey injections. Third, molecular data collected during the demonstration as part of the ER-0318 project (which is reported separately) reveal that *Dehalococcoides spp.* DNA and RNA measurements were essentially indistinguishable for the different injection concentrations, suggesting that these bacteria did not grow more, nor were they more active for the higher whey concentrations. This implies that carbon and hydrogen were not limiting under either injection condition. Based on these three lines of evidence, it appears that the mechanism most responsible for the factor of 3 to 8 total mass discharge enhancement from the treatment cells undergoing 10% whey injections was the abiotic enhanced solubilization of TCE due to interaction with the dissolved organic matter in the whey.

The data collected from the downgradient wells provided a powerful, incontrovertible tool to document the enhanced mass transfer caused by the 10% whey injections compared to the 1% injections. However, they provided an additional benefit never envisioned in the original demonstration plan. These wells provided an additional 4 months of data to document long-term effects on downgradient mass flux due to the enhanced mass transfer and accelerated mass removal that resulted in the source area. The results demonstrated that flushing the source area with the 10% whey solution for only a few months not only dramatically increased mass transfer in the short term, it also achieved sufficient mass removal to have a major long-term effect on downgradient flux from the source area. In fact, just two months after the highest aqueous concentrations of chloroethenes for the entire demonstration were observed at FX3-03, concentrations were observed to decrease to just 14% of baseline concentrations in that location.

Furthermore, concentrations in FX3-03 in the last three sampling events (April, May, and June 2006) ranged from just 2 to 6% of baseline concentrations. In other words, downgradient mass flux from Treatment Cell 1 was decreased by 94 to 98% after only 8 months of whey injections. Even more impressive is that in seven of the eight downgradient wells, mass flux based on total chloroethene concentrations had decreased by a factor of 94 to 99% in May 2006. The only well where this was not observed was FX3-08, which was at the far southern end of the downgradient wells, and might very well have been influenced by chloroethene concentrations from the greater plume surrounding non-aqueous phase liquid (NAPL) Area 3 in addition to what was happening in Treatment Cell 2. Some increase in concentrations was observed in the other wells downgradient from Treatment Cell 2 in June, but it is not clear whether this was due to rebound in that part of the source area, or a similar influence from the greater contaminant plume to the south of NAPL Area 3.

This demonstration of the B.E.T.TM process represents the first time the phenomenon of enhanced mass transfer in chlorinated solvent source areas as a function of the concentration of whey injection solutions has been thoroughly documented at the field scale. These results far

exceeded expectations, and demonstrate the potential impact the enhanced mass transfer during bioremediation can have not only on source areas, but on downgradient plumes as well. It is important to note that the rapid effect on downgradient contaminant flux observed at the Ft. Lewis site might be a best-case scenario because of the high ambient groundwater flow rates, but having a similar effect in 1 to 2 years rather than the few months observed here would still be an extremely beneficial result at most sites. An important cautionary note for this technology is that the higher mass transfer rates will likely increase volatilization significantly when conversion of parent compounds to vinyl chloride and ethene occurs. This is a concern for shallow aquifers that have a potential for a complete exposure pathway for vapors to receptors above the treatment zone.

The costs of the demonstration were carefully tracked in order to provide a realistic estimate of the cost of implementing the technology for chlorinated solvent source area cleanup. The model site used was the NAPL Area 3 source area at Ft. Lewis. Based on a 3-year operations period, the total cost for cleanup of the 0.5-acre site was estimated to be \$0.9M using B.E.T.TM. On a unit basis, this equates to \$56/yd³. These costs were compared to the actual cost of cleaning up this same source area using electrical resistance heating (ERH). Immediately following the demonstration, ERH was applied to the 0.5-acre site at a cost of \$5M, or \$313/yd³.

These costs were then compared to cleanup costs reported in the Strategic Environmental Research and Development Program (SERDP) Source Depletion Decision Support System (version 1.5.6) for bioremediation, thermal remediation, chemical oxidation, and surfactant/cosolvent remediation. The B.E.T.TM cost projection based on the demonstration results was between the 50th and 75th percentiles for bioremediation unit costs in that database. The ERH unit cost, however, exceeded the maximum of the six unit costs in the database for thermal remediation. It is not clear why this was the case. The B.E.T.TM unit costs were significantly lower than those for any of the other technologies in the database.

1. INTRODUCTION

This report provides the demonstration results for enhanced mass transfer of chloroethenes from dense non-aqueous phase liquid (DNAPL) to groundwater during in situ bioremediation (ISB) at the Fort Lewis East Gate Disposal Yard (EGDY). Enhanced mass transfer can occur as a direct result of biological anaerobic reductive dechlorination (ARD), or simply due to the physicochemical interaction of the electron donor itself and the nonaqueous contaminant(s). Increased mass transfer from DNAPL to groundwater through the latter mechanism by addition of certain electron donors, such as sodium lactate or whey powder, has been demonstrated to increase contaminant bioavailability and thereby rates and extents of biological degradation via ARD in both laboratory and field-scale studies (U.S. patents 6,783,678; 7,045,339; and 7,141,170). This technology is referred to as Bioavailability Enhancement Technology™, or B.E.T.™. This demonstration provided rigorous documentation of the electron donor (whey) concentration-dependence of enhanced mass transfer of chlorinated solvents in a source area for the first time in a field study. It was also observed that ARD occurred concurrently with the enhanced mass transfer and resulted in rapid source strength reduction.

Two hydraulically isolated treatment cells, each consisting of a network of monitoring wells, an injection well, and an extraction well, were installed at the EGDY. One treatment cell was located on the fringe of the DNAPL source area (Treatment Cell 1) and the other was located within the DNAPL source area (Treatment Cell 2). Two injection strategies were applied to each treatment cell. For Treatment Cell 1, the first injection strategy was high concentration (10%) whey powder injections and the second strategy was low concentration (1%) whey powder injections. For Treatment Cell 2, the first injection strategy was the low concentration (1%) injections and the second strategy was the high concentration (10%) injections. The results of the two injection strategies were compared for each treatment cell.

Based on previous laboratory studies, it was expected that, at low concentrations, enhanced mass transfer would be achieved only due to mechanisms related to the biological ARD stimulated by the electron donor. At high concentrations, however, it was anticipated that mass transfer would be enhanced to a greater extent due to physicochemical interactions between the electron donor solution and nonaqueous contaminant mass that exists in the source area either as a nonaqueous liquid, or as sorbed mass. Comparison of the demonstration results in each treatment cell during injection of low and high whey concentrations facilitated quantification of the relative difference of the enhanced mass transfer mechanisms both within and downgradient of the DNAPL source area.

Three phases of activities were completed for each treatment cell during this demonstration, as follows:

- **Phase 1 – Equilibration.** Hydraulic characterization of the treatment cells was conducted.

- **Phase 2 – Baseline.** ARD performance indicators were collected to evaluate electron donor concentrations, redox conditions, geochemistry, and contaminant concentrations in each treatment cell without electron donor addition.
- **Phase 3 – Biostimulation and enhanced mass transfer demonstration.** ARD performance indicators were monitored under biostimulation conditions during both low and high concentration whey powder injections.

The remainder of Section 1 briefly discusses background information, objectives of this demonstration, regulatory drivers and stakeholder and end user issues. A description of the technology demonstrated is discussed in Section 2. The demonstration design is presented in Section 3. Section 4 contains the performance assessment. Sections 5 and 6 address cost assessment and implementation issues, respectively.

1.1 Background

Chlorinated solvents are the most common class of contaminants in groundwater at hazardous waste sites in the United States. In 1993, the Agency for Toxic Substances and Disease Registry (ATSDR) compiled a list of the top 25 contaminants detected at hazardous waste sites on the National Priorities List (NPL). The ATSDR ranking identified eight of the top 20 contaminants as chlorinated solvents and their intrinsic degradation products, including two of the top three (Pankow and Cherry 1996). The ranking was updated by the ATSDR on their Internet site based on 1996 data with similar results. Of particular significance is the identification of trichloroethene (TCE) and tetrachloroethene (PCE) as the first and third most common contaminants at NPL sites in both surveys. Not surprisingly chlorinated solvents are also the most common contaminants at U. S. Department of Defense (DoD) sites.

The prevalence of chlorinated solvents is due both to their widespread use and to their longevity in the environment. Their longevity is partly due to the hydrophobic nature that makes them such good solvents, as well as their relatively oxidized states that prevent them from serving as electron donors for microorganisms. At many sites, the subsurface solvent sources referred to as DNAPLs are present. DNAPLs are hydrophobic liquids with a density greater than water. Pertinent to their longevity is the fact that the solubility of the common chlorinated solvents (PCE, TCE, 1,1,1-trichloroethane [TCA], and carbon tetrachloride) ranges from about 200 to 1,400 mg/L at 25°C (Sale 1998). These relatively low solubilities play a significant role in limiting mass transfer to the aqueous phase once the solvents contaminate ground water. Interphase mass transfer (dissolution) of a solvent non-aqueous phase liquid (NAPL) into ground water is governed by the difference between the aqueous solubility of the compound and the actual concentration in ground water (Sale [1998] provides an excellent discussion of fundamental interphase mass transfer from DNAPL). At typical ground water velocities, the aqueous concentration of the solvent in the immediate vicinity of the ground water-NAPL interface approaches the solubility within the first few centimeters of flow along the interface (Bouwer and McCarty 1983). Because ground water flow is generally laminar, very little mixing of the water near the interface occurs with water even a few centimeters from the interface.

The lack of mixing characteristic of laminar flow has at least two important implications. First, it explains why ground water concentrations of chlorinated solvents greater than 10% of their solubility are rarely measured, even at contaminated sites with large quantities of DNAPL. Second, the attainment of concentrations approaching solubility within a few centimeters of ground water flow along the interface effectively prevents mass transfer out of the DNAPL for the remainder of flow along the interface. For example, if ground water flows across a pool of DNAPL (or through an area of residual saturation) several meters long in the direction of flow, mass transfer into the aqueous phase will be insignificant along all but the first few centimeters of the flow path. The result is that chlorinated solvents persist in ground water for many decades, or perhaps even centuries.

Cleanup of chlorinated solvent sources in ground water is often considered technically (or economically) impracticable because of their density and hydrophobicity, often compounded by subsurface heterogeneity. As a result, many sites have resorted to pump and treat or other containment technologies. Operations and maintenance costs of such systems become very large over time, however, because of the longevity of the subsurface sources discussed above. As noted historically on the Strategic Environmental Research and Development Program website.

*“...the operations and maintenance of engineered containment systems has become a large proportion of DOD environmental budgets, and these costs may continue long into the future. Technologies designed to remove subsurface sources of contaminants, particularly DNAPLs, have received tremendous recent interest. Several approaches have been developed and tested, including thermal treatment technologies, chemical oxidation, **bioremediation**, and enhanced physical removal (using cosolvents or surfactants, for example).” [Emphasis added]*

While significant progress has been made in addressing solvent source areas, parties responsible for cleaning up sites with chlorinated solvent residual source areas in ground water are still faced with several technologies with significant capital costs, secondary waste streams, the involvement of hazardous materials or energy, and the potential for additional worker or environmental exposure. A more ideal technology would involve lower capital costs, would not generate secondary waste streams, would be non-hazardous to workers and the environment, would destroy contaminants in situ, would be low maintenance, and would minimize disturbance of the site.

While bioremediation satisfies all of the characteristics of an ideal technology listed above, it has traditionally been viewed as very passive with respect to source area remediation. That is, conventional wisdom suggests that bioremediation is limited by the rate at which nonaqueous contaminants dissolve or diffuse to where bacteria can degrade them. If that were true, bioremediation would still have all the benefits of an in situ technology regarding low capital cost, lack of secondary waste streams, low maintenance, minimal site disturbance, etc., but would not be much different than pump-and-treat in terms of cleanup times. Recent advances have shown however, that mass transfer rates of chlorinated solvents from the nonaqueous phase to the aqueous phase (where they are bioavailable) can be substantially increased during bioremediation through B.E.T. TM (Sorenson, 2002; Song et al., 2002).

1.2 Objectives of the Demonstration

The overall objective of this demonstration is to show that facilitating enhanced mass transfer allows bioremediation to be applied to chlorinated solvent source areas in groundwater in a manner that realizes many of the benefits of more expensive and hazardous technologies, while retaining its benefits as a low cost, in situ technology. Specific performance objectives for each test scenario during each phase are provided in Section 3.

1.3 Regulatory Drivers

As discussed previously in Section 1.1, solubilities of the common chlorinated solvents (PCE, TCE, TCA, and carbon tetrachloride) range from about 200 to 1,400 mg/L at 25°C (Sale 1998). These solubilities exceed Federal Safe Drinking Water Act maximum contaminant levels (see Table 1-1) by five to six orders of magnitude. The persistence of chlorinated solvents in groundwater, their prevalence, and their solubilities far in excess of health-based levels drive the need for cost-effective remediation technologies.

Table 1-1. Safe Drinking Water Act Maximum Contaminant Levels for Ft. Lewis EGDY Contaminants of Concern.

Compound	Regulatory Limit (µg/L ¹)
TCE	5
cis-DCE	70
trans-DCE	100
VC	2
1: 40 Code of Federal Regulations (CFR) 141.61	

1.4 Stakeholders/End-User Issues

ISB is generally well-received by the regulators and the public for many reasons, including:

- **Low risks.** Since most or all of the contaminant treatment occurs in the soil or groundwater, risks to human health and the environment during implementation are low compared to ex situ technologies.
- **Low secondary waste generation.** Most of the contaminant treatment occurs on-site, with little off-site disposal of residuals required.
- **Minimal impacts during operations.** Very little infrastructure is required to implement and operate the technology, resulting in minimal disruption to businesses and residences.

- **Low cost.** ISB is typically less expensive when compared over project life cycles to more aggressive technologies.
- **Overall risk reduction.** This demonstration will help to determine the extent of DNAPL source reduction, and thereby the extent of reduction of risk to human health and the environment, achievable by ISB-ARD.

Potential risks posed by increased contaminant flux as a result of electron donor injections are mitigated by the concomitant increase in rates and extents of biological anaerobic reductive dechlorination. At the Idaho National Laboratory (INL) Test Area North (TAN) site, for example, increased contaminant flux following electron donor injections was evidenced by a rapid increase in ethene concentrations above the initial aqueous phase molar chloroethene concentrations (Sorenson, 2002; Song et al., 2002). This indicated rapid and complete dechlorination of all chloroethenes that partitioned out of the source, ultimately resulting in a net reduction in aqueous phase contaminant concentrations, as well as decreased mass in the nonaqueous phase.

In cases where a concern exists regarding the potential for increasing contaminant flux over a short time and distance, hydraulic control can be used. Another potential strategy is to establish favorable dechlorination conditions in the treatment zone using relatively low electron donor concentrations before proceeding to higher concentrations. This would allow the biological treatment zone to become established before mass transfer is maximized during high electron donor concentration injections. One outcome of this demonstration was to determine the extent to which increased downgradient contaminant flux might be a concern while implementing B.E.T.™.

Groundwater chemistry may be locally altered by implementing ARD; however the extent to which this occurs depends on the initial conditions. In highly contaminated aquifers where significant amounts of organic substrates are already present, the aquifer redox conditions are typically already anoxic and potentially methanogenic, which are required for ARD. Reduction of sulfate to hydrogen sulfide occurs, sometimes resulting in odorous water. These conditions are ameliorated downgradient as water from the treatment zone reverts to background water quality through dilution and dispersion. Water in the source zone should similarly return to background water quality after completion of treatment, provided upgradient water is relatively uncontaminated.

2. TECHNOLOGY DESCRIPTION

2.1 Technology Development and Application

Enhanced in situ bioremediation (ISB) for chlorinated ethene-contaminated groundwater using microbial reductive dechlorination has been well documented in published literature both in the laboratory (Parsons et al. 1984; Vogel and McCarty 1985; Fathepure and Boyd 1988; Freedman and Gossett 1989; DiStefano et al. 1991; deBruin et al. 1992; DiStefano et al. 1992; Ballapragada et al. 1997; Fennell et al. 1997; Carr and Hughes 1998) and in the field (Major et al 2002, Song et al 2002, Rahm et al 2006 (Sharma and McCarty 1996). Dechlorination-based source-zone restoration, however, has not been rigorously evaluated. Enhanced bioremediation in residual source zones is a particular application of the technology that has only recently been investigated in the laboratory (Yang and McCarty 2000 and 2002, Carr and Hughes 2000, and Cope and Hughes 2001 NRC 1994,), and in the field (Sorenson 2002, ARCADIS 2002, Bury and Miller 1993). Initially, there was concern regarding the potential toxicity of high contaminant concentrations on the microbial populations, but several studies have confirmed effective biological dechlorination at aqueous saturation PCE concentrations and high concentrations of TCE (NRC 1994; Carr and Hughes 1998; Sharma and McCarty 1996; Isalou et al. 1998; Nielsen and Keasling 1999). In fact, there has been some evidence that halo-respiring organisms might actually have a competitive advantage in environments of high PCE and TCE concentrations, such as NAPL source zones, where organisms normally competing with them for energy sources are not able to thrive (NRC 1994; Holliger et al. 1993; Holliger et al. 1998; Neumann et al. 1994; Scholz-Muramatsu et al. 1995).

Most importantly, recent research has demonstrated that rapid rates of biological dechlorination in NAPL-containing source areas can dramatically reduce the length of time that a NAPL will continue to be a source of chlorinated solvent contamination (Carr et al. 2000; Cope and Hughes 2001; NRC 1994). A combination of two processes is responsible for this observation in laboratory tests. First, the dechlorinating bacteria are capable of living in close proximity to the NAPL/water interface. Thus, their metabolic activity increases the driving force for mass transfer (i.e., the concentration gradient). Secondly, the metabolic products of dechlorination are less hydrophobic than the parent compounds and they partition more extensively to the aqueous phase. In recent laboratory studies conducted in glass-bead columns, Cope and Hughes (2001) observed a 16-fold increase in PCE removal from a NAPL in biotic systems as compared to abiotic "washout". This result was similar to the observation of a 14-fold increase in PCE removal rates from a NAPL in a continuous-flow stirred-tank reactor (Carr et al. 2000). If similar results are obtained in field systems, a 100-year source of PCE would be present for only 6.25 years.

Figure 2-1 illustrates the effect of reductive dechlorination on total chlorinated ethene removal from the column studies performed by Cope and Hughes (2001). The columns were fed electron donor at three different concentrations: low donor concentration (LDC), intermediate donor concentration (IDC), and high donor concentration (HDC). In 75 days, the total removal was about 5 to more than 6 times greater in the LDC and IDC columns, respectively, than in the abiotic column, while it was only slightly greater in the HDC column. The HDC column removal was less than the other biologically active columns because dechlorination was not as effective when high pyruvate concentrations were added. In addition to the enhanced removal during the 75-day test, the dechlorination of PCE to its less hydrophobic daughter products greatly reduces the longevity of the NAPL because dissolution rates are faster for those products.

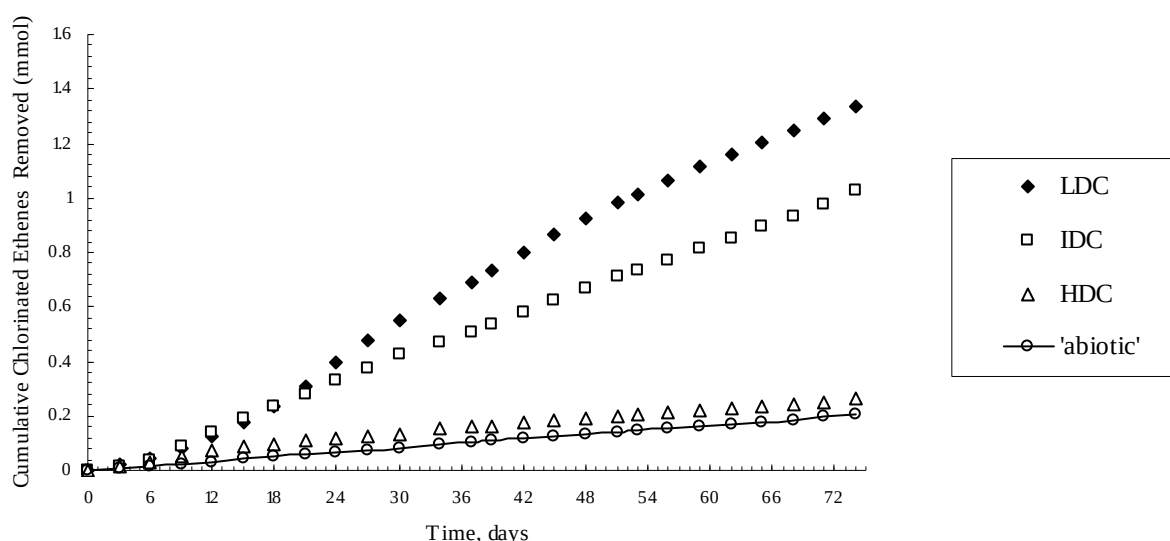


Figure 2-1. Enhanced Chlorinated Ethene Removal from NAPL in Column Studies (Cope and Hughes 2001).

Several possible scenarios can be envisioned where this process of enhanced source-zone dissolution (also referred to as source-zone bioremediation) may be advantageous. One is a bioremediation system where electron donor is added to source zones. A second is where the residual NAPL will be commingled with the chemicals used for surfactant and cosolvent flushing, solubilization, and mobilization (Pankow and Cherry 1996). A third system is a combination of the first two in which the electron donor solution itself enhances solubilization. In each case, the potential exists for the stimulation of an active anaerobic microbial consortium, including dechlorinators and halorespiring organisms, within source zones that will influence the time required to completely exhaust the NAPL of chlorinated species. In both the first and third scenarios, all of the cost, safety, land-use and aesthetic advantages of in situ treatment are retained. These two scenarios are the focus of this demonstration.

This work (as described above [Carr et al. 2000; Cope and Hughes 2001; NRC 1994]) lays the foundation for the demonstration and validation of the first scenario, in which reductive dechlorination enhances NAPL mass transfer through increasing the concentration gradient and producing more soluble degradation products. The justification for demonstration and validation of the third scenario is derived from a large-scale field evaluation of enhanced ISB in a TCE source at the INL's TAN (Sorenson 2000; Sorenson and Ely 2001; Martin et al. 2001). During the TAN project, high concentrations of sodium lactate were injected as an electron donor into the deep, fractured rock aquifer at the site, producing some surprising results. Unlike other applications to date, very high sodium lactate concentrations (3 to 60%) were used to prevent fouling of the injection well and to drive the treatment zone to strongly reducing conditions very rapidly. In addition to achieving these objectives, the high concentration lactate solution also appeared to increase the bioavailability of TCE for subsequent degradation. Within 5 months of the first lactate injection and following the rapid transition of the treatment zone from weakly reducing to methanogenic conditions, complete dechlorination of TCE to ethene was observed.

An interesting and surprising observation during the field evaluation was the dramatic increase in TCE concentrations deep in the aquifer soon after sodium lactate addition began (see Figure 2-2). The large increase of TCE and total ethenes in Well TAN-26 is an observation that has important implications. The TCE increase occurred simultaneously with the arrival of the highly concentrated electron donor solution. In addition, the peak TCE concentration was actually significantly higher than historical measurements for Well TAN-26. These observations strongly suggest that the transport of TCE to Well TAN-26 was associated with the downward migration of the electron donor. Mechanisms that may contribute to this observation include displacement of sorbed TCE by the electron donor solution, mild surfactant-like effects, or perhaps cosolvent effects. Simple physical displacement of source material can be ruled out because inorganic co-contaminants known to be in the source material at the site were not transported with the electron donor solution.

The most important aspect of the behavior of the TCE in Well TAN-26 is that its dechlorination after the peak concentration suggests that it was extremely bioavailable. The drop in TCE concentration from the peak concentration to non-detect levels occurred with a TCE half-life of less than 20 days (assuming first-order kinetics for illustration). Just as important, cis-DCE increased to a peak concentration within 20% of the peak TCE concentration (indicating an excellent mass balance), and then remained elevated near that peak concentration. The significance of this point is that the lactate injection was continuing, so if the hypothesis were valid lactate would be expected to continue bringing the organic contaminants with it as it migrated through the residual source. After the redox conditions changed, the TCE was transformed to cis-DCE before reaching Well TAN-26, but as shown in Figure 2-2, the total ethene level remained approximately constant. After several months, the total ethene compound concentration dropped; however, this was expected (and intentional) because the lactate solution concentration had been reduced by a factor of 20 in June. This change reduced the density of the solution significantly, so less lactate (and therefore less total ethenes) was transported to Well TAN-26. Thus, the concentration decrease also supports the hypothesis of facilitated transport.

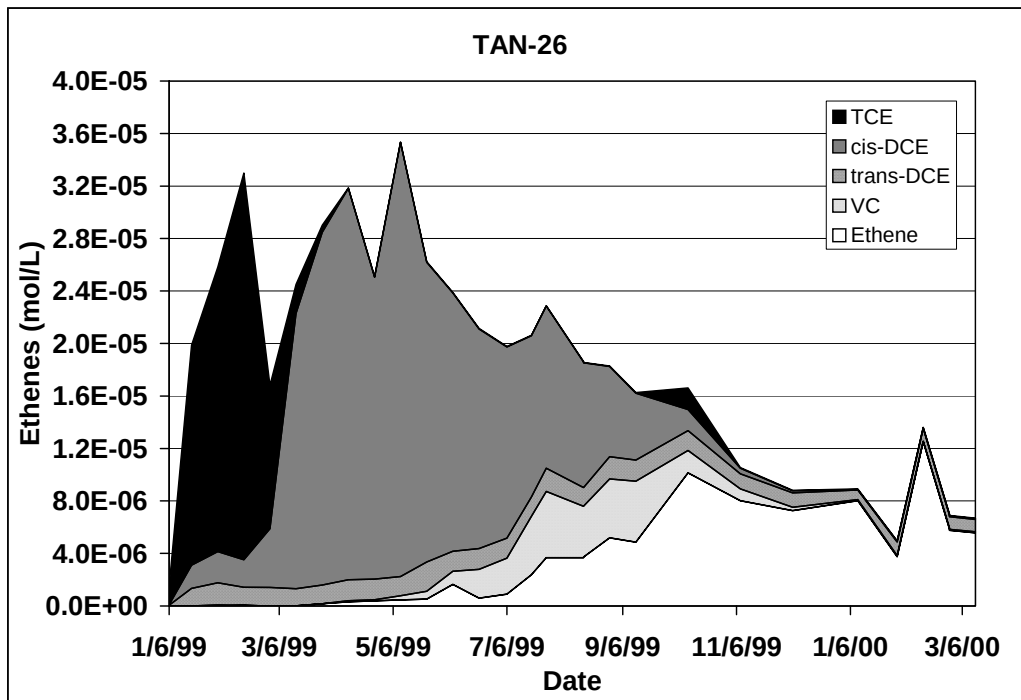


Figure 2-2. Enhanced Mass Transfer and Bioavailability of TCE Through Sodium Lactate Addition.

The characteristic of the lactate solution described in this section is potentially quite significant with respect to the impact of ISB on source zones. The apparent facilitated transport makes available for reductive dechlorination large quantities of the chlorinated ethenes that otherwise would remain associated with the NAPL or in the sorbed phase. As shown by the Well TAN-26 data, once made available by the lactate solution, the TCE was, in fact, rapidly degraded. The intimate mixing of the TCE with the lactate solution in the aqueous phase that facilitates its degradation represents a significant enhancement to the bioavailability of the TCE. Enhanced bioavailability of chlorinated ethenes in the source zone is an effect that would greatly decrease the longevity of the source.

The hypothesis that high concentrations of sodium lactate (and potentially other electron donor solutions) enhance mass transfer, and therefore bioavailability, of TCE through enhancing solubility was further investigated through some simple laboratory studies at the INL. Two fundamental properties used to screen the solubility enhancement properties of a solution are surface tension and interfacial tension (IFT). Surface tension measures the force per unit length along the interface between a liquid and air due to its tension. When a co-solvent or surfactant is present in an aqueous liquid at increasing concentrations, the surface tension of that liquid generally decreases. IFT is similar to surface tension except that it measures the force per unit length along the interface between two liquid phases arising from the surface free energy. The higher the IFT between two liquids, the less likely one is to dissolve into the other and the more difficult it is for one to be transported within the other. Thus, perhaps the most significant

property of co-solvents and surfactants in the context of chlorinated solvent remediation is that they decrease the IFT between the aqueous phase (ground water) and a NAPL so that the solubility (or mobility for order-of-magnitude decreases) of the nonaqueous phase is enhanced.

The laboratory studies performed at the INL measured the surface tension of electron donor solutions at various concentrations, and the IFT between the same electron donor solutions and non-aqueous TCE. Two types of electron donor solutions were used. The first was different concentrations of sodium lactate. The second was various mixtures of sodium lactate and another electron donor solution, ethyl lactate, hereinafter referred to as Solution B (this information is considered proprietary and is included in a pending patent). Surface and IFT measurements were made using the pendant drop method (Rosen 1984; Bagnall 1978) coupled with real-time video imaging (Herd et al. 1992).

At sodium lactate concentrations from 0.01 to 7%, almost no change in surface tension occurred. As the concentration was increased to 30 and 60%, however, a dramatic decrease in the surface tension was measured. This result confirms that sodium lactate begins to decrease surface tension at high concentrations. These lactate concentrations are about three orders of magnitude higher than reported in other studies, which explains the surprising results discussed in the field test described above. The addition of 1% and 10% of Solution B to the different sodium lactate solutions had a pronounced effect on the solution's surface tension. Thus, Solution B enhances the electron donor's impact on surface tension. This suggests that the choice of optimum mixture would be a matter of design for a specific remediation. If only slightly enhanced bioavailability of the solvents were desired, the high concentration sodium lactate solution would be appropriate. If a large degree of enhanced bioavailability were desired, the addition of 1 to 10% Solution B would be appropriate.

The results of the IFT measurements are shown in Figure 2-3. For sodium lactate only, decreasing IFT occurred at lower concentrations than observed in the surface tension measurements. IFT decreased by about 26% when sodium lactate was increased from 0.1 to 3% (still two orders of magnitude above previous studies). When sodium lactate was increased to 30%, the IFT was decreased to 47% of the value at a sodium lactate concentration of 0.1%. As Solution B was added to the sodium lactate solutions, it is clear that its concentration is the primary factor affecting surface tension. Figure 2-3 shows that the IFT becomes relatively insensitive to sodium lactate concentration for the mixtures. From a remediation design standpoint, this simplifies things because the effects appear to be controlled by only one component of the mixture. Interestingly, only the 10% Solution B mixture displayed lower surface tensions than the 30% sodium lactate solution alone.

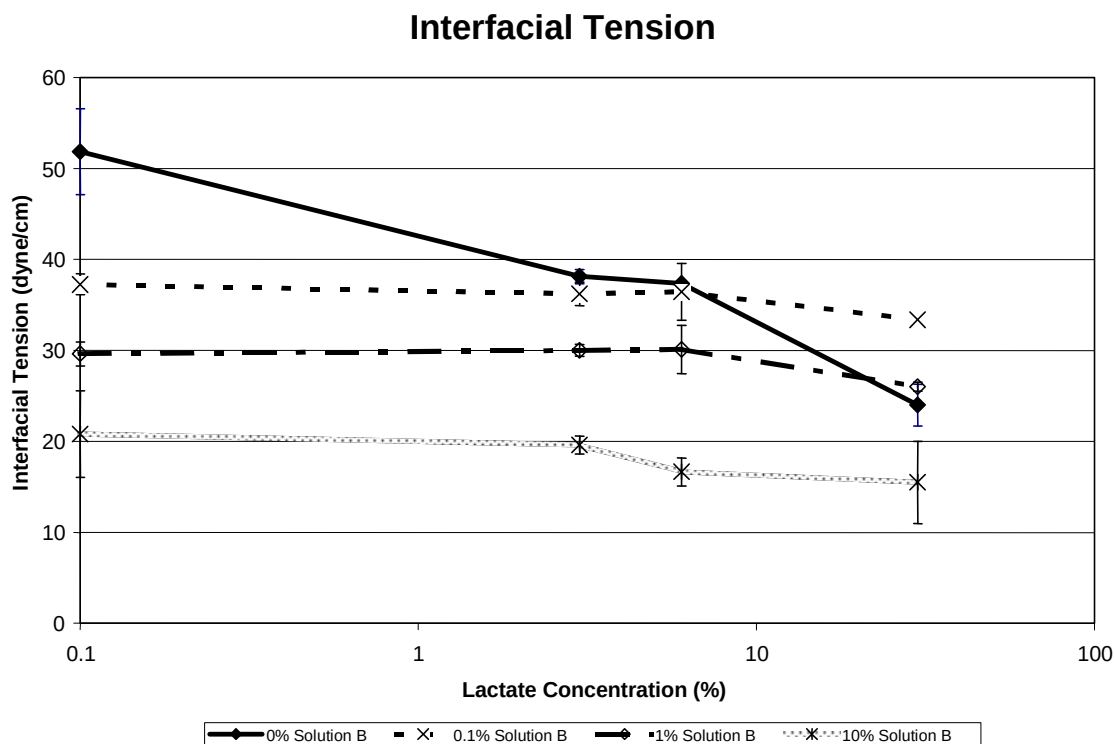


Figure 2-3. Effect of Electron Donor Solution on DNAPL/water IFT. Error Bars Represent Two Standard Deviations Around the Mean.

The combination of 1) laboratory data showing enhanced mass transfer due to increased concentration gradients and decreased hydrophobicity of contaminants during biodegradation of chlorinated ethenes, 2) field data showing enhanced bioavailability of TCE during electron donor addition, and 3) further laboratory data showing the impact of electron donor solutions on IFT demonstrates that the technology is sufficiently mature to justify demonstration. A remaining question that can best be addressed through scale-up is the extent to which heterogeneity in the subsurface will affect the results observed thus far in laboratory studies. The field test at TAN shows that the approach has the desired effect in the field, but may not fully answer the question. The next logical step is a demonstration designed specifically for measuring the enhanced mass transfer. A thorough documentation of accelerated mass removal from a residual source will address the most common criticism of ISB for source zones: that it is often slow because it is limited by the rate of passive mass transfer from the residual source to the aqueous phase. The demonstration will validate an innovation in bioremediation that extends its applicability into source-zone remediation in a way that achieves many of the benefits of aggressive, established source-zone technologies, while retaining its benefits of low cost, low maintenance, and in situ treatment.

2.2 Previous Testing of the Technology

Previous laboratory-scale testing of ISB-ARD for DNAPL remediation was described and referenced in Section 2.1, “Technology Development and Application.” A few examples of pilot- and full-scale testing of ISB-ARD are described in this section.

2.2.1 INL-TAN

The U. S. Department of Energy’s (DOE) TAN site, located at the INL in southeast Idaho, is the site of an approximately 2-mile long plume of TCE in groundwater. The geology is layered fractured basalts of the Snake River Plain Aquifer. The observed contamination is the result of the direct injection of solvent-containing wastewater into the aquifer via an injection well, and characterization data indicate the likely presence of TCE as a DNAPL phase in the source area surrounding the former injection well. ISB-ARD was selected for evaluation in a field pilot test within the TCE DNAPL source area. ISB-ARD operations consisted of the injection of large volumes of sodium lactate solution into the source area via the former wastewater injection well beginning in January 1999. Monitoring data indicated the complete ARD of TCE to ethene within 4 months of the start of injections. Results also indicated that the ISB-ARD technology enhanced the bioavailability of the TCE DNAPL in the source area, thus accelerating cleanup and shortening the overall remedial timeframe. After 9 months of pilot test operations, ISB-ARD was selected by DOE in a September 2001 Record of Decision Amendment (DOE-ID 2001) to replace pump and treat for source area clean-up. The project is currently in the remedial design phase for full-scale operations.

2.2.2 Pinellas Northeast Site

ISB-ARD was also applied at a chlorinated solvent plume at the Pinellas Northeast Site located in Largo, FL as part of a technology demonstration beginning in February 1997. A relatively heterogeneous, shallow, sandy aquifer was contaminated with chlorinated solvents at concentrations indicative of DNAPL in localized areas. The treatment area was approximately 45 ft × 45 ft and extended from the surface to a depth of 30 ft to a thick, clay-confining layer. Benzoate, lactate, and methanol were used as electron donors based on laboratory treatment studies. Volatile organic compound (VOC) reduction of 60 to 91% was noted within 4 to 8 weeks after injection of the electron donor. These results and extensive modeling, hydrogeologic, nutrient transport, and operating cost data developed during this technology demonstration, suggest that this site could be remediated using ISB-ARD. Moreover, nutrient addition to stimulate existing *in situ* anaerobic biological degradation of chlorinated solvent contaminated soil and groundwater was determined to be a feasible and cost effective remediation approach at the Pinellas Northeast Site for other areas containing moderate contaminant levels (FRTR 2002). Mass transfer effects were not evaluated in this demonstration.

2.2.3 Dover Air Force Base

ISB-ARD was implemented at pilot-scale for DNAPL remediation at Dover Air Force Base (AFB) by the Remediation Technology Demonstration Forum between May 1996 and March 1998 (FRTR 2002). Complete in situ degradation of chlorinated solvents to ethene was accomplished using groundwater recirculation and amendment system, through augmentation of the native microbial community with a culture from Largo, Florida.

The demonstration site in Area 6 of the Dover AFB overlies a portion of a groundwater contaminant plume, which contains average TCE concentrations of approximately 4,800 µg/L, and average cis-1, 2- dichloroethene concentrations of approximately 1,200 µg/L. Contamination is more widespread in the deep zones of this shallow aquifer. The saturated thickness at the demonstration site is approximately 38 ft and the depth to groundwater is approximately 10 to 12 ft. Although the aquifer acts as one unconfined unit, for monitoring purposes it was divided into three zones of roughly equal thickness. Based on characterization findings and subsequent aquifer studies, the deep zone was used for the pilot study.

Complete in situ degradation of chlorinated solvents to ethene was accomplished in a groundwater recirculation and amendment system through augmentation of the native microbial community using an imported culture from the Pinellas Northeast site in Largo, Florida, described previously. After a lag period of approximately 90 days, the augmenting culture began transforming cis-DCE to vinyl chloride (VC) and ethene.

2.3 Factors Affecting Cost and Performance

Factors significantly affecting cost and performance of this technology include:

- **Ability to Contact the NAPL with Electron Donor (Distribution).** This factor includes associated site-specific properties, including depth, permeability and heterogeneity of the formation, and NAPL distribution. This factor can be assessed by baseline characterization using NAPL locating techniques including geophysics, tracer tests, groundwater sampling and boreholes. This factor can be addressed by installing adequate numbers of electron donor injection wells in the source area and adjusting volumes and concentrations of electron donor used to achieve adequate contact. Wells may be screened or packers installed to target selected intervals for electron donor delivery.
- **Ability to Achieve Sufficiently Reducing Conditions.** This factor can be assessed through baseline sampling for redox conditions and competing electron acceptors. High transmissivity aerobic aquifers are less preferred regimes for implementing this technology than lower transmissivity anaerobic aquifers, since sufficient electron donor must be provided to reduce competing electron donors including nitrate, sulfate and ferric iron; and to produce anaerobic conditions throughout the residual source zone. This factor may be addressed by physically or hydraulically isolating the source zone; or by adjusting the volumes and concentrations of electron donor used.

- **Presence/absence of a Microbial Community Capable of Complete Conversion of TCE to ethene.** This factor can be assessed through baseline sampling for presence/absence of VC and ethene; or through laboratory studies including microcosms and/or evaluating microbial community diversity through polymerase chain reaction (PCR) and/or terminal restriction fragment length polymorphism (T-RFLP). These latter techniques can identify specific ribosomal DNA community profiles for comparison to those known to perform complete dechlorination. This factor may be addressed through bioaugmentation; a few sites have performed bioaugmentation to introduce dechlorinators to microbial communities lacking them.

2.4 Advantages and Limitations of the Technology

Technologies currently demonstrated at pilot- or full-scale for DNAPL remediation include steam injection, electrical resistance heating and in situ chemical oxidation. Steam injection and electrical resistance heating both heat soil and water to volatilize chlorinated solvents for recovery, while in situ chemical oxidation destroys contaminants in situ using Fenton's reagent. Pumping and treating groundwater is currently used more for hydraulic containment, or to induce a gradient, than for DNAPL remediation, however this technology is frequently used as a baseline for comparison. Table 2-1 lists advantages and limitations of each.

Table 2-1. Advantages and Limitations of Competing Technologies.

Technology	Advantages	Limitations
ISB-ARD	All treatment performed in situ; low infrastructure and energy requirements; no secondary waste produced; costs moderate	Relatively slower; requires longer monitoring period
Steam injection	Relatively rapid source reduction possible	Energy intensive, expensive; high secondary waste production
Electrical resistance heating	Relatively rapid source reduction possible	Energy intensive, expensive; high secondary waste production
In Situ Chemical Oxidation	Relatively rapid source reduction possible; very little secondary waste produced	Carbonates and organics compete for hydroxyl radical
In situ flushing	Relatively inexpensive	Large volumes of low-concentration secondary waste produced; diffusion-limited; little source reduction possible
Pump and treat	Effective for hydraulic containment during remediation	Ineffective for source removal; expensive

Significant advantages of this technology (listed in Section 1.4) include low risk to human health and the environment during implementation, low secondary waste generation, minimal impacts during operations, and relatively low cost. Additional potential advantages include:

- **Potential for Complete Source Cleanup Using One Technology, without Requirement for Separate Polishing Technologies.** Source removal technologies do not remove all of the NAPL present, and rely on polishing technologies including in situ bioremediation and MNA to achieve drinking water standards where required. ISB-ARD integrates source removal and polishing, thereby facilitating attainment of cleanup goals by reducing the need for further infrastructure, treatability studies, modification of site conditions, bioaugmentation, etc. that may be required to implement a polishing technology following source removal.
- **Flexibility of Implementation.** ISB-ARD is easily scaled to the size of the site, with commensurate cost savings, relative to more capital-and energy-intensive technologies. Given the minimal surface infrastructure requirements, the technology is also readily implemented around and under existing structures, and is not disruptive to most commercial or residential property uses.

Electron donors can also be selected for IFT reduction properties, dechlorination properties, slow verses fast-release properties, etc., for specific applications.

Challenges for this technology can include any of the site-specific conditions that limit application of many remedial technologies, including complex lithology, low permeability media, high concentrations of competing electron acceptors including oxygen, nitrate, sulfate and ferric iron; electron donor distribution factors discussed in Section 2.3. A possible disadvantage is the potential for incomplete dechlorination beyond cis-DCE. Bioaugmentation is showing promise to deal with this issue when it arises.

3. DEMONSTRATION DESIGN

The primary objective of the demonstration design was to validate that high concentration whey powder injections resulted in greater mass transfer and higher treatment efficiency compared to traditional injection strategies during enhanced ISB for chlorinated solvent source areas. Two hydraulically isolated treatment cells were used to compare two different whey powder injection strategies, and help quantify their performance. A phased approach to the demonstration ensured experimental control was sufficient to measure the effects of different whey injection concentrations on mass transfer with confidence.

- **Phase 1 – Equilibration.** Hydraulic characterization of the treatment cells was conducted.
- **Phase 2 – Baseline.** ARD performance indicators were collected to evaluate electron donor concentrations, redox conditions, geochemistry, and contaminant concentrations in each treatment cell without electron donor addition.
- **Phase 3 – Biostimulation and Enhanced Mass Transfer Demonstration.** ARD performance indicators were monitored under biostimulation conditions during both low and high concentration whey powder injections.

This section describes the overall design of the B.E.T.[™] technology demonstration. The detailed performance objectives are presented first, followed by a description of the selected site and its characteristics. Current operations at the site, as well as previous testing at the site, are then briefly discussed. This is followed by a detailed description of the Demonstration Test Plan. Finally, the project organization and schedule are presented.

3.1 Performance Objectives

The overall objective of this demonstration is to show that facilitating enhanced mass transfer allows bioremediation to be applied to chlorinated solvent source areas in groundwater to realize many of the benefits of more expensive and hazardous technologies, while retaining its benefits as a low cost, in situ technology. Detailed performance objectives have been developed for each phase of the demonstration to meet the overall objective. These performance objectives are derived from the decision rules (DR) formulated in Section 3.6.7.1.5 of the Technology Demonstration Plan (TDP; NWI 2003) using the data quality objective (DQO) process (EPA 1994). Three DR were defined and evaluated, based on the objectives of the demonstration. The DR that were tested are defined as:

- **DR 1:** If chloroethene and ethene aqueous concentrations in groundwater measured during biostimulation using low concentration electron donor is significantly greater than measured during baseline conditions at the 95% confidence level, then biostimulation will be determined to have increased contaminant mass transfer via concentration gradient increases and increased solubility of degradation products. If the DR is not supported by the data, and bioactivity, redox, and dechlorination indicators are favorable (i.e., biostimulation is

successful), then the hypothesis will be rejected. If the DR is not supported by the data, and if bioactivity, redox, and dechlorination indicators are unfavorable, then further evaluation will be recommended.

- **DR 2:** If chloroethene and ethene aqueous concentrations in groundwater measured during biostimulation using high concentration electron donor, as determined by mass balance calculations, are significantly greater than measured during baseline conditions at the 95% confidence level, then B.E.T.TM will be determined to have increased contaminant mass transfer via some combination of bioavailability enhancement (increased effective solubility) and the mechanisms discussed in DR 1. If the DR is not supported by the data, and if bioactivity and redox indicators are favorable, then the hypothesis will be rejected. If the DR is not supported by the data, and if bioactivity and redox indicators are unfavorable, then further evaluation will be recommended.
- **DR 3:** If chloroethene and ethene mass flux increase measured during biostimulation using high concentration electron donor, as determined by mass balance calculations, is significantly greater than that measured during low concentration electron donor biostimulation at the 95% confidence level; and if chlorine numbers (i.e., extent of dechlorination) are comparable between the two scenarios; then bioavailability enhancement will be determined to have increased contaminant mass transfer to a greater extent than the DR 1 mechanisms alone. If the DR is not supported by the data, and if bioactivity and redox indicators are favorable, then the hypothesis will be rejected. If the DR is not supported by the data, and if bioactivity and redox indicators are unfavorable, then further evaluation will be recommended.

Based on these DRs, performance criteria for the Technology Demonstration were developed. The critical performance elements that were measured include evaluation of the extent of dechlorination, and the changes in dissolution and aqueous concentrations of contaminants and degradation products through the treatment cells over time. The following null hypotheses were developed based on the results of the field test and the DR:

- **Hypothesis 1 (DR 1):** The mean total molar VOC concentrations measured in Treatment Cell 2 (located within the DNAPL source zone) during biostimulation with low concentration (1%) electron donor injections is not significantly greater than that measured during Treatment Cell 2 baseline conditions at the 95% confidence level.
- **Hypothesis 2 (DR 2):** The mean of total molar VOC concentrations measured in Treatment Cell 2 during biostimulation with high concentration (10%) electron donor injections is not significantly greater than that measured during Treatment Cell 2 baseline conditions at the 95% confidence level.
- **Hypothesis 3 (DR 3):** The mean of total molar VOC concentrations measured in Treatment Cell 2 during high concentration (10%) electron donor injections is not significantly greater than that measured during biostimulation of Treatment Cell 2 with low concentration (1%) electron donor injections at the 95% confidence level.

To test these hypotheses, the parameters to be monitored included chloroethenes and biodegradation daughter products, electron donor and fermentation products, and bioactivity and redox indicators. The performance criteria are identified specifically in Table 3-1.

3.2 Selecting a Test Site(s)

The Ft. Lewis EGDY NAPL Area 3 was identified as the demonstration site after evaluation of several characteristics, including:

- **Characterization.** Much of the characterization required to implement the test was already performed at the EGDY, including nature and extent of contamination and hydrogeology. Additional characterization performed during the equilibrium phase (e.g., hydraulic gradient, groundwater velocity and direction, and hydraulic conductivity) was used to design the baseline and demonstration phases.
- **Extent of NAPL.** Extensive NAPL was observed throughout NAPL Area 3 during the Phase II Remedial Investigation ([RI], United States Army Corps of Engineers [USACE] 2002). NAPL was observed at depths ranging from 2 ft to 30 ft below ground surface (bgs). This improved the likelihood of contacting NAPL with the electron donor. Following installation of the treatment cells, however, it was discovered that only one of the two treatment cells was located within a zone of high NAPL saturation. The original intent was to locate both treatment cells within the NAPL.
- **Hydrogeology.** The upper aquifer at the EGDY is very transmissive, which allowed for relatively easy electron donor distribution.
- **Microbiology.** TCE metabolites including cis- and trans-DCE were reported in the Phase II RI. In addition, previous testing of ISB-ARD at the site (NAPL Area 1) showed complete dechlorination to ethene in laboratory microcosms and at least VC production in the field. This indicated a high probability that the microbial community was capable of complete ARD of TCE.

3.3 Test Site Description

3.3.1 Site Location

The EGDY Phase II RI (USACE 2002) summarizes the history and characteristics of the test site, and the following discussion is summarized from that report. The Ft. Lewis Logistics Center is located in Pierce County, Washington, approximately 11 miles south of Tacoma and 17 miles northeast of Olympia. The Logistics Center occupies about 650 acres of the Ft. Lewis Military Reservation, located at Township 19 North, Range 2 East, Sections 21, 22, 26, and 27. It is bounded on the northwest by Interstate 5 and beyond by the town of Tillicum, on the north by the American Lake Gardens Tract, on the west by the Madigan Army Medical Center, and on the southwest by the Madigan Family Housing Area.

Table 3-1. Performance Objectives for B.E.T.™ Enhanced Mass Transfer Demonstration.

Type of Objective	Primary Performance Criteria	Secondary Performance Criteria	Performance Metrics	Actual Performance Objective Met?
Qualitative	Demonstrate that enhanced mass transfer allows for cost-effective bioremediation of chlorinated solvent source areas.	N/A	Mass transfer enhancement.	Yes, mass transfer was enhanced.
Quantitative				
Equilibration: Determine hydraulic conditions to be used for the baseline phase.	Determine flow characteristics and residence time in each treatment cell.	N/A	Hydraulic gradient, groundwater velocity and direction, hydraulic conductivity, residence time.	Yes, the results are reported in Section 4.
Baseline: Determine contaminant flux under baseline conditions.	Determine chloroethene and daughter product concentrations vs. time under baseline conditions.		Chloroethene and metabolite concentrations and fluxmeter assessment under baseline conditions.	Yes, the results are reported in Section 4.
		Determine extent of ARD under baseline conditions prior to biostimulation.	Bioactivity and redox parameters, and molar ratio of chloroethene reductive daughter products to parent compounds under baseline conditions.	Yes, the results are reported in Section 4.

Table 3-1. Performance Objectives for B.E.T.™ Enhanced Mass Transfer Demonstration. (continued).

Type of Objective	Primary Performance Criteria	Secondary Performance Criteria	Performance Metrics	Actual Performance Objective Met?
Biostimulation and Enhanced Mass Transfer Demonstration: Determine contaminant flux under biostimulation conditions relative to flux measured under baseline conditions.	Determine chloroethene and daughter product concentrations vs. time during high and low concentrations of electron donor in each treatment cell.		Chloroethene and metabolite concentrations and use of fluxmeter assessment.	Yes, the results are reported in Section 4.
		Determine extent of anaerobic reductive dechlorination under biostimulation conditions.	Bioactivity and redox parameters, and molar ratio of chloroethene reductive daughter products to parent compounds during low and high concentration electron donor injections.	Yes, the results are reported in Section 4.

The EGDY is located southeast of the Logistics Center in an otherwise undeveloped portion of Ft. Lewis. The EGDY is loosely defined as the area southeast of the intersection of Rainier Avenue and East Lincoln Drive in which landfill trenching and disposal activities historically occurred over an area of about 35 acres.

The EGDY is located on an extensive upland glacial drift plain, at an elevation of about 290 ft above mean sea level (msl). Trees and shrubs have been cleared from the areas of disposal trenches.

3.3.2 Operations History

Construction at the Logistics Center site began in 1941 with construction of the Quartermaster Motor Base, which was renamed the Mount Rainier Ordnance Depot (MROD) in 1942. It operated until 1963, furnishing ordnance supplies, maintenance and rebuilding services for Fort Lewis until 1963. In 1963, the MROD was turned over to the Logistics Center to serve as the primary non-aircraft maintenance facility for the post.

TCE was used as a degreasing agent at this facility until the mid-1970s, when it was replaced with TCA. Waste TCE was co-disposed with waste oils at several locations. The EGDY was used between 1946 and 1960 as a disposal site for waste generated at the MROD. Trenches were excavated in the yard and reportedly received TCE and petroleum, oils, and lubricants (POL) from cleaning and degreasing operations. These materials were transported to the EGDY in barrels and vats from the various use areas; about six to eight barrels per month of waste TCE and POL may have been disposed. These materials were also used to aid in burning other wastes.

3.3.3 Geology

At least three glacial and three non-glacial units have been identified in the sediments occurring above sea level at the EGDY. These units and a brief description are listed below, sequentially from youngest (shallowest) to oldest (deepest):

- **Holocene-Anthropomorphic Deposits.** These consist of man-made fill in the trench areas and include debris and burned material. These materials typically extend to less than 12 ft bgs.
- **Vashon Glacial Drift Deposits.** These consist of glacial deposits including recessional outwash, till and ice contact deposits, advance outwash and glaciolacustrine silt/clay. Vashon drift deposits typically extend from ground surface to approximately elevations of 210 to 185 ft.
 - Vashon Recessional Outwash—Interbedded brown to gray sand gravel and sand with minor silt intervals; also loose, well-graded brown to gray sandy, cobble gravel from at or near ground surface to 5 to 50 ft bgs.

- o Vashon Till and Ice Contact Deposits—Dense, gray silty-sandy gravel and gravelly sandy silt, 4 to 35 ft thick were present; typically 220 to 270 ft elevation.
- o Vashon Advance Outwash—Interbedded brown to gray sandy gravel and sand, some cobbles, with minor silt interbeds.
- o Glaciolacustrine Silt/Clay—Gray, laminated to massive silt and clayey silt with minor fine sand interbeds. Also very stiff to hard, dark gray clayed massive silt varying in thickness from 10 to 150 ft, typically between elevations of 50 and 200 ft.
- o Olympia Beds—Mottled, massive, organic-rich clayey sandy gravel or lavender silt, peat, sand and gravelly sand. May be up to 40 ft thick and located between elevations 180 and 250 ft where present. May not be present in the proposed study area.
- o Pre-Olympia Drift—Gray to brown, fine-to medium-grained sand with minor sandy gravel interbeds, oxidized at the top, common silt interbeds at the base, with discontinuous till. Where present this unit is typically 10 to 70 ft thick and located between elevations 110 to 190 ft.
- o Second Non-Glacial Deposits—Mottled, massive, organic rich, clayey, sandy gravel (mudflows) or lavender silt, peat, sand, and gravelly sand (fluvial over bank deposits). Occurs between elevations 170 to 110 ft.
- o Third Glacial Drift—Interbedded, orange to dark gray sand gravel and sand with minor silt interbeds, intensely iron oxide-stained at top (recessional outwash), dense, gray, silty, sandy gravel and gravelly sandy silt (till); and interbedded, gray to brown, to dark gray sandy gravel and sand with minor silt interbeds (advance outwash).
- o Third Non-Glacial Deposits—Lavender silt, peat, sand and gravelly sand.

3.3.4 Hydrogeology

The primary aquifers and aquitards are listed below, sequentially from shallowest to deepest:

- **Vashon Aquifer or Upper Aquifer.** The Vashon drift, Olympia beds, and Pre-Olympia drift comprise the Vashon unconfined aquifer. Vashon till and Olympia beds may act locally as discontinuous aquitards within the Vashon aquifer. Vashon outwash and pre-Olympia drift deposits comprise the aquifer materials within the Vashon aquifer. The Vashon aquifer varies in thickness from 100 to 130 ft and is continuous throughout the EGDY.
- **Intermediate Aquitard.** A somewhat laterally continuous till layer may separate the Vashon aquifer locally into an upper and lower permeable unit separated by this relatively low-permeability till or glaciolacustrine silt. This till is notably absent immediately north of NAPL area 3 where low permeability units do not separate the upper and lower portions of the Vashon aquifer. The demonstration was performed in the upper Vashon aquifer, above the intermediate aquitard.

- **Non-Glacial Aquitard.** A regional aquitard consisting of low permeability second non-glacial deposits separating the Vashon aquifer from the Sea Level (lower) aquifer.
- **Sea Level Aquifer.** Third glacial drift deposits and permeable lower deposits of the second non-glacial unit comprise the Sea Level aquifer. This unit is widely used as a source of groundwater for industrial and municipal use.

3.4 Pre-Demonstration Testing and Analysis

NAPL characterization performed as part of the EGDY Phase II RI was used to locate the treatment cells; this characterization is described in the EGDY Phase II RI Report. Hydrogeologic characterization during the Phase II RI provided the data necessary to develop the preliminary design of the treatment cells. The contaminant characterization and previous testing of ISB-ARD at the site indicated that the process had a high probability of achieving complete dechlorination. All additional baseline data required for the technology demonstration implementation and optimization were collected as part of this project.

3.5 Testing and Evaluation Plan

This section describes site preparation, equipment installation and start-up, and other activities required to implement the ISB-ARD technology demonstration at the Ft. Lewis EGDY. Two treatment cells were established and operated to evaluate the different mechanisms of enhanced mass transfer. The demonstration was implemented in three phases:

Phase 1: Hydraulic characterization of the treatment cells and equilibration of contaminant concentrations. This phase of testing established hydrogeologic baseline parameters.

Phase 2: Baseline testing, during which contaminant concentrations in each treatment cell were monitored. This phase of testing established the contaminant baseline parameters.

Phase 3: Biostimulation and enhanced mass transfer demonstration, during which contaminant concentrations and performance indicators were monitored under biostimulation conditions and compared to Phase 2 conditions.

3.5.1 Demonstration Installation and Startup

The objective of the demonstration was to compare the results of ISB implementation in two separate, hydraulically isolated treatment cells. Construction of these two treatment cells began in March 2003 and each cell consists of one injection well, one extraction well, and four monitoring wells. Figure 3-1 shows the as-built view of the original treatment cell configurations at the Ft. Lewis EGDY. Due to well construction inefficiencies, however, the injection and extraction wells were re-drilled using a different drilling method in April 2004.

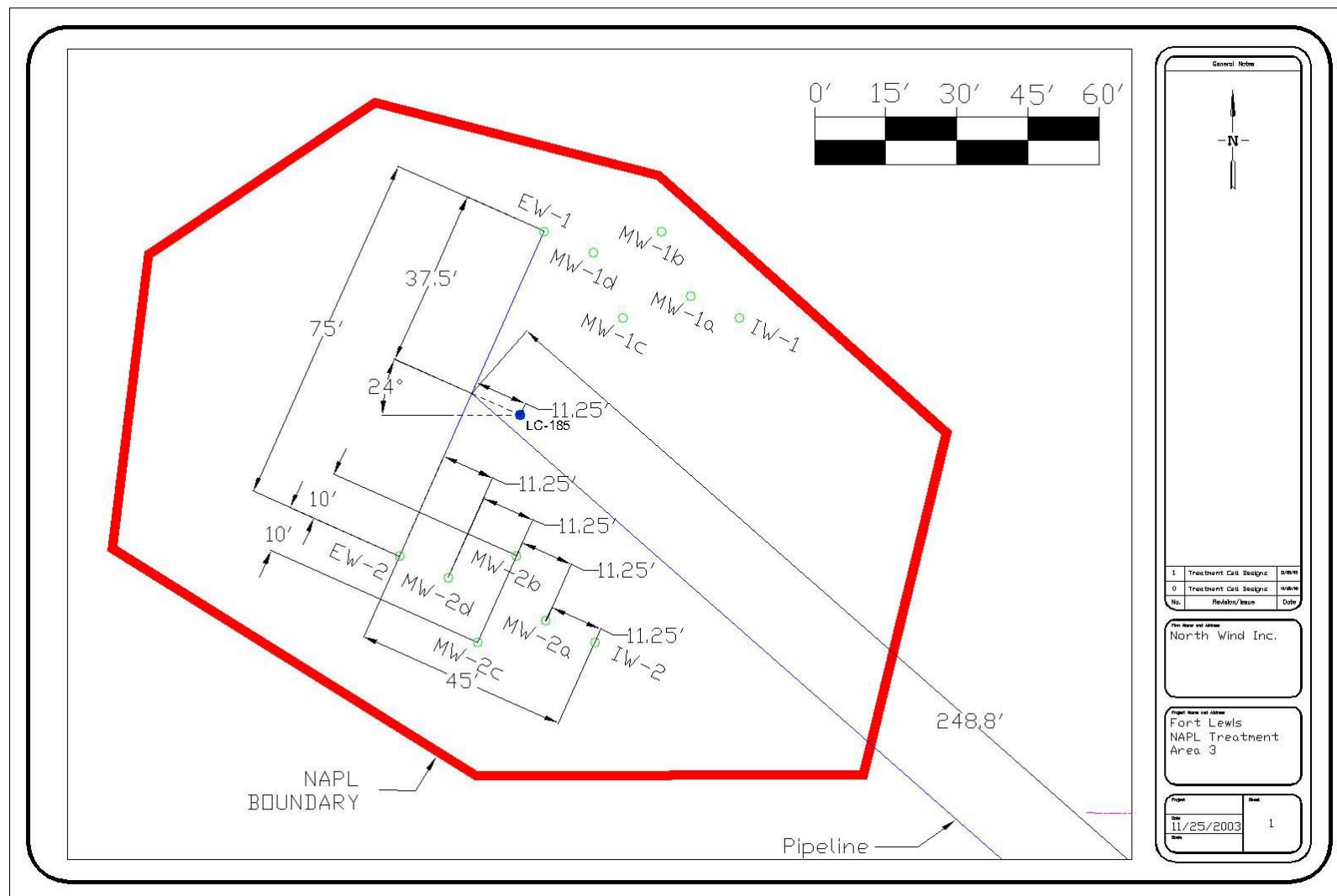


Figure 3-1. EDGY Demonstration Cells.

Assumptions for the original design of the treatment cells, including hydrogeologic parameters, locations and depths of NAPL occurrences, and site lithology, were based on information provided by the United States Army Corps of Engineers (USACE; 2002). Based on these preliminary assumptions the treatment cells were constructed such that:

- The treatment cell injection-extraction axes were aligned with expected flow direction,
- The mean hydraulic residence time between injection and extraction wells was expected to be about 30 days,
- The cells were sufficiently far apart that hydraulic isolation could be maintained, and
- Both cells were located inside NAPL Area #3 in areas of roughly equivalent NAPL extent.

Drill cuttings were logged during installation of the wells and the lithology was described based on the Unified Soil Classification System (ASTM-D 2488-93). Groundwater was detected at approximately 12 ft bgs for all of the wells. The presence of NAPL was determined using a photoionization detector (PID) or multigas detector and using visual inspection and odor. All wells were constructed and developed per the State of Washington, Department of Ecology “Minimum Standards for Construction and Maintenance of Wells” (Waste Acceptance Control [WAC]-173-160) and “Monitor Well Design, Installation and Documentation at Hazardous and/or Toxic Waste Sites” (USACE 1998, EM 1110-1-4000).

Treatment Cell Installation

The original injection (IW-1 and IW-2) and extraction (EW-1 and EW-2) wells (Figure 3-2) were installed using a 10-inch diameter auger in March 2003. The casings for the wells were 4-inch diameter schedule 40 polyvinyl chloride (PVC) with flush threading. The wells were constructed to approximately 30 ft bgs with approximately 15.5 ft of 0.030 slot screen extending from 14.5 to 30 ft bgs. Originally, a 0.050 slot screen was specified, but a 0.030 slot screen was used due to the amount of fine sediments observed in the logged soils. Following installation, these wells were developed by surge block and bailing. In April 2004, four new wells were installed to replace the existing extraction and injection wells (due to well efficiency issues and tracer test results described below). The wells were installed using an air rotary method with a 10-inch diameter borehole and a 4-inch diameter schedule 40 PVC casing. The extraction wells, designated EW-1A and EW-2A, were completed to 35 ft bgs with 0.050 slot (VEE-Wire) screen from approximately 15 ft bgs to depth. The injection wells, IW1A and IW2A, were completed to 20 ft bgs with 0.050 slot (VEE-Wire) screen from approximately 15 to 20 ft bgs.

The monitoring wells were installed using a sonic drilling method with a 6-inch diameter borehole in March 2003. Each monitoring well was configured with Solinst Continuous Multichannel Tubing (CMT) to provide multilevel sampling capability. Following completion of the well drilling, the CMT monitoring systems were installed through the temporary inner casing of the well. Installation of the CMT monitoring systems was accomplished by laying out an appropriate length of CMT tubing, installing the anchor plate on the tubing, drilling three to four holes in one of the seven separate vertical channels of the tubing, and clamping a stainless steel screen in place

over the holes. This process was repeated at four different depths along the tubing. Centralizers were installed on the CMT tubing as required. The CMT assembly was then placed into the borehole and a tremie pipe was used to install filterpack and bentonite seals for each of the monitoring depths. As sand pack and bentonite seals were installed for each of the four monitoring depths in each well, the temporary inner casing was withdrawn. In general, the sampling ports were placed at 13.5 ft, 18.5 ft, 23.5 ft, and 28.5 ft bgs, with a total well depth of approximately 30 ft bgs. These Solinst CMT wells were developed by inserting ¼-inch outside diameter polyethylene tubing down each of the four chambers until the bottom plug was encountered. A peristaltic pump was used to draw groundwater until the water was clear in appearance.

Following well construction, dedicated pumps were installed in the extraction wells, and piping and transfer pumps were installed between the extraction wells and the EGDY air stripper. This allowed extracted water to be treated at the air stripper if necessary. The piping was configured to allow for sampling of the effluent from the extraction wells. Electrical connections and potable water connections were made from the nearest existing service lines, using a State of Washington licensed electrician and plumber, respectively, and according to all applicable codes and regulations.

Figure 3-2 provides a final map of the two treatment cells and the various well locations within each treatment cell. Well locations identified with a '1' are in Treatment Cell 1 and well locations identified with a '2' are in Treatment Cell 2. Two injection wells (IW1A and IW2A), two extraction wells (EW1A and EW2A), four CMT monitoring wells (identified as MW1A, B, C, and D, or MW2A, B, C, and D), and two fluxmeter wells constructed as part of Environmental Security Technology Certification Program (ESTCP) project ER-0318 (identified as FW1A, FW1B, FW2A, and FW2B) were utilized in each treatment cell. The CMT wells had four discrete sampling ports, which drew water from depth intervals of approximately 12 to 15.0 ft (Port 1), 17 to 20 ft (Port 2), 22 to 25 ft (Port 3), and 27 to 30 ft (Port 4).

The nomenclature used to describe the monitoring locations uses MW to indicate the type of well. The first number indicates the treatment cell, and the last letter and number identify the monitoring well and the sampling port. For instance, MW1A1 indicates that the sample was collected in Monitoring Well A in Treatment Cell 1 at Port 1. Tracer test results were used to determine which ports would be sampled for each well. During Phase 3, eight sampling locations per treatment cell were collected, including three sampling depths in each of the MWA and MWD wells, and one sample depth for the MWB and MWC wells.

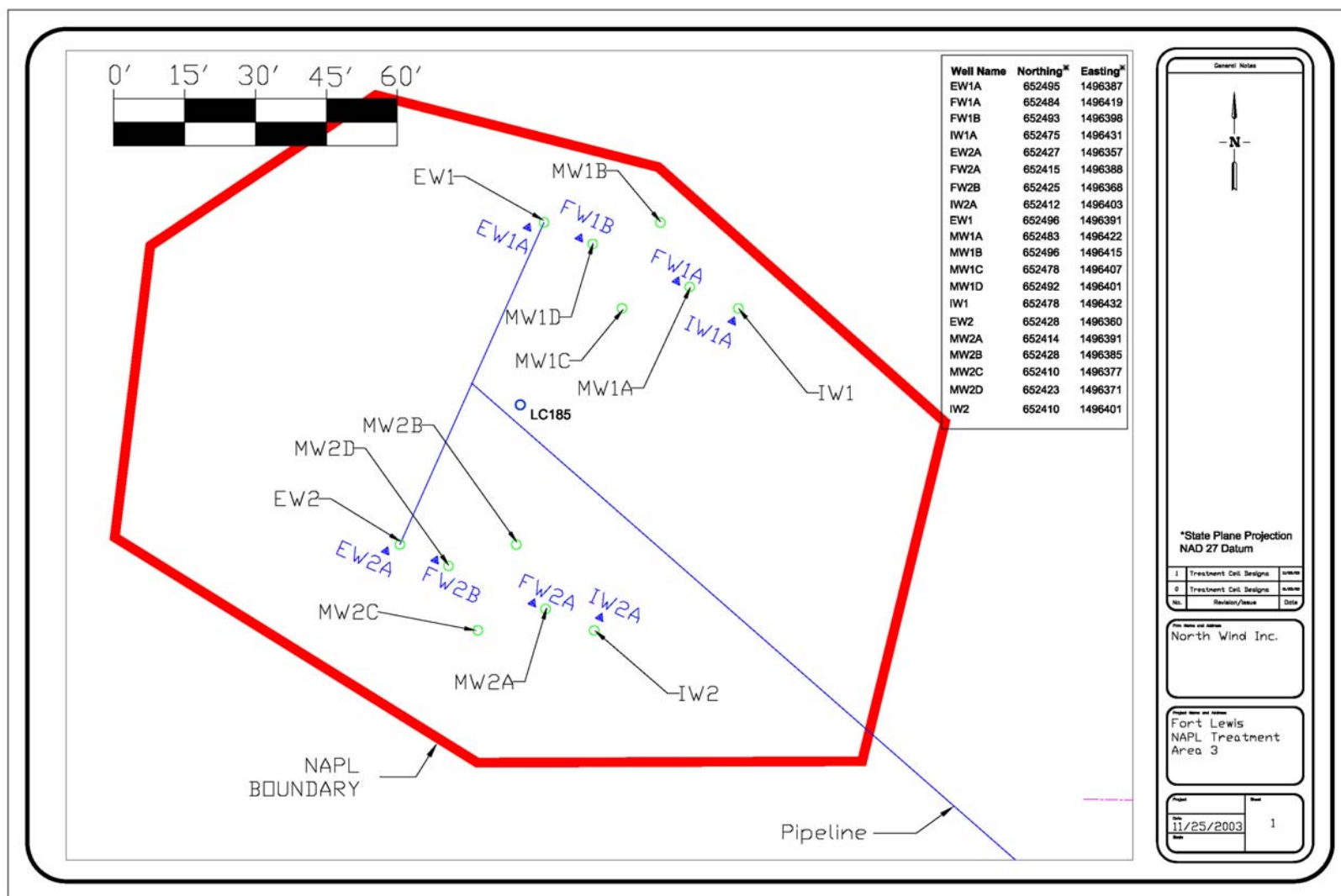


Figure 3-2. Well Locations within Treatment Cells at Ft. Lewis EGDY.

Installation of Flux Wells

Following this demonstration, electrical resistance heating was performed in NAPL Area 3 as part of the overall remedy for EGDY. Lines of flux monitoring wells were installed downgradient and upgradient of NAPL Area 3 by Ft. Lewis public works as part of the performance assessment for thermal treatment to assess contaminant flux prior to the application of thermal treatment. The wells were approximately 50 to 100 ft upgradient and downgradient of NAPL Area 3, perpendicular to the estimated direction of groundwater flow (Figure 3-2). The flux monitoring wells were installed during the ER-0218 demonstration. These wells provided an excellent, unexpected opportunity to evaluate the impact of the demonstration on the flux of contaminants downgradient from NAPL Area 3. In order to take advantage, samples were collected from these wells prior to the first differential concentration injection event conducted as part of the demonstration phase. Samples were collected again following subsequent injection events conducted during the demonstration phase of the enhanced mass transfer evaluation.

Drilling of the flux monitoring wells was accomplished using a truck-mounted rotosonic drilling rig and the sonic drilling technique. Sonic drilling, along with ancillary well installation and development at each completed borehole, was performed under contract to the USACE Seattle District by Prosonic Corporation, Portland, Oregon. A total of 28 NAPL Area 3 control plane flux characterization borings were drilled using a 5-inch diameter soil core barrel and 6-inch diameter temporary steel casing. The 2-inch diameter NAPL Area 3 flux wells were constructed of 2-inch diameter stainless steel screen and casing. The screens are continuous slotted “V-wire” with 0.020-inch openings.

Control plane flux characterization wells were installed in two lines perpendicular to the horizontal groundwater flow direction through NAPL Area 3. One line, consisting of 10 shallow wells was spaced about 30 ft apart. Eight of these shallow wells were directly downgradient of NAPL Area 3, designated FX3-01 through FX3-08, and were screened in the interval of interest for monitoring the impact of the B.E.T.TM demonstration. The screened interval of each was from 5 to 40 ft bgs. These wells were sampled along with the CMT monitoring wells within the NAPL Area 3 treatment cells to evaluate the effects of ISB downgradient of the treatment areas.

3.5.2 Period of Operation

All field demonstration activities were conducted between March 2003 and May 2006. Phase 1 activities occurred between June 2003 through March 2005. During this period, three tracer studies were conducted, and the injection and extraction wells were redrilled based on the results. Phase 2 activities occurred between March 2005 through June 2005 and included groundwater recirculation and baseline groundwater sampling within the two treatment cells. Phase 3 activities occurred between June 2005 and June 2006 and included preliminary low-concentration whey powder injections to initiate reducing conditions, bioaugmentation, differential concentration whey powder injections, and sampling within the treatment cells and at the downgradient flux well locations.

3.5.3 Amount/Treatment Rate of Material to be Treated

The technology demonstrated is an in situ treatment, and the amounts and rates of materials to be treated were estimated as part of the demonstration.

3.5.4 Residuals Handling

Residuals generated during this technology demonstration included water generated during well development and equipment decontamination, purge water from sampling, drilling cores, sampling equipment decontamination wastes, and personal protective equipment (PPE). Water generated during well development and purge water generated during sampling was temporarily stored in a tank, then treated in the existing EGDY air stripper and reinjected. Decontamination wash water was allowed to drain onto the ground surface.

Soil generated during drilling and coring was stored in a covered stockpile at the EGDY. All PPE generated was placed in a conventional dumpster to be disposed of off-site in a non-Resource Conservation and Recovery Act (RCRA) landfill.

3.5.5 Operating Parameters for the Technology

During both high and low concentration donor injections, whey powder was mixed with recirculated groundwater to the desired concentration and injected at a flow rate of 8 to 10 gallons per minute (gpm) every 4 to 6 weeks during Phase 3 for a total injected volume of 1,300 to 4,000 gallons of whey powder solution each injection. Details of rate, frequency, and concentration of all injection events are presented in Section 3.5.13. Injection rates and volumes were measured continuously and reported daily in the field team leader logbook, along with times and durations. Recirculated groundwater was injected for one-half to 1 hour following whey injection.

Groundwater monitoring was performed as described in Section 3.5.13. Water levels were measured at the injection well and at selected monitoring wells during injection.

3.5.6 Experimental Design

Conceptual Approach

The overall experimental design is based on the performance objectives stated in Section 3.1 and the mass balance conceptual model shown in Figure 3-3. Total moles of chloroethenes and metabolites in the aqueous phase during Phase 3 were compared to total moles of chloroethenes and metabolites in the aqueous phase during Phase 2 to determine whether or not addition of whey at low concentrations and/or at high concentrations increases the mass transfer (shown in the figure as dissolution, but could also include desorption) rate of residual-phase contaminants to the aqueous phase. As shown in Figure 3-3, TCE partitions out of the NAPL phase into the aqueous phase, where it is subject to apparent loss due to sorption on aquifer solids, transport out of the control volume (the aqueous phase in the treatment cell) and degradation. As flow conditions were the same, losses due to transport should be very similar in Phase 2 and Phase 3.

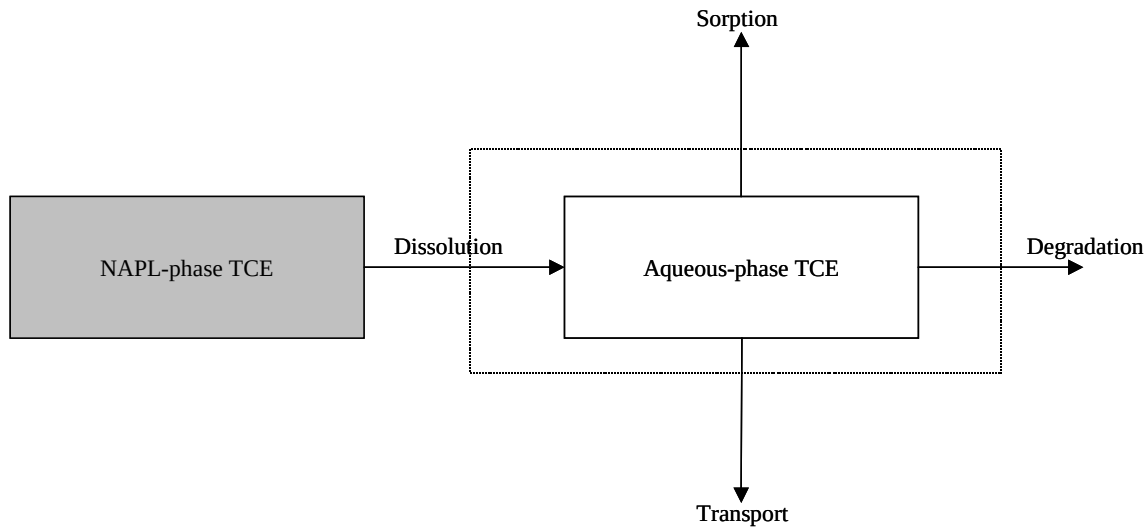


Figure 3-3. TCE Mass Balance.

Assuming ARD is occurring to a greater extent during Phase 3, any increases in chloroethene concentrations measured in Phase 3 relative to Phase 2 must be attributed to either increased mass transfer from the NAPL source term, or changes in the sorption characteristics of the TCE, or both.

In order to achieve a mass balance, total chloroethenes were measured (including TCE, cis- and trans-DCE, VC and ethene), and were converted to molar concentrations to estimate the total original contaminant mass present (which was mostly TCE). Total moles of chloroethenes and ethene were compared between Phases 2 and Phase 3 of the demonstration to determine whether biostimulation alone at the lower whey concentrations increased contaminant mass transfer rates (see Hypothesis 1), and whether biostimulation using the high concentration whey solution enhanced contaminant mass transfer rates further (see Hypothesis 3).

Implementation

The demonstration was implemented in three phases, as described previously:

- **Phase 1 – Equilibration.** Hydraulic characterization of the treatment cells was conducted.
- **Phase 2 – Baseline.** ARD performance indicators were collected to evaluate electron donor concentrations, redox conditions, geochemistry, and contaminant concentrations in each treatment cell without electron donor addition.
- **Phase 3 – Biostimulation and enhanced mass transfer demonstration.** ARD performance indicators were monitored under biostimulation conditions during both low and high concentration whey powder injections.

Implementation of each phase is described below.

Phase 1 – Equilibration

The objective of Phase 1 was to characterize baseline flow and transport within the treatment cells, and to allow contaminant concentrations to re-equilibrate. Therefore, testing was conducted to determine critical hydraulic properties of the two treatment cells necessary in order to design an effective injection strategy to meet project objectives. The following sections describe these activities. These results of these analyses were used to determine initial hydraulic gradient, groundwater velocity and direction, and residence time under the operational strategy conducted for Phases 2 and 3.

3.5.7 Pumping and Hydraulic Tests

Following installation of the two treatment cells, the pumping and injection system was tested to determine if it was capable of operating per specifications in the demonstration design. In addition, hydraulic tests, including tracer testing, were conducted to establish the hydraulic properties of the aquifer system. Substantial differences were observed between actual system performance and estimates based on the assumptions stated in the TDP (NWI 2003). The most significant issues with the original treatment system were low water yield from the two extraction wells and a substantial vertical gradient within both treatment cells, resulting in transport of the tracer to the lowest depth of the monitored treatment zone and little to no recovery of tracer in the extraction wells. Therefore, system modification, including the installation of new injection and extraction wells, was conducted such that the treatment system could perform per required specifications.

3.5.8 Tracer Studies

Tracer studies were conducted to determine the baseline aquifer properties including hydraulic gradient both horizontally and vertically, hydraulic conductivity, residence time, groundwater velocity and direction, tracer distribution, and to establish that the treatment cells were hydraulically isolated. Initial tracer studies (conducted June, August and November 2003) revealed groundwater velocities much higher than originally anticipated, a substantial vertical gradient, and no hydraulic connectivity between the treatment cells. Following installation of new injection and extraction wells, the fourth tracer study (June 2005) revealed that distribution of the tracer throughout the monitored treatment zone was substantially improved, allowing the demonstration to proceed to Phase 2.

Phase 2 – Baseline

The objectives of Phase 2 were to determine baseline contaminant concentrations, as well as redox and bioactivity concentrations. Baseline chemical characterization began after the tracer testing was complete. Sampling and analysis procedures are detailed in Section 3.5.13. All monitoring locations were sampled for all analytical parameters including chloroethenes and metabolites, redox parameters, and bioactivity and electron donor indicators during this period.

Originally, the baseline testing was planned to consist of monitoring contaminant concentrations and establishing equilibrium in each treatment cell under pumping conditions. As the Phase 1 activities demonstrated that the groundwater velocity and direction was sufficient for distribution of electron donor throughout the treatment cell area without pumping, providing an equilibrium period was unnecessary. Therefore, baseline testing established the contaminant baseline parameters under ambient hydraulic conditions. The baseline aquifer analytical parameters included contaminant and reductive daughter product concentrations, redox conditions, and available carbon.

The extraction system was only used during injections of whey powder solution. Groundwater was extracted from the extraction wells, pumped through the whey powder injection system, and reinjected into the injection wells. The short-term impacts of injection events on contaminant concentrations were also determined during the baseline phase by conducting an injection without amendment and collecting samples the day of and the day after injection.

3.5.9 Baseline Recirculation

Baseline recirculation events were designed to mimic the recirculation and whey powder electron donor solution injection to be performed during Phase 3. This ensured that flow conditions were nearly identical in the two phases. Groundwater was pumped from extraction wells EW-1A and EW-2A at a rate ranging from 8 to 10 gpm, and was reinjected into injection wells IW-1A and IW-2A without the addition of whey. The injections took place during the weeks March 7, March 21, and April 4, 2005, and the approximate volume of water recirculated is shown on Table 3-2.

Table 3-2. Recirculation Activity Summary.

Month Completed	Volume of Water Recirculated (gal)	
	Treatment Cell 1	Treatment Cell 2
March 2005	1,300	1,300
March 2005	2,000	2,000
April 2005	1,600	1,700

Phase 3 – Biostimulation and enhanced mass transfer demonstration

Phase 3 testing was performed under two operating scenarios summarized in Table 3-3 and described below. Injections occurred at least once per month through February 2006. Downgradient monitoring continued for several months thereafter.

3.5.10 Whey Powder Injections

Phase 3 began with two initial, moderate concentration (~3% w/w), biweekly whey powder injections conducted on June 19, 2005 and June 26, 2005 into each treatment cell in order to stimulate biological activity and reducing conditions prior to attempts to achieve significant enhanced mass transfer. The Phase 3 differential injection strategy, discussed below as Scenarios 1 and 2, began in July 2005.

Table 3-3. Phase 3 Whey Injection Summaries.

	Treatment Cell 1		Treatment Cell 2	
	Volume of Water (gal)	Concentration of Whey (%)	Volume of Water (gal)	Concentration of Whey (%)
Jun-2005	3,200	4	3,900	3
Jun-2005	3,200	3	3,200	3
Jul-2005	1,700	10	4,000	1
Aug-2005	0 ¹	0 ¹	1,800	1
Sep-2005	1,700	10	4,000	1
Oct-2005	1,900	10	1,800	1
Nov-2005	1,800	1	1,800	10
Dec-2005	1,800	1	1,800	10
Jan-2006	1,800	1	1,800	10
Feb-2006	1,300	1	1,800	10
¹ .No recirculation or injection of whey due to equipment difficulties. Note: Scenario 2 areas are shaded; Scenario 1 areas are left unshaded..				

3.5.11 Changes to Phase 3 Strategy

Actual field conditions observed during the baseline sampling (Phase 2) indicated that TCE concentrations within Treatment Cell 1 were much lower than the TCE concentrations in the Treatment Cell 2, making the comparison between the cells difficult to implement as envisioned in DRs 1 and 2 outlined in the TDP. The original plan was to perform one injection scenario in one cell, and one in the other, and then compare the results. However, to collect data that would ultimately be useable to evaluate mass transfer and dissolution in two cells with dramatically different source characteristics, the injection strategy had to be changed. The revised strategy was to perform both injection scenarios in both treatment cells. This operational change allowed for the direct comparison of the effects of enhanced mass transfer as a result of electron donor concentration-dependent effects within each treatment cell.

Scenario 1

The Scenario 1 injection strategy entailed high concentration (10% w/w) whey powder injections into well IW-1A of Treatment Cell 1 on July 19, 2005, September 13, 2005, and October 4, 2005; and in IW-2A of Treatment Cell 2 on November 8, 2005, December 13, 2005, January 15, 2006, and February 22, 2006. Injection flow rates were maintained between 5 and 12 gpm and injections were performed over a period of several hours. The total target volume injected was approximately 1,800 gallons.

Groundwater monitoring during Phase 3 was performed as described in Section 3.5.13. All monitoring locations were sampled for chloroethenes and metabolites, redox parameters, and bioactivity and electron donor indicators during this period.

Scenario 2

The Scenario 2 injection strategy entailed low concentration (1% w/w) whey powder injections into well IW-2A of Treatment Cell 2 on July 19, 2005, August 16, 2005, September 13, 2005, and October 4, 2005; and in IW-1A of Treatment Cell 1 on November 8, 2005, December 13, 2005, January 15, 2006, and February 22, 2006. Injection flow rates were maintained between 5 and 12 gpm and injections were performed over a period of several hours. The total target volume injected varied between approximately 1,800 and 4,000 gallons. All groundwater monitoring was conducted as described for Scenario 1.

3.5.12 Bioaugmentation

Biological degradation of TCE to ethene requires the presence and activity of microbial populations capable of complete reductive dechlorination. As mentioned earlier, previous testing of ARD in NAPL Area 1 at EGDY suggested that the indigenous microbial community might be capable of complete dechlorination to ethene. However, the schedule for the field demonstration was very limited due to the impending implementation of a thermal treatment system in NAPL Area 3. Therefore, bioaugmentation was performed in both treatment cells in order to ensure that a dechlorinating microbial community was quickly established. This was accomplished by injecting a laboratory grown culture that was shown to transform TCE completely to ethene under anaerobic conditions. The culture used was a derivative of the Bachman Road culture, and was prepared by the Utah Water Research Laboratory (UWRL) specifically for this purpose. A report provided by the UWRL on the conditions of the culture prior to injection is provided as Appendix A. The culture injection method and system setup is summarized in Appendix B.

3.5.13 Sampling Plan

Groundwater sampling was conducted during Phases 2 and 3 of the demonstration to collect a data set that would achieve project objectives. Phase 2 activities included three rounds of baseline sampling conducted around the three biweekly injection/recirculation events. Each sampling round included collection of samples for VOC and dissolved gas analysis prior to the injection event, immediately following the injection event, and on the day following the injection event for all sample locations. In addition, the groundwater sampling purge parameters of pH, oxidation reduction potential (ORP), specific conductivity, dissolved oxygen (DO), and temperature were measured during each round of sample collection to ensure that representative samples were collected. The field-analyzed parameters, alkalinity and ferrous iron, were analyzed once during the last two baseline sampling events, as were sulfate, nitrate, chloride, chemical oxygen demand (COD). At the same time, specific compounds expected to be introduced with whey powder were analyzed, including acetate, propionate, isobutyrate, butyrate, isovalerate, and valerate. This same sampling strategy was repeated during Phase 3.

Phase 3 sampling activities were conducted around whey powder injections. Three rounds of sampling were conducted before, immediately following, and one day following whey injections conducted in July, August, October, November and December of 2005 and February 2006. In addition, sampling rounds were conducted 1 and 2 months following the last whey powder injection (February 2006). Analyses for VOC and dissolved gas analysis, groundwater sampling

purge parameters of pH, ORP, specific conductivity, dissolved oxygen (DO), and temperature, and samples for COD were conducted for all samples. Analytical parameters alkalinity, ferrous iron, sulfate, nitrate, chloride, and volatile fatty acids acetate, propionate, isobutyrate, butyrate, isovalerate, and valerate were generally analyzed for samples collected prior to whey powder injection, with the exception of the July 2005 sampling event in which samples collected the day following whey injection were analyzed. Volatile fatty acid and anion analyses were not performed on samples collected around the December 2005 sampling event.

Sample Collection

Samples were collected for 1) contaminant concentrations; 2) purge parameters: pH, ORP, specific conductivity, DO, and temperature; 3) field parameters: alkalinity and ferrous iron; 4) anions: sulfate, nitrate, chloride; and 5) electron donor parameters: COD and volatile fatty acids (VFA). Sample containers, volumes, and holding times are shown in Table 3-4.

In addition to the performance monitoring samples, field blank and field duplicate samples were collected to assess quality assurance (QA) parameters. All sample collection and handling was conducted by trained personnel using standard operating procedures identified in the TDP (NWI 2003, Appendix A). In general, low-flow sampling principles were practiced for all groundwater sampling.

Sample Analysis

The VOC concentrations, which were used for statistical analysis of the technology performance, were analyzed by an off-site laboratory using the methods described in Appendix A, and as shown in Table 3-5. Other data were analyzed by Utah State University, by Hach field analysis, and/or by field portable instruments (as described in Appendix A).

Experimental Controls

Well data from upgradient wells were available for comparison to experimental data within the treatment cells. Phase 2 data provided the baseline against which Phase 3 data were compared. The “pseudo-injection events” in Phase 2 ensured that groundwater flow conditions were similar for the baseline samples as for the Phase 3 samples. Tracer test data provided assurance that the two treatment cells were hydraulically isolated. The large suite of analytes also ensured that individual data point outliers or anomalies could be easily identified because they would not be internally consistent with the rest of the data. Finally, operating both treatment cells under both injection scenarios provided a means to compare the results of the scenarios directly under identical hydrogeologic and contaminant source conditions in each of the two cells. This eliminated a lot of potential experimental uncertainty.

Table 3-4. Sample Collection and Analysis Summary.

Analytes	Sample Container Size and Type	Preservative	Analytical Method	Holding Time	Comments
Phase 1					
Field laboratory analyses (priority)					
Bromide	One 125-mL HDPE	4°C	Ion-specific electrode	24 hours	Check for sulfide and/or other anion interference at high concentrations
Iodide	One 125-mL HDPE	4°C	Ion-specific electrode	24 hours	Same as above
Phases 2 and 3					
Off-site laboratory analyses					
Volatile Fatty Acids (acetate, propionate, butyrate, isobutyrate, valerate, isovalerate)	One glass 40-mL VOA vial	4°C, filtered with a 0.2 µm	SW-846 8015	7 days	
Anions (chloride, nitrate, sulfate)	One 500-mL HDPE	4°C	EPA 300.0 SW-846 9056	28 days	
COD	250-mL HDPE	H ₂ SO ₄ to pH<2	EPA 410.1	28 days	
VOC	Three glass 40-mL VOA vials	4°C	SW-846 8260B	14 days	No headspace

Table 3-4. Sample Collection and Analysis Summary (continued).

Analytes	Sample Container Size and Type	Preservative	Analytical Method	Holding Time	Comments
Field laboratory analyses (priority)					
Alkalinity (2)	250-mL HDPE	4°C	Hach Method 8203	24 hrs	
Ethane/methane	Three glass 40-mL VOA vials	HCl to pH<2 cool to 4°C	SW-8015M	14 days	No headspace
Iron (1)	250-ml HDPE	none	Hach Method 8146	30 minutes	Must be analyzed immediately; no headspace
USEPA = Environmental Protection Agency HDPE = high-density polyethylene VOA = volatile-organic analysis					

Table 3-5. List of Groundwater Analytical Methods Collected During Phases 2 and 3.

Analyte	Analytical Method	Method Detection Limit¹
VOC		
TCE	SW-846 8260B	5 µg/L
PCE	SW-846 8260B	5 µg/L
cis-DCE	SW-846 8260B	-
trans-DCE	SW-846 8260B	-
VC	SW-846 8260B	-
Electron donor		
COD	EPA 410.1	20 mg/L
Acetate	SW-846 8015	5 mg/L
Propionate	SW-846 8015	5 mg/L
Volatile Fatty Acids	SW-846 8015	5 mg/L
Redox indicators		
Dissolved oxygen	Flow-through cell during purging	
Sulfate	SW-846 9056	1 mg/L
Nitrate	SW-846 9056	1 mg/L
Iron	Hach Method 8146	0.03 mg/L
pH	Flow-through cell during purging	0-14 units
ORP	Flow-through cell during purging	-999-+999 mV
Bioactivity indicators		
Alkalinity	Hach Method 8203	10 mg/L
Specific conductivity	Flow-through cell during purging	0-100 mS/cm
Temperature	Flow-through cell during purging	
Chloride	SW-846 9056	2 mg/L
Dissolved gases		
Ethene	RSK 175	1 µg/L
Ethane	RSK 175	1 µg/L
Methane	RSK 175	1 µg/L
1. Method detection limits for cis-DCE, trans-DCE, and VC varied depending on concentrations of TCE.		

Data Quality Parameters

QA data consist of duplicates, blanks, and matrix spikes that were collected to provide a means of assessing the quality of data collected during the demonstration. Requirements for the QA sampling frequency and control limits are contained in the Quality Assurance Project Plan (QAPP; Appendix C). QA sampling conducted during the study was performed to evaluate the completeness, precision, and accuracy of the data. Sampling for all VOCs from the monitoring well treatment cells was 100% complete.

Data Quality Indicators

The precision, or repeatability, of samples was measured by analysis of blind field duplicate samples. Precision was calculated as the relative percent difference (RPD), as follows:

$$\%RPD_i = \frac{2|O_i - D_i|}{(O_i + D_i)} \times 100\% \quad (1)$$

where:

$$\begin{aligned} \%RPD_i &= \text{RPD for compound } i \\ O_i &= \text{value of compound } i \text{ in original sample} \\ D_i &= \text{value of compound } i \text{ in duplicate sample.} \end{aligned}$$

All duplicate samples were completed as planned. Precision based on the duplicate sample analyses was found to be within the acceptable ranges as stated in the project QAPP (Appendix C).

Accuracy is the amount of agreement between a measured value and the true value. The laboratory accuracy was measured as the percent recovery of matrix spike/matrix spike duplicate (MS/MSD) samples. Accuracy was calculated as percent recovery of analytes, as follows:

$$\%R_i = (Y_i \div X_i) \times 100\% \quad (2)$$

where:

$$\begin{aligned} \%R_i &= \text{percent recovery for compound } i \\ Y_i &= \text{measured analyte concentration in sample } i \\ &\quad (\text{measured} - \text{original sample concentration}) \\ X_i &= \text{known analyte concentration in sample } i. \end{aligned}$$

The resultant percent recoveries were compared to acceptance criteria and were found to be acceptable within the QAPP acceptable range.

Calibration Procedures, Quality Control Checks, and Corrective Action

The original demonstration was modified to include alternating a higher and a lower whey concentration in each treatment cell because a direct comparison of the effects of whey injection between the two treatment cells was not practical once it was determined that the two treatment cells had dramatically different contaminant source characteristics. The target concentrations for whey were 10% and 1% by weight for the low- and high-concentration test scenarios. An automatic feeder system that used a screw feeder mechanism to control the concentration of whey was used to regulate the amount of whey that was added to the injection flow. A dial on the injection system could be set to control the amount of whey that was mixed into the injectate. The whey powder was sensitive to humidity conditions and if not kept dry would clump and consequently not feed through the mechanism properly. The introduction of clumps of whey to the screw feeder slowed the mechanism and decreased the amount of whey that was metered out. Using a bucket and scale to measure the mass of whey that was fed through the injection system per unit of time and the known flow of water a concentration was calculated to serve as a concentration check. In addition, a screen was added on line to take out clumps of whey that might interfere with the mixing of the injection solution.

3.5.14 Demobilization

Upon completion of demonstration activities and prior to the thermal treatment operations, all equipment and materials used for implementing the technology demonstration were removed from the site, decommissioning of the wells in the treatment cells was conducted, and all affected areas were regraded.

A total of four injection wells, four extraction wells, eight CMT wells, and four fluxmeter wells (20 wells total) were decommissioned. Prior to beginning the decommissioning tasks, "Notice(s) of Intent to Decommission a Well" and any associated fees were submitted to the Washington Department of Ecology (WDOE), as required by WAC 173-160.

For extraction of injection and fluxmeter type wells, the following standards, outlined in WAC 173-160 (as applicable), were employed:

1. Remove the bollards, protective well casing, and the surface seal.
2. Cut the casing at a depth of no more than 5 ft bgs.
3. Prepare cement silica grout mix in accordance with **WAC 173-160-221**.
4. Fill the casing from bottom to within 5 ft of land surface with silica cement grout.
5. Decontaminate the drilling/abandonment equipment prior to demobilizing from the Site. Collect all decontamination fluid in drums. Properly dispose of the decontamination fluid.

The eight CMT wells were decommissioned, following the standards outlined in **WAC 173-160** (as applicable), including:

1. Remove the bollards, protective well casing, and the surface seal.
2. Completely redrill the borehole to a minimum of the original borehole diameter (8-12 inches).
3. Remove all casing, screen, annular sealing material, drill cuttings, debris, and filter pack material prior to sealing.
4. Prepare cement silica grout mix in accordance with **WAC 173-160-221**.
5. Lower the tremie hose pipes to the bottom of the well and pressure grout from the bottom.
6. Pressure grout the well to the existing ground surface. The grout was topped off to account for settling.
7. Decontaminate the drilling/abandonment equipment prior to demobilizing from the site. Collect all decontamination fluid in drums. Properly dispose of the decontamination fluid.

Well abandonment records were filed with the WDOE at the completion of the well decommissioning. Disposal of the wastes generated during abandonment was conducted in accordance with applicable waste disposal regulations.

4. PERFORMANCE ASSESSMENT

The technology demonstration was designed to evaluate enhanced mass transfer of contaminants into the aqueous phase during the application of enhanced in situ bioremediation for treatment of chlorinated solvent DNAPLs. Performance metrics important to any enhanced bioremediation application, including delivery of amendments, achievement of reducing conditions, and stimulation of efficient biodegradation to non-hazardous end products, are still very important but an emphasis on optimizing bioremediation for DNAPL source areas was the priority.

4.1 Performance Criteria

Performance criteria for the demonstration are listed in Table 4-1. The table identifies performance criteria that were used to evaluate the results of the demonstration, and whether those criteria were considered primary or secondary based on the demonstration objectives.

Table 4-1. Performance Criteria.

Performance Criteria	Description	Primary or Secondary
Contaminant Reduction	Reduce concentration of chloroethenes including primarily TCE and cis-DCE to non-hazardous end products at Ft. Lewis EGDY.	Primary
Contaminant Enhanced Mass Transfer	Enhance the rate at which contaminants are dissolved from the DNAPL to the aqueous phase where they are available for biodegradation.	Primary
	Enhance mass transfer via maximizing the rate and extent of reductive dechlorination of parent compounds to reductive daughter products.	Primary
	Enhance mass transfer via increasing the aqueous effective solubility of the DNAPL using high concentration whey powder solution.	Primary
Hazardous Materials	All injected materials are non-hazardous. Incomplete degradation of chlorinated ethenes may result in elevated concentrations of reductive daughter products. In addition, enhanced mass transfer may increase the loading of these products to groundwater. Secondary water quality issues, including odor, color, and taste, may also occur but are non-hazardous.	Secondary
Process Waste Process	Waste was limited to soil cuttings from well installation and groundwater from well development and purging. Soil cuttings and groundwater were disposed of as described in the TDP. Leftover (unused) whey powder was composted.	Secondary

Table 4-1. Performance Criteria. (continued).

Performance Criteria	Description	Primary or Secondary
Factors Affecting Technology Performance	Ability to distribute high concentration whey powder solutions efficiently throughout DNAPL treatment area. It is essential to have good contact between whey powder mixtures and residual phase contaminant mass.	Secondary
	Achieve sufficiently reducing conditions to favor efficient anaerobic reductive dechlorination.	
	Maintain geochemical conditions conducive to microbial growth and activity.	
Reliability	Factors that affect reliability of technology include reliability of above ground injection equipment and ability to maintain efficient injections throughout target treatment area.	Secondary
Ease of Use	Applicability requirements are similar to what has been described before for in situ technologies including: 1) installation of injection, extraction, and monitoring well networks, 2) injection and monitoring equipment and personnel, 3) Occupational Safety and Health's (OSHA's) health and safety training is required because the site contains high concentrations of chlorinated solvents as well as other mechanical and physical risks.	Secondary
Versatility	Enhanced bioremediation can be applied to a variety of contaminant NAPLs in a variety of geologic aquifer environments.	Secondary
Maintenance	The largest maintenance requirement is the injection events. The frequency, concentration, and volume should be designed to maximize the rate at which contaminants are released from the residual to the aqueous phase coupled to efficient biodegradation of liberated contaminants.	Secondary
Scale Up Constraints	The potential issues of concern associated with scaling up the technology for full implementation include: 1) Variability of NAPL architecture and accessibility of contaminant mass throughout contaminant source area. 2) Composition of NAPLs throughout contaminant source area. 3) Variability in the lithology throughout the contaminant source area.	Secondary

4.2 Performance Confirmation Methods

Performance confirmation methods and brief summaries of results are listed in Table 4-2. While the table provides a brief overview of the results of the multiple lines of evidence evaluated to meet the project objectives, a detailed discussion of results is provided in Section 4.3. Therefore, the summary table also includes references to relevant text as needed. A comparison of demonstration results with objectives is given in Section 4.3.1.

The critical performance elements included distribution and concentration of injected whey solution, the rate and extent of dechlorination, and the changes in mass transfer of contaminants and biodegradation products within the treatment cells over time during low- and high-concentration whey powder injections. The parameters monitored included chloroethenes and metabolites, electron donor and fermentation products, and bioactivity and redox indicators.

A statistical evaluation was performed to determine whether differences in total VOC and ethene were statistically significant among the baseline, low-concentration whey injection, and high-concentration whey injection conditions. As stated in the TDP and in Section 3.1, DR were defined and restated as null hypotheses to allow for statistical evaluation of the data.

A one-way analysis of variance was used to determine whether or not total VOC concentrations are significantly changed between phases of the demonstration. Null Hypotheses 1 and 2 state that the mean VOC concentration for either high or low donor concentrations will not be significantly different than the baseline mean. Therefore, the alternative hypothesis is true if the mean concentrations show statistically different values than the baseline. Null Hypothesis 3 states that the mean for the high electron donor concentration biostimulation scenario will not be significantly different from the low donor concentration scenario; the alternative hypothesis is that there is a significant difference between the VOC concentrations after high and low donor injections. The initial significance level used for the t-tests was 0.1, based on the maximum acceptable error tolerance specified through the DQO process in Section 3.6.7 of the TDP. If the p-value is 0.1 or less for the t-test, then we reject the null hypothesis in favor of the alternative hypothesis and conclude with 90% confidence that there is a significant difference between the means.

Data for Treatment Cell 2 was used in the analysis because analytical data suggested that little or no significant DNAPL was present in Treatment Cell 1 (ESTCP Memo November 3, 2005). In order to evaluate enhanced mass transfer, it is very important that DNAPL, present as either residual or free phase, be present in the treatment cells otherwise, mass transfer is not a rate limiting process. Therefore only the data from Treatment Cell 2 are discussed in the body of this report, although all of the analytical data for both treatment cells are provided in Appendix E. The effects of the different concentration whey powder injections were also observed at the downgradient fluxmeter wells located approximately 150 ft downgradient of NAPL Area 3. Therefore, these results will be discussed for both treatment cells.

Table 4-2. Expected Performance and Performance Confirmation Methods.

Performance Criteria	Performance Metric	Performance Confirmation Method	Actual Performance
Phase 1: Hydraulic Characterization			
Bromide	Primary indicator of groundwater velocity, travel time.	Inverse analytical modeling (Quantitative).	Hydraulic gradient, groundwater velocity and direction, hydraulic conductivity, residence time all measured successfully. Hydraulic Conductivity: Cell 1 - 15 ft/d Cell 2 - 24 ft/d (June 2004).
Fluorescence/Rhodamine WT	No cross-communication of tracers indicates hydraulic isolation of treatment cells.	Analysis of Treatment Cell 1 tracer in Treatment Cell 2 and vice versa (Qualitative).	Tracers injected into one treatment cell were not observed in the other.
Phase 2: Baseline Contaminant Concentration and Intrinsic Reduction			
Chloroethenes including PCE, TCE, cis-DCE, trans-DCE, 1,1-DCE, and VC	Collection of data to provide indicator of dechlorination under baseline conditions; primary performance criterion.	Calculation of mole fraction of reductive daughter products (cis-DCE, VC) relative to parent compounds (TCE) (Quantitative).	During baseline, only cis-DCE was detected as a significant fraction of total molar concentration of VOC and ethane.
Ethene and Ethane	Collection of data to provide indicator of complete dechlorination under baseline conditions; primary performance criterion.	Calculation of mole fraction of ethene/ethane relative to parent compound (TCE) (Quantitative).	No ethene/ethane was observed during baseline sampling.

Table 4-2. Expected Performance and Performance Confirmation Methods (continued).

Performance Criteria	Performance Metric	Performance Confirmation Method	Actual Performance
Phase 3: Contaminant Concentration and Enhanced Reduction			
Chloroethenes including PCE, TCE, cis-DCE, trans-DCE, 1,1-DCE, and VC	Increased mole fraction of products indicates enhanced dechlorination; primary performance criterion.	Calculation of mole fraction of reductive daughter products (cis-DCE, VC) relative to parent compounds (TCE) (Quantitative).	The fraction of daughter products increased relative to parent compounds in Phase 3 relative to that observed in Phase 2.
Ethene and Ethane	Increased mole fraction of products indicates complete dechlorination; primary performance criterion.	Calculation of mole fraction of ethene/ethane relative to parent compound (TCE) (Quantitative).	Concentrations of ethene increased over the course of Phase 3, with the highest concentrations and mole fractions observed at the end of the test.
Phase 2 and 3: Enhanced Mass Transfer			
Chloroethenes and Ethene/Ethane in Treatment Cells	Increased total molar concentrations of chloroethenes and ethene/ethane are a primary indicator for enhanced mass transfer.	T-test (Quantitative).	Total chloroethenes and ethene were higher under Phase 3 conditions than under Phase 2 conditions, and were higher during high concentration whey powder injections in Treatment Cell 2 than observed during low concentration injections.
Chloroethenes and Ethene/Ethane in Downgradient Flux Wells	Increased total molar concentrations of chloroethenes and ethene/ethane are a primary indicator for enhanced mass transfer.	T-test (Quantitative).	Total chloroethenes and ethene were elevated downgradient of both treatment cells during periods when high concentration whey powder injections occurred relative to when low concentration injections occurred.

Table 4-2. Expected Performance and Performance Confirmation Methods (continued).

Performance Criteria	Performance Metric	Performance Confirmation Method	Actual Performance
Phase 2 and 3: Factors Affecting Technology Performance			
Electron donor : COD and VFAs including lactate, acetate, propionate, butyrate, valerate, isovalerate, isobutyrate	Measurement of electron donor throughout treatment cells indicates adequate distribution; production of VFAs indicates of rate and extent of fermentation.	Trend charts for COD and VFA distribution (Qualitative).	High concentrations of carbon were distributed throughout the treatment system during both low and high concentration whey powder injections, and as far downgradient as the flux wells during high concentration whey powder injections. In addition, significant production of VFAs was observed.
Redox indicators			
Dissolved oxygen (DO)	Low or no DO favorable for dechlorination.	Trend charts for DO (Qualitative).	Decreased from 2-3 mg/L at most locations during Phase 2 to < 1 mg/L at all monitoring well locations within the treatment cells following the first whey injection in Phase 3.
Sulfate	Low or no sulfate favorable for dechlorination.	Trend charts for sulfate (Qualitative).	Decreased from approximately 15-30 mg/L during Phase 2 to a maximum of 5-7 mg/L at all monitoring well locations within the treatment cells following the Phase 3 whey injections.

Table 4-2. Expected Performance and Performance Confirmation Methods (continued).

Performance Criteria	Performance Metric	Performance Confirmation Method	Actual Performance
Iron	Elevated iron favorable for dechlorination.	Trend charts for iron (Qualitative).	Increased from non-detect in Phase 2 to greater than 3.3 mg/L at all monitoring well locations within both treatment cells following whey injections in Phase 3.
Methane	Elevated methane indicates conditions most favorable for dechlorination.	Trend charts for methane (Qualitative).	Increased from non-detect in Phase 2 to > 5 mg/L at most locations by the last sampling event of Phase 3.
ORP	Large negative ORP values most favorable for dechlorination.	Trend charts for ORP (Qualitative).	Decreased from ~100-200 mV at most locations during Phase 2 to < 100 mV during Phase 3.
Bioactivity indicators			
Alkalinity	Increasing alkalinity indicates biological activity and increased buffering capacity of the groundwater.	Trend charts for alkalinity (Qualitative).	Increased from ~ 60 mg/L as CaCO ₃ at most locations during Phase 2 to > 100 mg/L at most locations during Phase 3.
pH	pH > 5.5 indicates conditions best suited for dechlorination activity by <i>Dehalococcoides spp.</i>	Trend charts for pH (Qualitative).	pH declined to < 5.5 at most monitoring well locations in both treatment cells following whey injections. The pH remained low for the first 6 months of the test, after which it began to rebound to near neutral levels between whey powder injections.

4.3 Data Analysis, Evaluation, and Interpretation

All of the performance criteria in Table 4-2 were evaluated to determine whether reductive dechlorination was enhanced, and whether the B.E.T.TM technology was demonstrated to enhance mass transfer successfully in the DNAPL source area at EGDY NAPL Area 3. Baseline conditions for each of the treatment cells were established by sampling of groundwater parameters before and after recirculation events. These baseline conditions were then compared to analytical data collected before and after the whey injections.

Results of the Phase 1 hydraulic characterization and equilibration period, along with their implications, are presented in Section 4.3.1. The electron donor and bioactivity and redox parameters are presented in Sections 4.3.2 and 4.3.3, respectively. Dechlorination and enhanced mass transfer results are presented in Section 4.3.4 and 4.3.5, respectively. Complete data sets for all parameters are included in Appendix E.

4.3.1 Hydraulic Characterization

Hydraulic characterization was conducted to obtain parameters necessary to design an effective ISB injection strategy to meet the demonstration objectives. Pumping tests were performed to evaluate sustainable yield of extraction wells and to estimate hydraulic conductivity in the area of the demonstration. Following the pumping tests, tracer studies were conducted to determine the baseline aquifer properties including hydraulic gradient both horizontally and vertically, hydraulic conductivity, residence time, and groundwater velocity and direction. In addition, it was important to establish that the treatment cells were hydraulically isolated. Initial tracer studies (beginning in June, July, and November 2003) revealed groundwater velocities much higher than originally anticipated, a substantial vertical gradient, no hydraulic connectivity between the treatment cells, and an injection system that was ineffective at distributing tracer through the high concentration residual contaminant zone due to vertical heterogeneity in permeability. Following installation of new injection and extraction wells, the third tracer study (June 2004) demonstrated effective distribution of the tracer throughout the targeted treatment zone.

4.3.1.1 Extraction Well Pumping Tests

Initial pumping tests revealed that the original extraction wells yielded nearly an order of magnitude lower production rate than expected with a maximum sustainable yield of approximately 4 gpm in well EW-1 (North) and approximately 2.8 gpm for EW-2 (South) compared to the initial design assumptions of 10-20 gpm. The low actual yields were attributed to unusually low well efficiency due to the original drilling method. In addition, initial tracer test results (discussed below) demonstrated that most of the produced water was coming from near the bottom of the extraction wells, which were completed to 30 ft bgs. After the installation of new extraction wells in April 2004 using a different drilling method to depths of 35 ft rather than 30 ft, the sustainable yields increased to 10 and 18 gpm for the new extraction wells EW-1A (North) and EW-2A (South), respectively.

4.3.1.2 Tracer Test 1 (June 2003) and 2 (July 2003)

Two tracer tests were performed in June and July of 2003. The first test (June 2003) provided an initial indication of groundwater velocity and tracer distribution, as well as evaluating the potential for “cross-communication” between the treatment cells. Results of the June 2003 tests demonstrated that tracer breakthrough could not be resolved by the sampling frequency used. Therefore, the second tracer test was performed in July 2003 to resolve the breakthrough curves at multiple monitoring points.

Tracer Test 1 was conducted using sodium bromide in both treatment cells in June 2003. In addition, rhodamine WT was injected into Treatment Cell 1 and fluorescein into Treatment Cell 2 in order to determine whether the two treatment cells were hydraulically isolated. Water tanks (250 gal) were used to mix approximately 275 kg of sodium bromide and 190 mL of the concentrated fluorescent dyes in water for a total volume of approximately 130 gal. Tracer was injected for a total of 23 hours during Day 0 (June 21, 2003) and Day 1 (June 22, 2003). The tracer was injected at a rate of 2.8 gpm in each treatment cell with injection concentrations of approximately 17,000 ppm bromide, 18,000 parts per billion (ppb) rhodamine WT, or 24,000 ppb fluorescein measured on Day 0. Sample collection began on Day 3 with samples collected from port 2 of the CMT multiport monitoring (approximately 21 ft bgs) in all of the monitoring wells, as well as the injection and extraction wells on Days 3, 6, 9, 12, and 20 following injection. In addition, samples were collected from all of the CMT monitoring well ports (approximately 16, 21, 26, and 31 ft bgs), and the injection and extraction wells on Days 5, 11, and 17.

In Treatment Cell 1, bromide tracer was only detected the first sampling event following injection. Concentrations along the treatment cell axis included the injection well (110 ppm), MWD (410 ppm), and the extraction well (130 ppm). The cross-gradient wells initially had approximately the same concentration of bromide (150 vs. 180 ppm). This suggested that nearly all of the tracer had moved through the monitoring area within about 12 hours after the end of the second day of injection. The highest concentrations of bromide observed for each of the monitoring wells was in the deepest sampling port, with concentrations 10-1,000 times higher than in any of the shallow ports. These results suggested that the flowpath in Treatment Cell 1 was aligned with the treatment cell axis, and that a significant downward vertical gradient made detections of tracer difficult in all but the deepest ports of the installed monitoring system.

Fluorescein results were slightly different than the bromide. The highest concentrations of fluorescein were observed in MWA, port 4 (not MWD as for bromide). Also, cross gradient MWB had much higher concentrations of fluorescein (80 ppb) than MWC (3 ppb). In any case, no fluorescein was detected in Treatment Cell 2, indicating that no risk of “cross-communication” existed between the treatment cells.

Overall, the bromide concentrations were lower for Treatment Cell 2 than for 1. In Treatment Cell 2, significant bromide was detected in the injection well (14,500 ppm) the day after injection. The only other well with significant bromide (>100 ppm) was MWC port 3. The overall trend over time was that the deep ports 3 and 4 (27 to 31 ft bgs) saw much higher

concentrations of tracer than did the shallow ports 1 and 2 (16 to 21 ft bgs.). This effect became more pronounced as the tracer moved downgradient with two to three times as much tracer observed in MWA deep ports as the shallow ports, and with 1,000 times more tracer observed in MWD deep ports as the shallow ports. Also, more tracer was observed in MWC compared with MWB. Very little tracer was observed in the extraction well. This trend was also observed with Rhodamine, except that the highest concentration was observed in the cross-gradient well MWC (392 ppb), rather than in the downgradient well MWD (200 ppb), as observed with the bromide. These data suggest that the flowpath in Treatment Cell 2 was somewhat south of the axis from the injection to the extraction well. In addition, a significant vertical gradient was also prevalent in Treatment Cell 2.

The inability to determine a peak breakthrough time in any of the monitoring wells because of the rapid transport observed during the first tracer study prompted a second tracer study. Tracer Test 2 was conducted using sodium bromide in July 2003 to attempt to measure more complete breakthrough curves. Large drums (55-gal) were used to mix approximately 113 kg of sodium bromide into 42 gal of water. The tracer was injected at a rate of 2.8 gpm in each treatment cell. The resultant injection concentrations were approximately 32,000 ppm. Samples were collected twice a day from all of the monitoring well ports, the injection wells, and the extraction wells on the day of injection (Day 0), and Day 1 and 2 following injection.

The second tracer study confirmed much of what was concluded after the first tracer study (see Figures 4-1 and 4-2). Again, the majority of tracer was observed in the deepest monitoring locations. Bromide tracer solution was injected into each treatment cell for 6 hours. Treatment Cell 1 had extremely high (14,500 ppm) bromide concentrations 6 hours after injection began in MWA port 4, which tapered off to 1,460 ppm after 23 hours. Near non-detect concentrations of bromide were observed in the shallow sampling ports of MWA during all sampling events. Peak bromide concentrations in MWD port 4 (750 mg/L) occurred 23 hours after injection began. Also, similar to the first tracer study, very little tracer was observed in either of the cross-gradient wells (maximum concentrations 50 ppm) or in the extraction well (20 to 80 ppm).

In Treatment Cell 2, the highest concentrations of bromide were observed in MWA port 4 (7,600 ppm), MWC port 4 (5,500 ppm), and MWD port 4 (2,300 ppm) 6 hours after bromide injections began. Bromide concentrations in the injection well were measured at 31,000 ppm during both the 23-hour and 27-hour sampling points. Concentrations in MWB were lower (81 ppm) at the 6-hour time point, but were significantly higher 23 hours after injection began (1,260 ppm). At 23 hours, all wells, except MWB, were significantly lower in concentration than the previous time point at 6 hours. Again the highest concentrations were observed in the deepest sampling ports, and MWC experienced higher concentrations of tracer than MWB (5,000 and 2,000 ppm vs. 80 and 1,260 ppm).

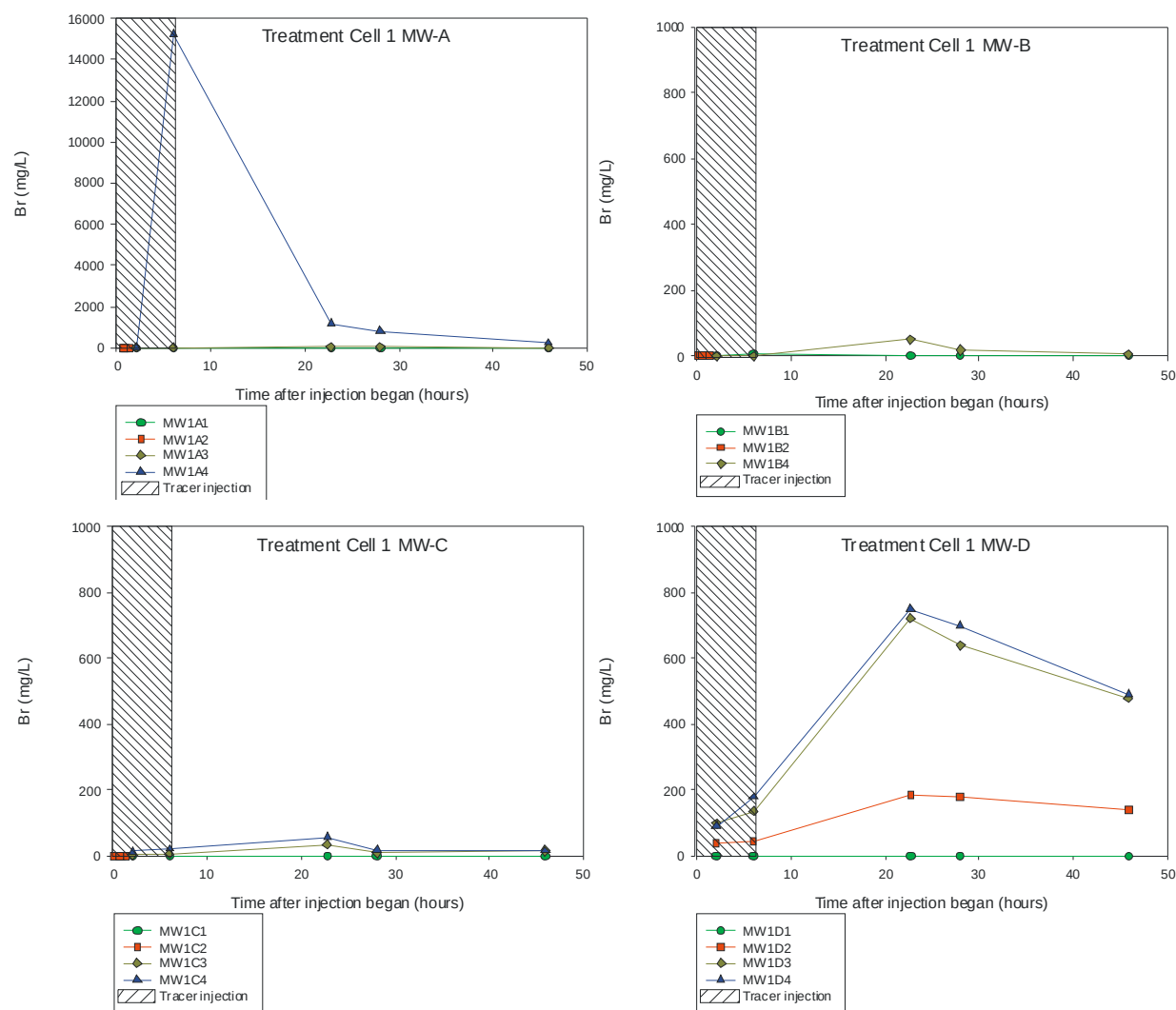


Figure 4-1. Distribution of Bromide in Treatment Cell 1 for Tracer Test 2.

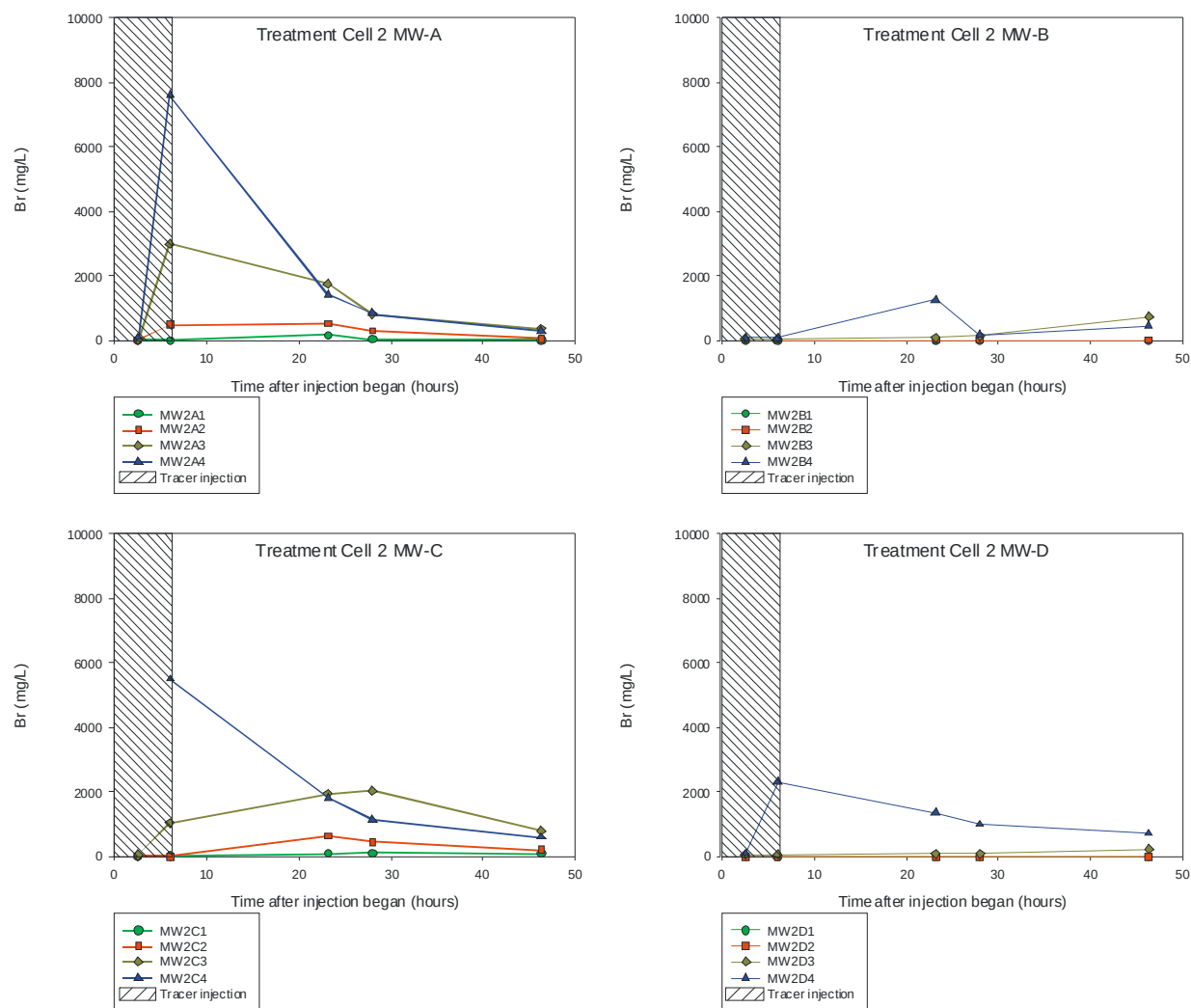


Figure 4-2. Distribution of Bromide in Treatment Cell 2 for Tracer Test 2.

Overall, Tracer Tests 1 and 2 demonstrated that tracer transport in the treatment cells was extremely rapid, but that it was limited primarily to the bottom portion of the cells and appeared to have a significant downward vertical component. The distribution of injected fluids almost exclusively at the bottom of the treatment cells (and below) was very undesirable for Phase 3 of the demonstration. The tests also demonstrated that the treatment cell axes were fairly well aligned with the groundwater flow directions in the cells. Finally, these initial tests provided assurance that fluids injected in one cell would be very unlikely to impact the other cell.

4.3.1.3 Tracer Test 3 (November 2003)

The most serious concern identified in the initial tracer tests was the lack of distribution of tracer in the upper half to three quarters of the treatment cells, where the majority of residual-phase contamination was present, due to aquifer heterogeneity and a significant vertical gradient. In order to evaluate the impact of nearby pump and treat extraction wells on transport of tracer within the treatment cells, pump and treat wells LX-19 and LX-17 were shut off, and extraction rates at wells LX-18 and LX-21 were reduced. A third tracer test was conducted beginning November 18, 2003, approximately 1 month after the pumping modifications were made. The tracer test design was nearly identical to Tracer Test 2, with increased sampling frequency. The sampling strategy included collecting samples from all of the wells in monitoring port 4 (approximately 31 ft bgs) and from both the injection and the extraction wells before tracer injection began, twice during injection, three times the day after injection, and then once again 2 days after injection. Samples were also collected from all of the monitoring well ports (approximately 16, 21, 26, and 31 ft bgs), once during injection, twice the next day, and once 2 days after injection.

The data from this tracer test were virtually identical to those observed during Tracer Test 1 and 2 (data not shown). Therefore, it was determined that reducing the extraction rate of the pump and treat system near NAPL Area 3 had little/no influence on the groundwater velocity or the vertical gradient observed in both treatment cells. Given the configuration of the treatment systems, it was determined that it would be difficult to track any amendments given the low mass balance of recovered tracer. Hydraulic control of the treatment systems was not being realized using the existing extractions wells. Therefore, in order to maximize the opportunity for success during the demonstration, the following activities were conducted:

- Additional injection wells were drilled to 20 ft bgs and additional extraction wells were drilled to 35 ft bgs to improve vertical distribution,
- Additional hydraulic efficiency testing was performed on the new system, and
- Tracer testing was repeated with the new system.

4.3.1.4 Tracer Test 4 (June 2004)

New injection and extraction wells were drilled for each treatment cell in April 2004 to improve the treatment cell design. Tracer Test 4 was conducted using sodium bromide beginning June 10, 2004, in order to determine if the system performance was improved. Large drums (55-gal) were used to mix approximately 62 kg of sodium bromide into 42 gal of water. The tracer was injected at a rate of 8.0 gpm in each treatment cell for approximately 3 hours, and a water flush was conducted for 1 hour post-bromide injection. The resultant injection concentrations were approximately 6,000 ppm. The sampling strategy included collecting samples from all of the monitoring wells in all of the monitoring ports (approximately 16, 21, 26, and 31 ft bgs) before tracer injection, twice during injection, and twice shortly after injection. Samples were then collected from all of the monitoring ports twice the day after injection and on the fifth day after tracer injection when all ports were sampled twice. This sampling strategy was more intensive than previous sampling strategies, especially during the day of and day after tracer injection, in order to generate more refined tracer breakthrough curves at each monitoring location.

The maximum sustainable flow rate achieved using the new extraction wells was 10 and 18 gpm in Treatment Cells 1 and 2, respectively. Hydraulic parameters were calculated to determine the hydraulic characteristics of the treatment cells with the new injection/extraction systems. Conductivity values calculated for each treatment cell using the Thiem equation (equation 3) suggest that the new extraction wells tapped a higher transmissivity zone at the greater depth than the previous extraction wells. The conductivity calculated during the June 2003 tracer test ranged from 2.3 to 9.5 ft/d for Treatment Cell 1, and from 3.2 to 16.6 ft/d for Treatment Cell 2, depending on the wells used to perform the calculation. Values calculated during the June 2004 tracer test ranged from 6.0 to 15.0 ft/d for Treatment Cell 1, and 24.2 to 53.0 ft/d for Treatment Cell 2. The conductivity values obtained using the new extraction wells are more reliable overall due to the higher flow rates and the greater drawdown in the extraction wells that resulted. Extremely high groundwater velocities of approximately 360 ft/d during injection were observed with ambient groundwater velocities closer to 1 ft/d.

$$K = \frac{Q}{\pi(h_2^2 - h_1^2)} \ln\left(\frac{r_2}{r_1}\right) \quad (3)$$

where:

- K = hydraulic conductivity
- Q = pumping rate
- h_1 = head at distance r_1 from the pumping well
- h^2 = head at distance r_2 from the pumping well.

Results of this tracer study were markedly different than the results of previous tracer studies. Vertical distribution of the bromide tracer was greatly improved along the axis of both treatment cells with much greater consistency in peak tracer concentrations between all ports of the A and D monitoring wells (Figures 4-3 and 4-4). For instance, in Treatment Cell 1 MWA (MW1A) peak tracer concentrations were 6,470 mg/L in port 1, 4,020 mg/L in port 2, 3,015 mg/L in port 3, and 4,700 mg/L in port 4. The peak arrival times were all within 3 hours, which took place while the injection was still being conducted. In Treatment Cell 2 MWA (MW2A), peak tracer concentrations were 3,570 mg/L in port 1, 3,565 mg/L in port 2, 2,025 mg/L in port 3, and 5,535 mg/L in port 4. Peak arrival times were 3 hours after injection began in ports 1-3, and 5 hours after injection began in port 4. The peak tracer concentrations downgradient at the MWD wells in Treatment Cell 1 were: 1,427 mg/L at MW1D2 (port 2), 920 mg/L at MW1D3, and 873 mg/L at MW1D4. For Treatment Cell 2, they were 2,090 mg/L at MW2D1, 2,190 mg/L at MW2D2, 1,352 mg/L at MW2D3, and 1,303 mg/L at MW2D4 (Figures 4-3 and 4-4). The arrival times for all ports in MWD in Treatment Cell 1 were approximately 4 hours, and for Treatment Cell 2 were approximately 6 to 8 hours after injection began.

Tracer recovery in the extraction wells during this tracer study was also much better compared to the previous tracer studies, with peak concentrations reaching 801 mg/L in Treatment Cell 1 and 1,045 mg/L in Treatment Cell 2. A mass balance conducted during the 4-hour period in which the extraction wells were pumping suggest that approximately 13% and 10% of the total tracer mass was recovered in Treatment Cells 1 and 2 extraction wells, respectively. These data suggest that the new shallow injection wells allow for better vertical distribution of tracer, and the new extraction wells captured a much greater overall percentage of the tracer mass.

Some preferential vertical transport of tracer into the deep monitoring ports of the off-axis wells of Treatment Cell 1, however, was still apparent. In this cell, little tracer was observed at MW1B1 (110 mg/L) and MW1B2 (298 mg/L) compared with MW1B4 (1,985 mg/L). Likewise, MW1C1 and MW1C2 (56 mg/L maximum in both) saw little tracer compared with MW1C3 and MW1C4 (1,625 and 1,675 mg/L).

Transport of tracer to the off-axis wells in Treatment Cell 2, however, was very different than that observed in Treatment Cell 1. Evaluation of peak concentrations of tracer in MW2B indicated that nearly direct transport of tracer occurred to port 4, with peak concentrations that were near the injection concentration (5,420 mg/L) and occurring during the tracer injection (at approximately 3 hours into injection). Port 1 had the next highest peak concentration of tracer (1,245 mg/L), followed by port 2 (705 mg/L) and port 3 (478 mg/L). The arrival times of the peak breakthrough were also very different for each port with MW2B1 arriving at approximately 9 hours, MW2B2 at 24 hours, MW2B3 at 31 hours, and MW2B4 at 3 hours after tracer injection began. This suggests that there is substantial vertical stratification of different permeability zones between the injection well and MW2B.

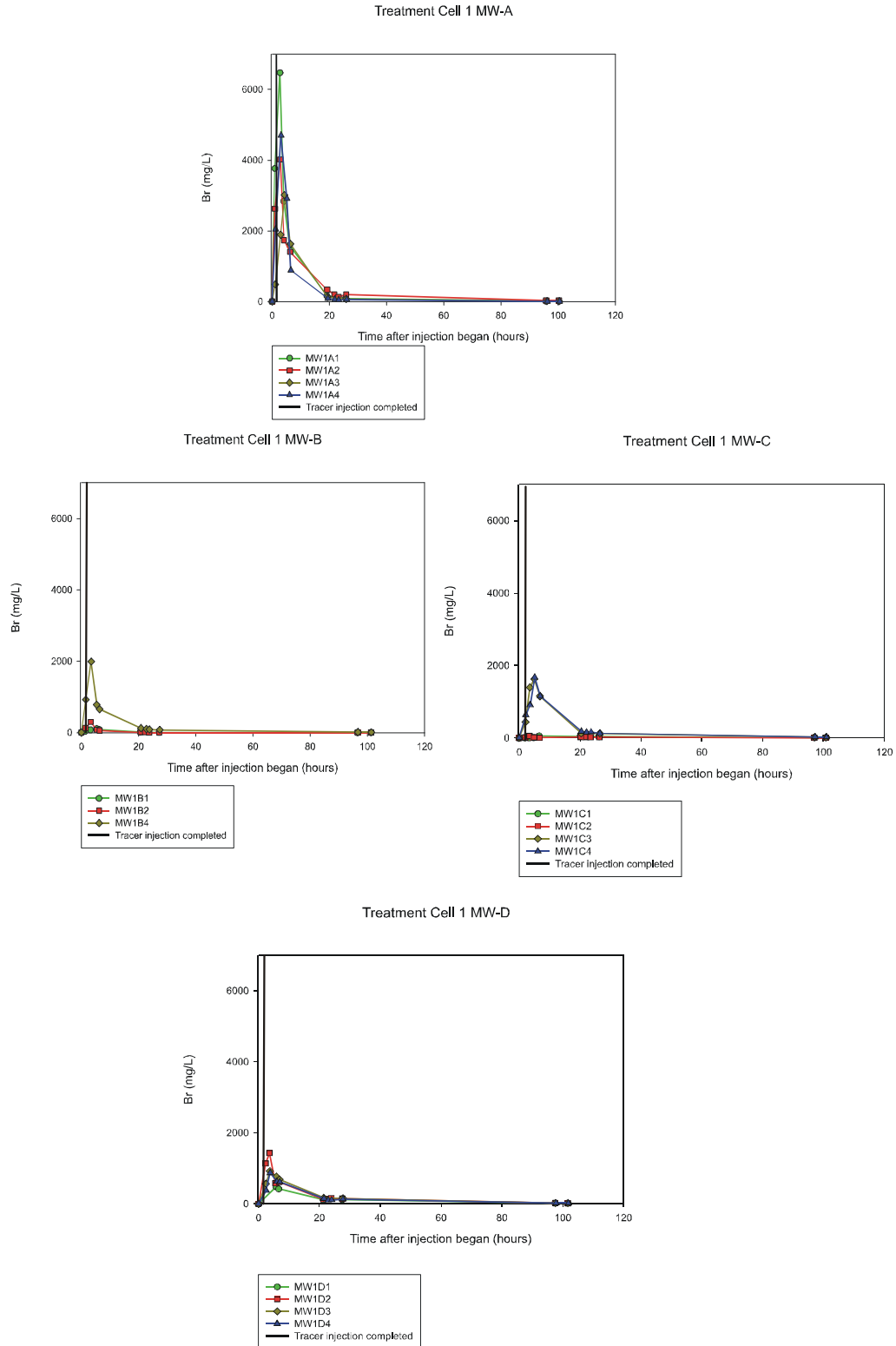


Figure 4-3. June 2004 Tracer Results Treatment Cell 1.

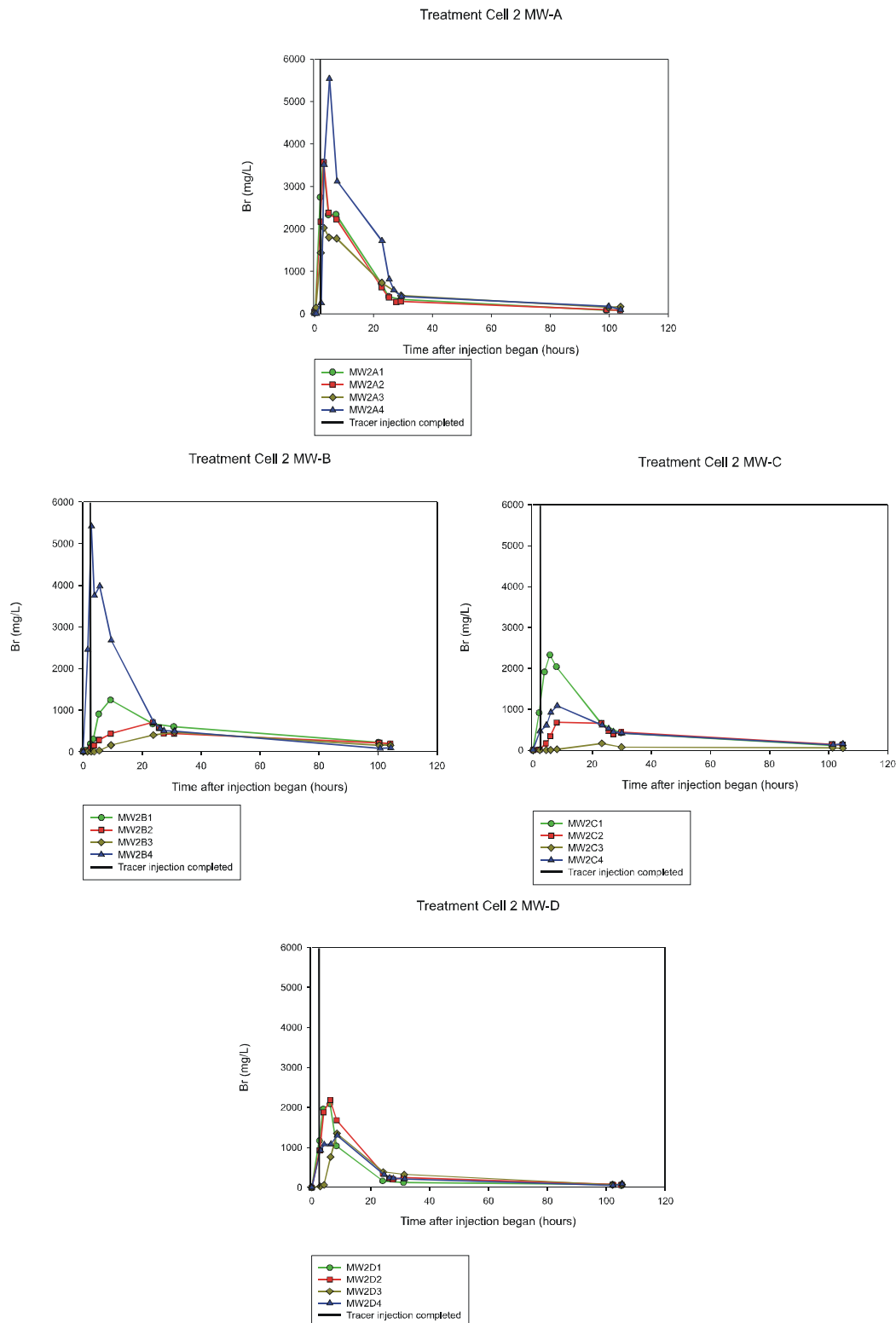


Figure 4-4. June 2004 tracer results Treatment Cell 2.

Evaluation of tracer arrivals and concentrations at MW2C also revealed different behavior than in Treatment Cell 1. Peak arrival at MW2C1 was approximately 5.5 hours after injection began with concentrations of 2,330 mg/L. MW2C2 and MW2C3 saw much lower peak concentrations of tracer (680 and 168 mg/L) and slower arrival times (23 hours for both). MW2C4 was more comparable to MW2C1, with peak concentrations of 1,058 mg/L at 8 hours after injection began.

Results from the tracer study conducted in June 2004 suggest that effective distribution of tracer both vertically and horizontally was realized along the axis of both treatment cells at Ft. Lewis EGDY using the new injection and extraction wells. Vertical distribution of tracer was also very good in the off-axis wells in Treatment Cell 2, and was improved in Treatment Cell 1, but still showed some preferential flow toward the bottom of the cell. This indicated that electron donor could be delivered to the treatment area effectively. Based on data from Tracer Test 4, it was recommended and agreed to proceed with Phase 2.

4.3.1.5 Hydraulic Characterization Conclusions

An overview of the Phase I hydraulic characterization, including pumping and tracer test results, is provided in Table 4-3. Overall, mitigation of complex hydraulic conditions including high groundwater flow rates, vertical gradients, and substantial aquifer heterogeneity was required through redesign of the injection and extraction wells to implement an effective injection strategy.

Table 4-3. Overview of Hydraulic Parameters Determined During Hydraulic Testing of the Two Demonstration Treatment Cells.

Activity Objective	Performance Confirmation Method	Expected Performance	Resultant Outcome
Tracer Test 1 (June 2003)			
Verify gradient	Measure water levels and calculate gradient	Gradient East to West	Gradient East to West
Verify extraction well production rates	Run pumping tests	10-20 gpm	EW1 – 4 gpm EW2 – 2.8 gpm
Estimate groundwater velocity, travel time, and tracer distribution	Measure peak breakthrough of bromide	Peak breakthrough 1 week at extraction well	Travel times for both treatment cells less than 12 hours Significant vertical gradient noted
Verify hydraulic isolation of treatment cells	Inject different fluorescent tracers in the two treatment cells	Non-detect in cross-gradient cells	No significant tracer communication was measured between treatment cells

Table 4-3. Overview of Hydraulic Parameters Determined During Hydraulic Testing of the Two Demonstration Treatment Cells. (continued).

Activity Objective	Performance Confirmation Method	Expected Performance	Resultant Outcome
Tracer Test 2 (July 2003)			
Estimate groundwater velocity, travel time, and tracer distribution	Measure peak breakthrough of bromide Perform inverse analytical modeling	Peak breakthrough 1 day at extraction well Adequate curve matching – hydraulic conductivity expected - 54 ft/d	Peak breakthrough between 6 and 24 hours Significant vertical gradient Hydraulic conductivity calculated: Cell 1 - 2.3 to 9.5 ft/d, Cell 2 - 3.2 to 16.6 ft/d
Tracer Test 3 (November 2003)			
Estimate groundwater velocity, travel time, and tracer distribution without pump and treat wells	Measure peak breakthrough of bromide	Improved tracer distribution	Little effect noted, results similar to previous tests
Tracer Test 4 (June 2004)			
Verify extraction well production rates	Run pumping tests	10-20 gpm	EW1A – 10 gpm EW2A – 18 gpm
Estimate groundwater velocity, travel time, and tracer distribution with new injection and extraction wells	Measure peak breakthrough of bromide Perform inverse analytical modeling	Improved tracer distribution Conductivity based on June 2003: Cell 1 - 2.3 ft/d Cell 2 – 3.2 ft/d	Peak breakthrough between 4 and 31 hours Horizontal and vertical tracer distribution much improved Hydraulic conductivity calculated: Cell 1 - 15.0 ft/d Cell 2 - 24.2 ft/d

4.3.2 Electron Donor Distribution and Utilization

Spatial and temporal trends in COD were used to evaluate distribution of whey powder mixtures following 1% and 10% injections to the downgradient and cross-gradient monitoring locations in the treatment cells. Discussion of results is limited to results for Treatment Cell 2 because little/no residual DNAPL saturation was observed in Treatment Cell 1. In addition to COD, VFA analysis was used to evaluate whey powder utilization and fermentation. 1% whey powder injections were performed in Treatment Cell 2 in July, August, September, and October 2005, and 10% whey injections were conducted in November and December 2005 and January and February 2006 (see Section 3.5 for details). The whey powder used for injections was comprised of 70 to 75% w/w lactose and 10 to 13% protein.

During the demonstration, anaerobic fermentation of the whey resulted in the production of the VFAs butyrate, acetate, and propionate at relatively high concentrations with minor production of lactate, isobutyrate, isovalerate, and valerate (Figure 4-5 and Table 4-4b). Concentrations of COD and VFAs were generally low or nondetect prior to whey injection (Phase 2) within the treatment cells and dramatically increased following Phase 3 whey powder injections. COD concentrations were generally highest near the injection locations (MWA monitoring locations) and along the axis of the treatment cells (MWA and MWD), and were generally much lower at the cross-gradient locations (MWB and MWC) immediately following injections. COD and VFAs were also detected at the fluxmeter wells nearly 150 ft downgradient from the injection location. Trend charts of COD and VFA mass concentrations vs. time are presented for two primary axial monitoring locations, MW2A4 and MW2D4 in Figure 4-5 below. Similar charts for all monitoring locations, including the downgradient fluxmeter wells, are provided in Appendix E. The results for Treatment Cell 2 are discussed below.

Phase 2—Baseline. COD was detected within the treatment cells at relatively low concentrations during Phase 2 sampling, averaging 40 ± 7 mg/L in the eight monitoring locations in Treatment Cell 2. Of the VFAs analyzed, only low levels of acetate (<2 mg/L) and butyrate (<12 mg/L) were detected in Treatment Cell 2 at MW2D1 and MW2D4.

Phase 3—Biostimulation. In order to evaluate distribution of whey powder during the Phase 3 injections, COD concentrations were measured prior to whey powder injection and the day following whey powder injection at each of the eight monitoring locations in each treatment cell. In general, COD accumulated in the treatment cell to some extent during the course of injections. Therefore, the change in COD observed the day following whey injection compared to the day prior was calculated (Table 4-4a) and used to evaluate changes in carbon following injections. The results for Treatment Cell 2 are presented below.

Following the 1% whey injection conducted in July 2005, COD concentrations were highest in axial wells MW2A and MW2D (Figure 4-5). In addition, the change in COD was evaluated to determine the impacts of the July injection. Some COD was already present in Treatment Cell 2 due to the 3% whey powder injections conducted to create reducing conditions within the treatment cells prior to bioaugmentation.

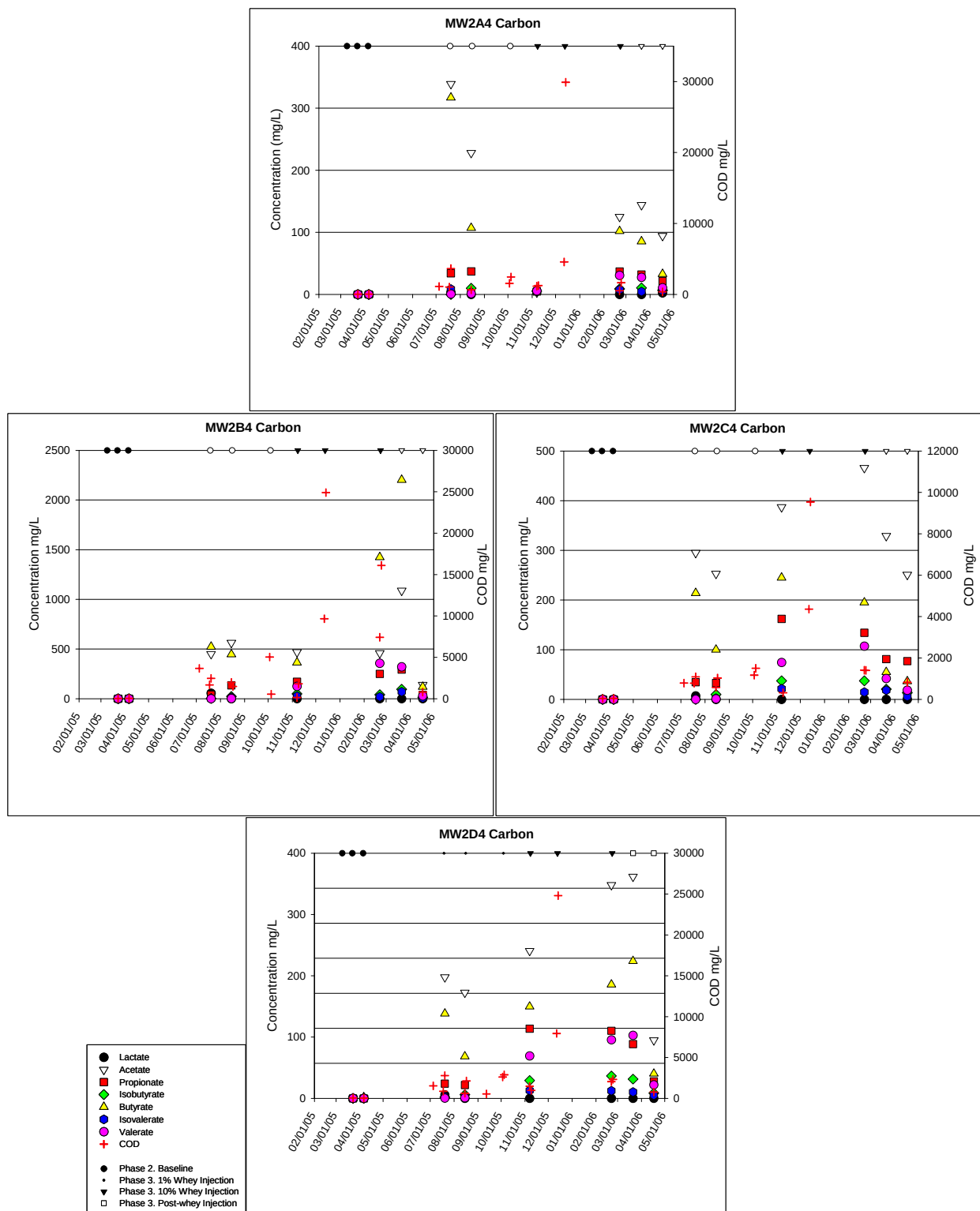


Figure 4-5. Distribution of COD and Whey Powder Fermentation Products in Treatment Cell 2 during Phases 2 and 3 of the Demonstration.

Table 4-4a. Whey Injection Impacts to COD During Demonstration.

COD	Phase 2: Baseline^a	Phase 3: 1 % Whey Powder Injections		Phase 3: 10% Whey Powder Injections		Phase 3: Post- Whey Injection
	Average (mg/L)	Change in COD July 2005 Injection (mg/L)^b	Change in COD October 2005 Injection (mg/L)^b	Change in COD December 2005 Injection (mg/L)^b	Change in COD February 2006 Injection (mg/L)^b	COD April 2006 (mg/L)^b
MW2A1	41	6,898	3,520	16,530	9,190	426
MW2A2	53	4,617	3,540	17,100	1,131	405
MW2A4	38	2,600	900	25,320	1,131	355
MW2B4	37	780	-4,480	15,240	8,680	799
MW2C4	46	307	330	5,180	-10	821
MW2D1	32	7,083	1,100	13,960	7,427	183
MW2D2	35	5,936	-110	21,320	947	272
MW2D4	41	1,928	260	16,860	270	766

^a Value represents average concentration of two samples collected March and April 2005.

^b Value represents the difference in COD concentration between samples collected prior to and 1 day following whey powder injection.

Table 4-4b. VFA Concentrations During Phases 2 and 3 of the Demonstration.

MW2A4	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
Phase 2: Baseline^a	0	0	0	0	0	0	0
Phase 3: 1% Whey^b	0	283	57	5	191	3	2
Phase 3: 10% Whey^c	0	277	101	32	274	22	97
MW2D4	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
Phase 2: Baseline^a	0	0	0	0	2	0	0
Phase 3: 1% Whey^b	5	324	40	7	181	5	1
Phase 3: 10% Whey^c	0	515	196	57	294	22	144
^a Values represent the average of two samples collected March and April 2005. ^b Values represent the average of two samples collected July and August 2005. ^c Value represents the average of two samples collected November 2005 and February 2006.							

The change in COD observed prior to and following whey injection demonstrated that relatively higher amounts of COD were distributed to the monitoring locations as a result of injection (Table 4-4a). Near the injection location at MW2A1, the change in COD was 6,898 mg/L, with lower concentrations observed with depth – MW2A2 (4,617 mg/L) and MW2A4 (2,600 mg/L). The change in COD concentrations at MW2D, approximately 30 ft downgradient of the injection well, were also high following injection with highest concentration changes observed at port 1 (7,083 mg/L), followed by MW2D2 (5,936 mg/L) and MW2D4 (1,928 mg/L). Significant COD was also distributed to cross-gradient locations MW2B4 (780 mg/L) and MW2C4 (307 mg/L), though at concentrations one order of magnitude lower than the axial locations. This represented a very good overall electron donor distribution, as predicted by Tracer Test 4.

Over time, however, significantly less change in COD was observed at individual points throughout the treatment cell following the 1% injections. In particular, the relative change in COD observed at downgradient and cross-gradient locations was substantially lower with concentration changes from 260 to 1,100 mg/L at MW2D1, MW2D4, and MW2C4 and negative relative changes observed at MW2B4 and MW2D2 following the October 2005 injection event (Table 4-4a). The significant reduction in overall COD change following whey injections can be attributed to COD that had accumulated in the system between injection events. COD concentrations between approximately 1,100 and 5,000 mg/L were observed within Treatment Cell 2 prior to the October 2005 injection. Given that the accumulated COD was as high or higher before the October injection (i.e., MW2B4 was 5030 mg/L) as resultant concentrations observed following initial whey injection (i.e., 780 mg/L at MW2B4 following the July 2005 injection), the relative change in COD from continued whey injections was reduced.

Ten percent whey powder injections were initiated in Treatment Cell 2 in November 2005. Table 4-4a illustrates the change in COD concentrations during the December 2005 and February 2006 injection events. Significant increases in COD were observed with the onset of 10% whey injections relative to the 1% injections, with concentrations again highest along the treatment cell axis (Figure 4-5). Near the injection location at MW2A1 the change in COD concentrations was 16,530 mg/L following the December 2005 injection event, and increased slightly with depth at MW2A2 (17,100 mg/L), and MW2A4 (25,320 mg/L). High concentrations were also distributed downgradient to MW2D1 (13,960 mg/L), MW2D2 (21,320 mg/L) and MW2D4 (16,860 mg/L). Cross-gradient electron donor distribution was greater with the 10% injections than the 1% injections, as evidenced by COD concentrations at MW2B4 (15,240 mg/L) and MW2C4 (5,180 mg/L). As with the 1% injections, significant accumulation of COD was observed between injection events with concentrations ranging between approximately 500 and 7,500 mg/L throughout Treatment Cell 2. Therefore, the relative change in COD values by the February 2006 injection event were lower than observed during the December 2005 injection event, but were generally still higher than for the 1% injections (Table 4-4a).

The products of whey powder utilization were evaluated by measuring the VFAs generated during Phase 3. Table 4-4b illustrates the average VFA concentrations observed during Baseline, 1%, and 10% whey injections for MW2A4 and MW2D4. In general, the predominant fermentation products observed during 1% whey injection were acetate, propionate and butyrate.

During 10% whey injections, the predominant fermentation products were similar with the exception of significantly higher valerate concentrations (Table 4-4b and Figure 4-5). The observed distribution of VFAs would be expected to provide abundant hydrogen for reductive dechlorination.

4.3.3 Bioactivity and Redox Performance Measures

Bioactivity and redox parameters were measured within the treatment cells during Phases 2 and 3 to ensure that whey powder injections resulted in conditions conducive to the growth and activity of dehalogenating bacteria. Bioactivity indicators were monitored throughout the demonstration as an indicator of microbial activity within the treatment cells. Bioactivity parameters include pH and alkalinity. Redox parameters were also measured including ORP, DO, nitrate, ferrous iron, sulfate and methane. Anaerobic reductive dechlorination of TCE to ethene is generally most efficient at neutral pH values and when redox conditions are methanogenic, indicated in groundwater by the absence of DO, nitrate, sulfate and the presence of ferrous iron and methane. The changes observed in the bioactivity and redox parameters as a result of whey injections were nearly identical for both treatment cells irrespective of the concentration of whey injected. Therefore, results for Treatment Cell 2 are presented in Table 4-5, and representative charts for the axial monitoring locations MW2A4 and MW2D4 are presented in Figure 4-6. Bioactivity and redox results for all monitoring wells are presented in Appendix E.

pH. Optimal microbial activity for ISB occurs under circum-neutral pH conditions, typically in the range of 6 to 8. Perhaps more importantly, it has been observed that dechlorination by *Dehalococcoides* bacteria is inhibited below a pH of about 5 to 5.5. Following whey powder injection, fermentation of the primary substrate, lactose, occurs rapidly resulting in the production of organic acids, which lower pH if the buffering capacity of the aquifer system is not sufficient to neutralize the acid. Therefore, pH is a key monitoring parameter in the evaluation of whey performance.

Table 4-5 presents the average pH results for baseline, 1%, 10%, and post-whey injection periods. The ambient pH of the groundwater prior to whey injection was 6.1 to 6.4 in Treatment Cell 2. Following the onset of 1% whey injections, pH declined dramatically ranging from 4.66 to 5.61. The low pH was maintained for approximately 4 months before it began to rebound between injection events as a result of increased buffering capacity due to bicarbonate production associated with biological activity (Figure 4-6). Therefore, the average pH observed during the 10% whey injections was higher (range of 5.1 to 5.9) than observed following the 1% whey injections. By 1 month post-injection, the pH had rebounded to near the pre-whey values at most locations. The gradual pH increase following 1% w/w whey injections demonstrates the ability of the system to buffer itself naturally over time. This buffering occurs as carbon dioxide production results in the presence of more and more bicarbonate, which increases alkalinity. In this case, the power of this buffering was especially apparent when the pH was maintained at higher levels during 10% whey injections than during the earlier 1% injections. However, significant biological inhibition, and specifically reductive dechlorination inhibition, can occur during the period of low pH.

Table 4-5. Whey Injection Impacts to Bioactivity Indicator During Demonstration.

Treatment Cell 2	Phase 2. Baseline ^a						Phase 3. 1% Whey Powder Injections ^b					
	pH		Specific Conductivity (mS/cm)		Alkalinity (mg/L as CaCO ₃)		pH		Specific Conductivity (mS/cm)		Alkalinity (mg/L as CaCO ₃)	
	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
MW2A1	6.11	0.10	0.22	0.01	94	1	4.66	0.13	1.27	0.61	229	NA ^c
MW2A2	6.18	0.14	0.23	0.00	96	3	4.71	0.13	1.13	0.61	147	47
MW2A4	6.24	0.21	0.24	0.04	88	1	4.56	0.25	1.42	0.18	140	62
MW2B4	6.24	0.10	0.24	0.02	82	4	5.61	0.15	0.90	0.28	89	NA ^c
MW2C4	6.26	0.13	0.26	0.03	95	1	5.36	0.21	0.70	0.43	370	NA ^c
MW2D1	6.19	0.08	0.26	0.04	87	12	4.85	0.23	1.04	0.55	186	94
MW2D2	6.40	0.24	0.26	0.01	77	4	5.22	0.20	0.87	0.42	123	21
MW2D4	6.33	0.09	0.26	0.01	94	10	5.36	0.16	0.81	0.38	197	28

Table 4-5. Whey Injection Impacts to Bioactivity Indicator During Demonstration (continued).

	Phase 3. 10% Whey Powder Injections ^d						Phase 3. Post-Whey Powder Injection ^e					
	pH		Specific Conductivity (mS/cm)		Alkalinity (mg/L as CaCO ₃)		pH		Specific Conductivity (mS/cm)		Alkalinity (mg/L as CaCO ₃)	
	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
MW2A1	5.4	0.3	2.4	1.2	188	82	5.7	0.5	0.8	0.2	175	24
MW2A2	5.4	0.4	3.3	2.3	181	121	5.8	0.4	0.8	0.1	121.	3
MW2A4	5.4	0.4	2.2	1.3	216	90	6.1	0.0	0.7	0.1	146.	145
MW2B4	5.1	0.3	2.8	0.9	107	74	5.3	0.7	1.7	1.3	103	4
MW2C4	5.9	0.2	1.7	0.3	348	35	6.1	0.0	1.6	0.0	416	68
MW2D1	5.6	0.3	2.3	1.4	141	105	6.0	0.3	0.4	0.1	91	10
MW2D2	5.4	0.2	2.3	1.2	157	127	5.6	0.5	0.5	0.2	78	6
MW2D4	5.6	0.3	2.1	0.5	350	48	5.8	0.1	1.7	0.9	529	411
a. Values for pH and specific conductivity represent the average of nine samples collected before and after recirculation events during Phase 2 in March and April 2005 and one standard deviation from the mean. Values for alkalinity represent the average of two samples collected prior to Phase 2 recirculation events in March and April 2005 and one standard deviation from the mean. b. Values for pH and specific conductivity represent the average of nine samples collected before and after 1% whey injections during Phase 3 in July, August and October 2005 and one standard deviation from the mean. Alkalinity could not be measured using the Hach titration method during the July sampling event due to pH values near or below the titration endpoint of 4.8. Values for alkalinity represent either the average of two samples collected prior to Phase 3 1% injections in August and October 2005 and one standard deviation from the mean or one sample collected prior to the October 2005 injection. c. NA indicates that only the October sampling event had a measurable alkalinity using the Hach field titration method and so a standard deviation could not be calculated. d. Values for pH and specific conductivity represent the average of nine samples collected before and after 10% whey injections during Phase 3 in November and December 2005 and February 2006 and one standard deviation from the mean. Values for alkalinity represent the average of three samples collected prior to Phase 3 10% injections in November and December 2005 and February 2006 and one standard deviation from the mean. e. Values for pH, specific conductivity and alkalinity represent the average of two samples collected approximately 1 and 2 months post- whey injection in March and April 2006 and one standard deviation from the mean.												

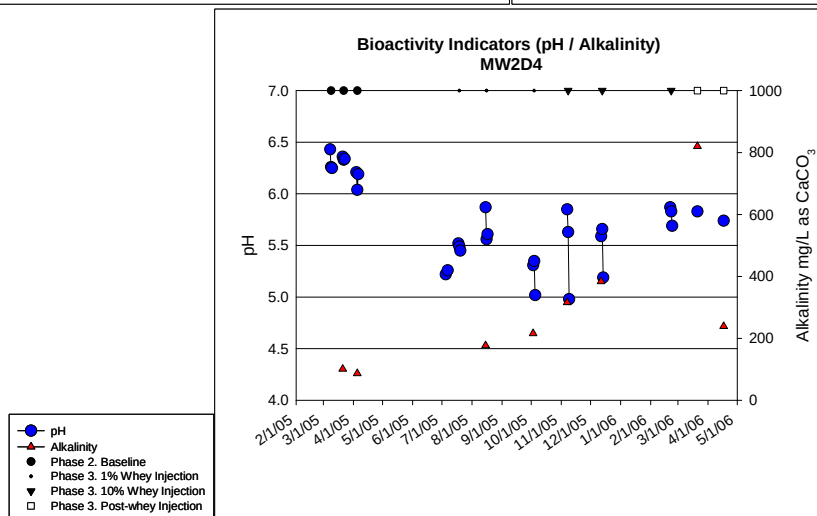
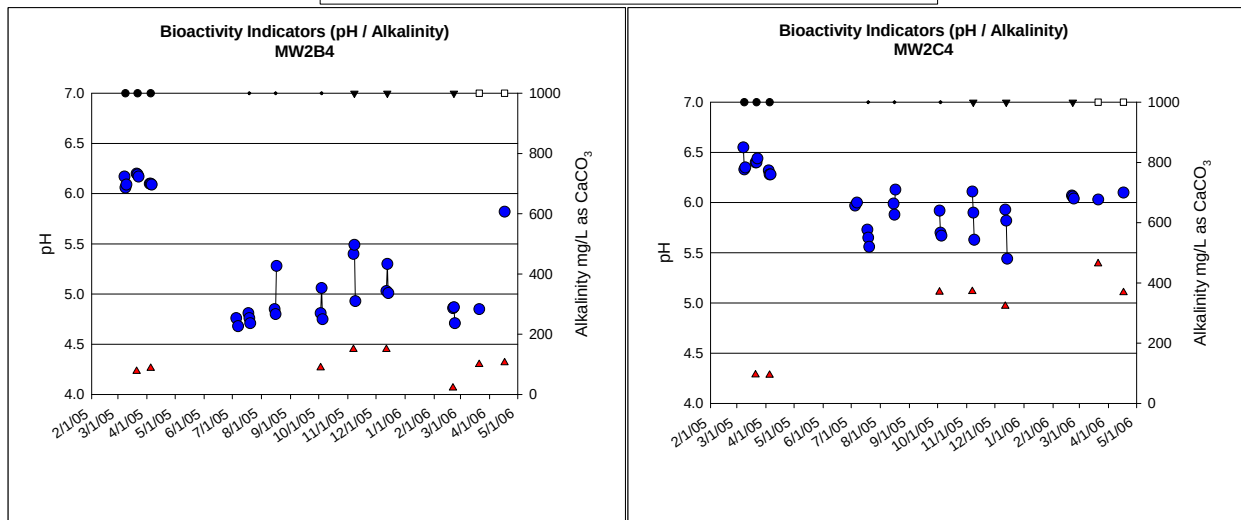
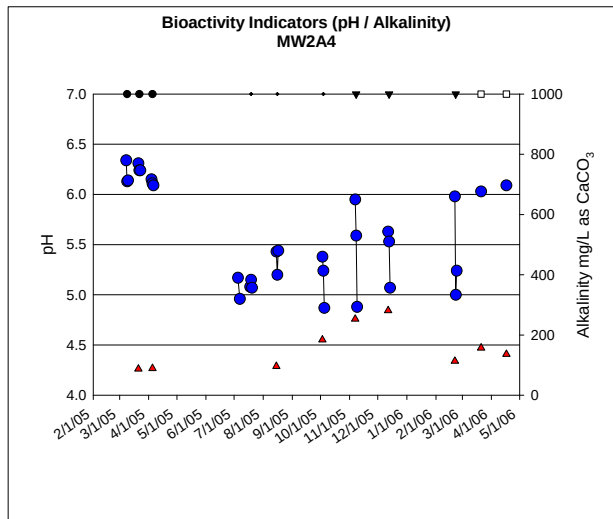


Figure 4-6. Treatment Cell 2 Port 4 Bioactivity Results.

Alkalinity. Alkalinity is a natural constituent in groundwater that acts to buffer the system. During enhanced bioremediation, utilization of the amended electron donor generally increases alkalinity due to the production of carbon dioxide, which is present in water as some combination of three species, carbon dioxide, bicarbonate, and carbonate, depending on pH. The buffering capacity of the aquifer system is particularly important when using whey powder, as it helps to buffer the system from the acid production that occurs during whey fermentation. In Treatment Cell 2, average alkalinity values ranged from 66 to 78 mg/L as CaCO₃ during baseline. Following the 1% w/w whey injections, average alkalinity concentrations increased to 123 to 370 mg/L as CaCO₃ after approximately 3 months of whey injections. Prior to this, alkalinity measurements could not be reliably measured using the Hach field test kit due to the low pH of the system, which was near the titration endpoint of the method (4.8). The ability to measure alkalinity at the October 2005 sampling at all monitoring locations, 3 months after injections began, illustrates the gradual increase in buffering capacity of the system, which increased pH and alkalinity measurements could be taken using the Hach method. The average measured alkalinity was higher during the 10% w/w whey injections, ranging from 107 to 350 mg/L as CaCO₃. Post-whey injection sampling results show continued elevated alkalinity concentrations for at least 2 months. These data suggest that increased biological activity over time resulted in increases in the buffering capacity of the aquifer system, which helped to mitigate reductions in pH observed after initial whey injections. In addition, the enhanced buffering capacity of the system generated during 1% injections also resulted in faster recovery of pH during 10% whey powder injections.

Oxidation Reduction Potential. ORP is used as a general indicator for redox conditions, with lower values indicative of a more reduced state. ORP values decreased considerably during Phase 3 compared to Phase 2 (Table 4-6a) during the demonstration. For instance, in Treatment Cell 2, average ORP values during Phase 2 ranged from 104 mV to 195 mV indicative of relatively oxidizing conditions. Following 1% w/w whey injections, ORP values dropped to an average of -137 to -23 mV, and decreased again following 10% w/w whey injections to an average of -155 to -106 mV. After whey injections were complete, post-injection samples revealed that ORP values had increased to an average range of -79 to 81 mV. Similar trends were observed in Treatment Cell 1. The reduction in ORP levels during the whey injection phases indicates reducing conditions were achieved throughout the treatment cells.

Dissolved Oxygen. DO concentrations were also depleted in Phase 3 relative to Phase 2 of the demonstration. In Treatment Cell 2, baseline DO concentrations were relatively low with a total average of 1.2 mg/L. Following 1% w/w whey injections, the total average was reduced to 1.0 mg/L, and was reduced further to 0.8 mg/L following 10% whey injections. DO concentrations remained low for the 2-month post injection samplings with an average DO concentration of 0.7 mg/L.

Nitrate. Measurable nitrate concentrations were observed in groundwater within the treatment cells during the baseline sampling, with an average concentration of 1.1 mg/L in Treatment Cell 2 (Table 4-6b). Nitrate concentrations, however, were generally depleted following whey injections, with average concentrations of 0.3 mg/L during 1% and 0.4 mg/L during the 10% whey injections. Nitrate concentrations remained low post-injection, with an average nitrate concentration of 0.5 mg/L 2 months after cessation of whey injections.

Table 4-6a. Whey Injection Impacts to Redox Parameters ORP, DO and Methane during Demonstration.

Treatment Cell 2	Phase 2. Baseline ^a						Phase 3. 1% Whey Powder Injections ^b					
	ORP (mV)		DO (mg/l)		Methane (µg/L)		ORP (mV)		DO (mg/l)		Methane (µg/L)	
	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
MW2A1	150	28	1.3	0.2	1.	0.2	-109	57	1.3	0.5	22	33
MW2A2	160	15	1.4	0.2	0.8	0.2	-132	67	1.1	0.4	22	36
MW2A4	104	108	1.6	0.3	0.7	0.2	-105	41	1.0	0.3	22	67
MW2B4	188	16	1.4	0.3	0.5	0.1	-84	99	0.9	0.3	12	12
MW2C4	117	14	0.7	0.2	1.6	0.3	-107	59	0.9	0.2	48	62
MW2D1	195	21	1.5	0.3	0.6	0.2	-137	101	1.2	0.4	17	37
MW2D2	190	21	1.3	0.3	0.6	0.2	-128	93	1.0	0.3	42	71
MW2D4	168	15	0.7	0.3	3.0	1.0	-23	47	0.9	0.3	61	99
	Phase 3. 10% Whey Powder Injections ^c						Phase 3. Post-whey Injection ^d					
	ORP (mV)		DO (mg/l)		Methane (µg/L)		ORP (mV)		DO (mg/l)		Methane (µg/L)	
	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
MW2A1	-138	45	0.8	0.1	1,203	1,559	-79	11	0.6	0.1	8,950	5,727
MW2A2	-148	53	0.7	0.1	1,228	1,936	-74	8	0.6	0.2	8,750	4,596
MW2A4	-142	53	0.7	0.1	1,730	1,517	81	21	0.7	0.2	4,450	70
MW2B4	-106	71	0.7	0.1	744	649	-42	28	0.5	0.1	2,250	636
MW2C4	-116	44	0.8	0.1	3,611	2,706	-44	17	0.9	0.2	6,850	1,626
MW2D1	-155	55	0.8	0.1	757	504	-66	5	0.7	0.2	2,850	1,768
MW2D2	-145	64	0.7	0.1	1,538	1,361	-43	14	0.7	0.2	6,800	4,525
MW2D4	-125	41	0.8	0.1	3,660	3,494	-50	11	0.9	0.3	7,450	2,475
a. All values represent the average of nine samples collected before and after recirculation events during Phase 2 in March and April 2005 and one standard deviation from the mean. b. All values represent the average of nine samples collected before and after whey injection events during Phase 3 in July, August and October 2005 and one standard deviation from the mean. c. All values represent the average of nine samples collected before and after whey injection events during Phase 3 in November and December 2005 and February 2006 and one standard deviation from the mean. d. All values represent the average of two samples collected in March and April 2006 and one standard deviation from the mean.												

Table 4-6b. Whey Injection Impacts to Redox Parameters Ferrous Iron, Nitrate and Sulfate During Demonstration.

Treatment Cell 2	Phase 2. Baseline ^a						Phase 3. 1% Electron Donor Injections ^b					
	Ferrous Iron (mg/L)		Nitrate (mg/L)		Sulfate (mg/L)		Ferrous Iron (mg/L)		Nitrate (mg/L)		Sulfate (mg/L)	
	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
MW2A1	0.1	0.0	1.0	0.1	18	5	3.2	0.1	0.0	0.0	5	1
MW2A2	0.1	0.0	1.0	0.1	18	40	3.0	0.2	0.1	0.1	33	40
MW2A4	0.2	0.1	1.2	0.1	18	5	3.2	0.1	0.0	0.0	4	5
MW2B4	0.0	0.0	1.2	0.1	19	7	2.6	1.2	0.8	1.1	7	4
MW2C4	0.1	0.1	1.0	0.1	17	3	3.2	0.1	0.4	0.6	9	2
MW2D1	0.0	0.0	1.2	0.3	20	7	3.0	0.5	0.3	0.5	0	0
MW2D2	0.0	0.0	1.1	0.2	24	3	3.0	0.5	0.8	1.1	0	0
MW2D4	0.0	0.0	0.9	0.1	18	2	3.0	0.4	0.2	0.0	4	2
	Phase 3. 10% Electron Donor Injections ^c						Phase 3. Post Electron Donor Injection ^d					
	Ferrous Iron (mg/L)		Nitrate (mg/L)		Sulfate (mg/L)		Ferrous Iron (mg/L)		Nitrate (mg/L)		Sulfate (mg/L)	
	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation	Value	Standard Deviation
MW2A1	3.1	0.4	0.0	0.0	3	33	3.3	0.0	0.0	0.0	4	6
MW2A2	2.9	0.7	0.0	0.0	24	32	3.3	0.0	0.0	0.0	7	1
MW2A4	2.8	0.8	3.5	4.7	5	5	3.3	0.0	0.0	0.0	2	0
MW2B4	2.8	0.8	0.0	0.0	24	23	3.3	0.0	0.0	0.0	0	0
MW2C4	2.8	0.9	0.0	0.0	4	5	3.3	0.0	0.0	0.0	10	2
MW2D1	3.0	0.6	0.0	0.0	11	14	3.3	0.0	2.3	1.5	1	1
MW2D2	3.1	0.3	0.0	0.0	10	13	3.3	0.0	2.1	2.9	11	14
MW2D4	3.0	0.5	0.0	0.0	9	12	1.9	1.9	0.0	0.0	10	4
a. All values represent the average of two samples collected before and after recirculation events during Phase 2 in March and April 2005 and one standard deviation from the mean. b. All values represent the average of two samples collected before and after whey injection events during Phase 3 in July, and August 2005 and one standard deviation from the mean. c. All values represent the average of two samples collected before and after whey injection events during Phase 3 in November 2005 and February 2006 and one standard deviation from the mean. d. All values represent the average of two samples collected in March and April 2006 and one standard deviation from the mean.												

Ferrous Iron. Ferrous iron concentrations measured prior to whey injections (Phase 2) were generally non-detect in Treatment Cell 2 (Table 4-6b). Ferrous iron concentrations increased following whey injections and were generally greater than 3.0 mg/L during 1% and 10% whey powder injections, indicative of iron reduction.

Sulfate. Sulfate concentrations measured during Phase 2 baseline sampling were generally between 15 and 30 mg/L in the treatment cells, with an average of 19 mg/L in Treatment Cell 2 (Table 4-6b). Sulfate concentrations declined following the 1% w/w whey injections to an average of 7 mg/L. Significant variability in sulfate concentrations was observed during Phase 3, however, which can likely be attributed to sulfate in the whey powder amendment itself. The contribution of the sulfate during whey injection is supported by depletion of sulfate concentrations following cessation of whey injections. Sulfate concentrations during the post-whey injection samplings were the lowest of all sampling periods with an average value of 5 mg/L.

Methane. Methane concentrations were generally non-detect during Phase 2 sampling within the treatment cells. During Phase 3, significant methane production was not observed until approximately 5 months after whey injections in both treatment cells (Figure 4-7) irrespective of the whey injection strategy. The highest concentrations of methane were observed during the post-injection phase sampling with average concentrations of 6.04 mg/L (Table 4-6a). The lag in the onset of significant methanogenesis can be attributed to one or more factors including: 1) lag in period of reducing conditions, 2) slow growth of methanogens, and/or 3) the low pH following the onset of whey injections. In any case, methane-producing conditions were achieved within both test cells approximately 4 months after whey injections began and continued for at least 2 months following cessation of whey injections.

4.3.4 Reductive Dechlorination Performance Measures

During Phases 2 and 3 of the demonstration, the efficiency of the ARD reactions was assessed by examining changes in relative concentrations of TCE, cis-DCE, VC, and ethene. If TCE, cis-DCE, and VC concentrations decrease or remain at or near detection limits and if ethene concentrations are relatively high, then the operational strategy is operating efficiently. If, however, significant concentrations of TCE and cis-DCE are present in downgradient monitoring locations, then ARD is not occurring in the entire treatment cell. The following sections describe the response of chloroethene and ethene concentrations at the Treatment Cell 2 monitoring locations following Phase 3, 1% and 10% whey powder injections.

To evaluate ARD performance, charts that include single species PCE, TCE, cis-1,2-DCE, trans-1,2-DCE, VC, and ethene aqueous mass concentration plotted vs. time were generated for each monitoring location. Charts for MW2A4, MW2B4, MW2C4 and MW2D4 are presented for Treatment Cell 2 (Figure 4-8). Trends observed for these locations are consistent with what was observed at the other monitoring locations within Treatment Cells 1 and 2 (Appendix E).

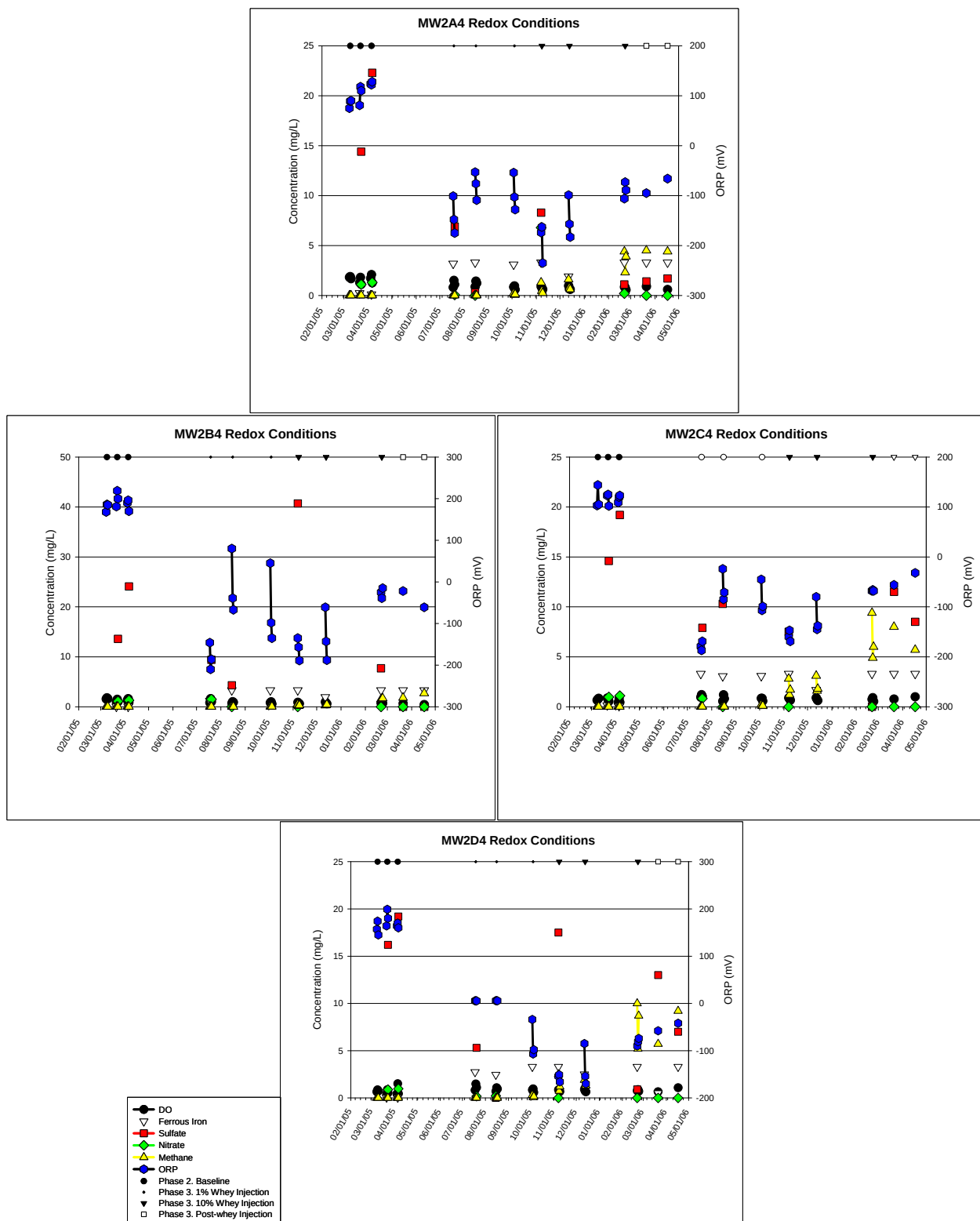


Figure 4-7. Trends in Treatment Cell 2 Port 4 Redox Conditions During Demonstration.

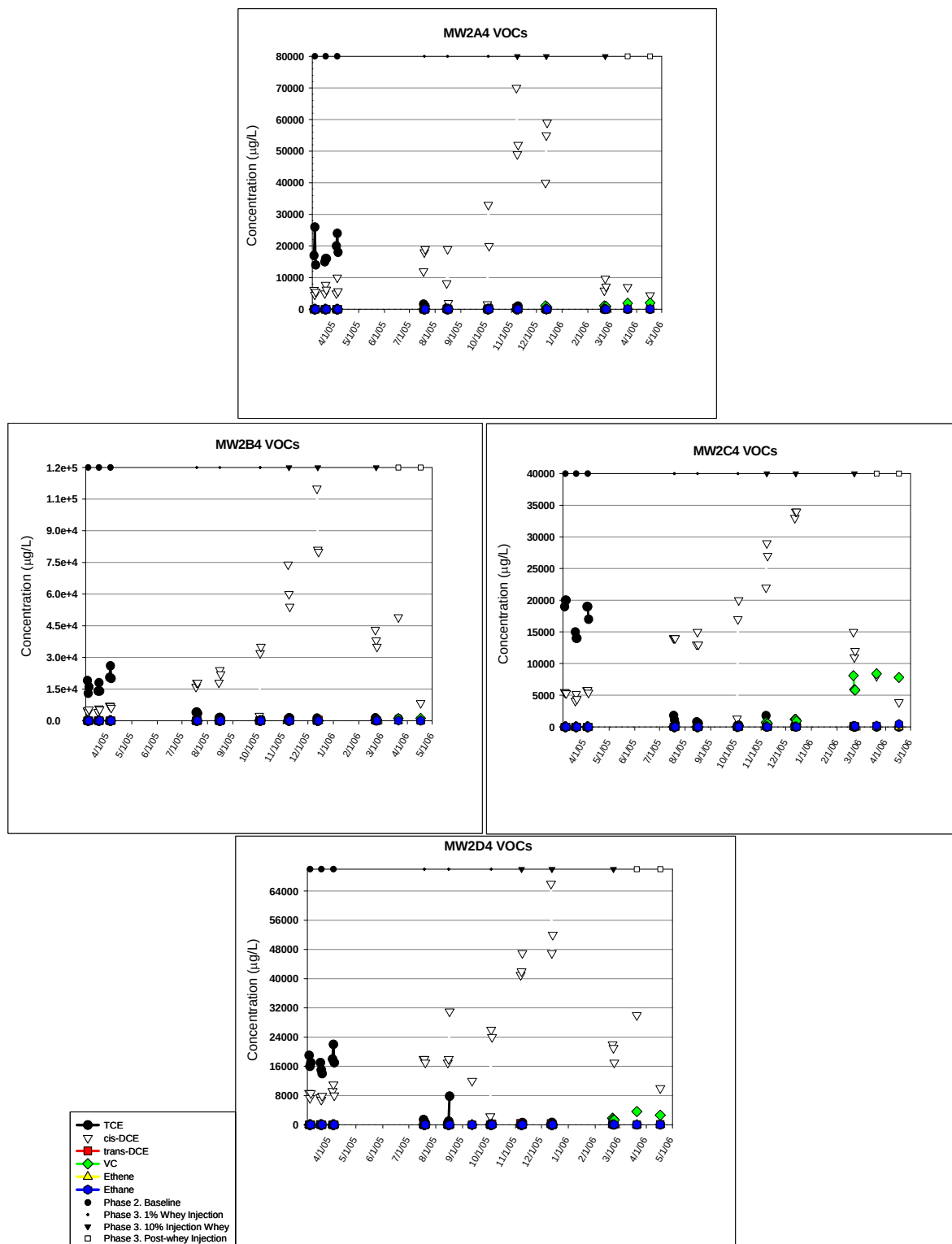


Figure 4-8. Trends in Treatment Cell 2 Port 4 Contaminant Mass and Degradation Products during Demonstration.

Following the onset of whey powder injections, efficient conversion of nearly all aqueous phase TCE to cis-DCE was observed in both treatment cells. Cis-DCE remained the predominant contaminant product by mass throughout the remainder of the demonstration. Concentrations of VC and ethene increased, however, throughout the demonstration with the highest concentrations observed during the two post-injection sampling events conducted at the end of the demonstration.

Molar VOC and ethene concentrations were used to assess the mass balance of the ARD reaction. During Phase 2, TCE was the predominant VOC observed by mass (Figures 4-8 and 4-9), comprising an average of $66\% \pm 5\%$ of the total molar contaminant mass within Treatment Cell 2. The first sampling event conducted in July 2005, however, was approximately 1 month following the initial 3% whey powder injections. By this time, nearly all VOC mass observed was present as cis-DCE, which comprised $96\% \pm 5\%$ of the total molar contaminant mass. Cis-DCE remained the predominant ARD product until February 2006, when the concentration of VC and ethene increased significantly. The improvement in overall dechlorination efficiency at the end of the demonstration is consistent with the bioactivity and redox data, showing rebound in pH to more neutral values, increasing alkalinity, and the onset of significant methane production.

The mass balance of total VOC and degradative daughter products, however, was significantly reduced with the onset of more efficient ARD, and specifically once significant VC and ethene production occurred (Figure 4-9). For instance, the average total molar concentration of VOC and ethene was $634 \pm 188 \mu\text{mol/L}$ for all eight monitoring locations in Treatment Cell 2 during the November 2005, and December 2005 sampling events ($n=48$). By the February 2006 sampling event, however, concentrations of total VOC and ethene declined to an average of $238 \pm 93 \mu\text{mol/L}$, and concentrations continued to decline post-injection from an average of $245 \pm 139 \mu\text{mol/L}$ in March 2006 to an average of $105 \pm 51 \mu\text{mol/L}$ in April 2006 in Treatment Cell 2 (Figure 4-9). Concomitantly, the fraction of VC and ethene increased during the same period from 1.7% of the total in November 2005, to 32% of the total molar mass by February 2006, and to a final molar percentage of 42% of the total by April 2006.

Although some of the reduction in total molar mass observed in groundwater between the November 2005 and April 2006 sampling events may have been due to a decline in total residual mass as a result of the bioremediation treatment and contaminant mass removal, soil gas sampling conducted by the USACE Seattle district in August 2006 indicated extremely high concentrations of VC and ethene in the vadose zone within NAPL Area 3, indicating that significant VC and ethene was lost to the vadose zone during ARD (see Appendix E for detailed data set). This loss of mass balance once cis-DCE conversion to VC and ethene is robust appears to be common in relatively shallow, thin contaminated aquifers because of the ease with which dissolved gases are transferred to the vadose zone. Given that an accurate measurement of enhanced mass transfer is dependent on a relatively rigorous mass balance, only the November and December 2005 data sets are used to represent the 10% w/w whey injection results for purposes of estimating enhanced mass transfer in Treatment Cell 2. It was, therefore, fortuitous for this demonstration that complete transformation to VC and ethene was not widespread until a few months after 10% injections began.

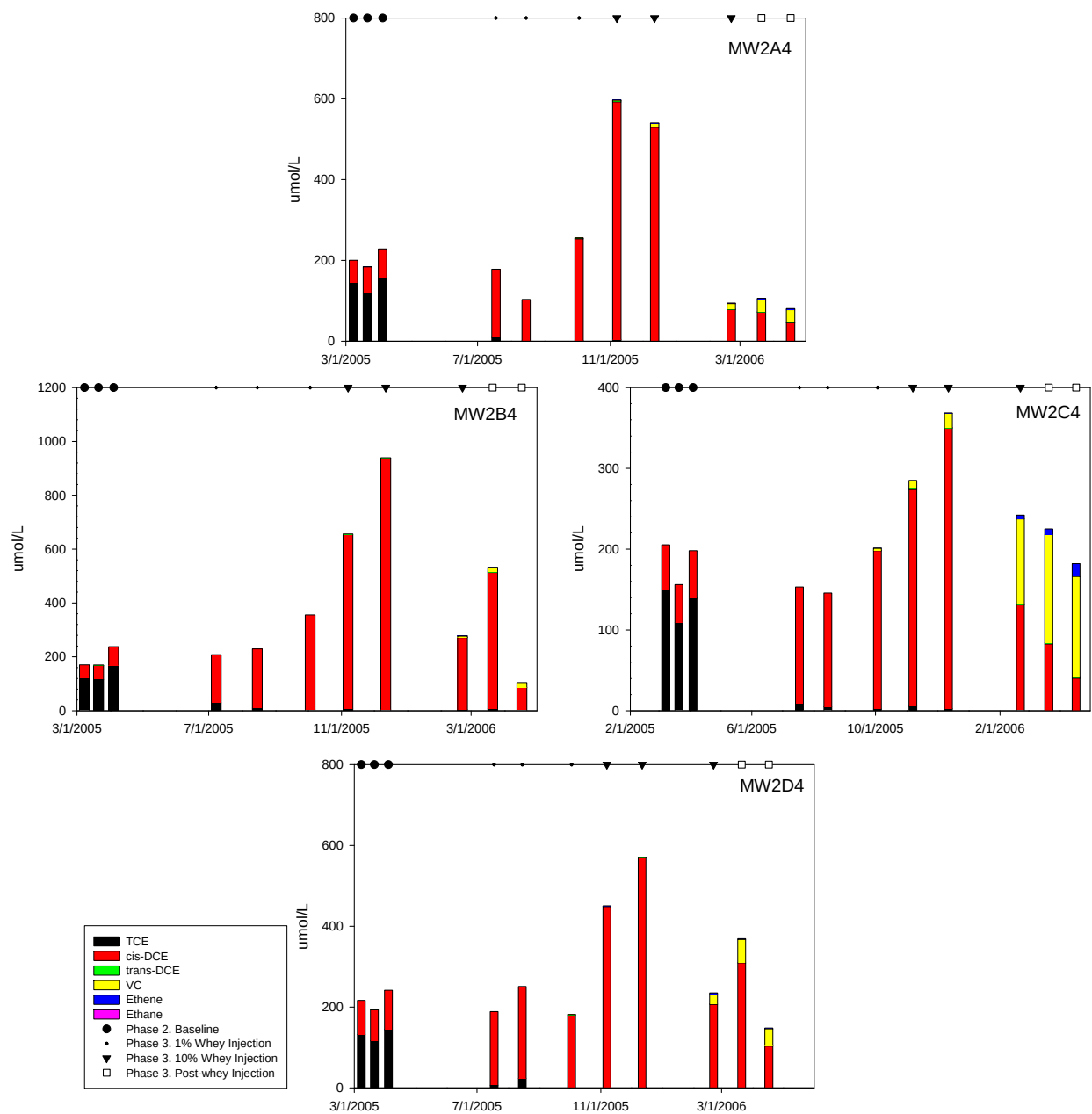


Figure 4-9. Trends in Treatment Cell 2 Port 4 contaminant Molar Mass and Degradation Products During Demonstration.

4.3.5 Evaluation of Enhanced Mass Transfer

The primary objective of the demonstration was to show that enhanced mass transfer via B.E.T.[™] allows for cost-effective bioremediation of chlorinated solvent source areas. Specifically, it was desired to demonstrate that mass transfer from nonaqueous phases to the aqueous phase could be enhanced not only due to mechanisms related to ARD (increased concentration gradients and increased solubility of some degradation products), but also due to abiotic mechanisms such as increased effective solubility of the contaminants due to interaction with the electron donor solution injected. Further, it was desired to demonstrate the relative magnitudes of these two types of enhanced mass transfer. The three quantitative DRs presented in Section 3.1 were defined in order to evaluate the enhanced mass transfer effects. Enhanced mass transfer of contaminants observed during the different Phase 3 injection strategies is discussed below with statistical analysis to evaluate the significance of observed differences in mass transfer.

4.3.5.1 Mass Transfer within Treatment Cell 2

The total molar concentration of TCE and reductive daughter products was evaluated during each of the three operational Scenarios (baseline, 1%, and 10% whey injections). As discussed in Section 4.3.4, the mass balance between parent compound (TCE) and ARD products was substantially affected following the onset of significant VC and ethene production (observed starting in February 2006). Therefore, the evaluation of enhanced mass transfer as a result of the various injection scenarios includes only those data collected during Phase 3 where cis-DCE was the predominant ARD product (November and December 2005).

Whey powder concentration-dependent mass transfer was evaluated by comparing the relative difference in VOC mass in the aqueous phase during baseline recirculation, low (1% w/w), and high (10% w/w) concentration whey powder injections. Statistical analysis was applied to the total molar VOC concentrations in order to test the three DRs discussed in Section 3.1. Statistical analyses were performed on the data compiled from Treatment Cell 2 directly following the baseline recirculation, 1% whey injection and/or 10% whey injection to test the DRs. The data set includes three sampling events (three samples per event) conducted during Phase 2 baseline (two events in March 2005 and one in April 2005 for n=9 for each monitor location); three sampling events conducted during Phase 3, Scenario 1, 1% whey powder injections (July, August and October 2005 for n=10 for each monitoring location); and two sampling events conducted during Phase 3, Scenario 2, 10% whey powder injections, (November and December 2005 for n=5 for each monitor location). The first sample collected in the November 2005 sample event was included in the Scenario 2 data set because it was collected prior to the November 2005 whey injection. The average total molar mass concentration for chloroethenes (TCE, cis-DCE, VC) and ethene for each of these three operational scenarios is presented in Table 4-7 for each Treatment Cell 2 monitoring location. Abbreviated versions of the DRs used to evaluate these data are provided here for convenience.

Table 4-7. Total Molar VOC Mass as TCE^a During Baseline, 1% and 10% Whey Injection Scenarios.

Sample Locations	Total Molar Chloroethene and Ethene Mass as TCE (mg/L)^a						Decision Rule (DR)		
	Phase 2. Baseline^b		Phase 3. 1% Whey Injections^c		Phase 3. 10% Whey Injections^d		DR 1:	DR 2:	DR 3:
	Average	STDEV	Average	STDEV	Average	STDEV	Factor Difference^e	Factor Difference	Factor Difference
MW2A1	33.9	8.3	47.1	22.9	97.7	30.0	1.4	2.9	2.1
MW2A2	32.4	7.7	45.9	26.1	97.1	23.4	1.4	3.0	2.1
MW2A4	26.9	5.1	30.7	25.4	70.5	9.0	1.1	2.6	2.3
MW2B4	25.3	5.4	41.4	22.9	105.5	29.7	1.6	4.2	2.5
MW2C4	24.5	3.1	23.1	5.1	44.8	5.0	0.9	1.8	1.9
MW2D1	28.9	6.6	50.7	18.6	102.5	27.3	1.8	3.5	2.0
MW2D2	28.7	3.8	52.1	13.8	94.3	24.1	1.8	3.3	1.8
MW2D4	28.5	3.9	30.1	14.9	69.2	12.6	1.1	2.4	2.3
Average TC2	28.6	5.5	40.1	18.7	85.2	20.1	1.4	3.0	2.1
a. Molar concentrations of TCE, cis-DCE, VC and ethene were summed to obtain an equivalent molar concentration of parent compound TCE. b. Average of results of nine samples collected over three sample events conducted around three recirculation events in March and April 2005 and one standard deviation from the mean. c. Average results of 10 samples collected over three sample events conducted around three 1% whey injections in July, August and October 2005 and one sample collected prior to the November 2005 whey injection. d. Average results of five samples collected over two sample events conducted around two 10% whey powder injections in November and December 2005. e. Ratio of the appropriate averages; e.g., DR 1 factor difference = average for 1% injections/average for baseline.									

- **DR 1:** If chloroethene and ethene aqueous concentrations in groundwater measured during biostimulation using low concentration electron donor (Scenario 2) are significantly greater than those measured during baseline conditions (Scenario 1) at the 95% confidence level, then biostimulation will be determined to have increased contaminant mass transfer via concentration gradient increases and increased solubility of degradation products.
- **DR 2:** If chloroethene and ethene aqueous concentrations in groundwater measured during biostimulation using high concentration electron donor are significantly greater (Scenario 3) than those measured during baseline conditions (Scenario 1) at the 95% confidence level, then biostimulation will be determined to have increased contaminant mass transfer via some combination of electron donor-dependent bioavailability enhancement (increased effective solubility) and the ARD-driven mechanisms of DR 1.
- **DR 3:** If chloroethene and ethene mass transfer (based on aqueous concentrations) measured during biostimulation using high concentration electron donor (Scenario 3) is significantly greater than that measured during low concentration electron donor (Scenario 2) biostimulation at the 95% confidence level, are comparable between the two Scenarios, then bioavailability enhancement due to electron donor concentration-dependent effects will be determined to have increased contaminant mass transfer to a greater extent than the ARD-driven mechanisms alone.

The average total chloroethene and ethene concentration (umol/L) was established for each relevant sampling event at the eight sampling locations within Treatment Cell 2. As shown in Table 4-7, samples were collected following the three baseline recirculation/injection events, the three 1% whey recirculation/injection events, and two 10% whey recirculation/injection events. The average total chloroethene and ethene concentrations were calculated for each sample location for each operational Scenario (Phase 2: Baseline; Phase 3: 1% Whey injection; and Phase 3: 10% Whey injection) and are reported along with one standard deviation from the mean (Table 4-7). In addition, a factor difference associated with each DR was calculated. For DR 1, the average total chloroethene and ethene molar concentrations were a factor 1.4 greater for all eight Treatment Cell 2 monitor locations during 1% whey powder injections compared to baseline. For DR 2, the average total chloroethene and ethene molar concentrations were a factor of 3.0 greater during 10% whey powder injections compared to baseline. For DR 3, the average total chloroethene and ethene molar concentrations were a factor of 2.1 greater during 10% whey powder injection compared to 1% whey powder injections. In order to determine if these factor differences were significant, a one-way analysis of variance (ANOVA) was performed on the DR sample sets to compare the means using the f-distribution with GraphPad statistical software.

Three Scenarios were evaluated for each DR. For DR 1 Scenarios 1 (baseline sample set) and 2 (1% whey injection sample set) were compared; for DR 2, Scenario 1 and 3 (10% whey injection sample set) were compared; and for DR 3, Scenarios 2 and 3 were compared. Each DR was evaluated to determine whether the Scenario sample sets for each monitoring location showed statistically significant differences at a 95% confidence level. The DRs were evaluated for each monitoring location in Treatment Cell 2 and results are reported in Table 4-8.

At this point it is important to recall that the hypotheses were framed as null hypotheses. That is, each hypothesis is that no significant difference would be observed for each Scenario comparison group at the 95% confidence level. Using Bonferroni's Multiple Comparison Test, the calculated t-Test variable for each comparison group was compared to a significant t-value based on the degrees of freedom and the 95% confidence interval. If the calculated t-Test variable was less than the significant t-statistic, the hypothesis was accepted, meaning the comparison groups were not statistically different at the 95% confidence interval. If the calculated t-Test variable was greater than the significant t-statistic, the hypothesis was rejected, meaning the comparison groups were different at the 95% confidence level.

For each DR, the difference in average total chloroethene and ethene molar concentration was calculated for every sampling port. The average difference and standard deviation was calculated and illustrated in Figure 4-10. The greatest mean difference occurs between baseline conditions and 10% whey injection conditions at all Treatment Cell 2 monitoring locations. The mean difference between 1% and 10% whey injections was also large, while the mean difference between baseline and 1% whey injections was a factor of about 4 to 6 smaller and was actually exceeded by its own standard deviation at MW2A, MW2B and MW2C.

Based on the mean difference and standard deviation, t-Test values were calculated from each DR and are shown in Table 4-8. Based on the comparison of the values with the 95% confidence interval variable, the DR null hypothesis was rejected for DRs 2 and 3 at all monitoring locations. Rejection of each null hypothesis means that increased VOC molar concentrations from 10% electron donor injections relative to baseline conditions, and from 10% relative to 1% electron donor injection conditions were statistically significant. For DR 1, the null hypothesis was accepted for all but one monitoring location. This means that average molar VOC concentrations were not increased to a statistically significant extent in seven out of eight locations.

In other words, the Treatment Cell 2 results conclusively demonstrated that the B.E.T.TM process significantly enhanced mass transfer during injections of 10% whey. The average factor of increase relative to baseline was 3.0. Furthermore, mass transfer based on aqueous VOC concentrations was at least a factor of 2.1 higher during 10% whey injections than during 1% whey injections.

Interestingly, the extent of enhanced mass transfer appeared to be a function of the electron donor concentration, even for the 1% whey injections. For the eight sample ports in Treatment Cell 2, the factor of increase from baseline to 1% whey injections ranged from 0.9 to 1.8, with MW2C4 the only monitoring location with a factor less than 1.0, and was also the location that had the lowest change in COD from baseline to 1% whey injections during the July 2005 injection (Table 4-4a). In contrast, the sample ports with the highest factors of increase (1.8) were MW2D1 and MW2D2. These locations had two of the three highest COD concentration increases during 1% whey injections.

Table 4-8. Statistical Results from Hypothesis Testing for Treatment Cell 2 Data.

		MW2A1	MW2A2	MW2A4	MW2B4	MW2C4	MW2D1	MW2D2	MW2D4
	Degrees of Freedom	8	8	8	2	2	8	8	8
Decision Rule 1:	t-Test	1.332	1.173	0.1441	1.181	1.452	2.316	3.266	0.2492
	Null Hypothesis	Accept	Accept	Accept	Accept	Accept	Accept	Reject	Accept
	Conclusion	No statistically significant difference in total chloroethene and ethene concentrations between Scenarios 1 and 2.						Statistically significant difference	No statistically significant difference
Decision Rule 2:	t-Test	5.757	5.844	3.946	6.706	6.003	9.602	8.553	5.309
	Null Hypothesis	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Reject
	Conclusion	Statistically significant difference in total chloroethene and ethene concentrations between Scenarios 1 and 3.							
Decision Rule 3:	t-Test	4.844	4.968	3.898	5.838	7.332	7.421	5.97	5.198
	Null Hypothesis	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Reject
	Conclusion	Statistically significant difference in total chloroethene and ethene concentrations between Scenarios 2 and 3.							

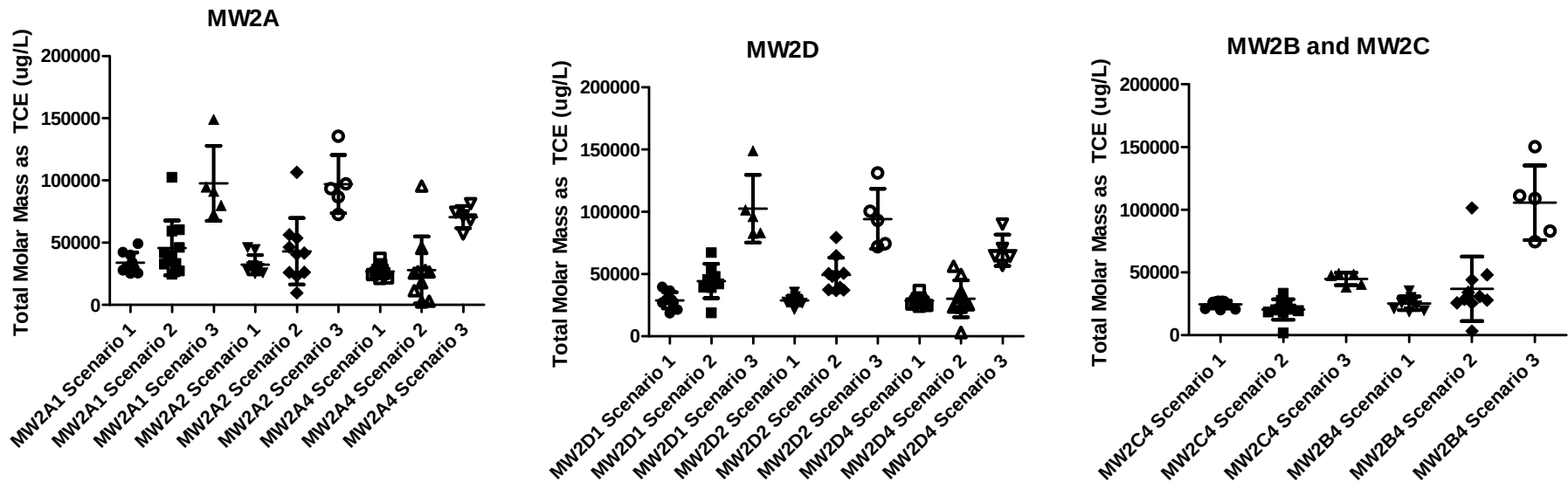


Figure 4-10. Scenario Sample Sets Evaluated During Statistical Assessment of DRs Illustrating Data, Mean and the 95% Confidence Interval from the Mean.

Unlike the low-concentration whey injection period, which showed slight increases in total average molar concentrations of chloroethenes and ethene (although not statistically significant), high-concentration whey injections significantly enhanced mass transfer of chloroethenes and ethenes in groundwater relative to both baseline and 1% whey injections, as noted above. A detailed evaluation of those data reveals some interesting points. First, the factor of increase in aqueous chloroethene and ethene concentrations from baseline to 10% whey injections ranged from 1.8 to 4.2, with only one sampling location showing an increase less than a factor of 2.0, and four locations were 3.0 or greater. These increases greatly exceeded those observed during the 1% injections, even though the extent of dechlorination was constant for the data used in the analysis (i.e., dechlorination was complete to cis-DCE, but little VC or ethene production had begun yet). In fact aqueous chloroethene and ethene concentrations during 10% injections increased by factors ranging from 1.8 to 2.5 in Treatment Cell 2 as compared to those during 1% injections. The overall range of factor of chlorinated ethene concentration increase of 1.8 to 4.2 is consistent with mass transfer enhancements observed in the ER-0008 project at Dover AFB, where increases of total mass discharge from the treatment cell following bioaugmentation in a PCE source zone ranged from about 2 to 4.5 (NAVFAC 2007). It should be noted that these data are based on point measurements within the cell, not total mass discharge measurements. It can be argued that the downgradient enhanced mass flux in this demonstration (Section 4.5.3.2) is probably a better analogy to the total mass discharge in the Dover demonstration.

Second, the correlation between COD concentrations and aqueous chloroethene concentrations was again quite evident. The monitoring point with the lowest chloroethenes increase during 10% injections compared to baseline (a factor of 1.5) was MW2C4, one of the off-axis locations. This location also had the lowest COD concentration during 10% injections relative to baseline, almost a factor of 2 lower than the next lowest (Appendix E). The monitoring locations with higher COD all had much higher enhanced mass transfer factors.

In order to evaluate this apparent correlation more rigorously, COD concentrations for 1% and 10% whey injections at each monitoring location were plotted against the appropriate enhanced mass transfer factor (Figure 4-11). The COD values used in Figure 4-11 are from the day following injection for the July 1% whey injection and the December 10% injection (the first events for each strategy from Table 4-4a). This figure demonstrates that there is a positive correlation between increasing COD concentration and increased aqueous VOC concentrations. Once the COD exceeds 15,000 mg/L, more variability around the trend is apparent, but the trend is still clear.

These results clearly demonstrate not only that chloroethene mass transfer to the aqueous phase was enhanced during biostimulation in the Treatment Cell 2 source area, but also that the extent of enhanced mass transfer was a strong function of electron donor concentration. This was illustrated by the fact that enhanced mass transfer that occurred due to abiotic interactions of the high concentration electron donor solution with the source material was significantly greater (a factor of 1.8 to 2.5 greater) than that due to the biological ARD process alone. The implications of this accelerated source removal for downgradient flux from a source area are discussed in the next section.

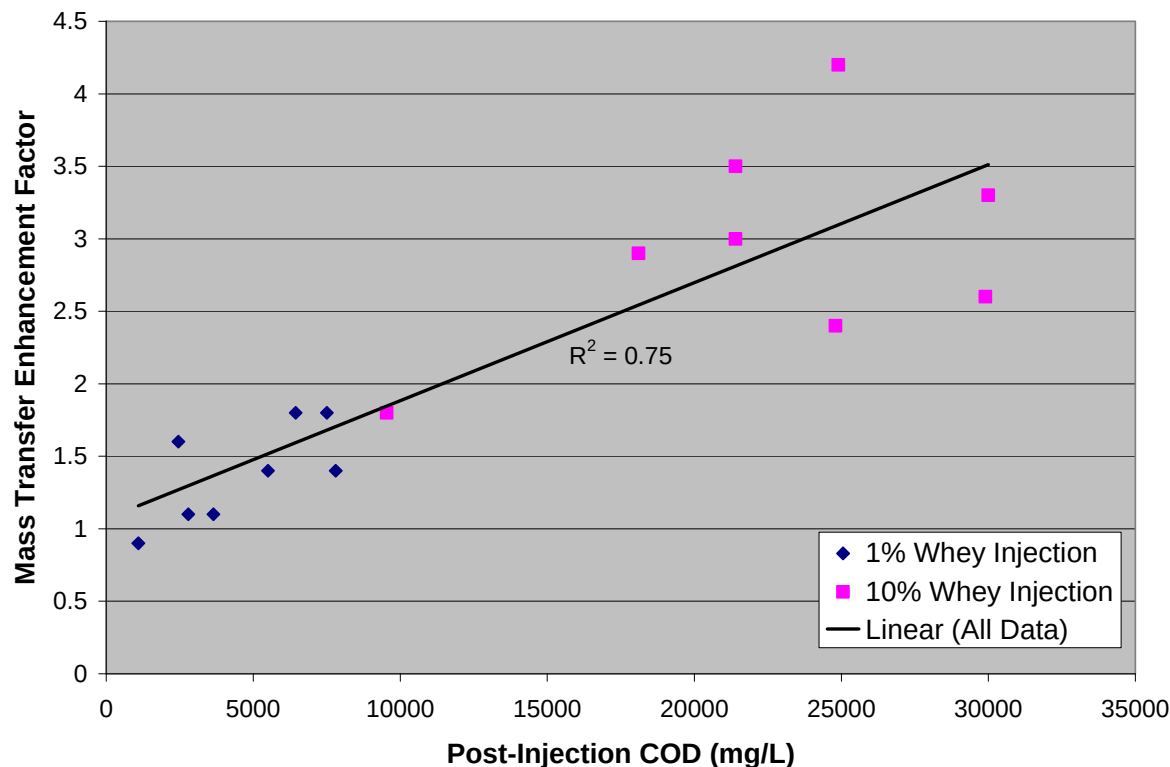


Figure 4-11. Correlation of Mass Transfer Enhancement Factors Based on Aqueous VOC Concentration Increases with COD Concentration at Treatment Cell 2 Monitoring Locations Following 1% and 10% Whey Injections.

4.3.5.2 Evaluation of Downgradient Enhanced Mass Flux

The installation of a line of wells downgradient of NAPL Area 3 (and therefore downgradient of the demonstration treatment cells) as part of an Army Environmental Center performance evaluation of the thermal treatment that followed the demonstration fortuitously provided critical information toward meeting project objectives. Figure 4-12 shows the location of the line of flux wells relative to the treatment cells. Based on the apparent direction of the ambient hydraulic gradient, wells FX3-01, FX3-02, and FX3-03 were downgradient of Treatment Cell 1. FX3-05 was a little north of directly downgradient. Wells FX3-04, FX3-06, and FX3-07 appeared to be directly downgradient from Treatment Cell 2, while FX3-08 might have been a little south of directly downgradient. Samples from all of these wells were collected in July 2005, about a month after the initial 3% whey injections in both treatment cells. They were collected again in early November 2005, following the 3 months of 10% whey injections in Treatment Cell 1 and 1% whey injections in Treatment Cell 2. Beginning in December 2005, after the injection strategies were switched to 1% in Treatment Cell 1 and 10% in Treatment Cell 2, the wells were sampled monthly with additional funding provided by ESTCP. This change was due primarily to the results observed at these wells in July and November.

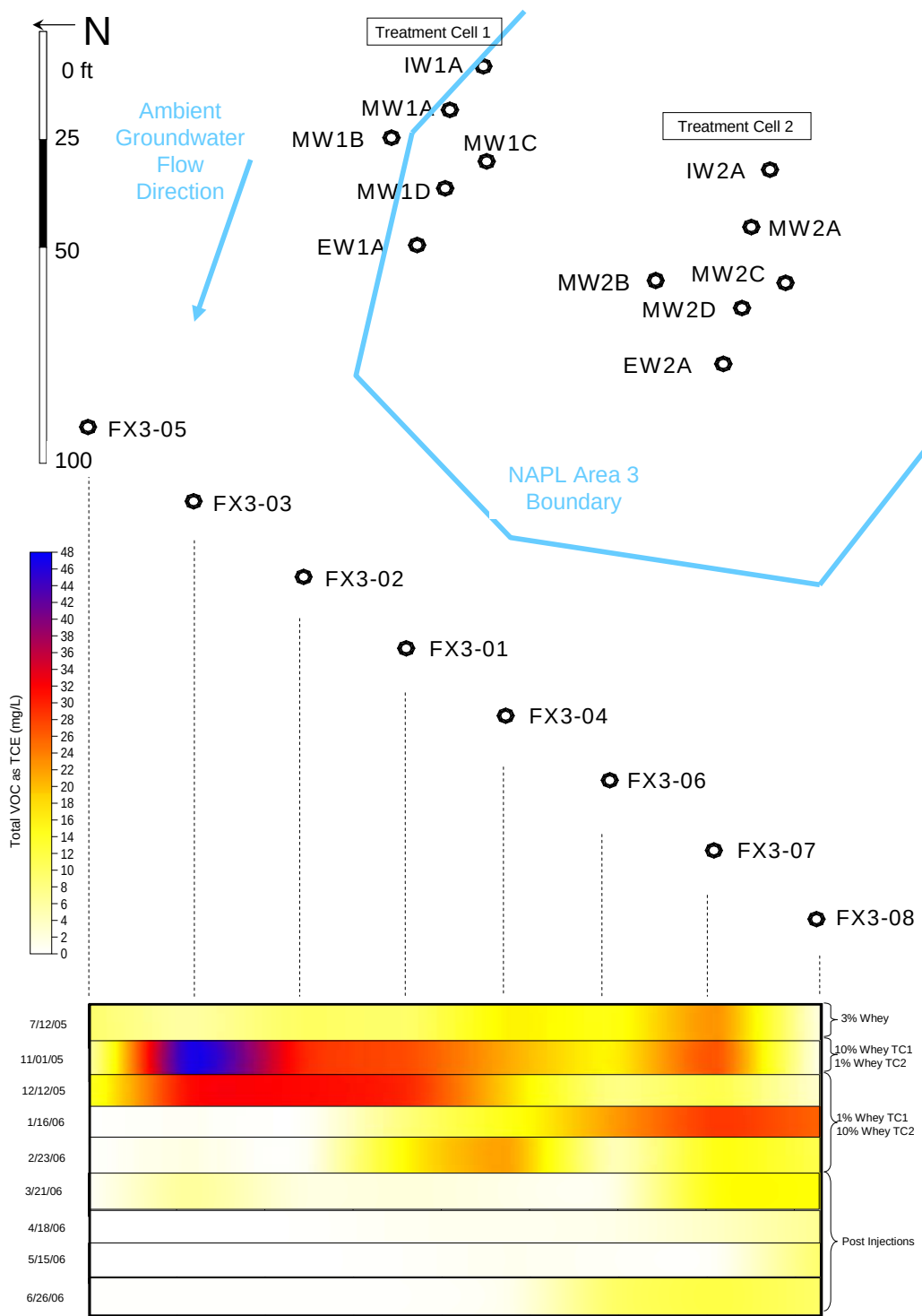


Figure 4-12. Total Chlorinated Ethene Concentration Contours at Select Time Points.

The July 2005 chloroethene concentration data were collected about 1 month after the initial 3% whey injections were made in the treatment cells, approximately 150 ft upgradient. Therefore, these concentrations are assumed to represent a baseline condition. Concentrations of total chloroethenes in the downgradient wells ranged from just over 1.4 to over 21 mg/L in July 2005 (Figure 4-12), with the highest concentration being observed at FX3-07, downgradient of Treatment Cell 2 (all of the data for the downgradient wells are provided in Appendix E). This is consistent with the observations within the treatment cells showing significantly more evidence of high strength source material in Treatment Cell 2 than in Treatment Cell 1.

A dramatic change occurred in the data collected in November 2005, three months after 10% whey injections began in Treatment Cell 1. FX3-03, which had the second lowest total chloroethene concentration in July, had by far the highest total chloroethenes concentration in November, having increased by more than a factor of 8. FX3-02 and FX3-03 both increased as well, by a factor of 3 in both cases. While concentrations downgradient of Treatment Cell 1 increased by a factor of 3 to 8, total chloroethenes concentrations in wells FX3-04, FX3-06, FX3-07, and FX3-08 changed only by a factor of 0.8 to 1.3. In other words little or no change in aqueous concentrations was observed downgradient of the 1% whey injections in Treatment Cell 2, although previously the highest concentrations were observed there. These results suggested that while little residual source was present in Treatment Cell 1, the high concentration whey solution encountered source material as it migrated beyond Treatment Cell 1 to the downgradient wells. The increased aqueous concentrations resulting from the 10% whey solution were consistent with the increase by a factor of 6 measured by Macbeth et al. (2006) in column studies.

The observed response in the downgradient wells in November made it clear the whey injections in the treatment cells were having a significant effect on chloroethene flux downgradient. For this reason, ESTCP provided additional funding to monitor the wells monthly. In addition, the decision was made to switch the 10% whey injections to Treatment Cell 2 and the 1% injections to Treatment Cell 1. If the increased flux downgradient from Treatment Cell 1 actually resulted from the 10% whey injections and not some other unknown influence, changing the injection strategy would be expected to cause concentrations in the wells downgradient from Treatment Cell 2 to increase, and concentrations downgradient from Treatment Cell 1 to decrease.

The December 12, 2005 monitoring event was about 2 months after the last 10% whey injection in Treatment Cell 1 and 1 month after the first injection of 1% in Treatment Cell 1 and 10% in Treatment Cell 2. At this point, concentrations were still highest downgradient from Treatment Cell 1, though they had decreased in FX3-03. When the wells were sampled again in January 2006, however, the distribution of chloroethenes in downgradient wells had undergone a complete reversal from the November 2005 data. The highest concentrations were measured at FX3-07 and FX3-08 downgradient from Treatment Cell 2, and the lowest concentrations were measured downgradient from Treatment Cell 1, including wells FX3-02 and FX3-03, which only 1 month earlier had the highest concentrations in the transect. In fact, chloroethenes concentrations at FX3-08 were a factor of 16 higher than baseline and a factor of more than 8 relative to December. Concentrations in FX3-06 and FX3-07 increased in January by factors of

2.8 and 2.5 compared to December. This change in concentrations downgradient from Treatment Cell 2 of a factor almost 3 to greater than 8 from December to January is nearly identical to the change observed downgradient from Treatment Cell 1 in November 2005 compared to the baseline in July. All of these results are again remarkably similar to the column study results of Macbeth et al. (2006) for 10% whey solutions. As noted earlier, these downgradient mass transfer (or mass flux) enhancements are probably more analogous to the total mass discharge enhancements in the Dover demonstration (NAVFAC, 2007) than the point measurements in the treatment cells. The range of the factors of increase of 3 to greater than 8 observed downgradient of 10% whey injections is higher than the range of 2 to 4.5 observed at Dover. This suggests an additional mechanism for enhanced mass transfer is occurring with high concentration whey injections.

As observed within the treatment cells, COD data collected from the downgradient wells confirms the correlation between enhanced mass transfer and electron donor concentration. Unfortunately, COD data were not collected until December 2005, when ESTCP funded the sampling of these wells. From that point forward, both COD and chloride were collected along with the chloroethenes, ethene, ethane, and methane. The highest COD observations downgradient from Treatment Cell 1 in wells FX3-01, FX3-02, and FX3-03 occurred in the first 2 months it was analyzed, December 2005 and January 2006, after which it decreased by one to two orders of magnitude with the exception of one measurement in May 2006 in FX3-03 (Appendix E). In contrast, the COD downgradient from Treatment Cell 2 in December 2005 was still 0 mg/L in FX3-04, FX3-06, and FX3-07, while it had increased to 320 mg/L in FX3-08. This changed along with the chloroethenes concentrations in January 2006, when COD increased to its maximum levels in all four of these wells downgradient of Treatment Cell 2. This sampling event also had the highest chloroethenes concentrations observed in three of these 4 monitoring locations for the entire demonstration (the exception was FX3-04, where the maximum was observed 1 month later).

The COD data not only demonstrated that the enhanced mass transfer in the source area, and increased mass flux downgradient, was a strong function of the electron donor concentration, they also showed that approximately 2 months was required for the effects of changes in injections in the treatment cells to be fully apparent at the downgradient monitoring wells. One month after the initial 10% injections in Treatment Cell 2, most of the wells downgradient from that cell still had COD values of 0 mg/L, but then reached a peak 2 months after the first 10% injections in Treatment Cell 2. This is consistent with the fact that both COD and chloroethene concentrations were still high in December downgradient of Treatment Cell 1 because the last 10% injection there occurred in October, just 2 months prior. By January, 3 months after the last 10% injection in Treatment Cell 1, both COD and chloroethenes concentrations dropped dramatically.

Chloride concentrations correlated strongly with chloroethene concentrations, demonstrating that ARD was occurring concomitant with the enhanced mass transfer. For example, in FX3-03, chloride was at 61 mg/L in December 2005 when chloroethenes were still elevated at over 23 mg/L (Appendix E). When chloroethenes dropped to below 0.7 mg/L a month later, chloride

dropped to about 4 mg/L. Similarly, chloride was at 58 mg/L in December 2005 in FX3-02 when total chloroethenes were at 23 mg/L. In January 2006, total chloroethenes had dropped to less than 0.4 mg/L, and chloride decreased to 13 mg/L. Similar trends were observed in the remaining downgradient wells.

4.3.5.3 Evaluation of Enhanced Mass Transfer Mechanisms

While it is clear that the enhanced mass transfer in this demonstration was a function of the concentration of the whey injection solution, the discussion to this point has made little effort to distinguish between the potential mechanisms occurring during high concentration whey injections that are facilitating the enhancement relative to lower concentrations. From a practical standpoint, it can be argued that differentiating the mechanisms is not nearly as important as documenting that the enhanced mass transfer occurs due to the aggregate effects of the mechanisms. However, if it is possible to identify the mechanisms and even to characterize their relative contributions, the ability to predict performance under different site conditions and for different electron donors would be improved.

The mechanisms that are currently understood to have the potential to increase mass transfer during bioremediation of chlorinated solvent source areas include (Sorenson, 2002; ITRC, 2005; ITRC, 2008):

- Increased concentration gradient – biodegradation of aqueous contaminants in the immediate vicinity of a DNAPL-water interface maximizes the concentration gradient, thereby maximizing the driving force for mass transfer
- Increased solubility of degradation products – the solubility of less chlorinated compounds is generally significantly higher than the more chlorinated parent compounds such as PCE or TCE, thereby allowing more contaminant mass in solution as reductive dechlorination occurs; in addition, the less chlorinated compounds can result in less sorbed mass because they also have lower K_{oc} values than the parent compounds
- Abiotic electron donor interactions – high concentrations of some electron donors might either increase effective solubility, increase desorption of sorbed contaminant mass, or both.

The first two mechanisms occur due to transformation of parent compounds in a DNAPL, such as PCE or TCE, to less chlorinated products through ARD. These mechanisms are therefore dependent upon biological activity, specifically the activity of dechlorinating bacteria such as *Dehalococcoides spp.* The third mechanism occurs independent of biological activity because it is a function of the properties of the electron donor solution itself. Three potential mechanisms for the electron donor solution to enhance mass transfer include: cosolvency, surfactant partitioning, and dissolved organic matter partitioning (Macbeth, 2008). For purposes of this discussion, the mechanisms for enhancing mass transfer during bioremediation of chlorinated solvent areas will be grouped as biological mechanisms (first two mechanisms above) and abiotic mechanisms (third mechanism above).

In the evaluation of the potential mechanisms enhancing mass transfer in the demonstration, three major points were considered. First, the pattern of enhanced mass transfer observed following whey injections can be accounted for entirely by previously documented enhanced solubilization of TCE by abiotic whey solutions over a range of concentrations due to its dissolved organic matter. Second, the extent of reductive dechlorination (complete conversion of TCE to DCE with little vinyl chloride or ethene) was the same for both 1% and 10% whey injections. Third, molecular data collected during the demonstration as part of the ER-0318 project (which is reported separately) reveal that *Dehalococcoides spp.* DNA and RNA measurements were essentially indistinguishable for the different injection concentrations, suggesting that these bacteria did not grow more, nor were they more active, for the higher whey concentrations. Each of these points is discussed in detail below.

The abiotic impacts of several electron donors on the solubility and mass transfer of TCE in batch and column studies were evaluated by Macbeth (2008), and many of the details of the evaluation of whey were reported by Macbeth et al. (2006). As shown in Figure 4-13, abiotic whey solutions increased the solubility of TCE by up to a factor of about 6. In particular, it was noted that the interaction of the whey with TCE was consistent with enhanced solubilization by dissolved organic matter partitioning. Specifically, a linear correlation of TCE solubility and whey powder concentration was observed up to whey concentrations of about 6%, along with an exponential decrease in interfacial tension. Above 6% whey concentrations, the increase in TCE solubility was much more gradual. This dissolved organic matter partitioning effect of whey on TCE solubility is attributed to the β -lactoglobulin protein present in whey based on the fact that experiments with lactose alone did not enhance TCE solubility (Macbeth et al., 2006). Thus, the enhanced mass transfer observed in the demonstration, which showed a factor of 3 to greater than 8 increase in chlorinated concentrations downgradient of the treatment cells following 10% whey injections, but not 1% whey injections, could be accounted for solely by the well-documented behavior of abiotic whey solutions shown in Figure 4-13.

The second consideration in the evaluation of mass transfer mechanisms was the extent of dechlorination. If conversion proceeded further along the dechlorination pathway during 10% whey injections than during 1% whey injections, then it could be concluded that this might account for a significant portion of the enhanced mass transfer. As shown in Figures 4-8 and 4-9, however, dechlorination only progressed as far as DCE during both 1% and 10% injections in Treatment Cell 2 until the pH increased near the end of and after whey injections (Figure 4-6). Therefore, no increase in TCE concentration gradients or higher solubility/lower sorption of less chlorinated degradation products can be implicated in the enhanced mass transfer observed.

The third and final consideration for distinguishing between biological and abiotic enhanced mass transfer mechanisms was to evaluate molecular data related to the growth and activity of *Dehalococcoides spp.* bacteria in the treatment cells. Samples were collected to analyze both DNA and RNA from *Dehalococcoides spp.* throughout the demonstration as part of the ER-0318 project. These data will be discussed in detail in the final report for that project, but the pertinent information for this discussion is summarized here. If it could be demonstrated either that growth of these bacteria was greater during 10% injections based on DNA data, or that the activity was

greater based on RNA data, then one could conclude that increased dechlorination activity was at least partially responsible for the enhanced mass transfer during 10% injections.

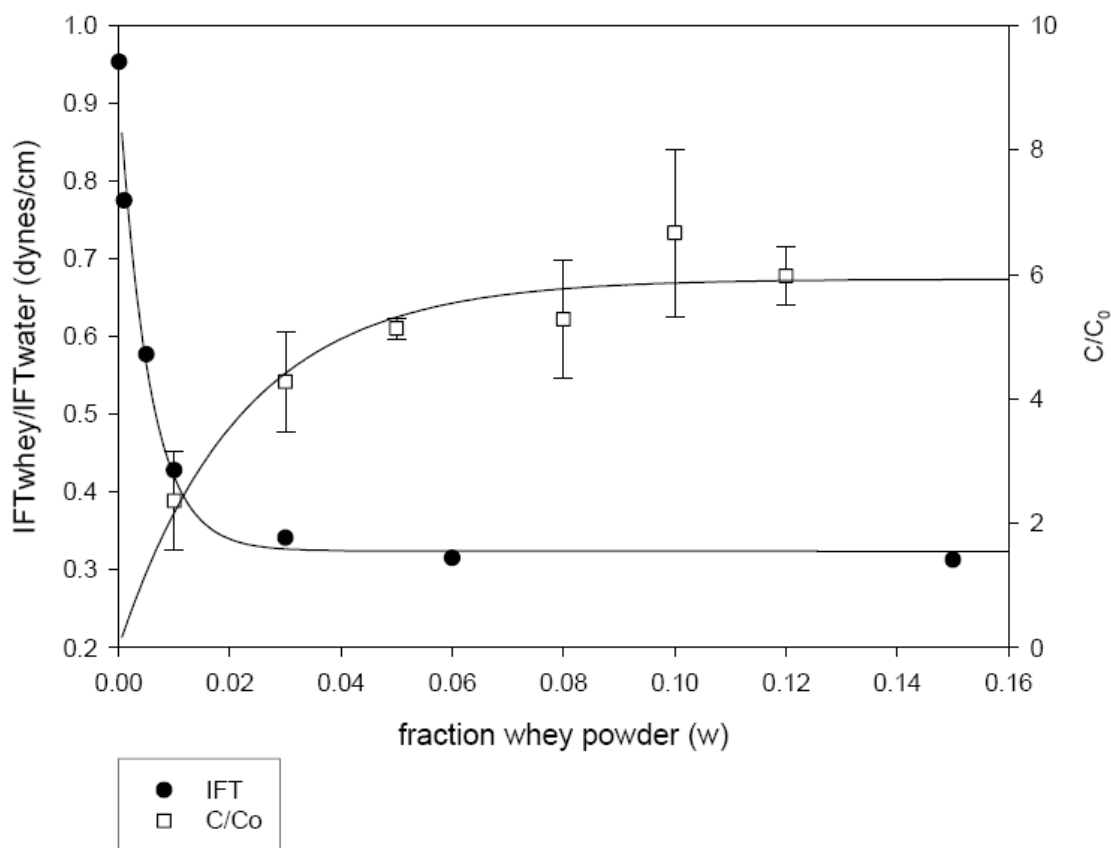


Figure 4-13. Relationship between Interfacial Tension Reduction and Enhanced Solubility of TCE DNAPL as a Function of Whey Powder Concentration (from Macbeth, 2008).

The DNA analysis comprised quantitative polymerase chain reaction for the 16S gene representative of *Dehalococcoides spp.* bacteria, as well as for the *tceA*, *bvcA*, and *vcrA* functional genes that encode for enzymes responsible for various steps in the ARD pathway. Increases in DNA measurements over time indicate growth in *Dehalococcoides spp.* cells, including those with the genes of interest. Figure 4-14 illustrates the DNA results. The concentrations of both the 16S rRNA gene and the functional genes during baseline sampling were about an order of magnitude higher in Treatment Cell 2 than 1. This is most likely attributable to the higher TCE concentrations in that cell. By September, following 10% whey injections in Treatment Cell 1 and 1% injections in Treatment Cell 2, the 16S rRNA and functional gene concentrations had become about equal, or perhaps slightly higher in Treatment Cell 1. By November, 1 month after switching the injection concentrations, DNA concentrations were again somewhat higher in Treatment Cell 2, though not by as much as during baseline sampling. After the final whey injections in February 2006, DNA concentrations were approximately equal in the two cells. Therefore, from November 2005 to February 2006, after

several months of 10% whey injections in Treatment Cell 2 and 1% injections in Treatment Cell 1, DNA concentrations of interest were approximately equal in the two cells, and actually increased more in Treatment Cell 1 during that span.

qPCR DNA and FISH Results DHC

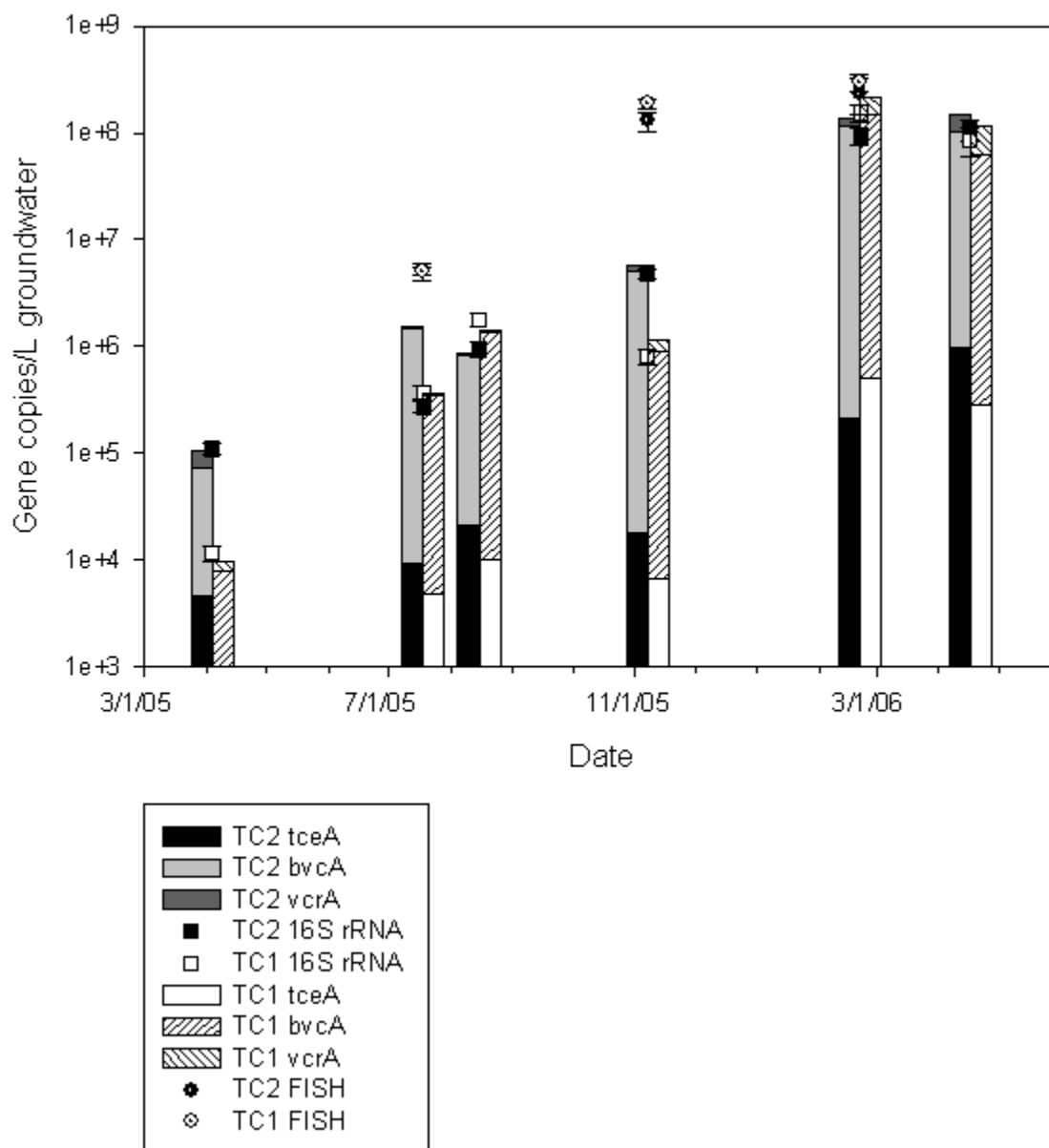


Figure 4-14. Quantitative Polymerase Chain Reaction and Fluorescent In Situ Hybridization Results Over Time in Both Treatment Cells.

Fluorescent in situ hybridization was used to analyze ribosomal RNA associated with the 16S rRNA gene for *Dehalococcoides spp.* bacteria. This is an indicator of metabolic activity of the bacteria at different time points during the demonstration. This analysis was performed in July and November 2005 and February 2006. As shown in Figure 4-14, given the error bars (representing one standard deviation from the mean of four sampling points per treatment cell) the results indicate that ribosomal RNA production was approximately equal in the two treatment cells at each time point analyzed. Thus, no evidence of an increase in *Dehalococcoides spp.* activity as a function of whey concentration is apparent.

In summary, whey solutions have previously been documented in abiotic batch and column studies to increase TCE solubility by about a factor of 6 due to dissolved organic matter partitioning (Macbeth et al., 2006; Macbeth, 2008). This increase is consistent with the extent of enhanced mass transfer observed in the demonstration. In addition, no difference in the extent the ARD pathway was observed between the treatment cells; both 1% and 10% injections resulted in dechlorination to DCE with little production of VC and ethene. Also, molecular analyses showed that no correlation of growth and activity of *Dehalococcoides spp.* bacteria with whey concentration was apparent. Finally, as shown in Table 4-8, although 1% injections (which dramatically increased biological activity) appeared to increase mass flux to some extent, that difference was not found to be statistically significant relative to baseline. In contrast, the mass transfer increases from baseline to 10% whey injections and from 1% to 10% whey injections were found to be statistically significant. Based on these lines of evidence, it appears that the mechanism most responsible for the factor of 3 to greater than 8 total mass discharge enhancement from the treatment cells undergoing 10% whey injections was the abiotic enhanced solubilization of TCE due to interaction with the dissolved organic matter in the whey.

4.3.5.4 Impact of B.E.T.™ on Downgradient Mass Flux Post-treatment

The data collected from the downgradient wells provided a powerful, incontrovertible tool to document the enhanced mass transfer caused by the 10% whey injections compared to the 1% injections. However, they provided an additional benefit never envisioned in the original demonstration plan. These wells provided an additional 4 months of data to document long-term effects on downgradient mass flux due to the enhanced mass transfer and accelerated mass removal that resulted in the source area. The results in Figure 4-12 demonstrated that flushing the source area with the 10% whey solution for only a few months not only dramatically increased mass transfer in the short term, it also achieved sufficient mass removal to have a major long-term effect on downgradient flux from the source area. In fact, just 2 months after the highest aqueous concentrations of chloroethenes for the entire demonstration were observed at FX3-03, concentrations were observed to decrease to just 14% of baseline concentrations in that location.

Furthermore, concentrations in FX3-03 in the last three sampling events (April, May, and June 2005) ranged from just 2 to 6% of baseline concentrations. In other words, downgradient mass flux from Treatment Cell 1 was decreased by 94 to 98% after only 8 months of whey injections. Even more impressive is that in seven of the eight downgradient wells, downgradient mass flux based on total chloroethenes concentrations had decreased by a factor of 94 to 99% in May 2006. The only well where this was not observed was FX3-08, which was at the far southern end of the

downgradient wells, and might have been influenced by chloroethene concentrations from the greater plume surrounding NAPL Area 3 in addition to what was happening in Treatment Cell 2. Some increase in concentrations was observed in the other wells downgradient from Treatment Cell 2 in June, but it is not clear whether this was due to rebound in that part of the source area, or a similar influence from the greater contaminant plume to the south of NAPL Area 3.

This demonstration of the B.E.T.TM process represents the first time the phenomenon of enhanced mass transfer in chlorinated solvent source areas as a function of the concentration of whey injection solutions has been thoroughly documented at the field scale. These results far exceeded expectations, and demonstrate the potential impact the enhanced mass transfer during bioremediation can have not only on source areas, but on downgradient plumes as well. It is important to note that the rapid effect on downgradient contaminant flux observed at the Ft. Lewis site might be a best-case scenario because of the high ambient groundwater flow rates, but having a similar effect in 1 to 2 years rather than the few months observed here would still be an extremely beneficial result at most sites.

5. COST ASSESSMENT

A critical evaluation criterion for any cleanup technology is cost. In this section, implementation costs for bioremediation of chlorinated solvent source areas are estimated based on the costs of the demonstration. It is important to note that the costs presented here are not necessarily the actual costs of the demonstration, but are the costs that would be expected if the B.E.T.TM technology were implemented for cleanup of NAPL Area 3 at Ft. Lewis. The cost basis assumptions are discussed further in Section 5.2. The costs are compared to the cost of cleanup of the same site using electrical resistance heating (ERH). The implementation costs of both technologies are then normalized to a cost per unit volume for comparison to costs in the SERDP/ESTCP database for bioremediation, thermal remediation, chemical oxidation, and surfactant/cosolvent remediation.

5.1 Cost Reporting

Table 5-1 provides the estimated implementation costs of the technology for the NAPL Area 3 site at Ft. Lewis. As noted above, these costs are not necessarily the actual costs of the demonstration, but in some cases are extrapolated for treatment of the larger area and volume of the entire NAPL Area 3 source area. In other cases, the demonstration costs were reduced to reflect, for example, the frequency of sampling that would be typical of implementation, as opposed to three sampling rounds for each electron donor injection. The cost categories in the table reflect those from ESTCP guidance that appeared to be appropriate. As shown in the table, the estimate total cost to treat NAPL Area 3 to similar levels as the alternative technology is \$0.9M. Based on the treatment volume for NAPL Area 3 (see Section 5.2.2), this equates to a unit cost of approximately \$56/yd³.

5.2 Cost Analysis

This section provides an analysis of the B.E.T.TM implementation costs in terms of: a comparison to costs of alternative technologies, the basis for the cost estimate in Table 5-1, anticipated cost drivers for the technology, and life cycle costs.

5.2.1 Cost Comparison

This demonstration offered a unique opportunity for comparison of costs to an alternate technology because immediately following the demonstration. ERH was implemented to clean up NAPL Area 3. Thus, the actual costs for using that technology at the same site, along with its performance, are well documented. At this time, the allocation of the ERH costs in the categories in Table 5-1 is not known, but the total cost is \$5M.

ERH was applied to NAPL Area 3 under a performance-based contract that required achieving and maintaining specified groundwater temperatures until it was determined that continued heating was no longer cost-effectively removing mass. The total cost for ERH at NAPL Area 3 was approximately \$5M. Given the approximate treatment volume (see Section 5.2.2), this equates to a cleanup cost of \$313/yd³.

Table 5-1. Projected Implementation Costs for B.E.T. TM in a DNAPL Source Area.

Cost Element	Sub-category	Detail	Costs
START-UP COSTS	Mobilization:		\$197,100
	- Work Plan (includes design, field sampling plan, health and safety plan, review, and revisions).	Total: Program Manager- 40 hr Senior Engineer- 115 hr Project Engineer- 180 hr Engineer- 100 hr Geologist-40 hr Health and Safety- 8 hr Project Chemist- 20 hr Technical Editor-35 hr	\$55,000 \$5,600 \$16,100 \$18,900 \$7,000 \$3,000 \$800 \$1,700 \$1,900
	- Field Preparation (includes contracting for sampling and drilling, drilling costs [two mobilizations] and permitting).	Total: Senior Engineer- 35 hr Geologist- 120 Field Technician- 120 Subcontract (Drilling) Materials	\$142,100 \$4,900 \$9,000 \$7,200 \$116,000 \$5,000
	Preliminary Site Characterization:		\$92,600
	- Hydraulic Testing (includes pumping tests; four tracer tests; labor for sampling, all equipment, supplies, and tracers for four tracer tests).	Program Manager- 20 hr Senior Engineer- 80 hr Project Chemist- 240 hr Field Technician- 220 hr Subcontract (Analytical) Materials Travel	\$2,800 \$11,200 \$20,400 \$13,200 \$20,000 \$15,000 \$10,000

Table 5-1. Projected Implementation Costs for B.E.T. TM in a DNAPL Source Area (continued).

Cost Element	Sub-category	Detail	Costs
CAPITAL COSTS	Extraction Well Pumps and Electrical Equipment (includes equipment and installation by subcontractor).	Subcontract (Equipment and Installation)	\$26,000
OPERATION AND MAINTENANCE COSTS	Capital Equipment Rental:	Subcontract (Whey Injection System)	\$23,000
	Ancillary Equipment Rental:	Subcontract (Tanks)	\$10,000
	Supervision:		\$180,400
	-Project management, routine reporting, regulatory interface, and technical oversight	Program Manager- 110 hr Senior Engineer- 1000 hr Travel	\$15,400 \$140,000 \$25,000
	Injection:		\$180,000
	- Assume 3 wells and 4 events/year for 3 years and 10% whey	Program Manager- 60 hr Senior Engineer- 90 hr Field Technician- 900 hr Materials Travel	\$8,400 \$12,600 \$54,000 \$90,000 \$15,000
	Sampling and Analysis:		\$165,200
	- VOC, carbon, bioactivity, redox, and DNA for 12 events	Program Manager- 60 hr Senior Engineer- 90 hr Field Technician- 900 hr Subcontract (Analytical) Travel	\$8,400 \$12,600 \$43,200 \$91,000 \$10,000
DEMOBILIZATION	Well Abandonment		\$26,000
WASTE DISPOSAL	No unique requirements recorded		NA
LONG-TERM MONITORING	standard groundwater monitoring- no cost tracking		NA
GRAND TOTAL			\$900,300

The next comparison made was to look at the estimated unit costs for cleanup by B.E.T.TM and ERH in the context of costs found in the SERDP Source Depletion Decision Support System (version 1.5.6) for bioremediation, thermal remediation, chemical oxidation, and surfactant/cosolvent remediation. Figure 5-1 illustrates the statistics on DNAPL remediation unit costs, as published in McDade et al. (2005). The \$56/yd³ cost estimated in Section 5.1 for application of B.E.T.TM to the DNAPL source area at Ft. Lewis is above the median of the 11 sites used to generate the bioremediation statistics in the figure, but well below the 75th percentile. Thus, the projected implementation costs appear to be in line with costs reported for other bioremediation projects in source zones.

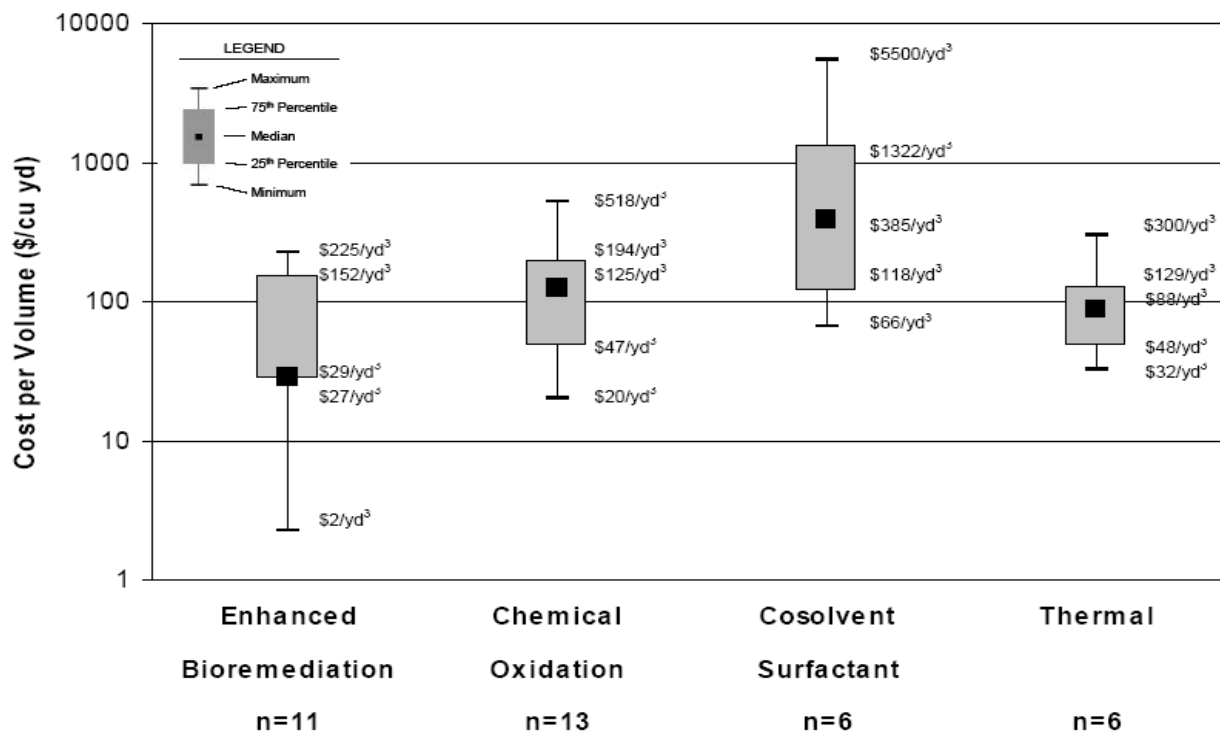


Figure 5-1. Costs of DNAPL Source Cleanup Technologies Reported in the SERDP Source Depletion Decision Support System (version 1.5.6) as Compiled by McDade et al. (2005).

The costs for ERH on the other hand actually exceeded the maximum cost of the six thermal remediation sites used to generate the figure. NAPL Area 3 was the third source area at Ft. Lewis where ERH was applied, with similar costs for all three. Based on the data from Ft. Lewis and other experience of this project team, it is believed that the statistics in Figure 5-1 for thermal remediation are lower than are typical for chlorinated solvent source zones. It should be noted that the sample size of six sites is fairly small, which might explain the significant difference between the costs in the figure and the Ft. Lewis costs.

Figure 5-1 also shows costs for chemical oxidation and cosolvent/surfactant applications in source zones. The median costs for these technologies were the highest of the four technologies evaluated. For 13 chemical oxidation sites, the median unit cost was greater than twice the projected B.E.T.TM cost based on the Ft. Lewis demonstration. The median cost for the surfactant and cosolvent sites was even greater than the ERH cost at NAPL Area 3. Again, it should be noted that the sample size for the statistics presented in the McDade et al. (2006) study for the thermal technology was small, with only six sites evaluated.

It should be noted that the \$56/yd³ is based on a B.E.T.TM operational period of 3 years, but that the amount of DNAPL mass present in NAPL Area 3 was unknown, making estimates regarding remedial timeframe difficult. One of the greatest uncertainties of B.E.T.TM, and with in situ remedial technologies in general, is an understanding of the remedial timeframe required to clean up DNAPL contamination. Factors such as the quantity and architecture of DNAPL within a given aquifer volume are often unknowns at DNAPL-contaminated sites. While B.E.T.TM can substantially enhance mass removal rates, the duration required to remove sufficient residual mass to meet site remedial objectives cannot be easily determined. In comparing the cost-effectiveness of B.E.T.TM with the alternate technology, ERH, however, it should also be noted that while ERH may have a much shorter operational duration (e.g., 4 to 5 months at NAPL Area 3), the cost was \$5M within a single year. This is equivalent to nearly 17 years of B.E.T.TM operation. Therefore, even using conservative estimates regarding required remedial timeframe, the life-cycle cost of B.E.T.TM will likely be much less expensive than the alternate technology. In addition, contaminant mass flux can also be effectively reduced during the entire period of treatment and therefore, application of B.E.T.TM would also likely reduce the size of the dissolved-phase plume over the treatment duration.

5.2.2 Cost Basis

The implementation cost estimated in Section 5.2.1 assumes B.E.T.TM bioremediation is applied to the entire NAPL Area 3 source area at Ft. Lewis. The costs collected during the demonstration were used as the basis for the estimate, but had to be modified to reflect both the size of the treatment area and the purpose. The demonstration included much more intensive sampling than would be typical of a cleanup because of the need to “prove” the technology and use experimental controls. Table 5-2 provides the parameters used to develop the costs in Table 5-1.

An effort was made to be conservative in several of the parameters so as to avoid being overoptimistic in the estimate. For example, the number of monitoring wells (especially the multilevel wells) is higher than many cleanups at the assumed scale. In addition, the costs included several tracer test iterations, as performed during the demonstration (and noted in Table 5-1). While this is not a typical cost, it added significant value, and would be recommended for implementation at a site that did not have such characterization data in order to ensure electron donor injection will have maximum effectiveness. The costs of two drilling mobilizations in order to achieve proper placement of the wells are also included. At many sites, sufficient data would likely be available such that this would not be required.

Table 5-2. Parameters Used as the Basis for Calculating Technology Implementation Costs.

Parameter	Value
Site Area	0.5 acre
Contaminated Thickness Treated	20 ft
Treatment Volume	16,000 yd ³
Number of Injection Wells	3
Number of Multilevel Monitoring Wells	8
Number of Fully Penetrating Monitoring Wells	8
Number of Extraction Wells	2
Duration of Operations	3 years
Frequency of Electron Donor Injection	4/year
Number of Monitoring Events	12
Monitoring Analytes	Same as ER-0218 demonstration with added costs for DNA analysis conducted as part of ER-0318

The 3-year duration assumed for treatment of NAPL Area 3 is an estimate based on the demonstration results. Flux reduction of greater than 90% could clearly be achieved much faster, but 3 years was chosen to allow plenty of time for degradation of cis-DCE and VC that remained in the source area after the 8 months of treatment during the demonstration.

The basis for the cost of cleanup of NAPL Area 3 by the alternative technology, ERH, was the actual cost, as described in Section 5.2.1. The basis for the unit costs of the four remediation technologies in Figure 5-1 are actual reported costs compiled by McDade et al. (2005) and also provided in the SERDP Source Depletion Decision Support System (version 1.5.6).

5.2.3 Cost Drivers

As with most in situ remediation technologies, the most important aspect of implementing bioremediation in chlorinated solvent source areas is delivery and distribution. That is, the electron donor must be distributed throughout the target treatment zone to stimulate the desired degradation and enhanced mass transfer. Therefore, the major cost drivers are likely to be the hydraulic conductivity and the degree of heterogeneity. The “bulk” hydraulic conductivity of the treatment zone will determine the spacing of injection wells, and will have a strong influence on

the required treatment duration. The heterogeneity will mostly impact the treatment duration because a high degree of heterogeneity will increase the potential for preferential flow. A high degree of preferential flow will result in a cleanup timeframe that is dependent upon diffusion more than advection, which will increase treatment duration, thereby increasing costs.

Similarly, the sheer mass of contamination can be a cost driver. As long as the source consists primarily of solvents at residual saturation or sorbed to the soil, mass removal can be fairly rapid as observed in the demonstration (subject to the potential constraints of hydraulic conductivity and heterogeneity discussed above). However, if DNAPL is present in pools, cleanup timeframe becomes limited by dissolution rates. While B.E.T.TM can enhance the mass transfer by a factor of more than 2.5 to even 10 or higher, large pools of DNAPL could still require decades to dissolve, driving costs up significantly.

Another potential cost driver is hydraulic containment. If a sufficient downgradient buffer zone is not available at a site and extraction of groundwater is required to prevent the temporary increase in mass flux caused by B.E.T.TM from impacting some nearby downgradient receptor, costs would increase. This is especially true if for some reason the extracted water cannot simply be reinjected in the source area.

A fourth potential cost driver is vapor intrusion. Bioremediation of chlorinated solvents via ARD generates VC and methane. For shallow, unconfined groundwater sites, this creates the potential for these gases to reach fairly high concentrations in the unsaturated zone above the water table. If potential receptors were present above the treatment zone and soil vapor extraction were required, this would also increase technology costs.

5.2.4 Life Cycle Costs

Life cycle costing provides the greatest utility when a project has a significant initial capital or short-term operating cost, followed by a much longer period of lower operating costs. This is not really the case either for the B.E.T.TM example in Section 5.2.1, or the ERH example in Section 5.2.2. For ERH, the cleanup costs were all incurred in about 1 to 2 years, while for B.E.T.TM, the costs were assumed to be incurred over about 4 to 5 years (including preliminary characterization, well drilling, etc.). Thus, the total costs reported in those sections essentially are the life cycle costs. Calculating net present value for such a short period of time would have almost no impact for ERH timeframe. For B.E.T.TM, the capital cost is relatively small and the operational period is still not very long, so again the utility of a net present value calculation is minimal and was not performed.

6. IMPLEMENTATION ISSUES

6.1 Environmental Checklist

North Wind, Inc. did not have to prepare a State of Washington underground injection control (UIC) permit application to inject whey and makeup water extracted from the area of contamination into the aquifer at the Ft. Lewis EGDY due to interpretation of the applicable sections of the Washington Administrative Code Chapter 173-218 WAC Underground Injection Control Program. Specific language in the WAC 173-218-040 *UIC well classification including allowed and prohibited wells*, allows for Class IV wells to reinject treated ground water . . . “into the same formation from where it was drawn as part of a removal or remedial action if such injection is approved by EPA in accordance with the Resource Conservation and Recovery Act, 40 CFR 144. Such wells must be registered and approved under RCRA and “Class IV wells that are not prohibited are rule authorized, after the UIC well is registered, for the life of the well if such subsurface emplacement of fluids is authorized under the Resource Conservation Recovery Act, 40 CFR 144.23(c).”

RCRA regulations [specifically 3020(b)] specifically allow for both injection of treatment agents, and reinjection of extracted water amended with bioremediation treatment agents if certain conditions are met: “Specifically, the groundwater must be treated prior to reinjection; the treatment must be intended to substantially reduce hazardous constituents in the ground water – either before or after reinjection; the cleanup must be protective of human health and the environment; and the injection must be part of a response action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Section 104 or 106, or a RCRA corrective action intended to clean up the contamination.” The demonstration met all these conditions and no other permitting requirements were required to implement the demonstration. No emissions were produced by demonstration of the in situ treatment technology.

The State of Washington classifies injection wells into classes based on construction and function. The state requires that all wells be registered and most wells must be rule authorized. The demonstration wells were registered with the WDOE and the injection well was rule authorized for the life of the well because it is authorized under the Resource Conservation Recovery Act, 40 CFR 144.23(c).

6.2 Other Regulatory Issues

RCRA provides opportunities for public involvement throughout the remedial action process to expand public access to information about the facility and its activities. Since the small scale ISB demonstration was supplemental to the permitted remedial activities, the actions were not subject to formal public involvement. All activities were performed within the previously disturbed, contaminated area. Generally, ISB is regarded by the public as a safe, effective, low-risk remedial alternative.

6.3 End-User Issues

End-users for this technology are contractors, potentially responsible parties, and state and federal agencies responsible for mitigating risks to human health and the environment posed by DNAPL in groundwater. This technology is readily scaled to any size site, as evidenced by deployments at scales ranging from dry cleaners sites to large-scale plumes such as the INL TAN. This technology as implemented uses a licensed, commercially available electron donor; all other process equipment is non-proprietary and readily commercially available. Deployment of this technology is tailored to the specific site. All or most of the previously identified design elements must be addressed during design and implementation, requiring the services of hydrogeologists and engineers.

An important cautionary note for this technology is that the higher mass transfer rates will likely increase volatilization significantly when conversion of parent compounds to vinyl chloride and ethene occurs. In addition to the chlorinated ethenes that might be present during volatilization, methane will also be present at significant concentrations. This is a concern for shallow aquifers that have a potential for a complete exposure pathway for vapors to reach receptors above the treatment zone, or where shallow subsurface construction or similar activities might encounter vapors.

B.E.T.[™] was originally developed at the U.S. Department of Energy's Idaho National Laboratory. It was commercialized through a technology transfer program. Currently, three U.S. patents relate to the B.E.T.[™] technology (U.S. patent numbers 6,783,678; 7,045,339; 7,141,170). The first two of these are licensed to North Wind, Inc. and JRW Bioremediation, LLC. The third is owned by North Wind, Inc. In general, licensed electron donor products can simply be purchased through JRW Bioremediation, and in some cases, no royalty is required for using the technology at government sites.

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Appendix A

Analytical Methods Supporting the Experimental Design Bioaugmentation Procedures: Ft. Lewis In Situ Bioremediation-Anaerobic Reductive Dechlorination Technology Demonstration

Section 1

On July 17, 2005, two Bachman Road culture batches were injected into Injection Well-1 (IW-1) and IW-2 at the In Situ Bioremediation (ISB) Anaerobic Reductive Dechlorination Technology Demonstration site. The two 18 L batches were prepared by the Utah Water Research Laboratory (UWRL) at Utah State University (USU) and transported to North Wind, Inc. in Idaho Falls, ID, on July 15, 2005. The UWRL Statement of Work for this task is provided for reference as Appendix A. Culture performance as measured in the laboratory is summarized in Sections 2 and 3, which were provided by the UWRL. Prior to injection the cultures were transported in an air-conditioned car to the site and stored in an air-conditioned building until the injection.

The two cultures provided to North Wind, Inc. were the GRStudy2 and NWPrep2 culture batches. These were provided because among four culture batches grown, they were of sufficient volume and had been demonstrated to transform trichloroethene (TCE) to ethene. General observations of culture performance were:

- Total cell counts of about 10^8 cells/mL.
- The presence of desulfuromonas, dehalospirillum, and dehalococcoides bacterium as demonstrated by conventional (not quantitative) polymerase chain reaction (PCR) using eight primer sets.
- In the GRstudy2, culture complete transformation of all TCE to ethene was observed.
- In the NWPrep2 culture, transformation of TCE to ethene was observed. However, the transformation rate of vinyl chloride (VC) to ethene had slowed prior to the planned injection date. The cultures had not completely transformed VC to ethene when the final culture sampling occurred.

The culture injection system and methods described in this report were employed in order to meet the following objectives:

- Maintain anaerobic conditions in the containers and injection system until the culture was injected below the water surface within the injection well casing.

- Provide an equal dose of each dechlorination culture into each treatment cell. The results of the culture monitoring suggested that GRStudy2 culture was better conditioned for complete transformation of TCE than the NWPrep2 culture. Therefore, half of each culture volume was injected into each injection well.
- Inject at a controlled flow rate. Achieving an exact injection rate was not necessary. However, to minimize turbulence within the injection lines and the well casing a controlled flow rate was necessary. It was estimated that the injection rate should be less than 1 gpm (3.78 L/min).

The following report briefly describes the injection system and procedures used during the injection. Observations and recommendations are also included.

System

The injection system shown on Figure A-1 was designed to be portable, be easy to use, and to meet the objectives previously stated. The system used pressurized ultra high purity (UHP) grade Argonne gas to force the liquid out of the pressurized stainless steel beverage containers used to transport the culture to the site. A pressure regulator and ball valve were used to control the pressure within the system and the flow rate of the liquid. The tank was suspended on a sawhorse by a scale, which was used to measure the quantity of liquid injected in order to inject half of each culture into each injection well. Tygon^R tubing lined with FEP was used to maintain culture purity and avoid introducing oxygen into the system. The tubing was transparent to allow observation of the liquid during the injection, which was useful for observing gas bubbles and potential change in liquid color from the Resazurin redox indicator.

Procedure

The injection procedure was devised based on a practice run performed prior to the day of injection. The following procedure describes the steps carried out on the day of injection including any modifications. The injection system was set-up for each culture injected. Prior to setting up the injection system the following steps were taken:

- Before the tanks were connected to the pressurized gas tank, headspace pressure in both tanks was confirmed, by briefly releasing pressure from the pressure relief valve on the top of the tank. This was done to ensure the integrity of the cultures and the container seal.
- A third empty container, with fittings connected, was suspended from the sawhorse by the scale to measure the weight of the container in order to obtain the net weight of the liquid in subsequent measurements. The tank weighed approximately 12.5 lbs.

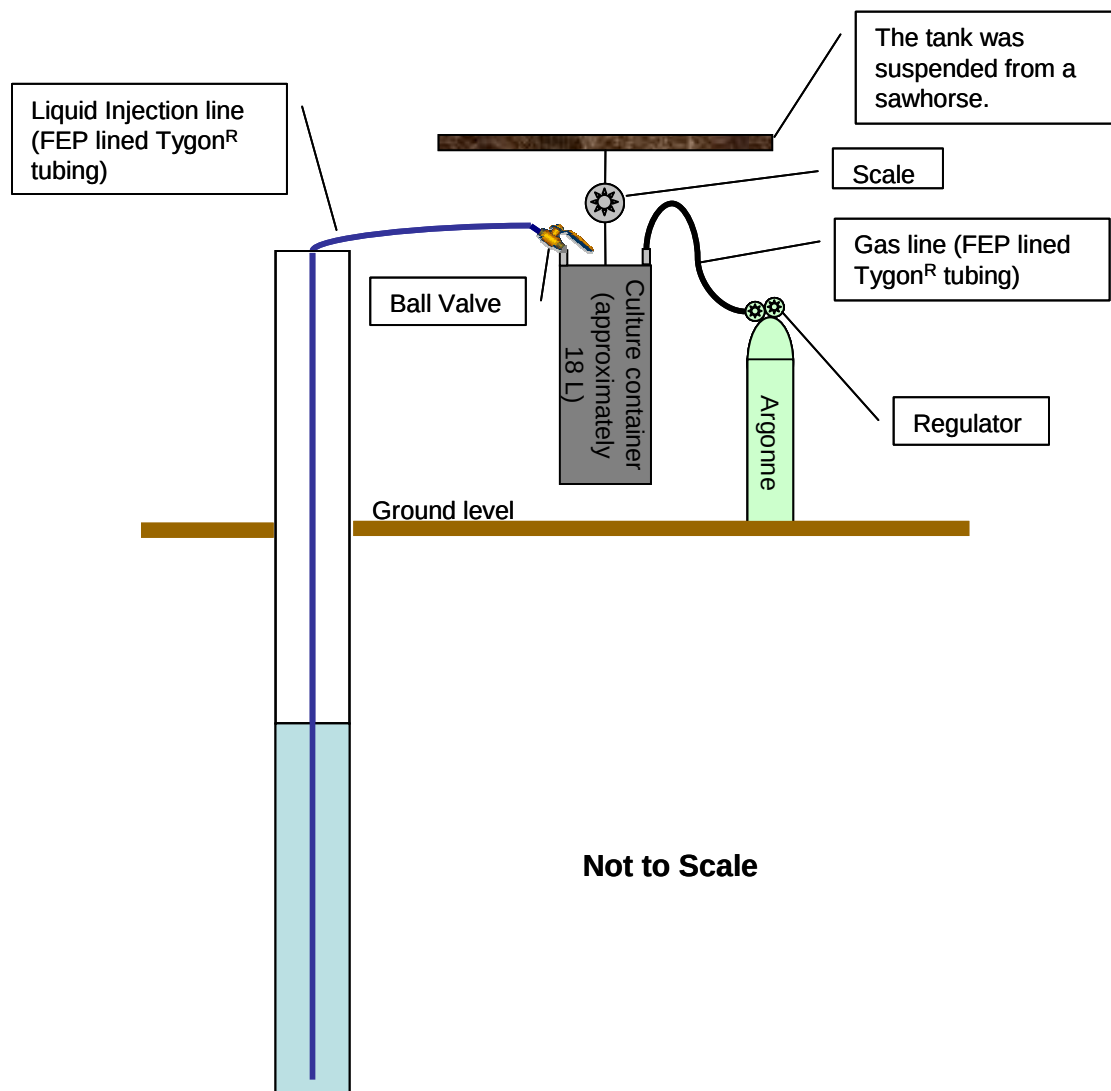


Figure A-1. Schematic of culture injection system.

As stated, half of each culture volume was injected into each of the two injection wells. The first culture injected was the GRStudy2 culture, which involved the following steps:

1. The tubing was purged of ambient gases by: connecting the gas inlet line to the liquid injection line using a coupling fitted with two nipples, opening the ball valve on the liquid injection line to fully open, pressurizing the lines by opening the gas regulator until the gauge read 10 psi, and allowing Argonne gas to run through the line for 10 min.
2. The GRStudy2 culture container was suspended on the sawhorses. The scale read approximately 53 lbs.
3. The liquid injection line was connected to the culture container and the line was primed with liquid by doing the following: with the ball valve $\frac{1}{4}$ open the liquid line was connected to the container, a small amount of liquid was allowed to flow into the line, the valve was closed, the gas line was connected, and the line was pressurized to 10 psi by opening the regulator valve.
4. A sample was taken by opening the ball valve $\frac{1}{4}$ open and taking a sample from the end of the liquid line after it had filled with liquid. The ball valve was closed.
5. The liquid injection line was pushed down well IW-2 until the tubing reached the bottom of the well. Then the line was pulled back out of the well approximately 6 in. to suspend the end of the line just above the bottom of the well.
6. The injection was started by opening the ball valve to approximately $\frac{1}{4}$ open and starting a timer. The culture liquid was allowed to flow out of the tank for approximately 15 minutes until the tank weighed approximately 33 lbs, at which time the ball valve was closed and the entire assembly was moved to well IW-1 without emptying the injection line. The calculated injection flow rates for each culture into each well are shown on Table A-2.
7. The injection line was placed in well IW-1 using the same method as was used for IW-2 (step 5), the ball valve was opened to $\frac{1}{4}$ open, and the entire contents of the tank were emptied in approximately 17 minutes.
8. The regulator and ball valve were closed and the fittings were disconnected from the tank.

All of the procedures for the injection of the NWPrep2 culture were identical to Steps 1 through 8 used to inject GRStudy2 cultures with the following exceptions:

- The lines were purged with Argonne for 15 minutes (as opposed to 10 minutes).
- Upon connecting the gas line to the NWPrep2 culture container and applying 10 psi the observed flow rate was slow. It was concluded that the gas line inlet in the tank had become blocked. Eventually the blockage was cleared by lightly shaking the tank. To prevent further problems the regulator was set to a pressure of 15 psi (as opposed to 10 psi) and the ball valve was opened to between $\frac{1}{4}$ and $\frac{1}{2}$ open. Subsequently the flow rates were faster and there was greater variability in the flow rates during injection of NWPrep2 culture into IW-2 because of adjustments made during the injection. The calculated average flow rates are shown in Table A-2.

Table A-2. Measured Injection Rates.

Culture	Well	Approximate Volume Injected, L	Approximate Average flow rate, L/min
GRStudy2	IW-1	9	1
GRStudy2	IW-2	9	1
NWPrep2	IW-1	9	2
NWPrep2	IW-2	9	2

Observations and Recommendations

The injection system and method appeared to achieve the objectives stated. The results of culture sampling and analyses and groundwater monitoring following bioaugmentation will provide more information on the culture vitality and injection system effectiveness. Some observations during the injection are:

- Gas bubbles were observed in the injection line during the injection of GRStudy2 cultures. The liquid within the lines did not change color, which would have indicated a change of redox conditions because of the presence of Resazurin, and the previous practice run using potable water did not have gas bubbles. Therefore, it was concluded that the gas bubbles were a result of degassing from the culture liquid and not introduction of air from a leak.
- As previously noted, during the injection of NWPrep2 cultures the gas inlet did not admit the pressurized Argonne gas. A higher operating pressure (15 to 20 psi) may be more appropriate to keep the tubing and fittings clear of blockages.

Section 2

USU shall prepare a dechlorinating culture for North Wind, Inc. North Wind, Inc. will use this culture to bioaugment groundwater at the Ft. Lewis EGDY In Situ Bioremediation-Anaerobic Reductive Dechlorination Technology Demonstration. The culture to be provided is the Bachman Road culture, which is capable of complete reductive dechlorination of chlorinated ethenes to the end product ethene. Conditions and requirements for this culture shall include:

- Strict anaerobic conditions during growth, addition of amendments to the culture, and transport,
- A total of 10 gallons (approximately 37.9 Liters) of culture provided in two 5 gallon containers,
- A total cell count of at least 3×10^8 cells per milliliter,
- Verification of culture integrity and capability including demonstration that the culture has transformed TCE and its reductive daughter products (including cis-dichloroethene, and vinyl chloride) to the ultimate daughter product ethene as well as PCR results documenting the presence of DHC, and the functional genes *tceA* and *vcrAB*,
- As discussed, the cultures shall be packaged in stainless steel air tight containers with a carbon dioxide/ nitrogen gas headspace induced under a low pressure (less than 30 lbs/in²) to maintain anaerobic conditions, and
- The cultures shall be ready for transport on July 18, 2005 or some other date as discussed between USU and North Wind, Inc.

Section 3

Attached below are TCE and daughter product results for the two Bachman Road culture batches being prepared for use by North Wind, Inc., at the Ft. Lewis Washington In Situ Bioremediation Demonstration Site. Figure A-2 summarizes TCE transformation in the second transfer of the BR culture into 18 L final volume of BR media. This second transfer culture (Figure A-2) has maintained active TCE/DCE/VC transformation capacity, providing complete VC transformation to ethene during 40 days of incubation. This 18 L culture will be transferred to North Wind, Inc., for use at the Ft. Lewis bioaugmentation site.

The TCE transformation history of the second of two third generation culture samples (NW Prep2) that have been specifically prepared for use at the Ft. Lewis site is summarized in Figure A-3. This 3rd generation culture sample has maintained its active TCE and cis-DCE transformation rates, completely removing TCE within 10 days and cis-DCE in 20 days. However, the VC transformation rate has slowed, and at the last sampling event, ethene represented approximately 20% of the total chlorinated ethenes remaining in the culture, or 10% of the original amount of TCE added to the culture at start of the growth cycle. The most recent sample of these cultures has also shown continued VC transformation to ethene, but at rates of approximately 80 µg/L/d rather than the 200 + µg/L rates observed in the original culture. It is important to note that VC transformation is demonstrated in the Ft. Lewis Pep culture samples (Figure A-3), and that complete VC transformation would be anticipated to be complete within an additional 15-day period under current transformation rates. Additional verification of VC transformation capacity is provided by the PCR results from these samples that are contained in a separate summary provided earlier to North Wind, Inc. This 18 L NW Prep2 culture will also be transferred to North Wind, Inc., for use at the Ft. Lewis bioaugmentation site.

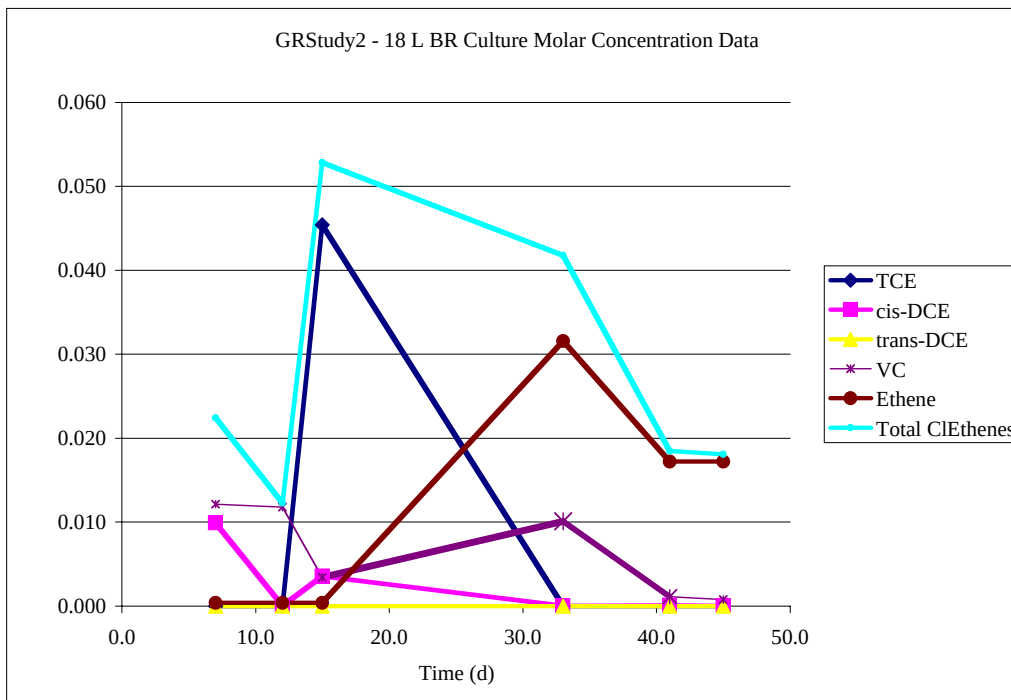


Figure A-2. Growth and Transfer Study 2, 2nd large volume transfer of original culture, GrStudy2 (18 L).

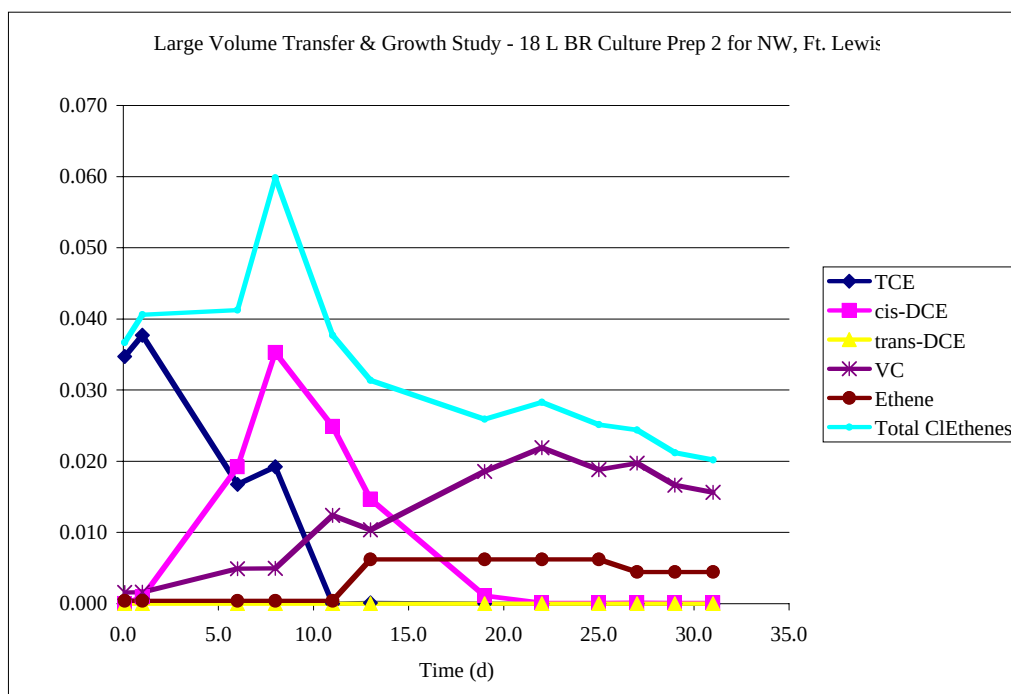


Figure A-3. Ft. Lewis Prep. 2, 3rd large volume transfer of original culture.

Section 4

Attached below are the PCR and total cell count results for a number of Bachman Road cultures being grown and maintained in the EQL of the Utah Water Research Laboratory, all related to the Bachman Road (BR) amendment samples being prepared for use by North Wind, Inc., at the Ft. Lewis Washington In Situ Bioremediation Demonstration Site. Table A-3 provides summary data for PCR data available at COB July 16, 2005 for all of the PCR probes identified in Table A-4 that were run for the culture samples. Results from Probe Sets 2, 9, 10, and 11 indicate the presence of *Dehalococcoides ethanogenes* (Table A-4) in all of the culture transfer samples, as well as positive control over the PCR reactions (via the use of the universal Primer 7, Table A-4), and replication of results from the positive control BR culture sample being run along with the culture transfer samples. A negative response from Primer Set 3 indicates that the DHC species detected is likely 195. Primer Set 4 results confirms *Desulfuromonas michiganensis* in all samples and the original BR culture, and the functional vcrAB primer (Primer Set 14) provides verification of VC degradation capacity in both the original BR culture and all subsequent transfer samples. These PCR results are consistent with previous BR culture results (Table A-3) indicating a gradual shift in dechlorinator population away from organisms detected using Primer Set 3, but suggest that the desired TCE dechlorinators and functional VC degradation capacity are present in the samples to be provided for augmentation of the Ft. Lewis site.

Total cell count numbers for the BR culture samples being prepared for augmentation at the Ft. Lewis site are summarized in Table A-5. These data indicate total cell numbers using the Petroff Hausser Counting method of 1.8×10^8 to 4×10^8 cells/mL for all culture samples from the 1st through the 3rd generation of culture transfers, and meet the performance requirement as set forth in the Statement of Work.

Table A-3. PCR results for BR culture samples being prepared for use at the Ft. Lewis Bioremediation Field Site.

Sample Name	Date Sampled	Primer Set Number							
		2	3	4	7	9	10	11	14
NW Prep 1 (18 L)	7/14/05	Pos	Neg	Pos, weak	Pos	Pos	Pos	Neg	Pos, weak
NW Prep 2 (18 L)	7/14/05	Pos	Neg	Pos	Pos	Pos	Pos	Neg	Pos
GrStudy1 (5 L)	7/14/05	Pos	Neg	Pos	Pos	Pos	Pos	Neg	Pos
GrStudy2 (18 L)	7/14/05	Pos	Neg	Pos	Pos	Pos	Pos	Neg	Pos
BR Culture	7/14/05	Pos	Neg	Pos	Pos	Pos	Pos	Neg	Pos
BR Culture	3/28/05	Pos	Pos, weak	Pos, weak	Pos	Pos	Pos	Neg	Pos
BR Cluture	3/1/04	Neg	Pos	Pos	Pos	Pos	Pos	Pos	
BR Cluture	6/27/03	Neg	Pos	Pos	Pos	Pos	Pos	Pos	

NW Prep 1 = North Wind Prep 1 sample – 3rd generation transfer of original BR culture.

NW Prep 2 = North Wind Prep 2 sample – 3rd generation transfer of original BR culture.

GrStudy1 = 1st generation transfer of original BR culture.

GrStudy 2 = 2nd generation transfer of original BR culture.

Table A-4. Description of Primer Sets used in the PCR analysis summarized in Table A-3.

Primer Information						
#	Product Size (bp)	Organism Detected		Strain	Starting Compounds	End Products
2	104	Dehalococcoides	ethanogenes	195	PCE/TCE/DCE/VC, DCA	Ethene, Ethane
		Dehalococcoides	ethanogenes	BAV1	DCE/VC	Ethene
		Dehalococcoides	sp.	CBDB1	TetraCB/TCB	TCB/DCB
		Dehalococcoides	sp.	Uncultured		
3	137	Dehalococcoides	sp.	FL2	TCE/cis-DCE	VC
		Dehalococcoides	ethanogenes	CBDB1	TetraCB/TCB	TCB/DCB
		Dehalococcoides	ethanogenes	BAV1	DCE/VC	Ethene
		Dehalococcoides	ethanogenes	Uncultured		
4	254	Dehalococcoides	sp.	FL2	TCE/cis-DCE	VC
		Desulfuromonas	michiganensis	BB1	PCE/TCE	DCE
		Dehalospirillum	multivorans	("Universal")	PCE	cis-DCE
		Dehalococcoides	ethanogenes	195	PCE/TCE/DCE/VC, DCA	Ethene, Ethane
7	218	Dehalococcoides	ethanogenes	BAV1	DCE/VC	Ethene
		Dehalococcoides	ethanogenes	CBDB1	TetraCB/TCB	TCB/DCB
		Dehalococcoides	sp.	FL2	TCE/cis-DCE	VC
		Dehalococcoides	sp.	Uncultured		
9	1377	Dehalococcoides	ethanogenes	195	PCE/TCE/DCE/VC, DCA	Ethene, Ethane
		Dehalococcoides	ethanogenes	BAV1	DCE/VC	Ethene
		Dehalococcoides	sp.	CBDB1	TetraCB/TCB	TCB/DCB
		Dehalococcoides	sp.	FL2	TCE/cis-DCE	VC
10	307	Dehalococcoides	ethanogenes	195	PCE/TCE/DCE/VC, DCA	Ethene, Ethane
		Dehalococcoides	ethanogenes	BAV1	DCE/VC	Ethene
		Dehalococcoides	sp.	CBDB1	TetraCB/TCB	TCB/DCB
		Dehalococcoides	sp.	FL2	TCE/cis-DCE	VC
11*	1711	Dehalococcoides	ethanogenes	195	PCE/TCE/DCE/VC, DCA	Ethene, Ethane
		Dehalococcoides	sp.	FL2	TCE/cis-DCE	VC
		Bacterium RC-VC2				
		Bacterium PM-VC1				
14*	1400	Dehalococcoides	bacterium VS		VC	Ethene
* Functional genes detected with this probe						
Probe 11 - tceA gene in all organisms, tceB gene in all but Dehalococcoides ethanogenes, TCE dehalogenase genes						
Probe 14 - vcrAB gene in bacterium VS vinyl-chloride reductive dehalogenase operon, partial sequence						

Table A-5. BR culture sample Total Cell Count results using the Petroff Hausser Counting Method.

Sample Name	Date Sampled	Replicate Counts/5 E-08 mL								Total Cell Count (Cells/mL)		
		1	2	3	4	5	Mean	SD		Mean	Upper 95% CI	Lower 95% CI
NW Prep 1 (18 L)	7/14/05	20	18	16	14	13	16.2	2.9		3.2E+08	4.0E+08	2.5E+08
NW Prep 2 (18 L)	7/14/05	13	112	18	8	3	10.8	5.6		2.2E+08	3.6E+08	7.6E+07
GrStudy1 (5 L)	7/14/05	10	11	12	16	19	13.6	3.8		2.7E+08	3.7E+08	1.8E+08
GrStudy2 (18 L)	7/14/05	13	19	15	16	13	15.2	2.5		3.0E+08	3.7E+08	2.4E+08
Negative Control	7/14/05	0	2	0	0	3	1.0	1.4		2.0E+07	5.5E+07	-1.5E+07

Appendix B

Analytical Methods

Supporting the Sampling Plan

B-1. Determining Technology Performance

Appendix B contains details of the analytical methods employed in sampling and analysis to determine the results of application (i.e., performance) of the technology. This demonstration directly compares enhanced ISB under two different whey powder injection strategies. Technology performance will be monitored throughout the two Operational Phases identified as:

- **Phase 2 – Baseline.** ARD performance indicators were collected to evaluate electron donor concentrations, redox conditions, geochemistry, and contaminant concentrations in each treatment cell without electron donor addition.
- **Phase 3 – Biostimulation and enhanced mass transfer demonstration.** ARD performance indicators were monitored under biostimulation conditions during both low and high concentration whey powder injections.

The SAP for the demonstration outlines the monitoring of the contaminant concentrations in groundwater. Geochemical indicators of the reactions occurring in both treatment cells will be monitored and the depletion of oxygen, sulfate, and production of ferrous iron and methane that facilitates reductive dechlorination will also be quantified. The following table provides details to the analytical or monitoring methods used to determine each of these operational parameters.

Table B-1. Performance Parameter Analytical Methods.

Analytes	Sample Container	Preservative	Analytical Method	Holding Time	Analytical Lab
Phases 2 and 3					
Water Levels	In situ	-		-	Field measurement and calculation
Purge parameters, Temperature, pH, Specific Conductivity, ORP, DO	Collect during purging in flow-through cell	-	Direct Measurement Water Quality Probes	-	Field Parameter
Alkalinity	One 125-mL HDPE	Cool to 4°C	Hach Digital Titration 8203	24 hours	Field Test
VOCs (TCE, DCE isomers, and VC)	Aqueous - Three glass 40-mL VOA vials	No headspace, cool to 4°C	SW846 8260b	14 days	Severn Trent
Dissolved gases (ethene, ethane, methane,)	Aqueous - Three glass 40-mL VOA vials	HCl pH<2, cool to 4°C	RSKSOP-175	14 days	Severn Trent
COD	One 500-mL HDPE	H ₂ SO ₄ pH<2	5220D (Spectroscopy) or 410.1 (Titration)	28 days	Severn Trent
Volatile Fatty Acids	Two glass VOA bottles	Filtered with a 0,2 µm filter and cool to 4°C	Ion chromatography – EPA 300.0	28 days	Utah State University
Anions sulfate, nitrate, chloride,	Glass or Plastic	Cool to 4°C	Ion chromatography – EPA 300.0	28 days	Utah State University
Ferrous Iron	One 125-mL HDPE	Analyze immediately	Colormetric Hach 8008	4 hours	Field Measurement
- = not applicable COD = Chemical Oxygen Demand GC/FID = gas chromatography/flame ionization detection HDPE = high-density polyethylene ORP = Oxidation Reduction Potential Severn Trent SOP = Standard Operating Procedure VOA = volatile-organic analysis					

Appendix C
Quality Assurance Project Plan

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Appendix 1	Standard Operating Procedures
Appendix 2	Laboratory Reporting Limits
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List of Abbreviations and Acronyms

ASTM	American Society for Testing and Materials
bgs	below ground surface
CGI	combustible gas indicator
cm	centimeter
CPT	cone penetrometer testing
CSM	conceptual site model
DCE	dichloroethene
DNAPL	dense nonaqueous-phase liquid
DQO	data quality objectives
DSITMS	direct sampling ion trap mass spectrometer
EGDY	East Gate Disposal Yard
EPA	United States Environmental Protection Agency
FLUTe	Flexible Liner Underground Technologies
FSP	Field Sampling Plan
GPR	ground-penetrating radar
GPS	Global Positioning System
LCSs	laboratory control samples
LIF	laser-induced fluorescence
LIMS	Laboratory Information Management System
LNAPL	light nonaqueous-phase liquid
MDLs	method detection limits
µg/L	microgram per liter
µmol/L	micromol per liter
mg/kg	milligrams per kilogram
MIP	membrane interface probe
mL/min	milliliter per minute
mm	millimeter
SQLs	method quantitation limits
MRLs	method reporting limits
MS/MSD	matrix spike/matrix spike duplicate
NAPL	nonaqueous-phase liquid
NWTPH-Dx	Northwest Total Petroleum Hydrocarbons–Diesel Extended
ORP	oxidation-reduction potential
PAHs	polycyclic aromatic hydrocarbons
PCE	tetrachloroethene
PE	performance evaluation
PID	photoionization detector
POL	petroleum, oil, and lubricant
ppm	parts per million
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
RPD	relative percent difference
SAP	Sampling and Analysis Plan
SCAPS	Site Characterization and Analysis Penetrometer System

List of Abbreviations and Acronyms

SOP	standard operating procedures
SVOCs	semivolatile organic compounds
TCE	trichloroethene
TPH	total petroleum hydrocarbon
USACE	United States Army Corps of Engineers
VOCs	volatile organic compounds

This Quality Assurance Project Plan (QAPP), in conjunction with the Field Sampling Plan (FSP), composes the Sampling and Analysis Plan (SAP), which is an integral part of the Management Plan for the East Gate Disposal Yard (EGDY) Phase II Remedial Investigation (RI) field exploration. The purpose of the SAP is to ensure production of high-quality data that meet project objectives and requirements and accurately characterize measurement parameters. The SAP provides protocols for collecting samples, measuring and controlling data, and documenting field and laboratory methods so that the data are technically and legally defensible. The SAP was prepared in accordance with guidelines set forth by the U.S. Army Corps of Engineers (USACE) requirements (USACE 2001 and 1998).

The SAP has two major components: Part I - the Field Sampling Plan (FSP) and Part II - the Quality Assurance Project Plan (QAPP). The FSP presents the detailed scope of work associated with field activities (e.g., sampling types, sampling locations) and specifies the procedures to be used for sampling and other field operations. The QAPP describes the analytical data quality objectives, field and laboratory analytical procedures, quality assurance/quality control (QA/QC) procedures, and data quality evaluation criteria.

Sampling and analysis procedures for the field exploration are designed to satisfy the data quality objectives (DQOs) identified in Section 6 of the Work Plan. This plan presents the analytical methods and associated QA/QC procedures selected to meet the DQOs.

The primary objective of this field exploration is to collect data required to better define the extent of trichloroethene (TCE) and nonaqueous-phase liquid (NAPL) contamination, which will be evaluated and integrated into the EGDY conceptual site model (CSM).

A dynamic investigation approach with a toolbox of sampling and analytical options has been developed for this investigation. Each investigation approach is based on the need to locate and characterize very high levels of contamination and to aid in the design of a method for successfully removing NAPL from the subsurface. The overall project DQOs are as follows:

- DQO 1 – Obtain data required for design of a thermal remedial action for NAPL source area treatment
- DQO 2 – Obtain data required to complete an evaluation of options for optimization of the existing pump and treat system
- DQO 3 – Obtain data required to complete an evaluation of reactive barrier wall placement options
- DQO 4 – Provide analytical results that can be used to segregate and classify investigation-derived waste as solid, hazardous, or dangerous waste according to Resource Conservation and Recovery Act (RCRA) and Washington state Dangerous Waste Regulations
- DQO 5 – Ensure that the turnaround time for the field-generated data supports the real-time decision making needs of the dynamic work plan

1.0 CHEMICALS OF CONCERN

EGDY is the source for widespread TCE contamination at the Fort Lewis Logistics Center. The source of two TCE-contaminated groundwater plumes is believed to be liquid waste containing mixtures of petroleum hydrocarbons and solvents. Previous activities at the site indicate that three distinct product types have been observed at the site:

- Product Type A – Heavy, viscous, dark brown waste oil with TCE
- Product Type B – Light, iridescent oil
- Product Type C – Pure TCE

Chemical and physical testing of these observed product types, plus any additional product types observed during this investigation, will be performed to identify specific chemicals of potential concern associated with these products (e.g., polycyclic aromatic hydrocarbons [PAHs], vinyl chloride, noncarcinogenic total petroleum hydrocarbons [TPH] fractions).

2.0 DATA COLLECTION APPROACH

A dynamic sampling and analysis process was developed to generate data to meet project objectives. A logical chain of reasoning will be followed so that the data gathered support the conclusions made by the technical staff. This investigation allows for changes in the number of locations/samples as the investigation progresses. Results from the early stages will be evaluated

and incorporated in refining the CSM prior to additional data collection. A more detailed description of the sampling rationale and project DQOs can be found in Section 6.2 of the Work Plan.

Site information will be gathered and data gaps filled by using a toolbox of sampling and analytical options:

- Geophysics – ground-penetrating radar (GPR) and/or electrical resistivity imaging
- Drilling – sonic drilling techniques and monitoring well installation
- On-site physical and chemical measurements – Site Characterization and Analysis Penetrometer System (SCAPS), cone penetrometer testing (CPT), GeoVIS soil video imaging, laser-induced fluorescence (LIF), membrane interface probe (MIP) with direct sampling ion trap mass spectrometer (DSITMS), Flexible Liner Underground Technologies (FLUTE) ribbon samplers
- Groundwater elevation measurements
- Soil, groundwater, and NAPL sampling
- Off-site analytical laboratory analysis – soil, groundwater, and/or NAPL chemical and physical testing
- Field monitoring – air, groundwater, and NAPL measurements
- Surveying – Global Positioning System (GPS) and traditional survey

All measurements will be made according to standard operating procedures (SOPs) documented in the SAP. Field sampling SOPs are included in Appendix A to the FSP. Laboratory analysis SOPs are included in Appendix 1 to this QAPP. This section describes the approach toward data generation in the field and off site, and describes sources of uncertainty and how uncertainty will be managed. The quality control program associated with this approach and documented in this QAPP has been developed to address these uncertainties.

3.0.0 Geophysics

GPR is used to characterize with high definition the surface topography of the intermediate aquitard (30 to 40 feet below ground surface [bgs]) and other less continuous shallow aquitards. Electrical resistivity imaging (including induced polarization) is used to characterize the definition of deeper stratigraphic units. These methods would allow the technical team to indirectly determine the aquitard thickness, composition, continuity, lateral extent, and physical/hydrogeologic properties. These methods provide highly defined data about the aquitard characteristics, they are non-invasive, and the results are immediate. This would allow the technical team the ability to change the sampling scope and add information to the CSM.

If these geophysical tools will be used in the RI, a separate management plan will be developed specifically for the geophysical investigation.

4.0.0 Field Measurements

Chemical field measurement results will be used to assess site conditions for worker health and safety (e.g., volatile organic compounds [VOCs]), measure the stability of groundwater conditions prior to sample collection, determine the extent of NAPL in soil (e.g., SCAPS LIF, FLUTe and GeoVIS), determine the extent of TCE in groundwater (e.g., SCAPS MIP/DSITMS), and determine geologic/hydrogeologic properties of soil (e.g., SCAPS CPT).

Methods and equipment have been selected to give rapid assessments of site conditions and therefore have a higher degree of uncertainty than more rigorous methods. The inherent uncertainty of these methods is acceptable for this project because the rapid assessment allows for immediate assessment of site conditions and a greater number of measurements (e.g., SCAPS CPT, LIF, and MIP). The SCAPS MIP/DSITMS instrument reporting limits (100 to 200 micrograms per liter [$\mu\text{g/L}$] for TCE) are higher than the risk-based screening level of 5 $\mu\text{g/L}$. Reporting limits (sensitivity) are limited by the MIP delivery system and the dissolved phase concentration indicative of NAPL. The estimated reporting limit for the DSITMS is 2 $\mu\text{g/L}$, which is lower than the risk-based screening level of 5 $\mu\text{g/L}$. This uncertainty in concentration is acceptable for this project because it allows the identification of presence or absence of VOCs at the site. A greater number of measurements allows for more representative sampling throughout the site and can compensate for the inherent variability in the measurement methods and contaminant distribution heterogeneity. Field measurements will be evaluated immediately in the field by the technical team who will make decisions on subsequent sampling locations, measurements tools, and site conditions.

5.0.0 SCAPS Laboratory

The SCAPS laboratory will analyze water samples collected from new sonic-installed multichamber wells, SCAPS Power Punch™ microwells, and surface water for VOCs using direct sampling with DSITMS. These lower reporting limits and rapid assessment for VOCs will allow a greater number of measurements, more representative sampling throughout the site, and definition of the extent of the groundwater plume. Results for VOCs will be evaluated immediately in the field by the technical team who will make decisions on subsequent sampling locations to ensure that the extent of the TCE groundwater plume is adequately evaluated.

6.0.0 Off-site Fixed Laboratories

Two off-site fixed laboratories will analyze soil, groundwater, and NAPL samples for physical and/or chemical characteristics. Project laboratories and analytes are listed in Table 2-1. Rapid turnaround analysis will be required only for soil and groundwater samples. Results will be evaluated as soon as they become available by the technical team who will make decisions on subsequent sampling locations to ensure that the extent of different fuel types present at the site is identified. Preliminary soil results will be reported on a wet weight basis. This uncertainty is acceptable because results will be evaluated qualitatively to define the extent of different fuel types present at the site. Dry weight results will be reported with final data packages. All other fixed laboratory analyses will be performed with routine turnaround times because results are not

needed immediately to define the extent of contamination. Methods and laboratories were selected that could provide data to support design needs of the thermal treatment systems. Associated quality controls are sufficient to support decisions based on these results.

Fixed laboratory analytical results will be used to confirm field measurements and define the nature and extent of contamination across the site. Fixed laboratory results for analyses using the Northwest Total Petroleum Hydrocarbons–Diesel Extended (NWTPH–Dx) method will also be used identify different petroleum products. Chromatograms generated for site samples will be compared to chromatograms generated by the project laboratory for numerous known fuel types (fuels chromatogram library) and probable fuel types identified.

7.0.0 Surveying

The horizontal coordinates for all SCAPS sampling locations will be determined by either referencing a aerial photograph or base map or through the use of a Trimble global positioning system (GPS). The GPS will not be mounted on the SCAPS rig. When aerial photographs or base maps of the work site are available with a coordinate grid overlay and sufficient ground reference points are present, the sampling locations may be measured with reference to the ground points with those measurements transferred to the photograph or map. The grid overlay will then be used to calculate the coordinates of the sampling location.

A differential GPS may be employed to obtain horizontal coordinates. Data collection will be performed when a position dilution of precision (PDOP) of less than 5.0 is measured. A minimum of 40 measurements at each sampling location will be collected to determine the horizontal coordinates.

Vertical coordinates will be determined using either an existing topographic map or a precision optical level.

8.0 ANALYTICAL METHODS

Analytical methods were selected to provide data to support project objectives. Analytical methods to be performed for the field exploration are described in Section 5. Laboratories performing these methods are listed in Table 2-1. Laboratory SOPs are included as Appendix 1.

9.0 ANALYTICAL METHOD DETECTION LIMITS, QUANTITATION LIMITS, AND REPORTING LIMITS

Sensitivity requirements for all methods and matrices are driven by the DQOs. Specific requirements by method and matrix are presented in Table 2-2, followed by the definitions for method detection limits (MDLs) method, quantitation limits (MQLs), and method reporting limits (MRLs).

10.0.0 Method Detection Limit

The MDL is the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero, and is determined from analysis of a sample in a given matrix containing the analyte (Appendix B of 40 CFR 136).

11.0.0 Method Quantitation Limit

The MQL represents the value for which the laboratory has demonstrated the ability to reliably quantitate target analytes within a prescribed performance criteria for the method performed. Operationally, it is equivalent to the concentration of the lowest calibration standard in the initial calibration curve.

12.0.0 Method Reporting Limit

The MRL is a threshold value below which the laboratory reports a result of nondetected. It may be based on project-specific concentrations of concern, regulatory action levels, or sensitivity capability of method and instrument. The MRLs are adjusted based on the sample matrix and any necessary sample dilutions. Operationally, it is equivalent to the MQL adjusted based on the sample matrix and any necessary dilutions. Routine laboratory MRLs for all target analytes are listed in Appendix 2.

Table 2-1
PROJECT LABORATORIES

LABORATORY	ANALYTE	MATRIX	ADDRESS AND CONTACT
SCAPS Team	VOCs ^a	Water	1645 S. 101st E. Ave. Tulsa, OK 74128 Contacts: Eddie Mattioda Chris Kennedy Phone: (918) 669-7445
	Stratigraphy TPH NAPL extent	Soil	
Sound Analytical Services, Inc.	VOCs	Water	5755 8 th Street East Tacoma, WA 98424 Contact: Dawn Werner Phone: (253) 922-2310 Fax: (253) 922-5047
	VOCs SVOCs TPH-Dx	Soil/product	
PTS Laboratories, Inc.	Grain size Permeability Density Porosity Cation exchange capacity Total organic carbon	Soil	8100 Secura Way Santa Fe Springs, CA 90670 Contact: Richard Young Phone: (562)907-3607 Fax: (562) 907-3610
	Oil/water interfacial tension Density/viscosity Boiling point distribution	Product	

Notes:

^a Target analyte list includes trichloroethene, cis-1,2-dichloroethene, vinyl chloride, and tetrachloroethene

Table 2-2
SENSITIVITY REQUIREMENTS

ANALYTE	MATRIX	SENSITIVITY DRIVER
TPH by LIF (SCAPS)	Soil	Technology limitations and site-specific factors. Threshold values (reporting limits) will be determined in the field.
TPH-Dx by GC/FID (fixed laboratory)	Soil	Less than LIF threshold value
TPH-Dx by GC/FID (fixed laboratory)	NAPL	Concentration determined by dilution
SVOCs (fixed laboratory)	Soil	Engineering design requirements
SVOCs (fixed laboratory)	NAPL	Concentration determined by dilution
VOCs by MIP/DSITMS and direct ITMS	Groundwater, surface water	MCLs
VOCs (fixed laboratory)	Soil	Engineering design requirements
VOCs (fixed laboratory)	Groundwater	MCLs
VOCs (fixed laboratory)	NAPL	Concentration determined by dilution
NAPL w/ FLUTe ribbon sampler	Soil	Technology limitations. Presence or absence of NAPL will be determined in the field.
NAPL w/ GeoVIS	Soil	Technology limitations. Presence or absence of NAPL will be determined in the field.
Other analyses	Soil, groundwater, NAPL	Engineering design requirements

Notes:

GC/FID gas chromatograph/flare ionization detector

MCLs maximum contaminant levels

TPH-DX total petroleum hydrocarbons – diesel extended

This section describes field measurement procedures, sample handling, and coordination procedures between the sampling team and analytical laboratories. Detailed sampling procedures are discussed in the FSP.

13.0 FIELD MEASUREMENT METHODS

Measurements to be collected during field activities include air screening for VOCs, soil stratigraphy, NAPL screening, and groundwater quality parameters.

14.0.0 Air Monitoring for Health and Safety

Air monitoring using a photoionization detector (PID) and a combustible gas indicator (CGI) will be used to evaluate health and safety conditions during drilling and other field activities when warranted. All meters used will be calibrated daily according to manufacturers' instructions. Specific monitoring requirements are discussed in the Site Safety and Health Plan.

15.0.0 Groundwater Field Measurements

Groundwater will be monitored during sampling for specific conductance, pH, temperature, oxidation-reduction potential (ORP), dissolved oxygen, and turbidity using a water quality meter with flow-through chamber. The instrument will be used and calibrated daily according to the manufacturer's instructions.

16.0.0 SCAPS CPT, LIF, MIP/DSITMS, GeoVIS, and FLUTe Ribbon Samplers

The SCAPS will be equipped with a CPT that measures tip penetration and sleeve friction that can be used to provide simultaneous and continuous geotechnical and stratigraphic information. Additionally, the SCAPS will be equipped with an LIF sensor that can be used to define the horizontal and vertical extent of the petroleum hydrocarbon plume. The MIP with DSITMS can be used to define the horizontal and vertical extent of the TCE plume in groundwater. The MIP can be used to collect direct, in situ VOC measurements. Also, the SCAPS rig can be used to collect groundwater samples (using a PowerPunch™ sampler) that can be analyzed in the SCAPS laboratory using DSITMS. Surface water samples also can be analyzed using DSITMS. The SCAPS rig will also be equipped with a GeoVIS system and FLUTe ribbon samplers. The GeoVIS system collects images gathered by a video camera focused out of a port on the side of a standard push probe. The images can be used to determine the extent of NAPL in the subsurface. The FLUTe ribbon sampler is an everting, air-driven liner with absorbent materials that will change color when in contact with NAPL. After the ribbon has been extracted from a push location, NAPL intervals can be mapped by the technical team. At the end of each penetration by the SCAPS, sensor data will be plotted as a function of depth and archived. Brief descriptions of each of these sensors are included below. The SOPs for the SCAPS LIF, MIP/DSITMS, FLUTe ribbon samplers, GeoVIS, and the groundwater sampling equipment are included in Appendix 1. Confirmation soil and water samples will be collected and analyzed at an off-site laboratory (see Section 4.1.5).

17.0.0.0 *Soil Classification Using Geotechnical Sensors*

The SCAPS geotechnical sensors will be used to provide simultaneous and continuous geotechnical and stratigraphic information. The SCAPS probe will be operated to collect subsurface stratigraphy data in accordance with procedures described in American Society for Testing and Materials (ASTM) Method D3441.

18.0.0.0 *Hydrocarbon Presence Using LIF*

The LIF sensor can detect the presence of hydrocarbons in the bulk soil matrix throughout the vadose zone, capillary fringe, and saturated zones. The SCAPS will be used to collect a continuous record of possible contaminant locations and more complete delineation of the area of contamination. The SCAPS LIF system is capable of providing information on contaminant distribution of POL compounds. Since the SCAPS fluorescence intensity is generally proportional to in situ concentration, SCAPS LIF data can be used to effectively delineate not only the presence, but also the relative concentration, of contaminants. This proportional feature of the SCAPS LIF data can be used to pinpoint the zones of highest contaminant concentration and screen the variation in concentration across the site. Additionally, LIF wavelengths profiles provide information on contaminant types. These results will be evaluated along with NWTPH–Dx chromatograms to determine fuel product types.

The SCAPS LIF uses a nitrogen laser as the ultraviolet excitation source. The N₂ laser has a wavelength of 337 nanometers and pulses at a rate of 10 times per second. This wavelength will excite aromatic compounds with three or more rings as well as some two-ring compounds. Fluorescence intensity is generally proportional to in situ hydrocarbon concentration. The SCAPS LIF sensor provides spatial resolution of 4 centimeters (cm) when driven at 1 meter/minute.

The SCAPS LIF sensor response is checked using an aqueous solution of Rhodamine 6G (10 micromols per liter [μmol/L]) before and after each penetration event to monitor LIF system response and document any system drift.

The linear range for the LIF is approximately 100 milligrams per kilogram (mg/kg) to 50,000 mg/kg measured as TPH. The site-specific fluorescence threshold will be determined by comparing SCAPS POL sensor LIF response to soil analyses for TPH–Dx and PAH. The fluorescence threshold is the quantitative limit that the fluorescence intensity must exceed in order to qualify as a detection.

Non-linearity of LIF response tends to occur at concentrations greater than 10,000 mg/kg. Sample intervals with LIF fluorescence response above this level will be targeted for off-site TPH–Dx and PAH analyses of soil samples. In sandy soils, the non-linearity occurs at lower concentrations than in clay-rich soils, possibly due to self-adsorption or saturation.

Verification soil samples will be collected at depths of interest, including areas of strong, medium, low, and no fluorescence response, and analyzed for TPH–Dx at the off-site laboratory as well as aboveground with the SCAPS/LIF. Aboveground LIF measurements will be made to assess comparability of in situ LIF and off-site TPH–Dx results. LIF and TPH–Dx results should be in agreement on detect and nondetect for a minimum of 80 percent of the samples, with a false negative rate of less than 5 percent. In addition, verification soil samples will be collected

from areas of different soil types and fluorescence emission spectra. Soil verification samples will be collected concurrently with the LIF field effort, and will be used to assist with interpretation of the three-dimensional map of fluorescence response.

The LIF is subject to interference that can make data reduction complicated, and limit the real-time nature of data analyses and decisionmaking. Moisture in soil and fluorescing compounds or minerals (e.g., carbonates) may affect the LIF readings and influence performance statistics. The LIF sensitivity to POL generally increases with greater soil moisture content. LIF sensitivity generally increases with increased grain size.

The potential presence of fluorescence emission from nontarget (nonhydrocarbon) analytes within the soil matrix must also be considered when assessing LIF data. Because the LIF sensor collects full spectral information it is almost always possible to discriminate between hydrocarbon and non-hydrocarbon fluorescence by analyzing the spectral features associated with the data. The SCAPS LIF sensor system uses a multichannel detection scheme to capture a complete fluorescence emission spectrum at each point along the push. Suspected nontarget fluorescence emission based on spectral response will be investigated by obtaining a soil sample at the appropriate depth and analyzing this sample for TPH-Dx. The LIF response will be considered nontarget fluorescence if the TPH-Dx indicates a nondetect. Once the nontarget fluorescence has been confirmed using TPH-Dx, the emission spectra will be used to differentiate nontarget fluorescence in subsequent penetrations.

19.0.0.0 *Volatile Contaminant Presence using MIP/DSITMS*

The MIP sensor can detect the presence of VOCs in the bulk soil matrix throughout the vadose zone, capillary fringe, and saturated zones. However, there appears to be a matrix-moisture content effect for vadose soils. The SCAPS will be used to collect a continuous record of possible contaminant locations and more complete delineation of the area of contamination. The SCAPS MIP/DSITMS system is capable of providing information on contaminant distribution of VOCs. The target analytes for DSITMS analysis are TCE, dichloroethene (DCE), tetrachloroethene (PCE), and vinyl chloride. The MIP/DSITMS is composed of the MIP, a metal/teflon composite membrane that samples VOCs in situ and the DSITMS that identifies and quantifies the VOCs. Since the MIP/DSITMS is capable of multiple, discreet VOC measurements in a single penetration, the MIP/DSITMS data can be used to effectively delineate not only the presence of VOCs, but also the concentration of the compounds. This feature of the SCAPS MIP/DSITMS data can be used to pinpoint the zones of highest contaminant concentration and screen the variation in concentration across the site.

The MIP is a permeable membrane device used to detect volatile contaminants as it is driven to depth in soil or other unconsolidated materials. A thin film membrane is impregnated into a stainless steel screen on the face of the probe. This membrane is heated to 100 to 120 degrees Celsius leading to quick diffusion of VOC contaminants across the membrane into the helium carrier gas, which flushes the back of the membrane and transports the contaminants to the aboveground DSITMS. The DSITMS is composed of a quadrupole ion-trap mass spectrometer, a capillary interface, and a variety of sample inlets for use with gas (air and soil gas), soil, and water. The capillary interface limits flow into the DSITMS to 0.1 to 1.0 milliliter per minute (mL/min), which is compatible with both electron impact and chemical ionization sources. Direct injection of groundwater and surface water samples into the DSITMS is also possible.

The MIP/DSITMS is calibrated daily. Once calibration is achieved, calibration standards are analyzed twice a day during the direct sampling method, and once after each penetration is completed. A blank sample is analyzed for background subtraction to ensure there is no carryover in the transfer line, any time samples having greater than 500 parts per million (ppm) of VOC contamination are analyzed, and between analyses of samples from different sources. During the MIP/DSITMS, a system blank will be performed before and after each set of in situ measurements. Sample results with concentrations greater than the highest calibration standard will be verified by analyzing additional standards with concentrations at or above the sample concentration.

The linear range of the MIP/DSITMS is 500 ppm. Soil with TCE concentrations greater than 500 ppm can saturate the MIP, which would cause the system to be inoperable while it is being flushed out.

Validation data indicated that the system provides quantitative estimates of subsurface contamination distribution; however, there appears to be a matrix moisture-content effect for vadose soils. The MIP/DSITMS will be used as a high-level field screening technique to rapidly delineate the distribution of VOC contamination in groundwater. Verification samples will be collected to include a range of contaminant concentrations and will be analyzed by the analytical laboratory by U.S. Environmental Protection Agency (EPA) SW-846 Method 8260B (USEPA 1994a).

20.0.0.0 *NAPL Extent Using GeoVIS*

The GeoVIS soil video imaging system is integrated into a CPT probe. Soil in contact with the side of the probe is imaged through a sapphire window and lens system with a miniature color video camera as the probe is pushed into the ground. The soil is illuminated with an array of white light-emitting diodes located in the probe. The video signal from the camera is returned to the surface where it is displayed in real-time on a video monitor, recorded on a video cassette recorder, and/or captured digitally with a frame grabber installed in a microcomputer system. In its current configuration, the system images an area that is 2 millimeters (mm) by 2.5 mm, which provides a magnification factor of approximately 100x when viewed on a standard 13-inch monitor.

21.0.0.0 *NAPL Extent Using FLUTe Ribbon Sampler*

The FLUTe system consists of an impermeable flexible liner and an exterior covering on the liner that reacts with NAPL to form a bright red dye stain on a white background. The liner/cover system can be emplaced via several push rod methods. The pressurized liner forces the reactive cover tightly against the hole wall. The reactive cover is recovered from the hole by inverting/peeling the liner from the hole. In this manner, the cover does not touch the hole wall anywhere else as it is removed. The cover can then be examined for the presence and extent of layers, and even globules, of NAPL in the subsurface. This technique of installation and removal of the reactive covering through the interior of push rods provides a relatively inexpensive method for mapping of light nonaqueous-phase liquid (LNAPL) and dense nonaqueous-phase liquid (DNAPL) in the source region.

The liner installation method can be applied to the many driven casing “drilling” methods. The same method is employed, regardless of the casing diameter, to allow the casing to be withdrawn without excessive drag of the liner on the casing. The rods are pushed to the full depth of interest. The liner with its reactive covering is inserted into the interior hole in the rods to the full depth. The rods are then filled with air. The rods are raised one rod section at a time to expose the hole wall. The liner is pressurized with a charge of air to hold the hole open and to anchor the liner in the hole. More air is added to the interior of the liner as the rods are pulled. Once the rods are fully removed, the hole is supported and sealed by the air-filled liner. The covering is pressed against the hole wall for approximately 1 hour and then the liner is inverted (peeled inside out) from the hole. The covering is therefore interior to the inverted liner. The covering is then peeled from the interior of the liner to reveal the stained map of the distribution of NAPL in the subsurface.

22.0 FIELD MEASUREMENT INSTRUMENT CALIBRATION PROCEDURES

The calibration and general maintenance of field instruments will be the responsibility of the URS Field Investigation Manager or the SCAPS leader. Field instruments requiring calibration include:

- PID
- Groundwater quality meter
- CGI
- SCAPS CPT and LIF
- MIP/DSITMS

All calibration procedures and measurements will be performed in accordance with manufacturers’ specifications and standard operating procedures. Field instruments will be checked and calibrated prior to their use on site, and batteries will be charged and checked daily where applicable. Instrument calibrations will be performed at the beginning of each work day and checked and recalibrated if necessary through the course of the day according to manufacturers’ specifications or if deemed necessary by sampling personnel. Special attention will be given to instruments that may drift with change in ambient temperature.

Equipment that fails calibration and/or becomes otherwise inoperable during the field investigation will be removed from service and segregated to prevent inadvertent use. Such equipment will be properly tagged to indicate that it should not be used until repaired. Equipment that cannot be repaired or recalibrated will be replaced.

All documentation pertinent to the calibration and/or maintenance of field equipment will be maintained in an active field logbook. Logbook entries regarding the status of field equipment will contain, at a minimum the following information:

- Date and time of calibration
- Name of person conducting calibration
- Type and identification of equipment being serviced (make, model and serial number)
- Reference standard used for calibration (such as pH of buffer solutions)

- Calibration and/or maintenance procedure used
- Other pertinent information

23.0 SAMPLE HANDLING, CONTAINERS, PRESERVATION, AND HOLDING TIMES

Sample containers, preservation, and holding times are summarized by matrix in the FSP (in Tables 4-6 to 4-10). Soil and water samples will be collected in glass or plastic containers purchased for the project. NAPL samples will be collected in glass containers. The containers will have screw-type lids to assure adequate sealing of the bottles. Lids of the containers will have Teflon inserts to prevent sample reaction with the lid and to improve the quality of the seal.

Commercially available pre-cleaned jars will be used and the USACE will maintain a record of certification from the supplier. The bottle shipment documentation will record batch numbers for the bottles. With this documentation, bottles can be traced to the supplier and bottle wash analysis results can be reviewed. The bottle wash documentation will be archived by the supplier for a period of 5 years.

Sample preservation will be performed in the field. Sample preservation procedures are used to maintain the character of analytes as sampled (i.e., representative concentrations and/or speciation in situ) during storage and shipment. Regardless of the nature of the sample, absolute stability for all constituents cannot be achieved. Preservation techniques, such as pH control and refrigeration, may retard physiochemical and biochemical changes. As a general rule, analyzing the sample as soon as possible is the best way to minimize physicochemical and biochemical changes.

All samples will be placed in the appropriate sample container and refrigerated (on ice in a cooler or in a refrigerator in the field office) immediately upon sample collection. The samples will be transferred to the mobile field laboratory and contract laboratories as soon as possible and using chain of custody procedures as described in the FSP. Upon receipt at the contract laboratories, a cooler receipt form will be filled out to document sample condition. The laboratories will meet all specified holding times and should make every effort to prepare and analyze the samples immediately after they are received.

24.0 COORDINATION WITH ANALYTICAL LABORATORIES

Team members will work closely with the laboratories (mobile and fixed) to ensure that samples are handled and analyzed following procedures described in this QAPP. A schedule of field work and sampling will be established approximately 2 weeks prior to commencement of field work. Each day that samples are hand delivered or shipped to the laboratories, a designated team member will notify the laboratories to confirm that samples have been sent.

The laboratories will contact the URS Project Manager or Project Chemist as soon as possible and no later than 24 hours after it is suspected that re-analysis of a sample by the laboratory is unable to determine a result due to matrix interference.

Field QC and laboratory QC samples will be employed to evaluate data quality. Quality control samples are controlled samples introduced into the analysis stream whose results are used to review data quality and to calculate the accuracy and precision of the chemical analysis program. The purpose of each type of QC sample, collection and analysis frequency, and evaluation criteria are described in this section. Collection and analysis frequency are summarized in Tables 4-1 through 4-4. Laboratory control limits are listed in Appendix 3.

QC procedures for both the mobile field laboratory and the fixed laboratories' analyses will be consistent with the requirements described in the laboratories' protocols and methods. These requirements are defined in SOPs as part of the laboratory's QA program plan. Methods for establishing the quality of laboratory measurements and sample results will generally conform with EPA Contract Laboratory Program scope of work or EPA SW-846 (USEPA 1994a) QC requirements and quality criteria (when applicable). All QC measurements and data assessment for this project will be conducted on samples from and within batches of samples from this project alone; in other words, no "other project" samples will be used with samples from this project for assessment of data quality.

25.0 FIELD QUALITY CONTROL SAMPLES

Field QC checks are accomplished through the analysis of controlled samples that are introduced to the laboratory from the field. Rinsate and field blanks, field duplicates, matrix spike/matrix spike duplicate (MS/MSD), and performance evaluation (PE) samples will be collected and submitted to the mobile field laboratory and/or the fixed laboratories, where applicable, to provide a means of assessing the quality of data resulting from the field sampling program. Field QC samples will be selected by the sampling team and designated on the chain of custody form as appropriate.

26.0.0 Rinsate and Field Blanks

Rinsate blanks are collected to determine the potential for cross-contamination of samples during collection. Rinsate blanks will be collected and analyzed at the rate of 5 percent if utilizing non-dedicated sampling equipment. If dedicated or disposable sampling equipment is utilized, field blanks will be collected instead. Rinsate blanks will consist of store-bought distilled water collected from the final rinse of sampling equipment after the decontamination procedures described in Section 3.9 of the FSP. Blank sample collection methods and frequency are described in the FSP. Field blanks will consist of store-bought distilled water transferred directly into sample containers in the field.

All rinsate or field blanks will be submitted blind to the laboratory, with sample numbers that are indistinguishable from primary samples. Quality control criteria and corrective actions are the same as for method blanks (Section 4.2.2). Blank samples will be analyzed for the same parameters as the associated field samples.

27.0.0 Field Duplicates

Field duplicate samples will be used to check for sampling reproducibility. Field duplicates will be collected from locations with suspected high contamination levels. Field duplicates will be

submitted at a frequency of 10 percent of the field samples for every analytical method. Field duplicate samples will be submitted from locations having significant concentrations of target analytes as determined by results of field screening. Control limits for field duplicate precision are 30 percent relative percent difference (RPD) for aqueous samples and 50 percent RPD for soil and NAPL samples.

Field duplicates will be submitted blind to the laboratories, with sample numbers that are indistinguishable from primary samples. Quality control criteria for field duplicates and calculation and reporting of the RPD are described in Section 7.1.

28.0.0 Matrix Spike/Matrix Spike Duplicates

MS/MSDs are used to assess sample matrix interferences and analytical errors, as well as to measure the accuracy and precision of the analysis. The MS/MSDs will be collected and analyzed at a rate of 5 percent of the field samples for each off-site chemical laboratory and SCAPS laboratory analytical method or at least one for each analytical batch, whichever frequency is greater. Known concentrations of analytes are added to environmental samples; the MS or MSD is then processed through the entire analytical procedure and the recovery of the analytes calculated. Results are expressed as percent recovery of the known spiked amount (and RPD for MS/MSD pairs).

Because MS/MSD samples measure the matrix interference of a specific matrix, only MS/MSD samples from this investigation will be analyzed, and not samples from other projects. The MS/MSD samples will be analyzed for the same parameters as the associated field samples in the same QC analytical batch.

Additionally, MS/MSD samples should not be collected from locations with potentially high concentrations of target analytes that may mask the added MS/MSD compounds. Because of the high concentrations of target analytes, MS/MSD samples will not be submitted with NAPL samples.

29.0.0 Performance Evaluation Samples

Ten water PE samples will be submitted to the SCAPS laboratory and Sound Analytical Services, Inc., to evaluate the accuracy of the VOC analyses. PE samples will be submitted blind for chemical analysis. The PE samples will be spiked by the commercial supplier with the site chemicals of concern at concentrations consistent with those previously observed in groundwater at the site. One PE sample will be analyzed the first day of laboratory analysis. The PE sample results will be immediately compared to the vendor's documented acceptable control limits by URS. Sample analysis will not continue until the laboratory has met certified PE sample acceptance limits and approval has been obtained from USACE. Assuming criteria have been met, a second sample of that matrix will be analyzed at random the same week, with the remaining PE samples submitted blind to the laboratory at regular intervals through the remaining analysis schedule.

The PE material will be from commercial sources. The PE supplier will fill pre-cleaned sample bottles with the PE material. Fictitious sample identification numbers will be assigned in the field as described in Section 5.2 of the FSP.

30.0.0 Confirmation Analyses

Verification soil and/or water samples will be collected at selected depths. Visual evaluation of selected soil samples for NAPL contamination will be compared against LIF data. Sample intervals representative of different soil types, different emission spectra, and different emission intensity will be selected based on SCAPS LIF and geotechnical sensor measurements. The SCAPS will be used to obtain verification soil and/or water samples from some of these locations for off-site laboratory analyses of total petroleum Hydrocarbons–Diesel extended (TPH–Dx), VOCs, and semivolatile organic compounds (SVOCs) to control and assist with understanding uncertainty, bias, and interference associated with DSITMS, MIP/DSITMS, and LIF analyses. A specific percentage of samples will not be selected; rather these samples will be selected in the field by the technical team to assist in data interpretation. All analyses will be conducted within a 48-hour turnaround time. Soil data will be used for on-site validation and calibration of the fluorescence response obtained by the SCAPS LIF sensor. This data will assist with determining the relationship between LIF response and TPH and PAH concentration over the range of site soil and contaminant types. The relationship between LIF signal, TPH–Dx, and PAH soil data will be evaluated by the technical team. The SCAPS LIF data will be used to define the boundary of the NAPL and petroleum, oil, and lubricant (POL) contamination above the site specific threshold concentration (reporting limit).

31.0 LABORATORY QUALITY CONTROL SAMPLES

Laboratory QC checks are accomplished through analyzing initial and continuing calibration samples, method blanks, surrogate spikes, laboratory control samples (LCSs), and laboratory duplicate samples. Not all of these QC samples will be required for all methods. Typically, these samples are not required for methods other than EPA SW-846, methods such as ASTM methods. Method-specific QC samples are described in the laboratory SOPs.

32.0.0 Initial and Continuing Calibration Samples

Laboratory instrument calibration requirements are summarized in Tables 4-2 through 4-5, and are discussed in Section 6.

33.0.0 Method Blanks

Method blanks are used to check for laboratory contamination and instrument bias. Laboratory method blanks will be analyzed at a minimum frequency of 5 percent or one per analytical batch for all chemical parameter groups.

QC criteria require that no contaminants be detected in the blank(s) above the MQL. If a chemical is detected, the action taken will follow the laboratory SOPs as modified. Blank samples will be analyzed for the same parameters as the associated field samples.

34.0.0 Surrogate Spikes

Accuracy of an analytical measurement is evaluated by using surrogate spikes. Surrogate compounds are compounds not expected to be found in environmental samples; however, they

are chemically similar to several compounds analyzed in the methods and behave similarly in extracting solvents. Samples for organics analysis will be spiked with surrogate compounds consistent with the requirements described in the laboratory SOPs.

Percent recovery of surrogates is calculated concurrently with the analytes of interest, using the equation in Section 7.2. Since sample characteristics will affect the percent recovery, the percent recovery is a measure of accuracy of the overall analytical method on each individual sample.

35.0.0 Laboratory Control Samples

LCSs are used to monitor the laboratory's day-to-day performance of routine analytical methods, independent of matrix effects. The LCSs are prepared by spiking reagent water or silica sand with standard solutions prepared independently of those used in establishing instrument calibration. The LCSs are extracted and analyzed with each batch of samples. Results are compared on a per-batch basis to established control limits and are used to evaluate laboratory performance for precision and accuracy. Laboratory control samples may also be used to identify any background interference or contamination of the analytical system that may lead to the reporting of elevated concentration levels or false positive measurements.

36.0.0 Laboratory Duplicate Samples

Precision of the analytical system is evaluated by using laboratory duplicates. Laboratory duplicates are two portions of a single homogeneous sample analyzed for the same parameter. Laboratory duplicates will be prepared and analyzed with project samples as listed in Tables 4-2 through 4-5.

Table 4-1
**FIELD QUALITY CONTROL SAMPLE COLLECTION SUMMARY—
SOIL, NAPL, AND GROUNDWATER**

SAMPLE TYPE	LABORATORY	FREQUENCY
Rinsate/field blanks	Fixed, SCAPS (ITMS)	5 percent
Field duplicates	Fixed, SCAPS (ITMS)	10 percent of all samples
MS/MSD (or laboratory duplicates)	Fixed, SCAPS (ITMS)	5 percent of all samples or as specified in SOP
Performance evaluation samples	Fixed, SCAPS (ITMS)	See discussion above

Notes:
 ITMS ion trap mass spectrometer
 MS/MSD matrix spike/matrix spike duplicate
 SCAPS Site Characterization and Analysis Penetrometer System
 SOP standard operating procedure

Table 4-2
**SCAPS LABORATORY QUALITY CONTROL SAMPLE SUMMARY—
GROUNDWATER AND SURFACE WATER**

ANALYTE	BACKGROUND CORRECTION BLANKS	SYSTEM BLANK CHECK	MASS AXIS CALIBRATION	INITIAL CALIBRATION	CALIBRATION CHECK STANDARDS	PERFORMANCE EVALUATION CHECK STANDARDS
MIP/DSITMS	After samples with >500 ppm VOC and between samples from different sources		At startup and daily	3-pt		
DSITMS	After samples with >500 ppm VOC and between samples from different sources		At startup and daily	5-pt		
MIP		Before and after each set of in situ measurements			After each penetration	Daily at startup and end of each day
DS		NA			2/day	Daily at startup and end of each day

Notes:
 DS direct sampling
 DSITMS direct sampling ion trap mass spectrometer
 MIP membrane interface probe
 VOC volatile organic compound

Table 4-3
FIXED LABORATORY QUALITY CONTROL SAMPLE SUMMARY—SOIL

ANALYTE	METHOD REFERENCE	METHOD BLANKS ^a	MS/MSD (PERCENT) ^b	LABORATORY CONTROL SAMPLE (BLANK SPIKE) ^a	SURROGATE	INITIAL CALIBRATION	INITIAL CALIBRATION VERIFICATION	CONTINUING CALIBRATION STANDARD ^c
VOCs	SW-846 8260B	1/batch	5	1/batch	All samples	5-pt	1/batch	After every 12 hours
TPH-Dx	NWTPH-Dx	1/batch	5	5 percent	All samples	5-pt	1/batch	After every 12 hours
SVOCs	SW-846 8270C	1/batch	5	1/batch	All samples	3-pt	1/batch	After every 10 samples
Grain size	ASTM D422/D4464	NA	5 ^c	NA	NA	NA	NA	NA
Effective porosity	API RP40	NA	NA	NA	NA	NA	NA	NA
Permeability	ASTM D5084	NA	NA	NA	NA	NA	NA	NA
Total organic carbon	SW-846 9060	1/batch	5	1/batch	NA	NA	NA	NA
Cation exchange capacity	SW-846 9081	1/batch	5	1/batch	NA	1-pt	Standard and blank with every batch	Standard and blank after every 10 samples
Bulk density	ASTM D2937	NA	5 ^c	NA	NA	NA	NA	NA

^aBatch is equivalent to 20 or fewer samples prepared and analyzed together with common QC samples.

^bMS/MSD for organics; MS/lab duplicate for inorganics

^cLaboratory duplicate only

Notes:

NA - not applicable

TAT - turnaround time

SECTION FOUR

Quality Control Samples

Table 4-4
FIXED LABORATORY QUALITY CONTROL SAMPLE SUMMARY—NAPL

ANALYTE	METHOD REFERENCE	METHOD BLANKS ^a	MS/MSD (PERCENT)	LABORATORY CONTROL SAMPLE (BLANK SPIKE) ^a	SURROGATE	INITIAL CALIBRATION	INITIAL CALIBRATION VERIFICATION	CONTINUING CALIBRATION STANDARD ^b
VOCs	SW-846 8260B	1/batch	NA	1/batch	All samples	5-pt	1/batch	After every 10 samples
SVOCs	SW-846 8270C	1/batch	NA	5 percent	All samples	5-pt	1/batch	After every 10 samples
TPH-Dx	NW-TPH-Dx	1/batch	NA	1/batch	All samples	5-pt	1/batch	After every 10 samples
Oil/water interfacial tension	ASTM D971	NA	NA	NA	NA	NA	NA	NA
Density/viscosity	ASTM D445/D1481	NA	NA	NA	NA	NA	NA	NA
Boiling point distribution	ASTM D86	NA	NA	NA	NA	NA	NA	NA

^aBatch is equivalent to 20 or fewer samples prepared and analyzed together with common QC samples.

^bContinuing calibration blank samples are analyzed immediately after continuing calibration standards.

Note:

NA - not applicable

Table 4-5
FIXED LABORATORY QUALITY CONTROL SAMPLE SUMMARY—GROUNDWATER

ANALYTE	METHOD REFERENCE	METHOD BLANKS ^a	MS/MSD (PERCENT)	LABORATORY CONTROL SAMPLE (BLANK SPIKE) ^a	SURROGATE	INITIAL CALIBRATION	INITIAL CALIBRATION VERIFICATION ^a	CONTINUING CALIBRATION STANDARD AND BLANK ^b
VOCs	SW-846 8260B	1/batch	5	1/batch	All samples	3-pt	1/batch	After every 12 hours

^aBatch is equivalent to 20 or fewer samples prepared and analyzed together with common QC samples.

^bContinuing calibration blank samples are analyzed immediately after continuing calibration standards.

This section describes the analytical procedures to be used for analytical laboratory measurements. The analytical methods and associated QA/QC procedures were selected based on consideration of the DQOs. The analytical methods, calibration procedures, and QC measurements and criteria are based on current analytical protocols in the following:

- EPA SW-846 test methods for evaluation of solid waste (U.S. EPA 1994a)
- American Society for Testing and Materials (ASTM annual updates)
- *Methods for the Chemical Analysis of Water and Wastes* (U.S. EPA 1979)
- Laboratory-specific SOPs

Laboratory method summaries, including reference and preservation, extraction, cleanup and instrumentation, are included in Tables 5-1 through 5-4. Laboratory-specific SOPs are included in Appendix 1. Project-specific modifications to these methods are discussed below.

Laboratory QA will be implemented and maintained as described in this plan and according to the laboratories' QA plans and SOPs. Quality control samples are described in Section 4 of this QAPP. Analytical method target analytes, routine reporting limits, and control limits are listed in Appendices B and C.

The methods selected are sufficient to meet the project DQOs. While a best effort will be made to achieve the project DQOs, there may be cases in which it is not possible to meet the specified goals. Any limitation in data quality due to analytical problems (e.g., elevated detection limits due to highly contaminated samples) will be identified within 48 hours and brought to the attention of the USACE technical team. In addition, this information will be discussed in the data evaluation report.

37.0 NONAQUEOUS-PHASE ANALYTICAL APPROACH

The laboratory will prepare NAPL samples according to the following:

- VOCs by EPA SW-846 Method 8260B: If the product sample is soluble in methanol, then 0.1 gram of the sample is weighed out and analyzed. If the product sample is not soluble in methanol, then 7 to 10 grams of the sample are weighed out and extracted with 10 milliliters of methanol.
- SVOCs by EPA SW-846 Method 8270C: 1 gram of the sample is weighed out and diluted to 10 milliliters.
- TPH-Dx by NWTPH-Dx: 0.1 gram of the sample is weighted and diluted to 10 milliliters.

Table 5-1
SCAPS LABORATORY METHOD SUMMARY—GROUNDWATER AND SURFACE WATER

ANALYTE	METHOD REFERENCE	PRESERVATION METHOD	EXTRACTION METHOD	CLEANUP METHOD	INSTRUMENT/ DETECTOR
VOCs-MIP/DSITMS	SCAPS SOP	NA	Membrane Interface Probe	NA	Ion Trap Mass Spectrometer
VOCs-DSITMS	SCAPS SOP	None	Direct Sparging	NA	Ion Trap Mass Spectrometer

Notes:
 NA – not applicable

Table 5-2
FIXED LABORATORY METHOD SUMMARY—SOIL

ANALYTE	METHOD REFERENCE	PRESERVATION METHOD	EXTRACTION METHOD	CLEANUP METHOD	INSTRUMENT/ DETECTOR
VOCs	SW-846 5035/8260B	4 + 2 °C	5030	NA	GC/MS
SVOCs	SW-846 8270C	4 + 2 °C	Sonication	GPC	GC/MS
TPH-diesel	NWTPH-Dx	4 + 2 °C	3550B	NA	GC/FID
Grain size	ASTM D422/D4464	None	NA	NA	NA
Permeability (hydraulic conductivity)	ASTM D5084	None	NA	NA	Flexible wall permeameter
Density	ASTM D2937	None	NA	NA	NA
Porosity	API RP40	None	Toluene	None	NA
Cation exchange capacity	SW-846 9081	None	Sodium acetate	NA	Atomic absorption
Total organic carbon	SW-846 9060	4 + 2 °C	Dean-Stark	None	Titration with Fe SO ₄

Notes:
 NA - not applicable

Table 5-3
FIXED LABORATORY METHOD SUMMARY—NAPL

ANALYTE	METHOD REFERENCE	PRESERVATION METHOD	EXTRACTION METHOD	CLEANUP METHOD	INSTRUMENT/ DETECTOR
VOCs	SW-846 8260B	4 ± 2 °C	5030	NA	GC/MS
SVOCs	SW-846 8270C	4 ± 2 °C	NA	GPC	GC/MS
TPH-diesel	NWTPH-Dx	4 ± 2 °C	3550B	NA	GC/FID
Oil/water interfacial tension	ASTM D971	Refrigeration	NA	NA	Central Scientific Direct Reading Tensiometer
Viscosity/density	ASTM D445/D1481	Refrigeration	NA	NA	Canon Crossarm Viscometer
Boiling point distribution/distillation	ASTM D86	Refrigeration	NA	NA	Thermometer

Notes:

GC/FID - gas chromatograph/flame ionization detector

GC/MS - gas chromatograph/mass spectrometer

GPC - gel permeation chromatography

NA - not applicable

Table 5-4
FIXED LABORATORY METHOD SUMMARY—GROUNDWATER

ANALYTE	METHOD REFERENCE	PRESERVATION METHOD	EXTRACTION METHOD	CLEANUP METHOD	INSTRUMENT/ DETECTOR
VOCs	SW-846 8260B	HCl acid to pH <2 4 ± 2 °C	NA	NA	GC/MS

Notes:

GC/MS - gas chromatograph/mass spectrometer

NA - not applicable

Analytical instrument calibration and maintenance will be conducted in accordance with the QC requirements identified in each laboratory SOP and QA plan, and the manufacturers' instructions. General requirements are discussed below.

38.0 STANDARD SOLUTIONS

A critical element in the generation of quality data is the purity/quality and traceability of the standard solutions and reagents used in the analytical operations. To ensure the highest purity possible, all primary reference standards and standard solutions will be obtained from a reliable commercial source. The laboratories will maintain a written record of the supplier, lot number, purity/concentration, receipt/preparation date, preparer's name, method of preparation, expiration date, and all other pertinent information for all standards, standard solutions, and individual standard preparation logs.

Standard solutions will be validated prior to use. Validation procedures can range from a check for chromatographic purity to verification of the concentration of the standard solution using another standard solution prepared at a different time or obtained from a different source. Stock and working standard solutions will be checked regularly for signs of deterioration, such as discoloration, formation of precipitates, or change of concentration. Care will be exercised in the proper storage and handling of standard solutions, and all containers will be labeled as to compound, concentration, solvent, expiration date, and preparation data (initials of preparer/date of preparation). Reagents will be examined for purity by subjecting an aliquot or subsample to the corresponding analytical method as well.

39.0 BALANCES

Analytical balances will be calibrated annually according to manufacturers' instructions and have a calibration check before each use by laboratory personnel. Balance calibration shall be documented in appropriate hard-bound log books with pre-numbered pages.

40.0 REFRIGERATORS

All refrigerators will be monitored for proper temperature by measuring and recording internal temperatures on a daily basis. At a minimum, thermometers used for these measurements will be calibrated annually, according to manufacturers' instructions.

41.0 WATER SUPPLY SYSTEM

The project laboratories will maintain an appropriate water supply system that is capable of furnishing ASTM Type II polished water to the various analytical areas.

42.0 LABORATORY INSTRUMENTS

As stated in EPA SW-846 (USEPA 1994a) and applicable laboratory SOPs, calibration of all analytical instrumentation is required to ensure that the analytical system is operating correctly and functioning at the sensitivity required to meet project-specific DQOs. Each instrument will be calibrated with standard solutions appropriate to the instrument and analytical method, in

accordance with the methodology specified and at the QC frequency specified in the project laboratory SOPs.

The calibration and maintenance history of the project laboratory instrumentation is an important aspect of the project's overall QA/QC program. As such, all initial and continuing calibration procedures will be implemented by trained personnel following the manufacturer's instructions and in accordance with applicable EPA protocols to ensure the equipment is functioning within the tolerances established by the manufacturer and the method-specific analytical requirements.

The DQOs for the EGDY Phase II RI field exploration are designed to ensure that the accuracy and precision of the data will be sufficient that the data will be useful for identifying the source of, evaluating the potential for natural attenuation of, and designing in situ treatment methods for NAPL and TCE at the site.

The data quality parameters presented in this section are precision, accuracy (bias), representativeness, comparability, completeness, and sensitivity. Project-specific control limits for these parameters are presented in Appendix 3. Required QA/QC sample frequency and calibration requirements are summarized for all laboratory analyses in Tables 4-1 through 4-4.

43.0 PRECISION

Precision is defined as the degree of agreement between or among independent, similar, or repeated measures. Precision is expressed in terms of analytical variability. For this project, analytical variability will be measured as the RPD or coefficient of variation between analytical lab duplicates and between the MS and MSD analyses. Monitoring variability will be measured by analysis of blind field duplicate samples.

Precision will be calculated as the RPD as follows:

$$\%RPD_i = \frac{2|O_i - D_i|}{(O_i + D_i)} \times 100\%$$

where:

$\%RPD_i$	=	Relative percent difference for compound i
O_i	=	Value of compound i in original sample
D_i	=	Value of compound i in duplicate sample

The resultant RPD will be compared to acceptance criteria and deviations from specified limits reported. If the objective criteria are not met, the laboratory will supply a justification of why the acceptability limits were exceeded and implement the appropriate corrective actions. The RPD will be reviewed during data quality review, and deviations from the specified limits will be noted and the effect on reported data commented upon by the data reviewer.

44.0 ACCURACY

Accuracy is the amount of agreement between a measured value and the true value. It will be measured as the percent recovery of MS/MSD, organic surrogate compounds, and PE samples. Additional potential bias will be quantitated by the analysis of blank samples (e.g., method and rinsate blanks).

Accuracy shall be calculated as percent recovery of analytes as follows:

$$\%R_i = (Y_i \div X_i) \times 100\%$$

where:

$$\begin{aligned} \%R_i &= \text{percent recovery for compound } i \\ Y_i &= \text{measured analyte concentration in sample } i \\ &\quad (\text{measured} - \text{original sample concentration}) \\ X_i &= \text{known analyte concentration in sample } i \end{aligned}$$

The resultant percent recoveries will be compared to acceptance criteria and deviations from specified limits will be reported. If the objective criteria are not met, the laboratory will supply a justification of why the acceptability limits were exceeded and implement the appropriate corrective actions. Percent recoveries will be reviewed during data quality review, and deviations from the specified limits will be noted and the effect on reported data commented upon by the data reviewer.

45.0 REPRESENTATIVENESS

Representativeness is the degree to which sample results represent the system under study. This component is generally considered during the design phase of a program. This program will use the results of all analyses to evaluate the data in terms of its intended use. Site locations for sampling are placed using a biased approach to maximize the likelihood of locating and identifying site contamination, if present. Areas of apparent contamination have been selected for determination of potential impacts from past activities.

46.0 COMPARABILITY

Comparability is the degree to which data from one data set on study can be compared with data from other similar analytical methods, studies, reference values (such as background), reference materials, and screening values. This goal will be achieved through using standard techniques to collect and analyze representative samples and reporting analytical results in appropriate units. Comparability will be evaluated during data quality assurance review (see Section 10). Specifically, comparability between TPH results reported from LIF and NWTPH-Dx methods, and between VOC reported from MIP/DSITMS, DSITMS, and EPA SW-846 8260B will be evaluated.

47.0 COMPLETENESS

Completeness for usable data is defined as the percentage of usable data out of the total amount of data generated. Because the number of samples that will be collected to measure each parameter exceeds that required for the analysis, approximately 100 percent completeness is anticipated. When feasible, the amount of sample collected will be sufficient to reanalyze the sample, should the initial results not meet QC requirements. Less than 100 percent completeness could result if sufficient chemical contamination exists to require sample dilutions, resulting in an increase in the project-required detection/quantitation limits for some parameters. Highly

contaminated environments can also be sufficiently heterogeneous to prevent the achievement of specified precision and accuracy criteria. The target goal for completeness shall be 98 percent for all data. Completeness for quality data shall be 95 percent for each individual analytical method. Quality data are data obtained in a sample batch for which all QC criteria were met. Completeness will be calculated as follows:

$$\%C = \frac{A}{I} \times 100\%$$

where:

$\%C$	=	Percent completeness (analytical)
A	=	Actual number of samples collected/valid analyses obtained
I	=	Intended number of samples/analyses requested

Nonvalid data (i.e., data qualified as “R” rejected) will be identified during the QA review (Section 10.3).

48.0 SENSITIVITY

The sensitivity of the analytical methods (i.e., method detection limits) identified for this project is sufficient to allow comparison of project results to decision criteria. Analytical method reporting limits for all requested analytes are listed in Appendix 2.

Field and laboratory instrumentation will be examined and tested prior to being put into service and will be maintained according to the manufacturers' instructions. Sampling personnel will maintain a supply of typical maintenance replacement items available in the field to help prevent downtime because of equipment malfunctions. Examples of typical equipment maintenance items may include but not be limited to filters, tubing, fittings, sample containers, and calibration standards.

49.0 FIELD INSTRUMENTS

The following equipment or instruments, if utilized, will be serviced before the project is initiated and at regular intervals during the project as required by the manufacturer's instructions:

- Water quality meter
- PID
- CGI

Manufacturers' instructions will be followed for any additional equipment that is required for the project.

50.0 LABORATORY INSTRUMENTS

All laboratory instruments will be maintained as specified in the project laboratories' QA plans and according to manufacturers' instructions.

The ultimate responsibility for maintaining quality throughout the field exploration of the EGDY site rests with the USACE and URS Project Managers. The day-to-day responsibility for ensuring the quality of field and laboratory data rests with the USACE technical team, URS Field Investigation Managers, the Project QA/QC Officer, and the laboratory program administrators.

Any nonconformances with the established QC procedures will be expeditiously identified and controlled. Where procedures are not in compliance with the established protocol, corrective actions will be taken immediately. Subsequent work that depends on the nonconforming activity will not be performed until the identified nonconformance is corrected.

51.0 FIELD CORRECTIVE ACTION

The SCAPS manager, URS Field Investigation Manager, and the on-site USACE technical team representative will review the procedures being implemented in the field for consistency with the established protocols. Sample collection, preservation, labeling, etc., will be checked for completeness. Where procedures are not strictly in compliance with the established protocol, the deviations will be field documented and reported to the Project QA/QC Officer. Corrective actions will be defined by the USACE technical team and documented as appropriate. Upon implementation of the corrective action, the Project QA/QC Officer will be provided with a written memo documenting field implementation, and will then review it and provide a copy to the USACE technical team. The memo will become part of the field exploration project file.

52.0 LABORATORY CORRECTIVE ACTION

The laboratory QA data reviewer will review the data generated to ensure that all QC samples have been run as specified in the protocol. Recoveries of LCSs, surrogates, MS samples for consistency with method accuracy, RPD for laboratory duplicate, and MSD samples for consistency with method precision, will be evaluated against the control limits listed in Appendix 3.

Laboratory personnel will be alerted that corrective actions are necessary if any of the following occur:

- The QC data are outside the warning or acceptance windows established for precision and accuracy. The laboratory project manager will contact the laboratory QA manager to discuss out-of-control limit data sets. If the analyses cannot produce data sets that are within control limits, a USACE Project Technical Leader will be notified within 48 hours of any analysis that fails to meet the data quality objectives specified in this QAPP.
- Blanks contain contaminants at concentrations above the levels specified in the laboratory QA plan for any target compound.
- Undesirable trends are detected in matrix spike or LCS recoveries, RPD between MSDs, or surrogates recoveries.
- Unusual changes in detection limits are observed.
- Deficiencies are detected by the laboratory QA manager during internal or external audits, or from the results of performance evaluation samples.

If any nonconformances in analytical methodologies or quality control sample results are identified by the analyst, corrective actions will be implemented immediately. Specific corrective actions are outlined in each method laboratory SOP. Corrective action procedures will be handled initially at the bench level by the analyst, who will review the preparation or extraction procedure for possible errors, check the instrument calibration, spike and calibration mixes, instrument sensitivity, etc. The analyst will immediately notify his/her supervisor of the identified problem and the investigation which is being conducted. If the problem persists or cannot be identified, the matter will be referred to the laboratory supervisor and laboratory QA manager for further investigation. Once the problem has been resolved, full documentation of the corrective action procedure will be filed by the laboratory QA manager, and if data are affected, the USACE technical team will be provided a corrective action memo for inclusion in the project file.

Corrective action may include, but will not be limited to the following:

- Reanalyzing suspect samples if holding time criteria permit
- Resampling and analyzing new samples
- Retrieving the archived sample for analysis
- Evaluating and amending sampling and/or analytical procedures (with USACE consultation)
- Accepting data with an acknowledged level of uncertainty (with USACE consultation)
- Recalibrating analytical instruments
- Evaluating and attempting to identify limitations of the data

Data deemed unacceptable following the implementation of the required corrective action measures will not be accepted by the USACE technical team and followup corrective actions will be explored.

53.0 CORRECTIVE ACTIONS FOLLOWING DATA EVALUATION

The Project QA/QC Officer will review the field and laboratory data generated for this project to ensure that all project quality assurance objectives are met. If any nonconformances are found in the field procedures, sample collection procedures, field documentation procedures, laboratory analytical and documentation procedures, and data evaluation and quality review procedures, the impact of those nonconformances on the overall project QA objectives will be assessed.

Appropriate actions, including resampling and reanalysis, may be recommended to the USACE Project Manager so that the project objectives can be accomplished.

The chemical data reduction and review process for this project will include data generation, reduction, and QA review:

- URS, SCAPS, and USACE technical team representatives will perform limited data quality reviews of preliminary field and laboratory data prior to uploading these data to eRoom.
- Project laboratories will conduct data reduction and data quality review (see Section 10.1)
- URS will conduct an independent data quality review upon receipt of data packages from the laboratories (see Section 10.2).
- URS will prepare a final quality control summary report after the field work and final analyses have been completed (see Section 10.3).

54.0 DATA REDUCTION, REVIEW, AND DELIVERABLES BY PROJECT LABORATORIES

55.0.0 Data Reduction Procedure

56.0.0.0 *Fixed Laboratories Data Reduction Procedures*

The fixed laboratories will perform in-house analytical data reduction under the direction of the laboratory QA manager. Data reduction will be conducted as follows:

- Raw data produced by the analyst will be processed and reviewed for attainment of QC criteria as outlined in this SAP and/or established EPA methods, for overall reasonableness, and for transcription or calculation errors.
- After the data have been entered into the Laboratory Information Management System (LIMS), a computerized report will be generated and sent to the laboratory QA data reviewer.
- Rapid turnaround data will be reported within 48 hours of sample receipt by the laboratory. Preliminary results prior to formal in-house review or re-analysis are acceptable.
- The laboratory QA data reviewer will decide whether any sample reanalysis is required and the laboratory project manager will discuss reanalysis with the Project QA/QC Officer as soon as possible. If corrective actions have been taken and data still do not meet project QA requirements, a USACE technical team representative will be notified by the Project QA/QC Officer within 48 hours of the corrective action.
- Upon acceptance of the preliminary reports by the laboratory QA data reviewer, final reports will be generated. Final data reports will be available within 30 calendar days of sample submittal.

Laboratory data reduction procedures will be those specified in EPA SW-846 (USEPA 1994a) and those described in the laboratory SOPs. The data reduction steps will be documented, signed, and dated by the analyst.

57.0.0.0 *Laboratory Qualifiers*

Laboratory qualifiers as described and defined in the laboratory QA plans will include:

- Concentration below required reporting limit
- Estimated concentration due to poor spike recovery
- Concentrations of the chemical also found in laboratory blank
- Other sample-specific qualifiers necessary to describe QC conditions

58.0.0.0 *Laboratory Recordkeeping*

The laboratories will maintain detailed procedures for laboratory recordkeeping in order to support the validity of all analytical work. Each data report package submitted to URS will contain the laboratory's written certification that the requested analytical method was run and that all QA/QC checks were performed. The laboratory program administrator will provide URS with QC reports of its external audits if appropriate, which will become part of the central project files.

59.0.0 In-house Laboratory Data Review by Fixed Laboratories

The laboratory review will be conducted by a laboratory QA reviewer who has the initial responsibility for the correctness and completeness of the data. The laboratory QA reviewer will evaluate the quality of the work based on an established set of laboratory guidelines and this QAPP to ensure that:

- Sample preparation information is correct and complete
- Analysis information is correct and complete
- Appropriate procedures have been followed
- Analytical results are correct and complete
- QC sample results are within appropriate QC limits
- Laboratory blanks are within appropriate QC limits
- Special sample preparation and analytical requirements have been met
- Documentation is complete (all anomalies in the preparation and analysis have been documented; holding times are documented)

60.0.0 Data Deliverables

To ensure that project data are sufficient to meet both qualitative and quantitative DQOs, laboratory data deliverables permitting a data quality assessment are required. Laboratory deliverables will be sufficient to permit a limited quality review of precision, accuracy, and adherence to the method SOP. The SCAPS team will conduct quality reviews on the data

collected using SCAPS techniques. URS will conduct quality reviews on the data obtained from fixed laboratories (Section 10.2).

Information provided will be sufficient to review the data with respect to:

- Holding times and conditions
- Detection/quantitation limits
- Initial and continuing calibration
- Surrogate recoveries
- Laboratory duplicates and MS/MSDs
- Precision and accuracy
- Representativeness
- Comparability
- Completeness

61.0.0 SCAPS Deliverables

For SCAPS LIF results for soil TPH, MIP/DSITMS for groundwater VOCs, CPT results for geotechnical data, FLUTe ribbon NAPL data, and GeoVIS NAPL imaging daily deliverables will include the following:

- Summary table with push identification, total push depth, push type, push start time, brief comments
- Field data form (either text or scanned) with push information such as push identification, total push depth, and comments regarding stratigraphy or LIF response (anomalous intervals, peak wavelength, possible contaminant identification)
- Graphical file of scanned field results for each push; this form contains graphical representation of cone resistance, sleeve friction, soil classification, fluorescence intensity, and wavelength at peak
- Graphical file of the map view of the site, showing push locations and cultural features (roads, buildings, etc.)
- Graphical file of the orthographic view with stratigraphy
- Graphical file of the orthographic view with LIF counts
- Graphical file of a three-dimensional view with iso-surface of LIF counts
- GMS support files needed to operate GMS (for example, bor, .map, .mat, .img, .mat, and .sol files); these files could be zipped together and packaged when transferred
- SCAPS raw data files generated by the SCAPS during each push
- FLUTe ribbon photograph
- GeoVIS video tape or photograph

The graphical files will be placed on the Webserver and the GMS files will go onto an ftp site.

For MIP/DSITMS results reported by the SCAPS team, the laboratory will prepare and retain full analytical and associated QC documentation. The SCAPS laboratory will report the data as an analytical batch of 20 or fewer samples, along with associated QC reporting data. The analytical results will be submitted to USACE via hard copy and electronic files. The formats for electronic deliverables are to be determined.

The laboratory will provide the following hard copy information regarding MIP/DSITMS sample results for each analytical data package submitted:

- Date received, extracted, and analyzed
- Sample identification
- Matrix type
- Identification and concentration
- Dilution values for analyses
- Reporting limits for undetected analytes
- Initial and continuing calibration results
- LCS recoveries
- Laboratory duplicate RPD
- Method blank results

62.0.0 Fixed Laboratories Deliverables

To ensure that project chemical data are sufficient to meet both qualitative and quantitative DQOs, laboratory data deliverables that will permit a data quality assessment are required.

The laboratory will prepare and retain full analytical and associated QC documentation. The laboratory will report the data as an analytical batch of 20 or fewer samples, along with associated QC reporting data. The final analytical data will be provided in complete Contract Laboratory Program (CLP)-type deliverable data format (all results).

The analytical results will be submitted to URS via hard copy and electronic files. The formats for electronic deliverables are included in Appendix 4.

The laboratory will provide the following hard copy information for each analytical data package submitted for the EGDY site field exploration project:

- The cover sheet will list the samples included in the report, provide narrative comments describing problems encountered in analysis, and identify any analyses not meeting quality control criteria, including holding times.
- Chain of custody forms and cooler receipt forms will be provided.
- Tabulated results will be provided with inorganic and organic compounds identified and quantified, and reporting limits for all analytes shown. All analytes will be reported for each

sample as a detected concentration or as not detected above the specific limits of quantitation, which must be stated. All soil samples will be reported on a dry-weight basis with percent moisture also reported. The laboratory will also report dilution factors, date of extraction, extraction batch number, date of analysis, and analytical batch number for each sample. Tentatively identified compounds will not be reported.

- Analytical results will be provided for QC sample spikes, laboratory duplicates, initial and continuing calibration verifications of standards and laboratory blanks, standard procedural blanks, LCSs, surrogates, laboratory reference materials, and detection limit check samples.
- Raw data system printouts (or legible photocopies) will be provided that identify date of reported analysis, analyst, parameters analyzed, calibration curves, calibration verifications, method blanks, any reported sample dilutions, cleanup logs, laboratory duplicates, spikes, control samples, sample spiking levels, preparation/extraction logs, run logs, and chromatograms.
- Chromatograms will be labeled with analyte peaks, internal standards, and surrogate standards where applicable.
- Mass calibration and mass and spectral tuning will be reported for gas chromatography/mass spectroscopy (GC/MS) analyses.

The narrative accompanying the data package will include the identification of samples not meeting total QC criteria as specified in this SAP, and/or the laboratory QA plans, and cautions regarding nonquantitative use or unusability due to out-of-control QC results. Data reduction and QC review steps will be documented, signed, and dated by an authorized representative.

63.0 INDEPENDENT DATA QUALITY REVIEW BY URS

The second level of review will be performed by URS (or designee) and will include a review of laboratory performance criteria and sample-specific criteria. One hundred percent of fixed laboratories' data will be reviewed. Additionally, URS will determine whether the DQOs have been met, and will calculate the data completeness for the project. The data quality review will be performed according to *EPA Region 9 RCRA Corrective Action Program Data Review Guidance Manual* (USEPA 1996).

Full data validation will also be performed on 10 percent of all data according to EPA functional guidelines (USEPA 1994b). Sample data groups will be selected by the USACE after receipt of all final data packages and following the initial data quality review.

Data quality review is a process to determine if the data meet project-specific DQOs. The data quality review will include verification of the following:

- Compliance with the QAPP
- Proper sample collection and handling procedures
- Holding times

- Field QC results
- Instrument calibration verification
- Laboratory blank analysis
- Detection limits
- Laboratory duplicates
- MS/MSD percent recoveries and RPDs
- Surrogate percent recoveries
- Data completeness and format
- Data qualifiers assigned by the laboratories

Qualifiers will be added to data during the review as necessary. Qualifiers applied to the data as a result of the independent review will be limited to:

- U The analyte was analyzed for but was not detected above the reporting limit.
- J The analyte was positively identified; the associated numerical value is an estimate of the concentration of the analyte in the sample.
- UJ The analyte was not detected above the sample reporting limit. However, the reporting limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.
- R The sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.

Results of the QA review and/or validation will be included in a data quality review report that will provide a basis for meaningful interpretation of the data quality and evaluate the need for corrective actions and/or comprehensive data validation. This report will be used to generate the quality control summary report.

64.0 QUALITY CONTROL SUMMARY REPORT BY URS

After the field work and the final analyses have been completed and reviewed, a final quality control summary report will be prepared by the Project QA/QC Officer. The report will summarize the QA and audit information, indicating any corrective actions taken and the overall results of SAP compliance. The Project QA/QC Officer, in coordination with the laboratory's QA manager or qualified designee, will prepare the final summary that will be included in the central project file and incorporated as part of the final field exploration report.

The QC summary report will provide a basis for meaningful interpretation of the data quality and evaluate the need for corrective actions and/or additional comprehensive data validation. Analytical data will be qualified by reviewing the laboratory's standard analytical QC such as laboratory blanks, duplicates, LCSs, PE samples, MS/MSDs, and surrogate recoveries. The data quality review will involve checking the laboratory data package against criteria established in

the QAPP. The data will be considered valid if they meet the criteria established in this QAPP for the following elements:

- Accuracy
- Precision
- Completeness
- Representativeness
- Comparability

The QC summary report will include evaluation of sampling documentation/representativeness, technical holding time, instrument calibration and tuning, field and laboratory blank sample analyses, method QC sample results, field duplicates, compound identification and quantitation, elevated reporting limits, and a summary of qualified data.

Performance and systems audits may be conducted to determine whether:

- The QA program has been documented in accordance with specified requirements
- The documented program has been implemented
- Any nonconformances were identified and corrective action or identified deficiencies was implemented

The URS Project QA/QC Officer will be responsible for initiating audits, selecting the audit team, and overseeing audit implementation. The URS Project QA/QC Officer is responsible for supervising and checking that samples are collected and handled in accordance with this management plan and that documentation of work is adequate and complete. The URS Project QA/QC Officer also is responsible for overseeing that the project performance satisfies the QA objectives as set forth in this QAPP.

Reports and technical correspondence will be peer reviewed by qualified individuals before being finalized.

65.0 PERFORMANCE AUDITS

Performance audits are utilized to quantitatively evaluate the accuracy of measurement data through the use of PE samples and blind check samples. Independent commercial PE samples will be submitted to the laboratories with the field samples for VOC analysis. The PE samples will be used to monitor the quality of the laboratory data instead of submitting split samples to a fixed analytical laboratory. This allows correction of problems in the field before analytical activities are complete.

All PE samples will be introduced blind to the analytical process. The performance audit will be conducted by URS and approved by a USACE Project Technical Leader.

66.0 SYSTEMS AUDITS

Systems audits of the field and laboratory procedures may be conducted during this project. Field audits will be conducted if the USACE Project Technical Leaders or Project QA/QC Officer identifies the need. Systems audits of the laboratory will be performed annually and when the laboratory QA manager identifies the need, which may be throughout this project. An additional systems audit may be requested by the Project QA/QC Officer, if warranted. The frequency of on-site audits will depend on the type of interaction and communications the Project QA/QC Officer experiences with the laboratory staff, and on the frequency of observations of noncompliance with QC criteria and SOPs.

The laboratory QA manager will regularly conduct the following internal audits:

- Technical audit including reviews of calibration and equipment monitoring records, laboratory logbooks, maintenance records, and instrument control charts
- Data quality audit reviews, including all aspects of data collection, reporting and review
- Management system audits verifying that management and supervisory staff are effectively implementing and monitoring all QC activities necessary to support the laboratory QA program

External laboratory reviews are conducted by various government agencies and clients, such as the EPA CLP, U.S. Naval Energy and Environmental Support Activity, and the USACE Hazardous Waste Remedial Actions Program.

67.0 AUDIT PROCEDURE

This section provides requirements and guidance for performing internal and external audits to verify compliance with the elements of the SAP.

The USACE and URS Project Managers, the USACE Project Technical Leaders and, if appropriate, other audited entities (e.g., Field Investigation Managers, laboratory supervisors) will be notified by the Project QA/QC Officer of an audit a reasonable time before the audit is performed. This notification will be in writing and will include information such as the general scope and schedule of the audit, and the name of the audit team leader.

A pre-audit conference will be conducted at the audit site with the appropriate manager or designated representative (e.g., Field Investigation Manager, laboratory supervisor). The purpose of the conference will be to confirm the audit scope, present the audit plan, discuss the audit sequence, and plan for the post-audit conference.

The audit is then implemented by the audit team. Selected elements of the SAP will be audited to the depth necessary to evaluate the effectiveness of implementation. Checklists prepared by the audit team and approved by the Project QA/QC Officer will be sufficiently detailed to document major audit components. Conditions requiring immediate corrective action will be reported immediately to the Project QA/QC Officer.

At the conclusion of the audit, a post-audit conference will be held with the Field Investigation Managers or laboratory supervisors, or their designated representative, to present audit findings and clarify any misunderstandings. A list of audit findings will be concisely stated by the audit team leader. The findings will be acknowledged by signature of a USACE Project Technical Leader or designated representative upon completion of the post-audit conferences.

An audit report will be prepared by the audit team leader and signed by the Project QA/QC Officer. The report will include the following:

- Description of the audit scope
- Identification of the audit team
- List of persons contacted during pre-audit, audit, and post-audit activities
- A summary of audit results, including an evaluation statement regarding the effectiveness of the SAP elements which were audited
- Details of findings and program deficiencies
- Recommendations for corrective actions to the Project QA/QC Officer, with a copy to the USACE and URS Project Managers, the USACE Project Technical Leaders, and others as appropriate

68.0 AUDIT RESPONSE

The USACE or URS Project Manager or designated representative will respond to the audit report within 7 days of receipt. The response will clearly state the corrective action for each finding, including action to prevent recurrence and the date the corrective action will be completed.

69.0 FOLLOW-UP ACTION

Followup action will be performed by the Project QA/QC Officer or designated representative to:

- Evaluate the adequacy of the Project Manager's response
- Evaluate that corrective action is identified and scheduled for each finding
- Confirm that corrective action is accomplished as scheduled

Followup action may be accomplished through written communications, re-audit, or other appropriate means. When all corrective actions have been verified, a memo will be sent to the USACE Project Manager signifying the satisfactory closeout of the audit.

70.0 AUDIT RECORDS

Original records generated for all audits will be retained in the central project files. Records will include audit reports, written replies, the record of completion of corrective actions, and documents associated with the conduct of audits that support audit findings and corrective actions as appropriate.

- U.S. Army Corps of Engineers (USACE). 2001. *Requirements for the Preparation of Sampling and Analysis Plans*. EM 200-1-3. February 2001.
- . 1998. *Chemical Data Quality Management for Hazardous, Toxic, Radioactive Waste Remedial Activities*. ER 1110-1-263. April 30, 1998. Appendix H. Shell for Analytical Chemistry Requirements.
- U.S. Environmental Protection Agency (EPA). 1996. *Region 9 RCRA Corrective Action Program Data Review Guidance Manual*. <http://www.epa.gov/region09/ga/r9-gadocs.html>. Accessed May 1999.
- . 1994a. *Test Methods for Evaluation of Solid Waste, Vol. II: Field Manual Physical/Chemical Methods (SW-846)*. Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C., 3rd Edition and Revised Update II. September 1994.
- . 1994b. *Laboratory Data Validation, Functional Guidelines for Evaluating Organics Analyses*. EPA Data Review Work Group. February 1, 1994.
- . 1979. *Methods for the Chemical Analysis of Water and Wastes*. EPA 600/4-79-020.

Appendix 1
Standard Operating Procedures

CONTENTS

Site Characterization and Analysis Penetrometer System/Laser-Induced Fluorescence (SCAPS/LIF)
SCAPS Membrane Interface Probe with Direct Sampling Ion Trap Mass Spectroscopy (MIP/DSITMS)
Flexible Liner Underground Technologies (FLUTe) Ribbon Sampler
Sound Analytical Services, Inc. – Semivolatile Petroleum Products Method for Soil and Water by NWTPH–Dx Modified
Sound Analytical Services, Inc. – Semivolatile Organic Compound (Base/Neutrals and Acids) Analysis by GC/MS, Method 8270C
Sound Analytical Services, Inc. – Method 8260B Modified: Volatile Organic Compound Analysis using Finnigan Mat INCOS50 GC/MS
Sound Analytical Services, Inc. – Method 8260B Modified: Volatile Organic Compound Analysis by Finnigan Mat ITS-40 GC/MS
PTS Laboratories – Method 9060 Total Organic Carbon (TOC)
PTS Laboratories – Interfacial Tension of Oil Against Water by the Ring Method – ASTM D971
PTS Laboratories – Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity) – ASTM D445
PTS Laboratories – Density and Relative Density (Specific Gravity) of Viscous Material by Lipkin Bicapillary Pycnometer – ASTM D1481
PTS Laboratories – Porosity – API RP40
PTS Laboratories – Dry or Native Bulk Density – ASTM D2937
PTS Laboratories – Manual Distillation of Petroleum Products – ASTM D86
PTS Laboratories – Particle Size by Mechanical Sieve – ASTM D422M-63
PTS Laboratories – Particle Size by Laser Light Scattering – ASTM D4464M-85
PTS Laboratories – Hydraulic Conductivity and Permeability to Water (Methods ASTM D5084, EPA 9100, and API RP40)
PTS Laboratories – Cation Exchange Capacity – EPA 9081

Appendix 2
Laboratory Reporting Limits

Appendix 2

Laboratory Reporting Limits

Table B-1

SCAPS LABORATORY REPORTING LIMITS—SOIL

Analyte	Method Reference	Reporting Limit
TPH by Fluorescence	ASTM D 6187 (SCAPS SOP)	Determined in the field

Table B-2

SCAPS LABORATORY REPORTING LIMITS—GROUNDWATER

Analyte	Method Reference	Reporting Limit (µg/L)
VOCs by ITMS	SW-846 8265	2.5

Table B-3

FIXED LABORATORY REPORTING LIMITS—SOIL

Analyte	Method Reference	Laboratory	Reporting Limit (µg/kg)
VOC	SW-846 5035 / 8260B	Sound Analytical Services, Inc.	
1,1,1,2-Tetrachloroethane			400
1,1,1-Trichloroethane			400
1,1,2,2-Tetrachloroethane			400
1,1,2-Trichloroethane			400
1,1,2-Trichlorotrifluoroethane			400
1,1-Dechloroethane			400
1,1-Dichloroethene			400
1,1-Dichloropropene			400
1,2,3-Trichlorobenzene			400
1,2,3-Trichloropropane			400
1,2,4-Trichlorobenzene			400
1,2,4-Trimethylbenzene			400
1,2-Dibromo-3-chloropropane			400
1,2-Dibromoethane			400
1,2-Dichlorobenzene			400
1,2-Dichloroethane			400
1,2-Dichloropropane			400
1,3,5-Trichlorobenzene			400
1,3,5-Trimethylbenzene			400
1,3-Dichlorobenzene			400
1,3-Dichloropropane			400
1,4-Dichlorobenzene			400
1,4-Dioxane			4000
2,2-Dichloropropane			400
2-Butanone			2000
2-Chloroethyl Vinyl Ether			2000
2-Chlorotoluene			400
2-Hexanone			2000
4-Chlorotoluene			400
4-Isopropyltoluene			400
4-Methyl-2-pentanone			2000
Acetone			2000
Acrylonitrile			2000
Benzene			400

Appendix 2

Laboratory Reporting Limits

Analyte	Method Reference	Laboratory	Reporting Limit (µg/kg)
Benzyl Chloride			400
Bromobenzene			400
Bromochloromethane			400
Bromodichloromethane			400
Bromoform			400
Bromomethane			400
Carbon Disulfide			400
Carbon Tetrachloride			400
Chlorobenzene			400
Chloroethane			400
Chloroform			400
Chloromethane			400
cis-1,2-Dichloroethene			400
cis-1,3-Dichloropropene			400
cis-1,4-Dichloro-2-butene			2000
Dibromochloromethane			400
Dibromomethane			400
Dichlorodifluoromethane			400
Ethyl Acetate			400
Ethyl Ether			400
Ethylbenzene			400
Hexachlorobutadiene			400
Hexane			400
Iodomethane			400
m,p-Xylenes			800
Methylene Chloride			400
Naphthalene			400
n-Butylbenzene			400
n-Propylbenzene			400
o-Xylene			400
sec-Butylbenzene			400
Styrene			400
t-Butylbenzene			400
methyl tert-butyl ether			400
Tetrachloroethene			400
Tetrahydrofuran			2000
Toluene			400
trans-1,2-Dichloroethene			400
trans-1,3-Dichloropropene			400
trans-1,4-Dichloro-2-butene			2000
Trichloroethene			400
Trichlorofluoromethane			400
Vinyl Acetate			400
Vinyl Chloride			400
SVOC	SW-846 8270C	Sound Analytical Services, Inc.	
1,2,4-Trichlorobenzene			100
1,2-Dichlorobenzene			100
1,2-Diphenylhydrazine			100
1,3-Dichlorobenzene			100
1,4-Dichlorobenzene			100

Appendix 2

Laboratory Reporting Limits

Analyte	Method Reference	Laboratory	Reporting Limit (µg/kg)
2,4,5-Trichlorophenol			100
2,4,6-Trichlorophenol			100
2,4-Dichlorophenol			100
2,4-Dimethylphenol			100
2,4-Dinitrophenol			100
2,4-Dinitrotoluene			100
2,6-Dinitrotoluene			100
2-Chloronaphthalene			20
2-Chlorophenol			100
2-Ethoxyethanol			100
2-Methylnaphthalene			20
2-Methylphenol			100
2-Nitroaniline			100
2-Nitrophenol			100
2-Nitropropane			100
3- & 4- Methylphenol			100
3,3'-Dichlorobenzidine			100
3-Nitroaniline			100
4,6-Dinitro-2-methylphenol			100
4-Bromophenylphenylether			100
4-Chloro-3-methylphenol			100
4-Chloroaniline			100
4-Chlorophenylphenylether			100
4-Nitroaniline			100
4-Nitrophenol			100
Acenaphthene			20
Acenaphthylene			20
Aniline			1000
Anthracene			20
Benzidine			200
Benzo(a)anthracene			20
Benzo(a)pyrene			20
Benzo(b)fluoranthene			20
Benzo(g,h,i)perylene			20
Benzo(k)fluoranthene			20
Benzoic Acid			100
Benzyl Alcohol			100
bis(2-Chlorethoxy)methane			100
bis(2-Chloroethyl)ether			100
bis(2-Chloroisopropyl)ether			100
bis(2-Ethylhexyl)phthalate			100
Butylbenzylphthalate			100
Carbazole			100
Chrysene			20
Cyclohexanone			200
Dibenz(a,h)anthracene			20
Dibenzofuran			100
Diethylphthalate			100
Dimethylphthalate			100
Di-n-butylphthalate			100

Appendix 2

Laboratory Reporting Limits

Analyte	Method Reference	Laboratory	Reporting Limit (µg/kg)
Di-n-octylphthalate			100
Fluoranthene			20
Fluorene			20
Hexachlorobenzene			100
Hexachlorobutadiene			100
Hexachlorocyclopentadiene			100
Hexachloroethane			100
Indeno(1,2,3-cd)pyrene			20
Isophorone			100
Naphthalene			20
Nitrobenzene			100
N-nitrosodimethylamine			100
N-nitroso-di-n-propylamine			100
N-Nitrosodiphenylamine			100
Pentachlorophenol			100
Phenanthrene			20
Phenol			100
Pyrene			20
Pyridene			100
Tetrachlorophenols			100
TPH	NWTPH-Dx	Sound Analytical Services, Inc.	
#2 Diesel			20 mg/kg
Motor Oil			40 mg/kg
Diesel (>nC12-nC24)			20 mg/kg
Motor Oil (C24-C36)			40 mg/kg
Conventionals			
Grain Size	ASTM D422M-63	PTS Laboratories	NA
Permeability (Hydraulic Conductivity)	PTS SOP	PTS Laboratories	NA
Density	ASTM D2937	PTS Laboratories	NA
Porosity	PTS SOP (APR RP40)	PTS Laboratories	0.1 porosity units
Cation Exchange Capacity	SW-846 9081	PTS Laboratories	5 mg/L
Total Organic Carbon	SW-846 9060	PTS Laboratories	1 mg/L

Notes:

mg/kg - milligrams per kilogram

TAT - turn-around time

Table B-4
FIXED LABORATORY REPORTING LIMITS—NAPL

Analyte	Method Reference	Laboratory	Reporting Limits
VOCs	SW-846 8260B	Sound Analytical Services, Inc.	Determined by dilution
SVOCs	SW-846 8270C	Sound Analytical Services, Inc.	Determined by dilution
TPH-Dx	NWTPH-Dx	Sound Analytical Services, Inc.	Determined by dilution
Oil/Water Interfacial Tension	ASTM D971-82	PTS Laboratories, Inc.	NA
Viscosity/Density	ASTM D445-83	PTS Laboratories, Inc.	NA
Boiling Point Distribution/ Distillation	ASTM D86	PTS Laboratories, Inc.	NA

Appendix 2

Laboratory Reporting Limits

Table B-5
FIXED LABORATORY REPORTING LIMITS—GROUNDWATER

Analyte	Method Reference	Laboratory	Reporting Limit (µg/L)
VOC	SW-846 8260B	Sound Analytical Services, Inc.	
1,1,1-Trichloroethane			0.4
1,1,2,2-Tetrachloroethane			0.4
1,1,2-Trichloroethane			0.4
1,1,2-Trichlorotrifluoroethane			0.4
1,1-Dechloroethane			0.4
1,1-Dichloroethene			0.4
1,2-Dichloroethane			0.4
1,2-Dichloropropane			0.4
2-Butanone			2
2-Chloroethyl Vinyl Ether			2
2-Hexanone			2
4-Methyl-2-pentanone			2
Acetone			2
Benzene			0.4
Bromodichloromethane			0.4
Bromoform			0.4
Bromomethane			0.4
Carbon Disulfide			0.4
Carbon Tetrachloride			0.4
Chlorobenzene			0.4
Chloroethane			0.4
Chloroform			0.4
Chloromethane			0.4
cis-1,2-Dichloroethene			0.4
cis-1,3-Dichloropropene			0.4
Dibromochloromethane			0.4
Ethylbenzene			0.4
m,p-Xylenes			0.4
Methylene Chloride			0.4
o-Xylene			0.4
Styrene			0.4
Tetrachloroethene			0.4
Toluene			0.4
trans-1,2-Dichloroethene			0.4
trans-1,3-Dichloropropene			0.4
Trichloroethene			0.4
Trichlorofluoromethane			0.4
Vinyl Acetate			0.4
Vinyl Chloride			0.4

Notes:

µg/L - micrograms per liter

Appendix 3
Laboratory Control Limits

Table C-1
SCAPS LABORATORY CONTROL LIMITS—SOIL

Analyte	Method Reference	Control Limits
TPH by Fluorescence	ASTM D 6187 (SCAPS SOP)	NA

Table C-2
SCAPS LABORATORY CONTROL LIMITS—GROUNDWATER

Analyte	Method Reference	Control Limits
VOCs by ITMS	SCAPS SOP	PECS: within 2 std dev of historic mean Calibration std: within 2 std dev of mean established during calibration

Appendix 3

Laboratory Control Limits

Table C-3
FIXED LABORATORY CONTROL LIMITS—SOIL

ANALYTE	METHOD REFERENCE	LABORATORY	CONTROL LIMITS
TPH-Dx	NWTPH-Dx	Sound Analytical Services, Inc.	Surrogate, MS %R: 50-150% Duplicate RPD: 50 Diesel BS: 67-139%, <22% RPD Motor Oil BS: 62-120%, <25% RPD
VOC	SW-846 8260B	Sound Analytical Services, Inc.	BS/MS: 1,1-Dichloroethene: 75-125%, <21%RPD 1,2-Dichloroethane: 75-125%, <18%RPD 1,4-Dichlorobenzene: 75-125%, <24%RPD 2-Butanone: 60-140%, <34%RPD Benzene: 75-125%, <17%RPD Carbon Tetrachloride: 75-125%, <22%RPD Chlorobenzene: 75-125%, <17%RPD Chloroform: 75-125%, <21%RPD Ethylbenzene: 76-125%, <26%RPD m,p-Xylene: 78-125%, <30%RPD o-Xylene: 77-125%, <21%RPD Tetrachloroethene: 75-118%, <17%RPD Toluene: 75-125%, <16%RPD Trichloroethene: 75-125%, <18%RPD Vinyl Chloride: 75-125%, <19%RPD Surrogates: Bromofluorobenzene: 89-109% Dibromofluoromethane: 82-112% Ethylbenzene-d10: 89-110% Fluorobenzene: 86-112% Toluene-d8: 91-108%
SVOC	SW-846 8270C	Sound Analytical Services, Inc.	BS/MS: 1,2,4-Trichlorobenzene: 48-140%, <30%RPD 1,4-Dichlorobenzene: 53-131%, <33%RPD 2,4-Dinitrotoluene: 51-140%, <33%RPD 2-Chlorophenol: 58-123%, <32%RPD 4-Chloro-3-methylphenol: 50-150%, <32%RPD 4-Nitrophenol: 36-130%, <41%RPD Acenaphthene: 54-128%, <32%RPD N-nitroso-di-n-propylamine: 43-130%, <35%RPD Pentachlorophenol: 21-144%, <41%RPD Phenol: 45-128%, <36%RPD Pyrene: 45-145%, <34%RPD Surrogates: 2-Fluorobiphenyl: 53-137% 2-Fluorophenol: 57-146% 2,4,6-Tribromophenol: 35-146% Nitrobenzene-d5: 56-145% p-Terphenyl-d14: 45-134% Phenol-d5: 54-140%

Appendix 3

Laboratory Control Limits

ANALYTE	METHOD REFERENCE	LABORATORY	CONTROL LIMITS
Grain Size	ASTM D422M-63	PTS Laboratories, Inc.	RPD: 20
Permeability (Hydraulic Conductivity)	PTS SOP	PTS Laboratories, Inc.	NA
Density	ASTM D2937	PTS Laboratories, Inc.	Standard Acceptance Range: 90-110%
Cation Exchange Capacity	SW-846 9081	PTS Laboratories, Inc.	Standard Acceptance Range: 80-120%
Porosity	PTS SOP (APR RP40)	PTS Laboratories, Inc.	Standard Acceptance Range: 98-102%
Total Organic Carbon	SW-846 9060	PTS Laboratories, Inc.	MS %R: $\pm 5\%$ Duplicate RPD: 20

Table C-4
FIXED LABORATORY CONTROL LIMITS—NAPL

Analyte	Method Reference	Laboratory	Control Limits
TPH-Dx	NWTPH-Dx	Sound Analytical Services, Inc.	LCS: 80-120%; CV:10
SVOC	SW-846 8270C	Sound Analytical Services, Inc.	LCS: 80-120%; CV:10
VOCs	SW-846 8260B	Sound Analytical Services, Inc.	Surrogate: 50-150% RPD : 40
Viscosity/Density	ASTM D445-83	PTS Laboratories, Inc.	CV: 01
Boiling Point Distribution/ Distillation (ASTM D86)	ASTM D86	PTS Laboratories, Inc.	Toluene Standard Acceptance Range: Boiling Point, $\pm 3^{\circ}\text{F}$
Oil/Water Interfacial Tension	ASTM D971-82	PTS Laboratories, Inc.	NA

Note:

CV - coefficient of variation

Appendix 3

Laboratory Control Limits

Table C-5
FIXED LABORATORY CONTROL LIMITS—GROUNDWATER

Analyte	Method Reference	Laboratory	Control Limits
VOC	SW-846 8260B	Sound Analytical Services, Inc.	BS/MS: 1,1-Dichloroethene: 80-120%, <11%RPD 1,2-Dichloroethane: 80-120%, <16%RPD 1,4-Dichlorobenzene: 80-120%, <20%RPD 2-Butanone: 60-140%, <36%RPD Benzene: 80-119%, <12%RPD Carbon Tetrachloride: 80-120%, <12%RPD Chlorobenzene: 80-120%, <12%RPD Chloroform: 80-120%, <12%RPD Ethylbenzene: 80-120%, <13%RPD m,p-Xylene: 80-120%, <14%RPD o-Xylene: 80-120%, <13%RPD Tetrachloroethene: 80-120%, <12%RPD Toluene: 80-120%, <12%RPD Trichloroethene: 80-118%, <12%RPD Vinyl Chloride: 80-120%, <15%RPD Surrogates: Bromofluorobenzene: 86-110% Dibromofluoromethane: 83-114% Ethylbenzene-d10: 87-108% Fluorobenzene: 84-114% Toluene-d8: 91-107%

Appendix 4
Electronic Data Deliverable Formats

Appendix 4

Electronic Data Deliverable Formats

The left column contains the column headings. The spreadsheet column headings should look just like the left column. The right column contains a brief description of the type of information that should go into the columns. The laboratory electronic files should be a text file (comma or tab delimited).

Site	Site name or project name
Location	Site location
LabName	Lab name
SDG	SDG
SampleID	Client sample ID
QAQCType	QAQC type like MS, duplicate, or blank
Matrix	Sample matrix
LabSampleID	Laboratory sample ID
RunNumber	Run number
ExtractMethod	Extraction method
AnalysisMethod	Analysis method number (i.e., EPA number)
Filter	This field is yes or no and only for water samples
DateSampled	Date Sampled
DateReceived	Date laboratory received the samples
DateExtracted	Date extracted
DateAnalyzed	Date analyzed
PercentSolids	Percent solids
PercentMoisture	Percent moisture (can fill out either the solids or the moisture column)
CAS	CAS number
Analyte	Analyte name
Result	Result (no text)
LabQual	Laboratory qualifier
ReportLimit	Reporting Limit
Units	Units
Dilution	Dilution
Surrogate	yes or no
Basis	dry or wet
SpikeAmount	Spike concentration for MS, LCS or surrogates
Recovery	spike percent recovery for MS, LCS, or surrogates
RPD	Relative percent difference for dups or MS/MSDs
LowerLimit	Lower control limit for MS, LCS, or surrogates
UpperLimit	Upper control limit for MS, LCS, or surrogates
RPDlimit	RPD control limits for dups or MS/MSDs
MethodDesc	Name of the analytical method

Appendix D

Health and Safety Plan

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Appendices

Appendix 1	URS Safety Management Standards
Appendix 2	USACE Tulsa District Health and Safety Plan

Project Identification and Approvals

Project Name: Phase II Remedial Investigation, East Gate Disposal Yard,
Fort Lewis Logistics Center, Fort Lewis, Washington

Project Number: 53F0074209.00

Business Unit: Seattle, Washington

Contract Manager: Dave Haddock

Delivery Order Manager: Janette Rau

Date of Issue: April 20, 2001

Effective Dates: July to October 2001

Approvals:

Delivery Order Manager
Janette Rau

Date

Health and Safety Representative
Heather Boge

Date

Regional Health and Safety Manager
Tim Reinhardt, CIH

Date

Site Safety and Health Plan Compliance Agreement

I, the undersigned, have received a copy of the Site Safety and Health Plan for the remedial investigation project at the East Gate Disposal Yard, Fort Lewis, Washington. I have been briefed on the plan and understand it, and agree to comply with all of the health and safety requirements established by the plan. I understand that I may be prohibited from continuing work on the project for failing to comply.

I have ____ have not ____ (check one) been briefed by a project safety authority on the health and safety requirements of the project.

Project Number: _____

Project Title: _____

Date of Plan: _____

Print Name: _____

Signature: _____

Firm: _____

Date: _____

List of Abbreviations and Acronyms

ANSI	American National Standards Institute
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHSA	Corporate Health and Safety Administrator (URS)
CPR	cardiopulmonary resuscitation
dba	decibels
DCE	cis-1,2-dichloroethene
EGDY	East Gate Disposal Yard
EOD	Explosives and Ordnance Disposal
HAZCOM	Hazard Communication Standard
HEPA	high-efficiency particulate air
HSO	Health and Safety Officer
IDW	investigation-derived waste
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
msl	mean sea level
NAPL	nonaqueous-phase liquid
OSHA	Occupational Safety and Health Administration
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PEL	permissible exposure level
PID	photoionization detector
POL	petroleum, oil, and lubricants
PPE	personal protective equipment
ppm	parts per million
RHSM	Regional Health and Safety Manager (URS)
RI	remedial investigation
SCAPS	Site Characterization and Analysis Penetrometer System
SMS	safety management standard
SPF	sun protection factor
SSC	Site Safety Coordinator
SSHP	Site Safety and Health Plan
SSO	Site Safety Officer
TCA	1,1,1-trichloroethane
TCE	trichloroethene
TPH	total petroleum hydrocarbons
URS	URS Group, Inc. (formerly Woodward-Clyde)
USACE	United States Army Corps of Engineers
UXO	unexploded ordnance
VOC	volatile organic compound

This Site Safety and Health Plan (SSHP) establishes guidelines and requirements for maintaining safe and healthy working conditions during the remedial investigation (RI) at Landfill 2, also known as the East Gate Disposal Yard (EGDY), at the Fort Lewis Logistics Center, Fort Lewis, Washington. All field personnel who are directly employed by or subcontracted to URS are required to read and understand this SSHP. URS and subcontractor personnel assigned field tasks at the site must agree to abide by the SSHP by signing the attached compliance agreement form. In addition, on-site employees and subcontractors must comply with the URS Corporate Health and Safety Program and the most recent edition of the U.S. Army Corps of Engineers (USACE), *Safety and Health Requirements Manual*, EM 385-1-1 (USACE 1996).

Health and safety guidelines and requirements are based on a review of available information concerning hazards expected to exist at the work site. The SSHP delineates health and safety procedures and equipment required to minimize the potential for injuries due to safety and physical hazards, biological hazards, and injuries due to occupational exposure to hazardous chemicals. If any hazards not anticipated by this plan are encountered in the field, the Site Safety Officer must stop work so that appropriate modification of the SSHP can be made. The SSHP may be modified by the Project Manager, the business unit Health and Safety Officer (HSO), and the Regional Health and Safety Manager (RHSM). Modifications to the SSHP must be approved by all three parties.

This plan follows the applicable requirements of 29 Code of Federal Regulations (CFR) 1910.120 Occupational Safety and Health Administration (OSHA) and the USACE *Safety and Health Elements for HTRW and EOW Documents*, ER 385-1-92 (USACE 2000). This SSHP follows the sequence of requirements described in ER 385-1-92.

1.1 SITE LOCATION AND HISTORY

EGDY was used from approximately 1946 through at least 1971 as a disposal site for liquid and solid wastes. Trenches were used for the disposal of trichloroethene (TCE) and petroleum, oil, and lubricants (POL) from equipment cleaning and degreasing activities conducted at the Fort Lewis Mount Rainier Ordnance Depot (now included in the Logistics Center). Past disposal practices at the EGDY have been identified as a likely source of present-day TCE groundwater contamination.

TCE was used as a degreasing agent at this facility until the mid-1970s, when its use was replaced with 1,1,1-trichloroethane (TCA). Waste TCE was disposed at several locations with waste oils. Trenches were excavated in the yard and on adjacent land southwest of the yard. The trenches reportedly received liquid TCE and POL from cleaning and degreasing operations, and solid waste (including drums that contained these wastes).

In 1985, the U.S. Army identified traces of TCE in several monitoring wells installed in the unconfined aquifer beneath the Logistics Center. A limited site investigation was performed in 1986 under the Department of Defense Installation Restoration Program, and a remedial investigation in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) began in 1987. The 1990 CERCLA record of decision for the Logistics Center specified that a pump-and-treat system be installed to prevent further migration of the plume. This system began operations in August 1995.

Currently the USACE is conducting drum removal operations at the EGDY. Hundreds of drums and other containers have been removed so far from former disposal trenches identified during a 1995 investigation. Many of the drums contain product consisting of mixtures of TCE and POL.

Land surface elevations at EGDY range from 270 to 280 feet above mean sea level (msl). Site topography is mostly flat or gently sloping. Site vegetation consists of thickets of Scotch-broom, grasses, and blackberry, interspersed with forested areas of Douglas fir, cottonwood, and alder.

1.2 SITE CONTAMINATION INFORMATION

The contaminant plume emanating from EGDY is over 2 miles long, between 3,000 to 4,000 feet wide, and 60 to 80 feet thick. The results of the 1986 remedial investigation and subsequent investigations by URS showed that groundwater in the shallow Vashon Drift Aquifer is contaminated principally with TCE. TCE concentrations in a few wells located within and just downgradient of EGDY have been as high as 1×10^6 micrograms per liter ($\mu\text{g/L}$). Other chemicals of concern include vinyl chloride, cis-1,2-dichloroethene (DCE), tetrachloroethene (PCE), and TCA.

Maximum soil concentrations detected during the Phase I expanded site investigation sampling for TCE, DCE, and total petroleum hydrocarbons (TPH) are 3,400 milligrams per kilogram (mg/kg), 370 mg/kg, and 45,000 mg/kg, respectively. Several chlorinated pesticides and polychlorinated biphenyls (PCBs) were detected in samples at concentrations typically below 0.060 mg/kg.

Although all of the soil sampling conducted in the EGDY study area during the remedial investigation and confirmational soil sampling was focused on likely areas of soil contamination, the results for chlorinated volatile organic compounds (VOCs) are quite variable. Only a few measurements are above 1 mg/kg, and many are in the 0.001 to 0.010 mg/kg range. This suggests either very localized disposal zones or small amounts of residual TCE in the unsaturated zone. In borings where TCE was detected at greater than 1 mg/kg, the highest concentrations occur in the upper 4 feet of the soil. Materials encountered in the test pits excavated during the confirmational soil sampling consisted of charred metallic debris, engine parts, crushed and rusted paint cans and buckets, crushed 55-gallon drums, glass bottles, and ceramic debris (hospital china).

Results of the Phase I expanded site investigation conducted in 1995 and the drum removal currently being conducted indicate that nonaqueous-phase liquid is present at the EGDY.

The Phase II RI activities are being performed to further characterize chemical contaminants in the soils and groundwater. The following sections describe field tasks associated with field work to be performed at EGDY. An activity hazard analysis for each task is also provided in this section.

2.1 SITE PREPARATION

A temporary road to access drill locations will be required. URS will provide oversight of road construction activities. A small dozer and front end loader will be used to accomplish this task.

2.2 SOIL BORINGS

Twenty-four soil borings will be drilled for soil sampling, describing the lithology of the site, and installing groundwater monitoring wells. URS will provide oversight of drilling activities.

All borings will be drilled using sonic drilling equipment. Sonic drilling employs an inertially activated drill head that generates high-frequency sinusoidal vibrations in a drill string to produce a cutting action at the bit face. This cutting action forces a continuous core of the formation into the drill string. Due to the forces developed by the resonance head and the uniform outer diameter of the drill string, excess formation material removed by the cutting face of the bit is forced back into the borehole wall, eliminating the production of cuttings during the drilling process. A geologist will log the soil cuttings and collect soil samples. Any excess soil will be disposed of as investigation-derived waste (IDW).

In addition, Site Characterization and Analysis Penetrometer System (SCAPS) testing on soil will be performed by USACE, Tulsa District. All USACE personnel will follow current safety and health requirements published by OSHA and stated with USACE's EM 385-1-1 Manual, as stated in the USACE standard operating procedure (SOP No: M-0005-SWT-01). A copy of USACE's Safety Manual will be on site during field activities. The USACE, Tulsa District Health and Safety Plan is attached (Appendix 2).

2.3 MONITORING WELL INSTALLATION, DEVELOPMENT, AND SAMPLING

Monitoring wells will be installed in 19 soil borings drilled in the study area. The wells will be constructed up to a depth of approximately 120 feet below ground surface (bgs).

After monitoring wells have been constructed, the wells will be developed and sampled. A WaTerra hand pump or other low-flow, minimal drawdown technique will be used for groundwater purging and sampling. A bailer or passive skimmer will be used to collect nonaqueous-phase liquid (NAPL). All water removed from the wells during development will be disposed of as IDW.

2.4 PHYSICAL AND SAFETY HAZARDS

This section discusses the physical and safety hazards associated with activities at the site. An Activity Hazard Analysis is included in Section 2.5. Chemical exposure hazards are discussed in Section 2.6. Procedures for minimizing the chance of injury due to the hazards are briefly described in this section and detailed information is included in URS' Safety Management

Standards (SMSs) included in Appendix 1. The procedures will be discussed in the initial site health and safety meeting and during daily safety meetings.

2.4.1 Slip, Trip, and Fall Hazards

Slip, trip, and fall hazards are generally present at any work site. These hazards are compounded by wet or sloped surfaces, and surfaces composed of unstable materials (loose soil, vegetation, etc.). Drilling activities present a significant hazard for slip, trips, and falls due to the presence of hoses, tools, and other obstructions in the work area. Site workers shall anticipate and correct, as practical, situations where these hazards exist. Keeping a work area free of unnecessary clutter greatly reduces the likelihood of an injury. Wearing supportive footwear with heavy soles in good condition can also reduce slip, trip and fall hazards. Additional information is provided in SMS 21, Housekeeping.

2.4.2 Lifting Hazards

Improper lifting techniques can cause injuries to the back or other portions of the musculo-skeletal system. The following actions will reduce the risk of lifting injuries:

- Use handcarts, dollies, or other lifting and moving equipment to move objects too heavy to comfortably lift.
- Always lift with the legs, keeping the back straight. Avoid twisting the back while lifting, take small steps, and use your feet to pivot.
- Get assistance or use the proper equipment if there is any question about your ability to lift the load properly.

Additional information is provided in SMS 45, Back Injury Prevention.

2.4.3 Eye Injury Hazards

Well development and sampling can produce a hazard of eye injury due to splashing of contaminated groundwater. Small particles from soil movement and drilling may also cause eye injuries. Suitable eye protection must be worn at any time when an eye injury hazard exists. Protective eyewear required for the various site activities is listed in Section 5.2. An American National Standards Institute (ANSI)-approved portable eyewash station will be available at the work site.

2.4.4 Heavy Equipment

Heavy equipment will be used during site preparation, drilling, and SCAPS testing. The URS oversight employee(s) should be familiar with proper operation of heavy equipment (i.e., drilling and steam cleaning equipment). Problems should be brought to the attention of the Site Safety Officer (SSO) and documented in the field logbook. URS personnel will observe the following precautions whenever heavy equipment is in use:

- Personal protective equipment (PPE) such as steel-toed shoes, safety glasses or goggles, and hard hats must be worn whenever working around drill rigs or heavy equipment.

- Traffic safety vests are required for URS personnel working near mobile heavy equipment, or in areas of high vehicle traffic.
- All non-essential personnel will be kept out of the work area.
- Each URS vehicle near the construction area will have a first aid kit and a fire extinguisher available. All URS personnel working near the site will know the location of these items and ensure that these items are properly maintained.

Additional information is provided in SMS 19, Heavy Equipment Operations.

2.4.5 Buried Utilities and Other Buried Hazards

It is unlikely but possible that unknown buried utility lines (electrical, communications, sewer and water supply, natural gas pipelines, etc.) will be present at the investigation areas near EGDY. Buried electrical and water lines are present near the East Gate air stripper tower and treatment plant, and lead from the treatment plant to the infiltration galleries. The location of these utilities will be marked prior to beginning field activities. A digging permit including a utility survey must be obtained through Fort Lewis Public Works prior to beginning drilling or excavation activities. Additional information is provided in SMS 34, Utility Clearances.

The potential for encountering buried ordnance/munitions in the EGDY is not considered to be significant enough to require additional protection during intrusive activities. This conclusion is based on the following:

- Other ordnance disposal areas were available on Fort Lewis during the time EGDY was active; therefore, ordnance generally would not have been disposed of at EGDY.
- The possibility of disposal of ordnance at EGDY was evaluated during the expanded site investigation and was considered to be unlikely.
- Intrusive work conducted to date has not uncovered any live ordnance/munitions.

In the event that munitions are uncovered during intrusive activities, the procedures described in Section 2.7.3 will be followed.

2.4.6 Decontamination Activities

Large sampling equipment will be decontaminated with a high-pressure, hot-water washer. These units use a gasoline-powered pump and diesel-powered boiler to produce water that is discharged from a spray nozzle at pressures exceeding 2,000 pounds per square inch and temperatures exceeding 160°F. The water discharged from a pressure washer nozzle can cause severe lacerations and burns if allowed to contact even covered parts of the body. The pressure washer can also violently dislodge pieces of soil or rock from the equipment being cleaned, propelling them at very high velocity. The hot water also can volatilize or aerosolize chemical contaminants and contaminated soils. Personnel using a pressure washer to decontaminate equipment must comply with the operator's instructions for the pressure washer and wear the PPE described in Section 5.

2.4.7 Heat Stress

At temperatures of 70°F and greater, workers may suffer heat stress, especially if wearing impermeable clothing such as Tyvek. Heat stress is not anticipated to be a significant health hazard during this project, due to the moderate prevailing temperatures at the site. Short-term temperature extremes, however, may create conditions favorable to developing heat stress. SMS 18, Heat Stress (Appendix 1) provides descriptions of symptoms, methods for prevention and control, and monitoring protocols for heat stress. This standard will be followed, as necessary, to prevent workers from suffering heat stress. Institution of physiological monitoring and work/rest schedules will be the decision of the HSO, Project Manager, and the USACE Technical Manager. This decision will be based upon site worker's response to site conditions (temperature, humidity, sunlight, wind).

2.4.8 Noise

Regulations require that hearing protection be used when noise levels exceed 85 decibels (dBA) averaged over an 8-hour work day. The only sources of noise that may exceed 85 dBA are anticipated to be during operation of sonic drilling, SCAPS, and dozer activity.

Noise monitoring is not planned because the use of the noise producing equipment is periodic and of relatively short duration and personnel will be wearing hearing protection during excessively noisy conditions.

Hearing protection will be worn when any site activities are performed that produce noise loud enough to make conversation difficult without raising the voice at a distance of 3 feet. Hearing protection will be required at all times during operation of the drill rig. Foam insert ear plugs or protective ear muffs capable of a 25 dBA noise reduction rating are considered sufficient. Additional information is provided in SMS 26, Noise and Hearing Conservation.

2.4.9 Solar Radiation

Working outdoors without proper skin and eye protection against solar radiation (sunlight) can result in sunburn of the skin and the retina and other eye tissues. Solar radiation can cause severe burns under certain conditions. Persons who are not conditioned (tanned) are more susceptible to sunburn. Eye injury due to solar radiation is more common when working near highly reflective surfaces such as water, snow, or light-colored surfaces. Severe sunburn can occur even during overcast or cloudy days. Long-term exposure to sunlight can increase the risk of skin cancer.

Symptoms of sunburn include reddening of the skin and minor to severe pain when the sunburned skin is touched. Severe sunburn may result in blistering and ultimate shedding of the burned skin. The potential for sunburn can be reduced by wearing clothing that covers portions of the body that are susceptible to sunburn such as the back of the neck, the top of the head and ears, and the arms. Long-sleeved shirts and long pants or other fully-covering protective clothing will be worn at all times. Head protection during drilling and excavation operations will be provided by wearing hard hats. Head protection from sunburn during other activities where overhead hazards do not exist can be provided by wearing hats or caps. Sunscreen lotion or gel will be worn over those portions of the body that are not conditioned, or which cannot be

protected by clothing (face, neck and ears). A sunscreen lotion or gel with a sun protection factor (SPF) of 25 or greater is considered acceptable. If desired, a light-colored cloth may also be worn over the back of the neck to further reduce exposure to sunlight.

Symptoms of retinal sunburn include a painful, dry, scratched feeling on the eye surface, extreme sensitivity to sunlight, headache, and in extreme cases, temporary blindness. Protective eyewear meeting ANSI Z-87.1-1989 will be worn. Site personnel may want to wear protective eyewear equipped with shaded lenses.

2.4.10 Radiological Hazards

The potential for a significant radiological hazard is considered to be low. Monitoring for radiological hazards will not be required.

2.4.11 Biological Hazards

Being bitten or stung by noxious organisms such as insects, spiders, and small mammals may be a significant hazard, especially to those with known or unknown allergic sensitivity to insect stings. There are no known noxious reptiles at the EGDY site. All persons with known allergies should be identified prior to beginning work. At the recommendation of their personal physician, persons with severe allergies may wish to carry a self-administered treatment for allergic reaction.

Infectious agents such as bacteria and viruses can be present in any environment, but may be more prevalent within landfill materials. Infections can result if minor cuts, punctures, and abrasions are not thoroughly washed, disinfected, and treated. Infections can also occur if proper personal hygiene practices are not followed.

2.5 ACTIVITY HAZARD ANALYSIS

Table 2-1 presents an Activity Hazard Analysis for the various work tasks to be performed during the investigation.

2.6 CHEMICAL HAZARDS

Potential routes of exposure for the compounds listed in the previous sections include inhalation, ingestion, and dermal contact. Trenching and drilling activities within buried waste materials are the tasks that are most likely to result in release of volatile chemicals to worker breathing zones. However, due to the length of time since wastes were last disposed of (more than 25 years), and the coarse nature of the soils, most accumulations of volatile chemicals have probably volatilized or migrated downward into the groundwater system. It is not anticipated that concentrations of VOCs into the air near the sampling or drilling sites will exceed the permissible exposure level (PEL) for TCE (100 parts per million [ppm]), the most prevalent compound expected to be present on site. However, real-time air monitoring with a photoionization detector (PID) will be performed during those activities that are most likely to result in a release of VOCs into the atmosphere. Respiratory and PPE upgrades will be instituted if the results for air monitoring exceed the action levels provided in Section 2.7.

With the exception of any residual VOCs present, most of the substances detected in soil at EGDY are not appreciably volatile. Contaminant-laden dusts may be generated during the planned work. Drilling and trenching operations may produce excessive dusts if the work is performed during dry summer or fall months. Generation of dusts at other times of the year is less likely because of soil moisture conditions. Ingestion of contaminated soils is unlikely to occur because workers will be wearing protective gloves while handling samples, and workers are required to wash their hands prior to eating, drinking, or smoking. Furthermore, these activities will not be allowed in the exclusion zone. The potential for exposure due to dermal contact is not considered significant because workers will be wearing protective clothing and gloves.

Exploratory trenching performed by URS during a previous project at the site failed to encounter hydrogen sulfide. Hydrogen sulfide can be present in landfills due to anaerobic decay of organic material. Hydrogen sulfide is unlikely to be present at significant concentrations at EGDY because it is unlikely that putrescible wastes were buried within the landfill. Buried materials encountered previously consisted of non-putrescible solid wastes, many of which showed evidence of burning prior to burial. Monitoring for hydrogen sulfide will not be required during the drilling or trenching tasks at EGDY. However, in the event that the odor of hydrogen sulfide is commonly detected by field personnel, the SSO must be contacted so that suitable modifications to this SSHP can be developed, if appropriate.

Methane was not encountered during the previous exploratory excavation conducted by URS. Methane is also a common byproduct of decay of organic landfill materials. Methane is an odorless, colorless, flammable gas. It is not toxic; however, it can be an asphyxiant in situations where it replaces the ambient air. The upper and lower explosive level for methane are 15 percent (150,000 ppm) and 5 percent (50,000 ppm), respectively. As indicated earlier, the majority of wastes encountered at EGDY are non-putrescible solid wastes. Monitoring for methane with a combustible gas indicator will be performed during drilling and excavation activities, because methane is an odorless gas and its presence cannot be determined without the use of monitoring instruments. Action levels for combustible gas are provided in Section 2.7.

Tables 2-2 through 2-5 present physical properties, regulatory thresholds, symptoms of overexposure, and target organs for TCE, DCE, vinyl chloride, hydrogen sulfide, methane, and other selected site contaminants.

2.7 ACTION LEVELS AND HAZARD MITIGATION

Action levels are conditions that must exist to require a certain action that is intended to reduce the hazards created by the condition. Action levels are presented in the following sections for the various safety, chemical, and physical hazards noted above.

2.7.1 Action Levels for Safety Hazards

Site workers shall be vigilant for and immediately correct any situation where a safety hazard exists. The recognition and mitigation of safety hazards is necessary to reduce the risk of injury due to these hazards. The use of common sense and communication of safety hazards to other site workers are proven methods of reducing the frequency of accidents. If any task appears to

present a safety hazard, site workers shall bring the matter to the attention of the SSO so that proper mitigation of the hazard can be implemented.

2.7.2 Action Levels for Chemical Hazards

The probability of chemical exposure is anticipated to be low to moderate for this project. Ingestion and skin contact with potential contaminants is not expected to occur due to PPE and work practice requirements. Although unlikely, exposure by inhalation to VOCs may occur if site materials are discovered to be severely contaminated with VOCs or if contaminant-laden dusts are generated. Action levels for chemical hazards are based on the presence of total organic vapors as measured with a PID (Photovac Model 2020 equipped with a an 11.7 eV lamp). Action levels for vinyl chloride are based on concentrations measured with colorimetric tubes. Action levels for methane are based on measurements with a multi-gas detector. Action levels for airborne particulates are based the presence of visible and persistent airborne dusts.

2.7.2.1 Action Level for Total Organic Vapors and Vinyl Chloride

The action levels listed below are based upon the OSHA PELs for TCE (100 ppm) and vinyl chloride (1 ppm). These compounds were selected because they are the compounds with the lowest PELs that are most likely to be present on site. Monitoring for total organic vapors will be performed continuously with the PID during drilling operations. The other field tasks are not likely to produce significant concentrations of organic vapors; therefore, monitoring will not be required for other field tasks unless odors of organic vapors are apparent. The action level for upgrading to Level C respiratory protection is detecting persistent (3 minutes or more) total organic vapors in the breathing zone at 5 ppm or greater when measured with a PID. The action level for evacuating the work area is 50 ppm when measured with a PID. These action levels are based on the assumption that the majority of organic vapors detected are TCE and the response factor for the PID is 0.5 when the PID is calibrated with isobutylene.

Monitoring for vinyl chloride will be instituted if the PID measurements of total organic vapors exceed 5 ppm in the breathing zone continuously for at least 3 minutes. Because vinyl chloride is readily polymerized in air and sunlight, the proportion of airborne vinyl chloride is expected to compose a very small fraction of any total organic vapors detected. The action level to perform monitoring for vinyl chloride is thus very conservative. Airborne concentrations of vinyl chloride will be measured with colorimetric gas detector tubes. Tubes manufactured by Draeger Company shall be used, as they are the only readily available tubes with a measuring range sensitive enough to measure these compounds at concentrations below their PELs. The vinyl chloride tube shall be capable of measuring concentrations of 0.25 to 6 ppm. Measurements will be taken in the breathing zone of the worker most at risk once every 15 minutes that PID readings exceed 5 ppm. The SSO may decrease the sampling frequency based on site conditions, but the frequency must be no less than once every two hours.

Table 2-6 presents health and safety action levels for total organic vapors (assumed to be composed primarily of TCE) and vinyl chloride.

When measurements with a PID and colorimetric tubes indicate the presence of total organic vapors or vinyl chloride equal to or exceeding the action level to evacuate the work area, the following actions must be taken:

1. Personnel shall be moved at least 100 feet upwind of work area.
2. The HSO shall be contacted.
1. At the instruction of the HSO and after waiting 10 minutes for organic vapors to dissipate, the SSO may don an air-purifying respirator equipped with organic vapor/high-efficiency particulate air (HEPA) cartridges, and cautiously approach the work site from an upwind direction to determine the extent and concentration of organic vapor or vinyl chloride emissions. The SSO shall not enter any area where any of these readings exceed the action level to evacuate.
2. Personnel may reenter the work area only by clearance of the SSO after the cause of the emission has been determined and the source abated.
3. An incident report shall be prepared and submitted to the HSO. If the release of these substances cannot be controlled, or does not diminish below the action levels, the work may have to continue with supplied-air respiratory protection, in which case this SSHP would need to be modified and approved.

2.7.2.2 Action Level for Combustible Gases

Monitoring for combustible gases will be performed continuously during drilling operations using a direct-reading, multi-gas meter equipped with a sample draw pump. The meter must be capable of measuring combustible gases as a percent of the lower explosive limit for methane, and percent oxygen. Measurements of percent oxygen must be made to ensure that oxygen is present at concentrations between 19.5 and 22 percent. A breathing hazard exists and combustible gas readings are not reliable if oxygen is below 19.5 percent. Excessively flammable atmospheres may be present if oxygen concentrations exceed 22 percent.

The action levels for combustible gases presented in Table 2-7 are based on the presence of oxygen within the range of 19.5 to 22 percent.

When measurements indicate the presence of combustible gas levels equal to or exceeding the action level in the work area, the following evacuation action must be taken:

4. Personnel shall be moved at least 100 feet upwind of the work area.
5. The HSO shall be contacted.
1. At the instruction of the HSO and after waiting 15 minutes for combustible gases to dissipate, the SSO may use the detector to cautiously approach the work site from an upwind direction to determine the extent and concentration of combustible gas emissions. The SSO shall not enter any area where readings exceed the action level, nor shall the SSO make any approach if there is possibility of fire or explosion.
2. Personnel may reenter the work area only by clearance of the HSO after the cause of the emission has been determined and the source abated.
3. An incident report shall be prepared for submittal to the HSO. If the release of combustible gases cannot be controlled, or does not diminish below the action levels, the work may have

to continue under additional engineering or administrative controls, in which case this SSHP would need to be modified and approved.

2.7.2.3 Action Level for Airborne Particulates

Semivolatile organic compounds, chlorinated pesticides, PCBs, and metals have been detected in soil samples at EGDY. These substances are not appreciably volatile and often adsorb strongly to soil particles. While these compounds are not likely to become airborne as vapors, they may be present in the breathing zone adsorbed to airborne dusts.

The action level for upgrading to Level C PPE is based on the presence of visible and persistent dusts in the breathing zone. It is emphasized that encountering or generating hazardous levels of dust is unlikely given that subsurface soils are moist or nearly saturated. Dust control measurements such as periodically wetting the soil with water will be instituted if persistent visible dusts are present. Real-time dust monitoring is not required for this project; however, if dusty conditions cannot be controlled, real-time monitoring for dusts may be necessary, which would require modification of this SSHP. The action levels for dusts are presented in Table 2-8.

2.7.3 Engineering Controls and Work Practices

It is not anticipated that engineering controls such as the use of fans or other equipment will be required at this site. Should discharge of significant levels of airborne contaminants be difficult to control, the HSO shall be notified so that appropriate engineering controls can be developed and incorporated into this SSHP.

The potential for injury or exposure can be greatly reduced by instituting the following work practices:

- If any ordnance (explosive shells, bombs, hand grenades, and other explosives) is discovered, the immediate area will be evacuated and Fort Lewis Explosives and Ordnance Disposal (EOD) will be notified. If munitions (small arms ammunition) are uncovered during excavation, the backhoe will place the munitions outside the immediate work area and Fort Lewis EOD will be called to make further identification and remove the munitions, if necessary. If munitions that are obviously spent are encountered, no further action is required, and work may proceed with caution. The decision to obtain the services of a military ordnance or hazardous materials disposal squad will be made by the Project Manager with consultation with Fort Lewis Public Works and the USACE Project Manager. The phone number for Fort Lewis EOD is (253) 967-5507.
- Personnel are forbidden from handling anything other than soil cuttings, pumped groundwater, and soil, sediment, seep, or groundwater samples collected for laboratory analysis.
- Dusts will be controlled by wetting the dust source areas with potable water obtained from a nearby hydrant.
- Ground fault circuit interruption safety cords, plugs and adapters will be used with any electrical tool or appliance to reduce the risk of electrical shock.

Work practices and PPE will be used to reduce the risk of injury due to certain site hazards. Personal protective equipment is discussed in Section 5 and work practices are described in Section 10.

2.7.4 Prevention of Public Exposure to Site Hazards

The EGDY site is sometimes used by military personnel and families for personal exercise (jogging, etc.). In the event that unauthorized person(s) approach a work area, the person(s) will be asked to remain approximately 100 yards outside the work area. Prior to the Phase I expanded site investigation, Fort Lewis Range Control indicated that the EGDY area is not used for military training/maneuvering. Therefore, it is not necessary to coordinate with Fort Lewis Range Control prior to starting work for the Phase II RI.

Table 2-1
ACTIVITY HAZARD ANALYSIS

ACTIVITY	POTENTIAL HAZARDS	RECOMMENDED CONTROLS
Site preparation with heavy equipment	1. Heat stress	A. Follow SMS 18 in Appendix 1
	2. Physical hazards (e.g., being struck or run over) from large equipment	A. Notify equipment operators of your presence in work area B. Work well away from the hazard radius presented by heavy equipment C. Work within the operator's field of view
	3. Slip, trip and fall hazards	A. Correct situations where such hazards exist B. Wear proper footwear C. Maintain a clutter-free work area
	4. Noise (>85 dBA)	A. Wear hearing protection
	5. Sunburn	A. Wear sunscreen on exposed portions of body
	6. Poisonous/hazardous animals and plants	A. Inspect area to identify hazards plants/animals/insects prior to beginning work B. Remove or eradicate pests C. Persons with known allergies to bee/wasp stings may carry antihistamines under advice of personal physician
EQUIPMENT	INSPECTION REQUIREMENTS	TRAINING REQUIREMENTS
Level D and other PPE as described in Section 5	1. Inspect all heavy equipment each day prior to use	A. Training as required in Section 4
	2. Inspect area to be cleared for the presence of bee and wasp nests	

Table 2-1 (Continued)
ACTIVITY HAZARD ANALYSIS

ACTIVITY	POTENTIAL HAZARDS	RECOMMENDED CONTROLS
Groundwater investigation (drilling, well construction, well development, collecting soil samples from well borings) and working near drilling rig	1. Heat stress	A. Follow SMS 18 in Appendix 1
	2. Physical hazards (e.g., being struck or run over or smashed fingers or toes) from large equipment	A. Follow requirements of SMS 19 in Appendix 1 B. Use machine guards as appropriate
	3. Lifting hazards	A. Use proper lifting techniques B. Use proper tools or request assistance if object is too heavy
	4. Slip, trip and fall hazards	A. Correct situations where such hazards exist B. Wear proper footwear C. Maintain a clutter-free work area
	5. Noise (>85 dBA)	A. Wear hearing protection
	6. Electrocution or explosions due to contact with underground utilities	A. Do not drill until utility survey is complete
	7. Airborne chemical hazards (methane, H ₂ S, organic vapor, dusts)	A. Monitor for chemicals using instruments/methods described in Section 8 B. Ventilate area to remove vapors or wet soils to prevent dusts C. Wear respiratory protection (Section 5) or evacuate area based on action levels specified in Section 2.7
	8. Encountering small arms munitions, ordnance	A. Identify and avoid metallic debris B. Minimize number of personnel in work area during drilling C. Do not touch or disturb ordnance, contact Fort Lewis EOD (253) 967-5507
	9. Fire hazards	A. Smoke only in designated areas B. Ensure spark arrester is in working order C. Refuel vehicles only at a commercial fuel dispenser D. Keep fire extinguisher readily available
EQUIPMENT	INSPECTION REQUIREMENTS	TRAINING REQUIREMENTS
Drilling rig and associated equipment, PPE and air monitoring equipment as described in SSHP	1. Have buried utility survey performed prior to work	1. Training as described in Section 4
	2. Inspect rig and equipment each day prior to work	2. Rig crew shall be trained in proper and safe operation of the rig

Table 2-1 (Continued)
ACTIVITY HAZARD ANALYSIS

ACTIVITY	POTENTIAL HAZARDS	RECOMMENDED CONTROLS
Decontamination activities (large or small equipment)	1. Heat stress	A. Follow requirements of SMS 18 in Appendix 1
	2. Lifting hazards	A. Use proper lifting techniques B. Use proper tools or request assistance if object is too heavy
	3. Slip, trip, or fall hazards	A. Correct situations where severe hazards exist B. Wear proper footwear
	4. Sunburn	A. Wear sunscreen on exposed portions of body
	5. Airborne chemical exposure	A. Monitor for airborne contaminants and wear respiratory protection, if necessary
	6. Contact with contaminated soil/water/sediment	A. Wear PPE as described in Section 5
	7. Contact with hot water pressure washer stream	A. Always point washer wand away from body. B. Wear PPE as described in Section 5
	8. Contact with acid or methanol rinse agents	A. Wear PPE B. Reneutralize acids with sodium bicarbonate after use, dilute methanol with water after use
EQUIPMENT	INSPECTION REQUIREMENTS	TRAINING REQUIREMENTS
Brushes, pressure washer, acid rinse, methanol rinse, Liquinox solution, potable and distilled water, PPE	1. Inspect pressure washer prior to use	A. Training as described in Section 4

Table 2-1(Continued)
ACTIVITY HAZARD ANALYSIS

ACTIVITY	POTENTIAL HAZARDS	RECOMMENDED CONTROLS
NAPL sampling	4. Heat or cold stress	A. Follow SMS 18 in Appendix 1
	5. Chemical exposure	A. Wear PPE described in Section 5 B. Limit amount of NAPL removed from well to the minimum necessary for analysis C. Work from cross-wind direction of potential airborne chemical source
	6. Lifting hazards	A. Use proper lifting techniques B. Use proper tools or request assistance if object is too heavy
	1. Slip, trip and fall hazards	A. Correct situations where such hazards exist B. Wear proper footwear C. Maintain a clutter-free work area
	2. Sunburn	A. Wear sunscreen on exposed portions of body
	1. Poisonous/hazardous animals and plants	A. Inspect area to identify hazards plants/animals/insects prior to beginning work B. Remove or eradicate pests C. Persons with known allergies to bee/wasp stings may carry antihistamines under advice of personal physician
EQUIPMENT	INSPECTION REQUIREMENTS	TRAINING REQUIREMENTS
Syringes, VOC containers, tubing, caps; PPE as described in Section 5	2. Determine presence of NAPL with drop line and water-finding paste	A. Training as required in Section 4
	3. Inspect well to be opened for the presence of bee and wasp nests	

Notes:

NAPL: nonaqueous-phase liquid

PPE: personal protective equipment

SSHP: Site Safety and Health Plan

VOC: volatile organic compound

Table 2-2
PROPERTIES OF POTENTIAL CHEMICALS OF CONCERN

CHEMICAL	LOWER EXPLOSIVE LIMIT (percent in air)	UPPER EXPLOSIVE LIMIT (percent in air)	APPEARANCE AND ODOR
Trichloroethene	8	10.5	Colorless, combustible liquid with chloroform-like odor.
1,2-Dichloroethene	5.6	12.8	Colorless, flammable liquid with chloroform-like odor.
1,1,1-Trichloroethane	6	15	Colorless, flammable liquid with chloroform-like odor.
Tetrachloroethene	Noncombustible	Noncombustible	Colorless liquid with mild chloroform-like odor.
Vinyl chloride	3.6	33	Flammable gas with pleasant odor at high concentrations.
Hydrogen sulfide	4	44	Flammable gas with odor of rotten eggs.
Methane	5	15	Flammable odorless gas.

Notes:

ppm: parts per million

Source: Genium Publishing Corporation Material Safety Data Sheets (MSDS) collection.

Table 2-3
REGULATORY THRESHOLDS FOR POTENTIAL CHEMICALS OF CONCERN

CHEMICAL	OSHA PEL	STEL	IDLH
Trichloroethene	100 ppm	200 ppm (ceiling)	1,000 ppm
1,2-Dichloroethene	200 ppm	--	1,000 ppm
1,1,1-Trichloroethane	350 ppm	--	700 ppm
Tetrachloroethene	100 ppm	200 ppm (ceiling)	150 ppm
Vinyl chloride	1 ppm	5 ppm (ceiling)	NA
Hydrogen sulfide	--	20 ppm (ceiling)	100 ppm
Methane	--	--	10 % LEL (5,000 ppm)

Source: Online NIOSH Pocket Guide to Chemical Hazards, <http://www.cdc.gov/niosh/npg/pgdstart.html>, June 27, 2001

Notes:

IDLH - immediately dangerous to life or health
 LEL - lower explosive limit
 NA - not applicable
 OSHA - Occupational Safety and Health Administration
 PEL - permissible exposure limit
 STEL - short-term exposure limit

Table 2-4
SYMPTOMS OF OVEREXPOSURE AND EFFECTS OF POTENTIAL CHEMICALS OF CONCERN

CHEMICAL	SIGNS OF OVEREXPOSURE							PRIMARY ENTRY ROUTE
	HEADACHE	IRRITATION ^a	DERMATITIS	GI DISTURBANCE ^b	NAUSEA	NERVOUS SYSTEM ^c	OTHER	
Trichloroethene		X	X		X		Fatigue, giddiness, cardiac arrhythmia	Inhalation, absorption, skin contact
1,2-Dichloroethene		X				X		Inhalation, absorption, skin contact
1,1,1-Trichloroethane		X	X			X		Inhalation, absorption, skin contact
Tetrachloroethene	X	X	X		X	X	Flushed face and neck, somnolence	Inhalation, absorption, skin contact
Vinyl chloride				X			Weakness, abdominal pain	Inhalation
Hydrogen sulfide	X	X		X	X	X	Apnea, convulsions, lacrimation, photosensitivity	Inhalation
Methane							Non toxic, but simple asphyxiant when it displaces oxygen	Inhalation

Notes:

^aIrritation means irritation of eyes, skin, respiratory system, mucous membranes

^bGastrointestinal (GI) disturbance includes abdominal pain, constipation, weight loss, etc.

^cNervous system effects include nervousness, narcosis, spasms, depression, euphoria, giddiness, light headedness, numbness, vertigo, dizziness, etc.

Table 2-5

TARGET ORGANS OF POTENTIAL CHEMICALS OF CONCERN

CHEMICAL	TARGET ORGAN							
	NERVOUS SYSTEM	SKIN	KIDNEYS	LIVER	RESPIRATORY SYSTEM	EYES	CANCER	OTHER
Trichloroethene	X	X		X	X	X	X	Heart
1,2-Dichloroethene	X				X	X		
1,1,1-Trichloroethane	X	X			X	X	X	
Tetrachloroethene	X	X	X	X	X	X	X	
Vinyl chloride	X	X		X		X	X	
Hydrogen sulfide	X				X	X		Causes olfactory fatigue
Methane								Simple asphyxiant, not toxic. Hazard due to flammable properties

Table 2-6
HEALTH AND SAFETY ACTION LEVELS FOR TOTAL ORGANIC VAPORS

MONITORING EQUIPMENT	RESULT	ACTION
PID	< 5 ppm	Monitor continuously with PID
PID	> 5 ppm and <50 ppm	Upgrade to Level C, continue monitoring with PID, measure for vinyl chloride every 30 minutes with colorimetric tubes. The SSO may decrease sampling frequency based on site conditions, but frequency may be no less than every 2 hours.
PID	> 50 ppm	Evacuate work area, contact HSO
Vinyl chloride detector tubes	> 0.5 ppm in breathing zone	Evacuate work area, contact HSO
Observation	Work conducted in visibly contaminated materials or splash hazard with potentially contaminated materials	Upgrade to modified Level D

Note:

The PID should be calibrated with isobutylene. The concentration identified on the cylinder for calibration of a PID with an 11.7 eV lamp should be a benzene equivalent.

Table 2-7
ACTION LEVELS FOR COMBUSTIBLE GASES

COMBUSTIBLE GAS MEASUREMENT	ACTION
Combustible gas < 10 percent LEL	Continue working and monitoring
Combustible gas $\geq$ 10 percent LEL	Extinguish all possible ignition sources in the work area and shut down all powered equipment. Evacuate work area.

Table 2-8
ACTION LEVELS FOR DUSTS

BREATHING ZONE OBSERVATION	REQUIRED PPE LEVEL
Visible and persistent dusts NOT present in the breathing zone	Level D PPE
Visible and persistent dusts present in the breathing zone	Institute dust control measurements. If dusts cannot be controlled, wear Level C PPE (organic vapor/HEPA cartridge)

URS' health and safety program has been established to provide sound, uniform health and safety practices and procedures company-wide. The Corporate Health and Safety Administrator (CHSA) is responsible for the comprehensive company-wide administration of the program. Regional administration and supervision is performed by the Regional Health and Safety Manager (RHSM). Administration of the Health and Safety Program within individual offices is the responsibility of the office of the Health and Safety Officer (HSO). Implementation of the program for specific projects is the direct responsibility of the Project Manager.

The CHSA and RHSM are typically Certified Industrial Hygienists who have extensive experience in hazardous waste operations. The HSOs are typically scientists or engineers with experience working at many different types of sites encompassing many different types of site hazards.

The personnel composing the project health and safety organization and their respective safety-related and project responsibilities are described in this section of the SSHP.

Corporate Health and Safety Administrator (CHSA) – Phil Jones, CIH

Responsibilities

- Track health and safety regulations and implement improvements to the contractor health and safety program
- Maintain records pertaining to medical surveillance, training, fit testing, chemical exposure, and incidents
- Update health and safety manual
- Manage medical surveillance program
- Develop and implement the health and safety training program
- Provide industrial hygiene/chemical safety guidance to RHSM and HSO
- Audit key aspects of health and safety program and report effectiveness to the Executive Vice President for the Practice

Authority

- Approve the health and safety qualifications of employees to work at hazardous waste sites
- Approve or disapprove Site Safety and Health Plans
- Establish employee training and medical surveillance procedures
- Suspend work on any project that jeopardizes the health and safety of personnel

Regional Health and Safety Manager (RHSM) – Tim Reinhardt, CIH

Responsibilities

- Direct the implementation of the health and safety program of the operating group and provide recommendations for improvement of the program
- Coordinate health and safety activities of the business unit offices in the operating group

- Determine need for project Site Safety and Health Plans
- Review and approve Site Safety and Health Plans
- Monitor implementation of Site Safety and Health Plans
- Investigate reports of incidents or accidents and report accidents or incidents to the CHSA
- Assist CHSA with employee health and safety training in the operating group
- Determine whether an accidental exposure or injury merits a change in the affected individual's work assignments and whether changes in work practices are required
- Coordinate business units with regard to health and safety equipment needs

Authority

- Approve or disapprove Site Safety and Health Plans
- Direct business unit HSO to prepare project Site Safety and Health Plans
- Access project files
- Direct changes in personnel work practices to improve health and safety of employees involved in hazardous waste management projects
- Remove individuals from projects if their conduct jeopardizes their health and safety or that of co-workers
- Suspend work on any project which jeopardizes the health and safety of personnel involved

*Health and Safety Officer (HSO) – Heather Boge**Responsibilities*

- Interface with project managers in matters of health and safety
- Report to RHSM on health and safety matters
- Develop or review and approve project Site Safety and Health Plans prior to submittal to the RHSM for review
- Conduct staff training and orientation on health and safety related activities
- Appoint or approve site safety officers
- Monitor compliance with Site Safety and Health Plans and conduct site audits
- Assist project managers to obtain required health and safety equipment
- Approve personnel to work on hazardous waste management projects with regard to medical examinations and health and safety training

Authority

- Suspend work or otherwise limit exposure to personnel if a Site Safety and Health Plan appears to be unsuitable or inadequate

- Direct personnel to change work practices if existing practices are deemed to be hazardous to health and safety of personnel
- Remove personnel from projects if their actions or condition endangers their health and safety or the health and safety of co-workers

Project Manager – Janette Rau***Responsibilities***

- Ensure that the project is performed in a manner consistent with the contractor health and safety program
- Ensure that the project Site Safety and Health Plan is prepared, approved, and properly implemented
- Provide the HSO with the information needed to develop Site Safety and Health Plans
- Implement Site Safety and Health Plans
- Ensure that adequate funds are allocated to fully implement project Site Safety and Health Plans
- Ensure compliance with Site Safety and Health Plans of contractor personnel
- Coordinate with the HSO on health and safety matters

Authority (Safety Related)

- Assign HSO-approved SSO to project and, if necessary, assign a suitably qualified replacement
- Suspend field activities if health and safety of personnel are endangered, pending an evaluation by the HSO and/or RHSM
- Suspend an individual from field activities for infractions of the Site Safety and Health Plan, pending an evaluation by the HSO, RHSM, and/or CHSA

Site Safety Officer (SSO) – John Rapp***Responsibilities***

- Direct health and safety activities on site
- Report immediately all safety-related incidents or accidents to the RHSM, HSO, and Project Manager
- Assist project managers in all aspects of implementing Site Safety and Health Plans
- Maintain health and safety equipment on site
- Implement emergency procedures as required

Authority

- Temporarily suspend field activities if health and safety of personnel are endangered, pending further consideration by the HSO and/or RHSM
- Temporarily suspend an individual from field activities for infractions of the Site Safety and Health Plan, pending further consideration by the HSO and/or RHSM

*Site Workers**Responsibilities*

- Perform all site activities described in this SSHP according to the guidelines and procedures established in this SSHP
- Report immediately all safety-related incidents or accidents to the SSO
- Assist the SSO in all aspects of implementing the SSHP
- Properly use, maintain, and store safety equipment according to the provisions of this SSHP and the contractor health and safety program
- Notify the SSO of any actual or potential emergency situations and correct those that require immediate attention

Authority

- Temporarily suspend field activities if health and safety of personnel are endangered, pending further consideration by the SSO, HSO and/or RHSM

*Subcontractors**Responsibilities*

- Perform all site activities described in this SSHP according to the guidelines and procedures established in this SSHP
- Report immediately all safety-related incidents or accidents to the SSO
- Properly use, maintain, and store safety equipment according to the provisions of this SSHP and the contractor health and safety program
- Notify the SSO of any actual or potential emergency situations and correct those that require immediate attention

Authority

- Temporarily suspend field activities if health and safety of personnel are endangered, pending further consideration by the SSO, HSO and/or RHSM

All URS and subcontractor employees will obtain health and safety clearance from the HSO before beginning work at the sites. Employees assigned to field operations must have had the training described in the following sections prior to working at the site.

4.1 HAZARDOUS WASTE SITE OPERATIONS

Personnel assigned to work at the site must have received Hazardous Waste Site Operations training as required by 29 CFR 1910.120. At a minimum, the requirements listed below apply to all site workers who handle samples or sampling equipment.

- All personnel must be currently participating in a medical surveillance program as required by 29 CFR 1910.120, be physically fit, and able to perform assigned field work as certified by an approved occupational health physician.
- Employees of URS and its subcontractors assigned to work at the site must have completed 40-hour basic Hazardous Waste Site Operations training as stipulated in 29 CFR 1910.120.
- Field Managers and SSOs who are directly responsible for, or who supervise employees engaged in hazardous waste site operations shall receive 40 hours of basic training and at least 8 hours of specialized supervisor training, as required by 29 CFR 1910.120. The specialized training must include topics such as the employer's Health and Safety Program, PPE, spill containment techniques, health hazard monitoring, and accident liability and reporting procedures. Persons who are on site to perform limited, specific tasks that do not have the potential to expose the worker to hazardous substances may substitute the 40-hour training with a 24-hour course as stipulated by 29 CFR 1910.120. The survey crew and site clearing crew may operate under the 24-hour training provision.
- As required by 29 CFR 1910.120, all employees will have received 8 hours of refresher training on an annual basis after the first year of 40-hour training (or 24-hour) has passed. The refresher training should include a review of information presented in the basic course, critique of safety incidents that may have occurred during the past year, and other relevant topics.
- The SSO and at least one other person on site shall have completed basic first aid and adult cardiopulmonary resuscitation (CPR) training, at a minimum. When any field activities are performed in isolated areas, a minimum of two persons trained in first aid/adult CPR must be present.
- All personnel must have passed a respirator fit test with isoamyl acetate and/or irritant smoke as an indicator of fit within the past year.
- Each employee assigned to work at the site shall also have a minimum of 3 days of field experience under the direct supervision of trained, experienced personnel. The field experience shall include hands-on training in the proper use and calibration of field instruments being used on site.

4.2 SITE-SPECIFIC TRAINING

Before beginning field work, employees and subcontractors must be briefed by the SSO on safety procedures as they pertain to individual anticipated work assignments at the site. At the end of the meeting, attendees will be requested to sign the Safety Compliance Agreement Form attached to the front of this SSHP stating that they have been briefed on the plan, understand it, and agree to comply with the provisions of this plan as they apply to their particular work assignments. Individuals refusing to sign the agreement will be prohibited from working at the site. The completed form is to be maintained in the URS project file. Additional daily safety meetings shall be held as necessary to ensure that health and safety procedures are being followed.

Visitors, including USACE and regulatory personnel, who wish to be present during sampling activities must also receive an initial health and safety briefing, and sign the Compliance Agreement Form. Visitors must also present documentation of training and medical surveillance. This is to ensure visitors are familiar with the activities to be performed, the hazards associated with these activities, and the controls for those hazards. This SSHP is to be followed by all visitors to protect the health and safety of both visitors and site personnel.

4.3 TRAINING DOCUMENTATION

Certificates and other documents providing proof that individual workers have received the necessary training described above must be readily available. URS reserves the right to request training certificates from any persons prior to allowing them to begin work at the site.

5.1 URS PERSONAL PROTECTIVE EQUIPMENT PROGRAM

As required by OSHA, URS maintains a written PPE program. The PPE program includes selection and use of PPE, including respiratory protection equipment, respirator fit testing, and care maintenance and storage of PPE. Additional information is provided in SMS 29, Personal Protective Equipment.

5.2 LEVELS OF PROTECTION

During site preparation and heavy equipment operation, Level D or modified Level D will be worn. Modified Level D will be worn when handling contaminated soil or groundwater. Level C will only be worn if action levels described in Section 2.7.2.1 are exceeded. Levels of protection for PPE requirements for this project are as follows:

Level D

- Long-sleeve, long-pant outfit.
- Additional wind-proof, water-proof, and insulating clothing to protect against prevailing weather conditions.
- Hard hat meeting ANSI Z-89.1-1986. (Hard hat required during site clearing, drilling, excavation, and direct-push sampling operations, or any other operation where a significant overhead hazard exists.)
- Steel-toe and shank boots meeting ANSI Z-41-1991. Chemical-resistant rubber boots must be worn while working in chemically impacted areas. Steel-toe leather boots may be worn if significantly contaminated soils will not be contacted.
- Safety glasses with side shields meeting ANSI Z-87.1-1989. Glasses may be tinted or clear depending upon lighting conditions. A face shield must be worn when operating chain saws, line-trimmers, or chipper/shredders during site clearing operations.
- Leather work gloves can be worn by the site clearing crew and any other personnel performing activities that require hand protection where potentially contaminated materials are not handled.
- Hearing protection, as required. Foam insert earplugs or earmuffs meeting ANSI S3.19-1974 are acceptable.
- Safety vest.

Modified Level D

- Standard Tyvek or KleenGuard-type coveralls.
- Additional wind-proof, water-proof, and insulating clothing to protect against prevailing weather conditions.

- Hard hat meeting ANSI Z-89.1-1986. (Hard hat required during site clearing, drilling, excavation, and direct-push sampling operations, or any other operation where a significant overhead hazard exists.)
- Steel-toe and shank boots meeting ANSI Z-41-1991. Chemical-resistant rubber boots must be worn while working in chemically impacted areas.
- Safety glasses with side shields meeting ANSI Z-87.1-1989. Glasses may be tinted or clear depending upon lighting conditions.
- Splash shield meeting must be worn when sampling chemically impacted water.
- Nitrile outer gloves with a minimum length of 13 inches when handling potentially contaminated materials.
- Latex or nitrile inner gloves when handling potentially contaminated materials.
- Hearing protection, as required. Foam insert earplugs or earmuffs meeting ANSI S3.19-1974 are acceptable.
- Safety vest.

Level C

- Full face respirator (approved by the Mine Safety and Health Administration and National Institute for Occupational Safety and Health and meeting ANSI Z-88.2-1968) with combination organic vapor/HEPA filter cartridges.
- Tyvek or coated Tyvek coveralls.
- Additional wind-proof, water-proof, and insulating clothing to protect against prevailing weather conditions.
- Hard hat meeting ANSI Z-89.1-1986. (Hard hat required during site clearing, drilling, excavation, and direct-push sampling operations, or any other operation where a significant over head hazard exists.)
- Chemical-resistant, rubber, steel-toe and shank boots meeting ANSI Z-41-1991.
- Nitrile outer gloves with a minimum length of 13 inches when handling potentially contaminated materials.
- Latex or nitrile inner gloves when handling potentially contaminated materials.
- Hearing protection, as required. Foam insert earplugs or earmuffs meeting ANSI S3.19-1974 are acceptable.
- Safety vest.

Level B

Level B PPE is beyond the scope of services for this project. This SSHP will need to be amended if site conditions require Level B personal protection. Level B PPE is described here purely for reference.

- Self-contained or supplied-air breathing apparatus with a positive-pressure, full-face air mask (approved by the Mine Safety and Health Administration and National Institute for Occupational Safety and Health and meeting ANSI Z-88.2-1968) utilizing Grade D breathing air. A 5-minute escape bottle must be used if a supplied-air respirator is used.
- Coated Tyvek or Saranex coveralls with hood, ankles, and arm cuffs taped closed with duct tape.
- Chemical-resistant rubber boots, with coverall cuff taped to outside of boot.
- Butyl outer gloves with a minimum length of 13 inches taped to the coated Tyvek suit on the outside of the arm.
- Latex or nitrile inner gloves.

5.3 PERSONAL PROTECTIVE EQUIPMENT EFFECTIVENESS AND RESPIRATOR FIT CHECK

Procedures to determine the effectiveness of the PPE program would include wipe testing of PPE, quantitative measurements of airborne chemical concentrations inside and outside of respiratory protective equipment, and measurement of biological exposure indices for specific contaminants in blood, urine, or other body fluids and tissues. This type of testing is more applicable to larger, longer-term projects where concentrations of contaminants are commonly above the PEL. This type of testing is not anticipated be required during this project because of the very low probability of encountering significantly hazardous levels of chemicals. However, this type of testing may be instituted if conditions encountered in the field indicate that the chemical hazards are significantly greater than anticipated. This type of testing would be described in a modification to this SSHP.

The SSO will ensure that site workers are wearing PPE as required by this SSHP.

URS and subcontractors shall perform qualitative respirator fit testing at a minimum frequency of once per year. Respirator fit testing certificates will be in possession by all field personnel. A respirator fit check shall be performed each time a respirator is donned. Respirators are to be properly cleaned, maintained, inspected, and stored according to the manufacturer's specifications after each use.

URS and subcontractor employees who are assigned to work at the site are required to participate in an on-going medical surveillance program satisfying the requirements of 29 CFR 1910.120.

An occupational health physician must have examined the employee within the past 12 months and must certify that the employee is physically fit to wear a respirator and perform work at hazardous waste sites. Documentation of medical clearance and the physician's opinion shall be in the form of a letter or document signed by the reviewing physician. Individuals whose medical clearance is not current will not be permitted to work on site. All medical records must be maintained by the physician in accordance with 29 CFR 1910.20.

6.1 EXAMINATION FREQUENCY AND PROTOCOL

The medical examination frequency and protocol must meet the requirements of 29 CFR 1910.120. URS and subcontractor personnel performing less than 30 days of field work per year at hazardous waste sites with low to moderate hazards may receive biennial physicals based on the reviewing physician's recommendations. Those persons who typically work more than 30 days per year at hazardous waste sites are required to have annual physical exams. Due to the relatively low probability of encountering significant chemical hazards at this site, special medical monitoring will not be required.

6.2 OCCUPATIONAL HEALTH PHYSICIAN

URS and subcontractor medical surveillance programs are required to be administered by a physician certified in occupational medicine by the American Board of Preventative Medicine.

6.3 MEDICAL MONITORING PROGRAM CERTIFICATION/PHYSICIAN'S OPINION

URS and subcontractor medical surveillance physicians may be required to provide health status medical reports for personnel participating in the program. The reports certify the employee's participation in a medical surveillance program and include the written opinion and signature of the occupational health physician.

6.4 MEDICAL MONITORING RECORDS

Medical monitoring records are retained by the occupational health physician in accordance with and for the period specified by 29 CFR 1910.20.

The probability of radiation sources being present at the site is very low. Radiation dosimetry will not be required unless evidence is encountered that suggests a significant probability that radioactive substances may be present in EGDY. Evaluation of radiation sources would require that this SSHP be amended to include a radiation safety plan.

The following SMSs, which are applicable to the work to be performed during this investigation, are provided in Appendix 1. These SMSs are referred to throughout this SSHP. The procedures are intended to provide a base of broadly applicable procedures and requirements.

SMS 18	Heat Stress
SMS 19	Heavy Equipment Operations
SMS 21	Housekeeping
SMS 26	Noise and Hearing Conservation
SMS 29	PPE
SMS 34	Utility Clearances and Isolation
SMS 42	Respiratory Protection
SMS 45	Back Injury Prevention
SMS 49	Injury/Illness/Incident Reporting

8.1 SITE RULES

The following rules apply to the activities to be conducted at EGDY.

- Whenever possible, field personnel will work from a position upwind of possible contamination.
- Personnel will not work alone at any time
- Smoking, eating, drinking, chewing gum or tobacco, storing food or food containers shall not be permitted in the work area. Food and water may be stored in the temporary site office. Good personal hygiene must be practiced by field personnel to avoid ingestion of contaminants or spread of contaminated materials.
- Hands shall be thoroughly cleaned with soap and water prior to eating, drinking, smoking, or other activities.
- No one will approach or enter areas or spaces where toxic concentrations of vapors or dust may exist without proper equipment available to enable safe entry.
- Entry into trenches is forbidden.

The sampling personnel shall work in pairs. Crew members must observe each other for signs of toxic exposure. Indication of adverse effects include, but are not limited to:

- Changes in complexion and skin discoloration
- Changes in coordination
- Changes in demeanor
- Excessive salivation and pupil response
- Changes in speech pattern

Also, employees shall inform each other and the SSO of non-visible effects of toxic exposure such as:

- Headaches
- Dizziness
- Nausea
- Blurred vision
- Cramps
- Irritation of eyes, skin, or respiratory tract

8.2 WORK PERMIT AND INSPECTION REQUIREMENTS

Fort Lewis Public Works must be notified 2 weeks prior to beginning work so that a Digging Permit can be issued. The Digging Permit requires that an underground utility survey be performed prior to the permit being issued.

8.3 MATERIAL HANDLING PROCEDURES

All samples shall be handled as described in the Sampling and Analysis Plan. All necessary protective equipment listed in Section 5 will be worn when handling sample material. IDW such as drill cuttings and excess sample material, used PPE, used decontamination solutions, and other solid wastes will be handled as described in the FSP.

8.4 CONTAINER HANDLING PROCEDURES

If it becomes necessary to store drill cuttings or other potentially contaminated materials, Washington State Department of Transportation (DOT)-approved type 1A2 drums (open-topped steel drums) will be used. Drums and other containers shall be handled using a drum dolly or other mechanical handling means, as applicable and necessary. Drum lids shall be fastened and sealed prior to handling or moving drums.

Drums shall be appropriately labeled and stored within an area indicated by the USACE. Following receipt of laboratory results, proper disposal of the drum contents can be arranged.

8.5 FALL PROTECTION

If it is necessary for a member of the drill rig crew to climb the drill rig derrick to make a repair of the derrick, every effort will be made to lower the derrick to allow the work to be performed from a lower position. If it cannot be lowered, the crew member must wear a full body harness system secured to a fall protective anchor with a 6-foot lanyard. The harness and lanyard must meet the requirements of 29 CFR 1926.104 and ANSI A10.14. The drilling subcontractor must have a written Fall Protection Work Plan meeting the requirements of 29 CFR 1926.104.

8.6 HAZARD COMMUNICATION

This SSHP serves to communicate to site workers all anticipated safety, chemical, physical, and biological hazards as well as methods for identifying and minimizing such hazards. Tables 2-1 through 2-4 describe health effects and physical properties of selected compounds that may be present on site. Material safety data sheets for contaminants potentially present in site media are not required, as these substances may be present as very low concentration residues rather than commercial products. All containers of chemicals or chemical wastes are required to be properly labeled. All personnel will have received Hazard Communication Standard (HAZCOM) training consistent with their tasks. This plan requires the use of engineering controls, safe work practices, and/or protective clothing for all tasks where hazardous substances or situations may be present.

8.7 ILLUMINATION

All tasks will be performed during daylight hours. Although it is not anticipated to be necessary to leave excavations open overnight, any excavations that may be left open will be marked with caution tape and fluorescent cones to protect military personnel who may be conducting night exercises in the area.

The temporary field office will be equipped with overhead fluorescent lighting capable of producing ample light for the intended use of the office.

8.8 SANITATION

A portable toilet will be brought on site, and potable water will be available in the field office for face and hand washing. The locations of sanitation areas will be discussed during the site safety briefing.

8.9 SIGNS AND LABELS

A warning sign indicating that the site is a “restricted area” will be posted at the main entrance. The drill rig must be equipped with all necessary signs and markings that indicate various hazards (steps, moving machinery, locations of fire extinguisher and first aid kit, etc.). Red or yellow barricade tape with the words “Caution Do No Enter” will be placed around each work area to indicate dangerous conditions and restrict entry of unauthorized persons.

8.10 COMMUNICATIONS EQUIPMENT

The sampling crew and drill rig crew will have cellular telephones. The numbers of the cellular telephones assigned to the field will be recorded by all necessary parties at the time of the initial site safety briefing. Fixed telephones also will be available in the field office.

9.1 SITE ACCESS AND SECURITY

The work will be performed in a remote area generally not available to public access. All work areas will be restricted to members of the sampling or drill rig crew. Unauthorized personnel entering EGDY will be requested to remain at least 100 yards from the work areas.

9.2 WORK ZONES

The area surrounding each immediate work area will be delineated by traffic cones and plastic barricade tape. Small sampling equipment (spoons, split-spoons, etc.) will be decontaminated within the exclusion zone at each separate drilling or sampling area. Large equipment will be decontaminated at each drilling or excavation location. The support zone is designated to be the field office. Actual work zones will be determined and delineated based on field conditions.

9.3 ON-SITE AND OFF-SITE COMMUNICATIONS

On-site communications will be by voice. Three two-second blasts of a vehicle horn or portable air horn will be used to signal site evacuations. If respirators are donned, the following hand signals/gestures will be used:

- Hand on throat - can't breathe
- Hand on wrist - leave exclusion zone
- Thumbs up - okay
- Thumbs down - not okay

Off-site communications will be by cellular telephone and fixed telephone. Cellular telephone numbers will be exchanged during the initial safety briefing.

10.1 SANITARY FACILITIES

A portable toilet will be brought on site, and potable water will be available in the field office for face and hand washing. The locations of sanitation areas will be discussed during the site safety briefing.

10.2 PERSONNEL DECONTAMINATION PROCEDURES

Because concentrations of contaminants are expected to be very low, construction of a multi-station personnel decontamination facility will not be required. Sampling personnel will decontaminate by removing gloves and any outer protective clothing and thoroughly washing their hands with soap and water. Soils adhering to boots may be washed off at each drilling area with a stream of water augmented by brushing with a nylon brush and Liquinox detergent solution, if necessary. All personnel shall thoroughly wash their hands prior to eating, drinking, or smoking and prior to leaving the site each day.

Emergency personnel decontamination will be performed if anyone is exposed to or comes in contact with severely contaminated materials.

Small sampling equipment such as spoons, split-spoons, shovels, drive-point sampling probes, etc., will be washed with a solution of Liquinox laboratory-grade detergent and potable water, and final rinsed with distilled water. The washed sampling equipment will be placed in an area or container to keep them clean until they are used for collecting another sample. The Liquinox solution and rinsewater can be discharged directly onto the ground next to the sampling locations. Small equipment will be decontaminated as follows:

- Rinse and brush with potable water
- Wash with Liquinox detergent and potable water solution
- Rinse with potable water
- Final rinse with distilled water
- Air dry
- Wrap in plastic, or place in a clean area such as an ice chest where dusts cannot be deposited onto the surface

Larger equipment such as excavation and drilling equipment will be decontaminated at each drilling or excavation site with a hot water, high-pressure washer or laboratory-grade detergent and potable water. A nylon brush may be used to loosen soils that cannot be removed by the pressure washer. Decontamination solutions will be discharged to the ground surface in the area just sampled/excavated.

12.1 FIRST AID EQUIPMENT AND SUPPLIES

One large industrial-sized (minimum 16-unit size) first aid kit will be available on site at all times. The kits shall be maintained fully stocked; all perishable materials within the kits must be replaced as soon as possible after the expiration date. The location of the kit will be discussed during the initial site briefing so that all site workers are aware of its location.

12.2 EMERGENCY EYEWASH AND SHOWER FACILITIES

An emergency eyewash meeting ANSI Z358.2-1990 (as a personal eyewash) will be available on site in the field office. Small hand-held eyewash bottles will be available in field vehicles or the drill rigs.

Emergency showers will not be required because of the low probability of encountering hazardous levels of contamination.

12.3 EMERGENCY-USE RESPIRATORS

Site contamination is not expected to be significant enough to keep emergency use supplied air respirators on site.

12.4 SPILL CONTROL MATERIALS AND EQUIPMENT

Fueling of vehicles and drill rigs will be performed at a commercial fueling facility. These facilities maintain equipment for controlling and cleaning up minor spills. Fueling of small equipment such as chain saws or brush trimmers will be performed over a tray or tub so that any spilled fuel can be recovered. Small spills of fuels onto soil will be immediately absorbed with clay. The clay will not be placed into a container or drum which then may accumulate explosive concentrations of fuel vapors. The clay may be placed onto plastic sheeting to allow the fuels to evaporate. The clay may be placed into a container after the fuels have evaporated sufficiently such that they are no longer able to produce flammable vapors. The clay will then be properly disposed of according to state and federal regulations.

12.5 FIRE EXTINGUISHERS

One 20-pound Class ABC fire extinguisher will be kept readily available during field operations. Site personnel shall be made familiar with the locations of extinguishers prior to beginning work, and training in the use of extinguishers will be presented during the initial site safety briefing.

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13.1 LOCAL FIRE/POLICE/RESCUE AUTHORITIES

The local fire, police, and rescue authorities can be contacted by dialing 911.

13.2 MEDICAL FACILITIES

The nearest medical facility offering 24-hour emergency care is Madigan Army Medical Center. Figure 13-1 depicts the route to the hospital from EGDY.

Route to Madigan Army Hospital

From the site entrance, cross East Lincoln Drive and follow Rainier Drive approximately 1 mile to South “F” Street. Turn left (west) onto South “F” Street and proceed approximately ½ mile to Jackson Avenue. South “F” Street will veer right, then left, and then right before intersecting Jackson Avenue at a traffic signal-controlled intersection. Madigan Hospital will be prominently visible from this intersection. Turn left (south) onto Jackson Avenue and proceed approximately ¼ mile to the emergency entrance on the right (west) side of Jackson Avenue. Large red signs indicating the emergency entrance will be visible.

13.3 EMERGENCY RESPONSE PLAN

In the event of an emergency (injury, fire, fuel spill, etc.) the proper procedures must be followed so that rapid attention by emergency care providers and emergency response agencies can be arranged. Proper emergency response requires planning and coordination prior to an actual emergency. This section describes the procedures that must be followed in order to ensure rapid and appropriate emergency response.

13.3.1 Pre-emergency Planning

This SSHP provides detailed information on the hazards and risks associated with the site. The SSHP requires that a site safety briefing be performed prior to beginning work, and daily safety meetings during the period the work is performed. The contents of the entire SSHP will be discussed during the initial safety meeting. During that meeting, the procedures of this section must be stressed so that all site workers are familiar with the emergency response procedures. The contents of this section must be reviewed and discussed during the daily safety meetings to ensure that site workers remain familiar with the emergency procedures.

13.3.2 Personnel Roles, Lines of Authority, Communications

In the event of an emergency, the following response operations will be enacted:

13.3.2.1 Notification

4. All site personnel will be alerted to the emergency. This may be done by speaking directly to all persons in the area or by three 2-second blasts of a vehicle horn.

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1. The SSO will assume responsibility and authority for coordinating all emergency response activities. The SSO or designee will call for emergency assistance if necessary. The SSO or designee will maintain responsibility until proper authorities arrive and assume control.
2. All work will stop, as necessary. All personnel will move to an agreed upon gathering area for a head count and further instruction.
3. The SSO will be briefed with essential information about the emergency. Information will include what happened; the location of the emergency; who was involved/injured; when and how the emergency occurred; the extent of damage/injury; what aid may be needed.

13.3.2.2 Evaluation

The information will be evaluated by the SSO and emergency response procedures will be considered. The following information should be considered prior to initiating emergency response:

- What happened: Type and cause of incident; extent of chemical release; extent of damage to structures and equipment.
- Casualties: Number, location, and condition of victims; treatment required; missing personnel.
- Possible secondary emergencies: potential for fire, explosion, and release of hazardous chemicals; potential for injuries to other on-site/off-site personnel.
- What actions can be taken: Equipment and personnel needed for victim rescue and hazard mitigation; number and skills of uninjured personnel available for response; resources available on site; resources available from outside groups and agencies; time required for outside resources to reach site; hazards involved for rescue and response.

13.3.2.3 Rescue/Response Action

Based on the information obtained about the incident, the type of action necessary should be decided, and the necessary steps implemented. Some actions may be done concurrently. No action should be taken that would result in injury to the rescuer(s). Rescue and response actions should always be performed using the buddy system. Rescue and response actions may include:

1. Survey casualties: Locate all victims and assess their condition; determine resources needed for stabilization and transport.
1. Request aid: Contact the appropriate responders (fire department, ambulance, hospital).
1. Institute control: Bring the emergency under control; begin procedures to stop or limit the spread of the emergency; if safe to do so, remove victims from danger areas.
1. Perform emergency medical care: Administer first aid to victims with any life-threatening injuries.
4. Evacuate: Move site personnel and victims to a safe location upwind of the incident; monitor the incident for significant changes that may affect rescuers or responders; do **not** institute large-scale public evacuation, this is the responsibility of public authorities.

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13.3.2.4 Follow-up

Before site activities resume, personnel must take the following actions to be fully prepared to handle another emergency:

1. Notify appropriate governmental agencies.
1. Restock equipment and supplies, repair or replace damaged equipment, clean and refuel equipment for later use.
1. Review and revise as necessary the emergency response and contingency procedures incorporating information gained from the incident so that emergency response during future incidents will be more efficient and effective.

13.3.2.5 Documentation

The incident should be thoroughly documented by the persons who are best qualified to describe the incident. An Incident Report Form (SMS 49, contained in Appendix 1), will be completed. Detailed information should be recorded, especially if injuries to site workers or the public occurred. Documentation may be used to avert future incidents, as evidence in litigation, for assessment of liability by insurance companies, and review by governmental agencies. The documents produced must be:

- Accurate and objective.
- Authentic: All documentation should be dated and signed by the preparer; no record should be erased or defaced. Entries should be deleted with a single strike mark. All entries should be in blue or black ink.
- Complete: At a minimum, the documentation should include chronological history of the incident, facts about the incident, names of personnel on site, list of decisions made and actions taken during the incident, and results of sampling and air monitoring.

13.3.3 Emergency Contacts

ALL EMERGENCIES

Fort Lewis Fire, Military Police and Ambulance 911

Fort Lewis Explosives and Ordnance Disposal (EOD).....253-967-5507

Fort Lewis Hazardous Materials Response.....253-967-4786

Fort Lewis Range Control.....253-967-7974

U.S. Army Corps of Engineers Project Manager:

Bill Goss (Seattle, Washington)..... (206) 764-3267

URS Project Manager:

Janette Rau (206) 438-2283

URS Health and Safety Officer:

Heather Boge (206) 438-2034

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URS Regional Health and Safety Manager:

Tim Reinhardt (206) 438-2286

URS Medical Surveillance Physician:

Peter Greany, M.D. (714) 535-8221

13.3.4 Emergency Recognition and Prevention

In general, any incident that results in the injury of personnel (including non-project personnel) and/or damage to property, structures, and equipment may be considered an emergency. Any circumstance that is observed to have the potential for creating a fire, explosion, chemical release, or injury is also considered an emergency. The key to preventing emergencies is the recognition of a potentially hazardous situation and subsequent actions that are taken to mitigate the hazard before an emergency develops. Site workers are required to communicate to each other hazardous circumstances (no matter how inconsequential the hazards may seem) that may cause an emergency.

13.3.5 Site Layout, Prevailing Weather Conditions

Sampling will be performed within and near EGDY. A temporary field office will be set up and will serve as the site support zone. Site features are shown in the Work Plan.

Prevailing weather conditions will be monitored by the sampling team. Observations such as wind speed and direction, temperature, and precipitation will be noted in the field logbook, as necessary. The prevailing weather conditions, and the effect that they may have on emergency response actions, will be given appropriate consideration should any emergency occur.

13.3.6 Site Evacuation

Evacuation of the site would occur during a life-threatening emergency such as encountering ordnance or if a fire is ignited that cannot be quickly extinguished and controlled. Evacuation of the site would be signaled verbally to nearby persons or by three 2-second blasts of a vehicle horn or portable air horn. All personnel shall be accounted for prior to leaving the work area and every effort should be attempted to leave the area as a group. The work area should be evacuated in the upwind direction in the case of a chemical release. Evacuation of the area in case of fire should be done in the direction away from the migrating path of the fire. All personnel should assemble at the field office, where all persons should be accounted for and emergency help should be summoned, if necessary.

In the event that ordnance (hand grenades, rockets, bombs, artillery shells, etc.) is discovered, the work area will be evacuated and the USACE Project Manager will be notified. The USACE Project Manager will be responsible for notifying military specialists trained to handle and dispose of chemical warfare agents. Work will not be resumed until a UXO clearance has been performed.

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13.3.7 Procedures for Decontamination and Emergency Medical Treatment of Personnel

13.3.7.1 Emergency Personnel Decontamination

Site personnel are not expected to become contaminated to such a degree that they would endanger emergency responders or medical personnel. Removal of gloves or other protective outer clothing is considered sufficient.

13.3.7.2 Emergency Medical Treatment

If an employee working in a contaminated area is physically injured, Red Cross first aid procedures will be followed. Depending on the severity of the injury, emergency medical response may be sought. If the employee can be moved, he/she will be taken to the edge of the work area where contaminated clothing will be removed (if necessary) and emergency first aid administered.

Emergency Medical Procedures

For severe injuries, illnesses, or overexposure:

1. Remove the injured or exposed person(s) from immediate danger.
2. If necessary, at least partial decontamination should be completed. Wash, rinse, and/or cut off protective clothing and equipment and redress the victim in clean coveralls.
Decontamination will be performed only if the victim will not be further endangered or injured by undergoing decontamination.
3. Render emergency first aid and call an ambulance for transport to local hospital immediately. Notify emergency personnel of contaminants on site. This information, which is included in Section 2, should be sent with the victim to the hospital.
4. Evacuate other personnel on site to a safe place until the SSO determines that it is safe to resume work.
5. Report the accident to the Project Manager, and HSO, RHSM, and USACE Technical Manager immediately and complete an incident report (SMS 49 in Appendix 1).

For minor injuries or illnesses:

1. Remove contaminated PPE, if necessary.
2. Administer first aid. Minor injuries may be treated on site, but all injuries will be examined by trained medical personnel. Victims of serious bites or stings will be taken to a medical center.
3. Notify the Project Manager and HSO immediately.

First Aid - Chemical Injury

If the injury to the worker is chemical in nature (e.g., overexposure), the following first aid procedures are to be instituted as soon as possible:

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Eye Exposure	If contaminated solid or liquid gets into the eyes, wash eyes immediately using emergency eyewash solution. Lift the lower and upper lids occasionally. Cover the eye with a dry pad and obtain medical attention immediately.
Skin Exposure	If contaminated solid or liquid gets on the skin, promptly wash contaminated skin for 15 minutes using soap or mild detergent and water. If solids or liquid penetrate through the clothing, remove the clothing immediately and wash the skin using soap or mild detergent and water. Obtain medical attention immediately if symptoms warrant.
Swallowing	If contaminated solid or liquid has been swallowed do not induce vomiting since the material may contain petroleum hydrocarbons. Obtain medical attention immediately.
Inhalation	Remove the victim from the hazardous atmosphere into fresh air. Provide emergency first aid, as necessary. Obtain medical attention immediately.

First Aid - Physical Injury

Animal Bites	Thoroughly wash the wound with soap and water. Flush the area with running water and apply a sterile dressing. Immobilize affected part until the victim has been attended by a physician. If possible, see that the animal is kept alive and in quarantine.
Burns (Minor)	Do not apply Vaseline or grease of any kind. Apply cold water applications until pain subsides. Cover with a wet sterile gauze dressing. Do not break blisters or remove tissue. Seek medical attention.
Burns (Severe)	Do not remove adhered particles of clothing. Do not apply ice or immerse in cold water. Do not apply ointment, grease or Vaseline. Cover burns with thick, dry sterile dressings. Keep burned feet or legs elevated. Seek medical attention immediately.
Cuts	Apply pressure with sterile gauze dressing, and elevate the area until bleeding stops. Apply a bandage and seek medical attention.
Eyes	Keep the victim from rubbing the eye. Flush the eye with water. If flushing fails to remove the object, apply a dry, protective dressing and consult a physician.
Fracture	Deformity of an injured part usually means a fracture. If fracture is suspected, do not attempt to move the injured part. Seek emergency help and medical attention immediately.
Heat Stress	See SMS 18 in Appendix 1.
Insect Stings or	Remove “stinger” if present. Keep affected part below the level of the heart. Apply ice bag. For minor bites and stings apply soothing

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Bites	lotions, such as calamine. Seek medical attention immediately if the person has a known allergy to insect bites or stings. Observe for signs of adverse reaction (swelling, difficulty breathing, hives). Seek medical attention immediately if a reaction develops. Persons with known severe allergies should carry treatment kits with their personal physician's approval.
Puncture Wounds	If puncture wound is deeper than skin surface, seek medical attention. Serious infection can arise unless proper treatment is received.
Sprains	Elevate injured part and apply ice bag or cold packs. Do not soak in hot water. Seek medical attention.
Unconsciousness	Never attempt to give anything by mouth. Keep victim flat, maintain an open airway. If victim is not breathing, provide artificial respiration and call for an ambulance immediately.

13.3.8 Fire/Explosion

In the event of a fire or explosion, Fort Lewis Fire Department should be notified immediately. Upon arrival of the fire personnel, the SSO will advise the fire commander of the location, nature, and identification of the hazardous materials on site.

Under the direction of the SSO, site personnel may:

- Use fire fighting equipment available on site to control or extinguish the fire
 - Remove or isolate flammable or other hazardous materials that may contribute to the fire
- Otherwise, evacuate the area immediately and summon emergency help.

13.3.9 Community Alert Program

The site hazards are extremely unlikely to affect off-site personnel. A community alert program is not necessary.

13.3.10 Critique of Emergency Response and Follow-up

Following any emergency, an incident report form (SMS 49 in Appendix 1) will be completed and submitted to the Project Manager, HSO, RHSM, CHSA, and the USACE Contracting Officer within 24 hours of the occurrence. Within 2 working days of any reportable accident, the Contractor will complete and submit an accident report on ENG Form 3394 in accordance with USACE requirements.

The emergency will be critically reviewed by all parties noted above. As necessary, this SSHP will be revised according to new site conditions and knowledge gained from the incident. Consideration of ways to improve the SSHP and prevent future incidents will be developed and incorporated into this and other SSHP, as necessary. A memorandum noting the results of the critique and any modifications to health and safety procedures will be developed and retained in the project file.

Figure 13-1
MADIGAN HOSPITAL LOCATION

(11" x 17" to be inserted)

14.1 SAFETY BRIEFINGS AND INSPECTIONS

Accident prevention depends on the recognition and mitigation of hazardous situations. This SSHP will be provided to URS and subcontractor personnel prior to mobilizing to the site so that all workers have time to thoroughly read and understand the SSHP. An initial safety briefing will take place on site prior to beginning work. All subjects covered in this SSHP will be discussed. The hazards that are most likely to cause injury will be discussed in detail. Recognition and prevention of hazardous situations and emergency response will be stressed.

Following the initial site safety briefing, all field personnel who are directly employed by or subcontracted to URS are required to sign the Health and Safety Compliance Agreement Form attached to the front of this SSHP. Those persons refusing to comply with the SSHP will not be permitted to work on site.

At the beginning of each day, an informal safety meeting will be held. Topics to be discussed include the work to be performed during the day and any problems or unsafe acts that have been observed. Daily safety inspections will be performed to identify and correct unsafe conditions before an accident or incident occurs. The daily safety inspection will be documented in the field logbook.

Any visitors who wish to enter the work area during sampling activities must be provided with a copy of this SSHP, briefed on the contents of the SSHP, and requested to sign a Health and Safety Compliance Agreement Form. Visitors entering the exclusion zones must meet all training, medical surveillance, and respirator fit testing requirements of this SSHP. Visitors must also provide their own respirator approved by the SSO.

14.2 REPORTING OF ACCIDENTS

All accidents and incidents will be reported to the SSO, who will notify the Project Manager, HSO, RHSM, and CHSA, as appropriate. The SSO will then prepare an incident report for submittal to URS and USACE safety personnel. An incident report form is in SMS 49, Injury/Illness/Incident Reporting.

The following logs, reports, and records shall be developed as necessary, and retained in URS and USACE project files.

15.1 TRAINING LOGS

Site specific training, other than the initial site safety briefing, is not required. The health and safety compliance agreement forms documenting the initial site safety briefing will be retained by URS and made available to the USACE on request.

Copies of certificates of health and safety training, medical surveillance status forms, first aid/CPR training, and respirator fit test forms will be made available upon request.

15.2 DAILY SAFETY INSPECTION LOGS

Daily safety inspections and briefings will be recorded into the field logbook. All persons present and a record of topics discussed and items inspected will be entered. The results of site safety audits and any health and safety deficiencies will also be noted in the field logbook.

15.3 EQUIPMENT MAINTENANCE LOGS

Records of maintenance and calibration of monitoring instrument will be entered into the field logbook.

15.4 EMPLOYEE/VISITOR REGISTER

A record of URS and subcontractor employees will be retained in the field logbook. Visitors will be requested to sign and print their name, date, and company affiliation on a visitor log. Visitors who wish to observe sampling and have received a site safety briefing will be required to sign a health and safety compliance agreement form.

15.5 ENVIRONMENTAL/PERSONAL EXPOSURE MONITORING RESULTS

Results for organic vapor monitoring, dust observations, and weather conditions and observations will be recorded in the field logbook.

U.S. Army Corps of Engineers (USACE). 2000. *Safety and Occupational Health Document Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) Activities*. ER-385-1-92. CESO. September 1, 2000.

_____. 1996. *Safety and Health Requirements Manual, ENG Form 5044-R*. EM-385-1-1. CESO. September 3, 1996.

Appendix 1
URS Safety Management Standards

CONTENTS

SMS 18	Heat Stress
SMS 19	Heavy Equipment Operations
SMS 21	Housekeeping
SMS 26	Noise and Hearing Conservation
SMS 29	Personal Protective Equipment
SMS 34	Utility Clearances and Isolation
SMS 42	Respiratory Protection
SMS 45	Back Injury Prevention
SMS 49	Injury/Illness/Accident Reporting

Appendix 2
USACE Tulsa District Health and Safety Plan

Appendix E

Analytical Data

Table E-1. Carbon Results.

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
MW1A1									
Phase 2. Baseline Sampling									
2B1A13	3/23/2005	27.0	00	00	00	00	00	00	00
3B1A13	4/6/2005	19.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C1A11	7/5/2005	1590							
Phase 3. 10% w/w Whey Injection									
2C1A11	7/18/2005	1160							
2C1A13	7/19/2005	18300	121.00	48.50	48.50	00	294.00	3.30	0.52
3C1A1	8/15/2005	2600	00	373.00	67.00	24.00	631.00	00	6.30
MW1A1	9/12/2005	3000							
4C1A11	10/3/2005	5010							
4C1A13	10/5/2005	17300							
Phase 3. 1% w/w Whey Injection									
5C1A11	11/7/2005	140	67.50	47.00	19.20	4.30	136.00	00	3.80
5C1A13	11/9/2005	400							
6C1A11	12/12/05	4640							
6C1A13	12/14/05	8480							
7C1A11	2/21/2006	2100	00	3500	1600	59.70	397.00	29.40	49.30
7C1A13	2/23/2006	2860							
Post- Whey Injection Sampling									
8C1A11	3/21/2006	986.0	00	103.00	65.00	18.50	92.00	11.50	12.50
9C1A11	4/17/2006	194.0	00	10.30	1.30	4.70	11.00	4.80	2.30
MW1A2									
Phase 2. Baseline Sampling									
2B1A23	3/23/2005	32.0	00	00	00	00	00	00	00
3B1A23	4/6/2005	21.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C1A21	7/5/2005	1080							

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
Phase 3. 10% w/w Whey Injection									
2C1A21	7/18/2005	947.0							
2C1A23	7/19/2005	16600	69.00	232.00	36.00	00	183.00	2.50	0.43
3C1A2	8/15/2005	2230	00	411.00	86.00	9.50	631.00	1.30	1.20
4C1A21	10/3/2005	4360							
4C1A23	10/5/2005	15900							
Phase 3. 1% w/w Whey Injection									
5C1A21	11/7/2005	1580	00	353.00	115.00	36.10	541.00	11.40	43.00
5C1A23	11/9/2005	298.0							
6C1A21	12/12/2005	3560							
6C1A23	12/14/2005	7060							
7C1A21	2/22/2006	1530	00	248.00	119.00	39.40	313.00	20.70	32.40
7C1A23	2/23/2006	1550							
Post- Whey Injection Sampling									
8C1A21	3/21/2006		00	177.00	88.00	23.00	1700	19.00	17.50
9C1A21	4/17/2006	111.0	00	20.60	11.10	2.80	4.30	3.60	1.20
MW1A4									
Phase 2. Baseline Sampling									
2B1A43	3/23/2005	18.0	00	00	00	00	00	00	00
3B1A43	4/6/2005	25.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C1A41	7/5/2005	7080							
Phase 3. 10% w/w Whey Injection									
2C1A41	7/18/2005	2010							
2C1A43	7/19/2005	71800	504.00	341.00	400	24.00	398.00	11.40	2.00
3C1A4	8/15/2005	3140	515.00	348.00	82.50	10.50	5700	13.00	0.80
4C1A41	10/3/2005	3800							
4C1A43	10/5/2005	21100							
Phase 3. 1% w/w Whey Injection									
5C1A41	11/7/2005	220	524.00	436.00	189.00	33.00	994.00	8.40	40.80
5C1A43	11/9/2005	438.0							
6C1A41	12/12/2005	12000							
6C1A43	12/14/2005	7320							
7C1A41	2/22/2006	787.0	00	155.00	90.90	25.30	123.00	21.40	20.60
7C1A43	2/23/2006	1290							

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
Post- Whey Injection Sampling									
8C1A41	3/21/2006		00	52.30	68.40	13.20	16.90	22.00	8.20
9C1A41	4/17/2006	103.0	00	7.20	1.20	2.60	1.40	3.90	1.20
MW1B4									
Phase 2. Baseline Sampling									
2B1B43	3/23/2005	10	00	00	00	00	00	00	00
3B1B43	4/6/2005	22.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C1B41	7/5/2005	1040							
Phase 3. 10% w/w Whey Injection									
2C1B41	7/18/2005	572.0							
2C1B43	7/19/2005	8780	23.00	201.00	38.00	00	196.00	2.80	0.40
3C1B4	8/15/2005	895.0	00	248.00	58.00	9.30	283.00	1.30	1.20
4C1B41	10/3/2005	1530							
4C1B43	10/5/2005	8520							
Phase 3. 1% w/w Whey Injection									
5C1B41	11/7/2005	1140	00	3300	117.00	32.50	325.00	10.10	34.40
5C1B43	11/9/2005	264.0							
6C1B41	12/12/2005	4220							
6C1B43	12/14/2005	4560							
7C1B41	2/22/2006	319.0	00	88.80	46.20	9.70	24.70	7.10	5.90
7C1B43	2/23/2006	356.0							
Post- Whey Injection Sampling									
8C1B41	3/21/2006		1.90	33.00	24.90	3.60	2.60	6.50	1.50
9C1B41	4/17/2006	116.0	00	32.30	8.10	0.80	0.80	1.30	00
MW1C4									
Phase 2. Baseline Sampling									
2B1C43	3/23/2005	24.0	00	00	00	00	00	00	00
3B1C43	4/6/2005	23.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C1C41	7/5/2005	2200							
Phase 3. 10% w/w Whey Injection									
2C1C41	7/18/2005	344.0							
2C1C43	7/19/2005	6840	0.26	1.30	24.00	1.40	77.50	1.80	00
3C1C4	8/15/2005	558.0	00	145.00	38.00	10.80	93.00	5.40	2.20

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
4C1C41	10/3/2005	1870							
4C1C43	10/5/2005	8060							
Phase 3. 1% w/w Whey Injection									
5C1C41	11/7/2005	590	00	454.00	155.00	35.20	517.00	9.90	35.70
5C1C43	11/9/2005	322.0							
6C1C41	12/12/2005	2260							
6C1C43	12/14/2005	3580							
7C1C41	2/22/2006	130	00	56.20	29.00	4.70	84.30	5.10	11.10
7C1C43	2/23/2006	752.0							
Post- Whey Injection Sampling									
8C1C41	3/21/2006		00	69.30	30.30	3.20	10.30	5.10	0.22
9C1C41	4/17/2006	67.0	00	16.40	3.10	00	00	00	00
MW1D2									
Phase 2. Baseline Sampling									
2B1D23	3/23/2005	13.0	00	00	00	00	00	00	00
3B1D23	4/6/2005	24.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C1D21	7/5/2005	2220							
Phase 3. 10% w/w Whey Injection									
2C1D21	7/18/2005	765.0							
2C1D23	7/19/2005	13300	2.20	292.00	57.00	00	2200	3.70	0.66
3C1D2	8/15/2005	100	00	4.50	62.00	24.00	462.00	16.00	4.50
4C1D21	10/3/2005	3800							
4C1D23	10/5/2005	12400							
Phase 3. 1% w/w Whey Injection									
5C1D21	11/7/2005	1300	34.50	267.00	94.30	27.60	337.00	10.80	46.60
5C1D23	11/9/2005	216.0							
6C1D21	12/12/2005	1400							
6C1D23	12/14/2005	5260							
7C1D21	2/21/2006	249.0	00	65.10	25.50	7.70	31.40	6.30	6.90
7C1D23	2/23/2006	1340							
Post- Whey Injection Sampling									
8C1D21	3/21/2006	10	00	43.20	19.30	3.30	8.20	5.70	3.40
9C1D21	4/17/2006	101.0	00	18.30	7.60	1.30	1.10	1.70	00
MW1D3									

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
Phase 2. Baseline Sampling									
2B1D33	3/23/2005	29.0	00	00	00	00	00	00	00
3B1D33	4/6/2005	20	00	0.61	00	00	4.00	00	00
Phase 3. Initial 3% w/w Whey Injection									
2C1D31	7/5/2005	1410							
Phase 3. 10% w/w Whey Injection									
2C1D31	7/18/2005	539.0							
2C1D33	7/19/2005	9220	00	199.00	400	4.10	144.00	5.40	0.55
3C1D3	8/15/2005	1010	00	175.00	39.00	100	193.00	0.17	2.50
4C1D31	10/3/2005	2720							
4C1D33	10/5/2005	9080							
Phase 3. 1% w/w Whey Injection									
5C1D31	11/7/2005	1140	7.60	235.00	97.90	32.90	264.00	19.50	42.30
5C1D33	11/9/2005	220							
6C1D31	12/12/2005	1160							
6C1D33	12/14/2005	3400							
7C1D31	2/22/2006	206.0	00	68.00	28.20	4.60	14.50	3.10	2.70
Post- Whey Injection Sampling									
8C1D31	3/21/2006		00	47.10	14.90	2.20	2.60	1.60	00
9C1D31	4/17/2006	538.0	00	20.50	5.00	00	00	00	00
MW1D4									
Phase 2. Baseline Sampling									
2B1D43	3/23/2005	39.0	00	00	00	00	00	00	00
3B1D43	4/6/2005	17.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
2C1D41	7/5/2005	1290							
Phase 3. 10% w/w Whey Injection									
2C1D41	7/18/2005	504.0							
2C1D43	7/19/2005	10000	12.00	1900	35.00	2.20	143.00	2.90	0.35
3C1D4	8/15/2005	786.0	00	154.00	32.00	8.70	164.00	2.40	1.70
MW104	9/12/2005	673.0							
4C1D41	10/3/2005	1950							
4C1D43	10/5/2005	6680							
Phase 3. 1% w/w Whey Injection									
5C1D41	11/7/2005	985.0	00	254.00	102.00	28.40	248.00	11.00	41.30

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
5C1D43	11/9/2005	210							
6C1D41	12/12/2005	1110							
6C1D43	12/14/2005	4400							
7C1D41	2/22/2006	249.0	00	65.50	26.30	4.40	12.80	3.20	3.00
7C1D43	2/23/2006	518.0							
Post- Whey Injection Sampling									
8C1D41	3/21/2006		00	47.50	16.10	2.20	2.50	1.90	00
9C1D41	4/17/2006	87.0	00	26.20	6.70	1.10	0.74	1.30	0.32
MW2A1									
Phase 2. Baseline Sampling									
2B2A13	3/23/2005	41.0	00	00	00	00	00	00	00
3B2A13	4/6/2005	41.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C2A11	7/5/2005	689.0							
Phase 3. 1% w/w Whey Injection									
2C2A11	7/18/2005	902.0							
2C2A13	7/20/2005	7800	00	425.00	41.00	00	294.00	2.80	0.83
3C2A1	8/15/2005	765.0	00	141.00	73.00	10.20	87.00	3.00	3.00
3C2A3	8/17/2005	3420							
MW2A1	9/12/2005	941.0							
4C2A11	10/3/2005	1260							
4C2A13	10/5/2005	4780							
Phase 3. 10% w/w Whey Injection									
5C2A11	11/7/2005	1200	00	293.00	1200	43.90	1900	27.70	93.80
5C2A13	11/9/2005	1080							
6C2A11	12/12/2005	1570							
6C2A13	12/14/2005	18100							
7C2A11	2/21/2006	1110	00	261.00	81.80	19.10	357.00	16.30	1000
7C2A13	2/23/2006	10300							
Post- Whey Injection Sampling									
8C2A11	3/21/2006		00	209.00	59.00	15.00	247.00	00	59.00
9C2A11	4/17/2006	426.0	00	92.10	23.10	6.40	41.90	5.00	14.30
MW2A2									
Phase 2. Baseline Sampling									
2B2A23	3/23/2005	53.0	00	00	00	00	00	00	00

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
3B2A23	4/6/2005	52.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C2A21	7/5/2005	696.0							
Phase 3. 1% w/w Whey Injection									
2C2A21	7/18/2005	883.0							
2C2A23	7/20/2005	5500	00	428.00	41.00	00	3400	6.80	0.59
3C2A2	8/15/2005	689.0	00	179.00	65.00	11.40	96.00	8.20	3.20
4C2A21	10/3/2005	1500							
4C2A23	10/5/2005	5040							
Phase 3. 10% w/w Whey Injection									
5C2A21	11/7/2005	1170	00	2800	108.00	37.00	179.00	26.80	86.80
5C2A23	11/9/2005	1120							
6C2A21	12/12/2005	4300							
6C2A23	12/14/2005	21400							
7C2A21	2/21/2006	1220	00	224.00	70.60	17.20	302.00	13.60	81.80
7C2A23	2/23/2006	11800							
Post- Whey Injection Sampling									
8C2A21	3/21/2006		00	188.00	48.00	11.50	204.00	00	48.00
9C2A21	4/17/2006	405.0	3.50	92.00	24.00	4.50	43.00	00	13.50
MW2A4									
Phase 2. Baseline Sampling									
2B2A43	3/23/2005	36.0	00	00	00	00	00	00	00
3B2A43	4/6/2005	40	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C2A41	7/5/2005	1120							
Phase 3. 1% w/w Whey Injection									
2C2A41	7/18/2005	1040							
2C2A43	7/20/2005	3640	3.10	339.00	34.00	00	317.00	8.50	0.61
3C2A4	8/15/2005	659.0	00	228.00	37.00	100	107.00	3.40	1.30
4C2A41	10/3/2005	1560							
4C2A43	10/5/2005	2460							
Phase 3. 10% w/w Whey Injection									
5C2A41	11/7/2005	1160	5.30	3.10	4.70	5.20	5.00	6.00	5.70
5C2A43	11/9/2005	1240							
6C2A41	12/12/2005	4580							

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
6C2A43	12/14/2005	29900							
7C2A41	2/21/2006	519.0	00	125.00	36.90	8.90	102.00	7.60	30.70
7C2A43	2/23/2006	1650							
Post- Whey Injection Sampling									
8C2A41	3/21/2006		00	144.00	32.10	10.60	85.40	4.50	27.40
9C2A41	4/17/2006	355.0	2.30	94.30	21.50	6.80	32.90	5.90	10.70
MW2B4									
Phase 2. Baseline Sampling									
2B2B43	3/23/2005	30	00	00	00	00	00	00	00
3B2B43	4/6/2005	44.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C2B41	7/5/2005	3660							
Phase 3. 1% w/w Whey Injection									
2C2B41	7/18/2005	1670							
2C2B43	7/20/2005	2450	55.00	4500	41.00	2.50	523.00	00	00
3C2B41	8/15/2005	1970	00	563.00	135.00	22.00	446.00	12.60	2.00
3C2B43	8/17/2005	1480							
4C2B41	10/3/2005	5030							
4C2B43	10/5/2005	550							
Phase 3. 10% w/w Whey Injection									
5C2B41	11/7/2005	140	00	469.00	1700	48.00	364.00	26.20	124.00
5C2B43	11/9/2005	1800							
6C2B41	12/12/2005	9660							
6C2B43	12/14/2005	24900							
7C2B41	2/21/2006	7420	00	459.00	2500	39.50	1425.00	19.60	356.00
7C2B43	2/23/2006	16100							
Post- Whey Injection Sampling									
8C2B41	3/21/2006		00	1088.00	293.00	94.00	2203.00	69.00	321.00
9C2B41	4/17/2006	799.0	00	139.00	38.60	13.20	119.00	8.00	28.20
MW2C4									
Phase 2. Baseline Sampling									
2B2C43	3/23/2005	45.0	00	00	00	00	00	00	00
3B2C43	4/6/2005	46.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C2C41	7/5/2005	788.0							

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
Phase 3. 1% w/w Whey Injection									
2C2C41	7/18/2005	783.0							
2C2C43	7/20/2005	1090	7.00	295.00	34.50	00	214.00	2.40	00
3C2C41	8/15/2005	577.0	00	253.00	33.00	9.80	1000	2.30	0.91
3C2C43	8/17/2005	1030							
4C2C41	10/3/2005	1170							
4C2C43	10/5/2005	1500							
Phase 3. 10% w/w Whey Injection									
5C2C41	11/7/2005	0	00	387.00	162.00	37.30	245.00	21.30	74.30
5C2C43	11/9/2005	320							
6C2C41	12/12/2005	4360							
6C2C43	12/14/2005	9540							
7C2C41	2/21/2006	1410	00	466.00	134.00	37.30	195.00	14.60	107.00
7C2C43	2/23/2006	1400							
Post- Whey Injection Sampling									
8C2C41	3/21/2006		00	329.00	81.00	20.50	55.00	18.50	42.00
9C2C41	4/17/2006	821.0	00	251.00	77.00	13.50	36.50	6.00	18.50
MW2D1									
Phase 2. Baseline Sampling									
2B2D13	3/23/2005	27.0	00	00	00	00	00	00	00
3B2D13	4/6/2005	36.0	00	2.70	00	00	23.10	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C2D11	7/5/2005	918.0							
Phase 3. 1% w/w Whey Injection									
2C2D11	7/18/2005	417.0							
2C2D13	7/20/2005	7500	00	19.50	36.50	8.20	51.00	12.00	1.10
3C2D1	8/15/2005	852.0	00	98.00	74.00	18.00	57.00	22.20	12.80
4C2D11	10/3/2005	2100							
4C2D13	10/5/2005	3200							
Phase 3. 10% w/w Whey Injection									
5C2D11	11/7/2005	833.0	00	194.00	86.90	30.80	121.00	14.60	68.50
5C2D13	11/9/2005	1230							
6C2D11	12/12/2005	7440							
6C2D13	12/14/2005	21400							
7C2D11	2/21/2006	273.0	00	50.80	15.10	4.00	47.70	4.80	14.10

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
7C2D13	2/23/2006	7700							
Post- Whey Injection Sampling									
8C2D11	3/21/2006		4.40	700	26.60	9.00	54.60	11.70	15.90
9C2D11	4/17/2006	183.0	00	21.80	6.50	2.10	8.00	2.80	2.90
MW2D2									
Phase 2. Baseline Sampling									
2B2D23	3/23/2005	29.0	00	00	00	00	00	00	00
3B2D23	4/6/2005	41.0	00	00	00	00	00	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C2D21	7/5/2005	1470							
Phase 3. 1% w/w Whey Injection									
2C2D21	7/18/2005	504.0							
2C2D23	7/20/2005	6440	00	147.00	46.50	7.90	107.00	13.10	1.60
3C2D2	8/15/2005	856.0	00	168.00	1.50	19.00	93.00	20.30	11.20
4C2D21	10/3/2005	3110							
4C2D23	10/5/2005	3000							
Phase 3. 10% w/w Whey Injection									
5C2D21	11/7/2005	1130	00	311.00	137.00	43.30	196.00	26.70	98.10
5C2D23	11/9/2005	1320							
6C2D21	12/12/2005	8680							
6C2D23	12/14/2005	30000							
7C2D21	2/21/2006	673.0	00	76.60	27.40	7.40	157.00	6.70	25.80
7C2D23	2/23/2006	1620							
Post- Whey Injection Sampling									
8C2D21	3/21/2006		3.20	142.00	52.70	15.70	197.00	17.80	39.30
9C2D21	4/17/2006	272.0	00	34.80	10.60	3.90	29.60	4.60	7.50
MW2D4									
Phase 2. Baseline Sampling									
2B2D43	3/23/2005	46.0	00	00	00	00	00	00	00
3B2D43	4/6/2005	36.0	00	0.53	00	00	3.30	00	00
Phase 3. Initial 3% w/w Whey Injection									
1C2D41	7/5/2005	1540							
Phase 3. 1% w/w Whey Injection									
2C2D41	7/18/2005	862.0							
2C2D43	7/20/2005	2790	100	346.00	42.00	3.40	242.00	5.10	0.64

Table E-1. (continued).

Sample ID	Date	COD (mg/L)	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)
3C2D41	8/15/2005	610	00	302.00	38.00	10.50	1200	5.70	1.60
3C2D43	8/17/2005	2130							
MW2D4	9/12/2005	540							
4C2D41	10/3/2005	2620							
4C2D43	10/5/2005	2880							
Phase 3. 10% w/w Whey Injection									
5C2D41	11/7/2005	1490	00	421.00	199.00	51.00	262.00	22.70	121.00
5C2D43	11/9/2005	976.0							
6C2D41	12/12/2005	7940							
6C2D43	12/14/2005	24800							
7C2D41	2/21/2006	2050	00	609.00	193.00	63.80	325.00	21.60	167.00
7C2D43	2/23/2006	2320							
Post- Whey Injection Sampling									
8C2D41	3/21/2006		00	633.00	155.00	55.00	392.00	18.00	1800
9C2D41	4/17/2006	766.0	00	166.00	48.50	15.00	70.50	9.00	38.50

Table E-2. Geochemical Results.

Sample ID	Date	pH	Temp (°C)	SpC (ms/cm)	Alkalinity mg/L as CaCO ₃
MW1A1					
Phase 2. Baseline Sampling					
1B1A11	03/08/05	6.17	11.20	0.222	
1B1A12	03/09/05	6.08	10.74	0.243	
1B1A13	03/10/05	6.13	10.42	0.208	
2B1A11	03/21/05	6.16	10.23	0.221	72.0
2B1A12	03/22/05	6.21	10.77	0.234	
2B1A13	03/23/05	6.13	10.83	0.228	
3B1A11	04/04/05	5.99	10.63	0.210	60
3B1A12	04/05/05	6.10	10.77	0.265	
3B1A13	04/06/05	6.13	10.36	0.230	
Phase 3. Initial 3% w/w Whey Injection					
1C1A11	7/5/2005	4.89	13.67	0.844	
1C1A13	7/7/2005	4.81	13.16	0.815	
Phase 3. 10% w/w Whey Injection					
2C1A11	7/18/2005	4.81	13.69	0.758	
2C1A12	7/18/2005	5.23	13.42	5.070	
2C1A13	7/19/2005	5.05	13.72	2.960	
3C1A11	8/15/2005	4.63	14.39	1.096	
4C1A11	10/03/05	4.55	14.88	1.950	
4C1A12	10/04/05	4.81	15.45	3.960	
4C1A13	10/05/05	4.55	15.02	2.960	
Phase 3. 1% w/w Whey Injection					
5C1A11	11/7/2005	4.96	14.25	1.256	30
5C1A12	11/8/2005	4.97	14.64	1.730	
5C1A13	11/9/2005	4.96	14.14	1.640	
6C1A11	12/12/05	5.19	12.30	1.320	45.0
6C1A12	12/13/05	5.18	12.46	1.610	
6C1A13	12/14/05	5.12	12.41	1.750	
7C1A11	02/21/06	5.63	11.11	1.260	
7C1A12	02/22/06	5.45	10.25	0.955	
7C1A13	02/23/06	5.49	10.95	1.087	
Post- Whey Injection Sampling					
8C1A11	3/21/2006	5.54	10.88	1.006	212.0
9C1A11	04/17/06	6	11.2	0.413	127.0
MW1A2					
Phase 2. Baseline Sampling					
1B1A21	3/8/2005	6.30	12.13	0.233	
1B1A22	3/9/2005	6.12	11.17	0.245	
1B1A23	3/10/2005	6.14	10.99	0.209	
2B1A21	3/21/2005	6.21	10.81	0.228	71

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
2B1A22	3/22/2005	6.25	11.01	0.235	
2B1A23	3/23/2005	6.21	11.12	0.230	
3B1A21	4/4/2005	6.02	11.04	0.231	77
3B1A22	4/5/2005	6.12	11.02	0.259	
3B1A23	4/6/2005	6.13	10.60	0.234	
Phase 3. Initial 3% w/w Whey Injection					
1C1A21	7/5/2005	5.23	13.30	0.677	
1C1A23	7/7/2005	5.03	12.93	0.648	
Phase 3. 10% w/w Whey Injection					
2C1A21	7/18/2005	4.86	13.90	0.624	
2C1A22	7/18/2005	5.26	13.04	4.490	
2C1A23	7/19/2005	5.16	13.20	2.600	
3C1A21	8/15/2005	4.64	13.87	0.956	
4C1A21	10/3/2005	4.62	14.20	1.810	
4C1A22	10/4/2005	4.81	14.71	3.640	
4C1A23	10/5/2005	4.60	14.34	2.810	
Phase 3. 1% w/w Whey Injection					
5C1A21	11/7/2005	5.14	14.13	0.983	80
5C1A22	11/8/2005	4.97	14.30	1.670	
5C1A23	11/9/2005	5.07	13.80	1.373	
6C1A21	12/12/2005	5.32	12.65	1.300	70
6C1A22	12/13/2005	5.17	12.81	1.650	
6C1A23	12/14/2005	5.31	12.82	1.510	
7C1A21	2/22/2006	5.68	11.53	1.047	
7C1A22	2/22/2006	5.63	10.72	0.952	
7C1A23	2/23/2006	5.72	11.29	0.928	
Post- Whey Injection Sampling					
8C1A21	3/21/2006	5.79	11.23	0.874	292
9C1A21	04/17/06	6.19	11.30	0.426	146
MW1A4					
Phase 2. Baseline Sampling					
1B1A41	3/8/2005	6.48	13.05	0.217	
1B1A42	3/9/2005	6.09	11.75	0.243	
1B1A43	3/10/2005	6.12	11.42	0.209	
2B1A41	3/21/2005	6.18	10.96	0.222	700
2B1A42	3/22/2005	6.24	11.61	0.234	
2B1A43	3/23/2005	6.22	11.49	0.232	
3B1A41	4/4/2005	6.07	11.47	0.281	79.00
3B1A42	4/5/2005	6.12	11.51	0.267	
3B1A43	4/6/2005	6.12	11.09	0.264	
Phase 3. Initial 3% w/w Whey Injection					
1C1A41	7/5/2005	4.62	14.09	1.830	
1C1A43	7/7/2005	4.46	12.93	1.710	
Phase 3. 10% w/w Whey Injection					
2C1A41	7/18/2005	4.75	29.12	1.221	
2C1A42	7/18/2005	5.04	13.40	4.260	
2C1A43	7/19/2005	4.92	14.71	3.600	
3C1A41	8/15/2005	4.28	17.25	1.490	
4C1A41	10/3/2005	4.66	13.48	1.550	
4C1A42	10/4/2005	4.76	14.18	3.390	

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
4C1A43	10/5/2005	4.45	13.24	3.070	
Phase 3. 1% w/w Whey Injection					
5C1A41	11/7/2005	4.88	13.14	1.131	00
5C1A42	11/8/2005	4.78	13.30	1.850	
5C1A43	11/9/2005	4.95	12.84	1.720	
6C1A41	12/12/2005	4.98	12.57	1.630	51.00
6C1A42	12/13/2005	5.03	12.65	1.740	
6C1A43	12/14/2005	5.03	12.60	1.760	
7C1A41	2/22/2006	5.86	11.81	0.835	
7C1A42	2/22/2006	5.81	11.24	0.851	
7C1A43	2/23/2006	5.76	11.59	0.780	
Post- Whey Injection Sampling					
8C1A41	3/21/2006	5.80	12.10	0.739	242.00
9C1A41	04/17/06	6.17	11.40	0.359	115.00
MW1B4					
Phase 2. Baseline Sampling					
1B1B41	3/8/2005	6.32	12.55	0.232	
1B1B42	3/9/2005	6.17	12.03	0.245	
1B1B43	3/10/2005	6.23	11.98	0.213	
2B1B41	3/21/2005	6.27	11.80	0.234	67
2B1B42	3/22/2005	6.32	11.81	0.237	
2B1B43	3/23/2005	6.24	12.39	0.234	
3B1B41	4/4/2005	6.12	12.04	0.263	90
3B1B42	4/5/2005	6.17	12.03	0.271	
3B1B43	4/6/2005	6.18	11.56	0.262	
Phase 3. Initial 3% w/w Whey Injection					
1C1B41	7/5/2005	5.49	12.77	0.764	
1C1B43	7/7/2005	5.51	12.61	0.926	
Phase 3. 10% w/w Whey Injection					
2C1B41	7/18/2005	5.77	13.06	0.674	
2C1B42	7/18/2005	5.46	12.39	1.910	
2C1B43	7/19/2005	5.48	12.54	1.520	
3C1B41	8/15/2005	5.49	13.95	0.819	173
4C1B41	10/3/2005	5.56	12.73	1.207	203
4C1B42	10/4/2005	5.41	13.01	1.810	
4C1B43	10/5/2005	4.98	12.65	1.920	
Phase 3. 1% w/w Whey Injection					
5C1B41	11/7/2005	5.76	12.76	1.063	193
5C1B42	11/8/2005	5.42	12.43	1.383	
5C1B43	11/9/2005	5.54	12.54	1.458	
6C1B41	12/12/2005	5.60	12.33	1.300	195
6C1B42	12/13/2005	5.51	12.51	1.490	
6C1B43	12/14/2005	5.49	12.33	1.480	
7C1B41	2/22/2006	6.25	12.26	1.020	
7C1B42	2/22/2006	6.30	11.95	0.985	
7C1B43	2/23/2006	6.30	11.78	0.980	
Post- Whey Injection Sampling					
8C1B41	3/21/2006	6.12	12.32	1.033	421

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
9C1B41	04/17/06	6.3	11.6	0.54	201
MW1C4					
Phase 2. Baseline Sampling					
1B1C41	3/8/2005	6.38	13.07	0.245	
1B1C42	3/9/2005	6.21	12.56	0.251	
1B1C43	3/10/2005	6.23	12.28	0.228	
2B1C41	3/21/2005	6.27	12.22	0.247	72
2B1C42	3/22/2005	6.32	12.44	0.242	
2B1C43	3/23/2005	6.25	12.55	0.243	
3B1C41	4/4/2005	6.13	12.21	0.293	81
3B1C42	4/5/2005	6.18	12.22	0.259	
3B1C43	4/6/2005	6.20	11.89	0.262	
Phase 3. Initial 3% w/w Whey Injection					
1C1C41	7/5/2005	4.93	12.69	0.983	
1C1C43	7/7/2005	4.88	12.62	0.866	
Phase 3. 10% w/w Whey Injection					
2C1C41	7/18/2005	5.59	13.18	0.383	
2C1C42	7/18/2005	5.33	12.34	1.322	
2C1C43	7/19/2005	5.34	12.70	1.020	
3C1C41	8/15/2005	5.33	13.64	0.517	94
4C1C41	10/3/2005	5.17	12.90	1.191	152
4C1C42	10/4/2005	4.90	13.47	2.240	
4C1C43	10/5/2005	4.69	12.91	1.740	
Phase 3. 1% w/w Whey Injection					
5C1C41	11/7/2005	5.26	12.86	1.185	145
5C1C42	11/8/2005	5.08	12.84	1.510	
5C1C43	11/9/2005	5.23	12.87	1.620	
6C1C41	12/12/2005	5.68	12.52	1.080	180
6C1C42	12/13/2005	5.41	12.48	1.370	
6C1C43	12/14/2005	5.52	12.54	1.172	
7C1C41	2/22/2006	6.15	12.26	0.505	
7C1C42	2/22/2006	6.10	12.21	0.697	
7C1C43	2/23/2006	5.99	11.79	0.604	
Post- Whey Injection Sampling					
8C1C41	3/21/2006	5.94	12.42	0.558	152
9C1C41	04/17/06	6.26	12.72	0.479	182
MW1D2					
Phase 2. Baseline Sampling					
1B1D21	3/8/2005	6.25	12.38	0.242	
1B1D22	3/9/2005	6.10	11.67	0.242	
1B1D23	3/10/2005	6.15	11.58	0.220	
2B1D21	3/21/2005	6.22	11.09	0.240	67
2B1D22	3/22/2005	6.24	11.26	0.234	
2B1D23	3/23/2005	6.19	11.58	0.243	
3B1D21	4/4/2005	6.10	11.22	0.304	86
3B1D22	4/5/2005	6.10	11.11	0.269	
3B1D23	4/6/2005	6.16	10.76	0.285	
Phase 3. Initial 3% w/w Whey Injection					

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
1C1D21	7/5/2005	4.65	12.60	0.978	
1C1D23	7/7/2005	5.04	12.43	0.706	
Phase 3. 10% w/w Whey Injection					
2C1D21	7/18/2005	5.11	12.95	0.599	
2C1D22	7/18/2005	5.23	12.76	3.180	
2C1D23	7/19/2005	5.18	12.90	2.100	
3C1D21	8/15/2005	4.66	13.67	0.865	
4C1D21	10/3/2005	4.78	13.52	1.660	
4C1D22	10/4/2005	4.86	14.34	2.970	
4C1D23	10/5/2005	4.68	13.74	2.370	
Phase 3. 1% w/w Whey Injection					
5C1D21	11/7/2005	5.25	13.65	0.869	176
5C1D22	11/8/2005	5.03	13.17	1.610	
5C1D23	11/9/2005	5.10	13.67	1.133	
6C1D21	12/12/2005	5.52	12.79	1.180	60
6C1D22	12/13/2005	5.29	12.68	1.560	
6C1D23	12/14/2005	5.21	12.69	1.460	
7C1D21	2/21/2006	6.23	11.23	0.567	
7C1D22	2/22/2006	5.59	11.21	0.921	
7C1D23	2/23/2006	5.76	10.65	0.774	
Post- Whey Injection Sampling					
8C1D21	3/21/2006	6.02	11.10	0.590	225
9C1D21	04/17/06	6.06	11.01	0.458	176
MW1D3					
Phase 2. Baseline Sampling					
1B1D31	3/8/2005	6.67	13.35	0.252	
1B1D32	3/9/2005	6.24	12.40	0.256	
1B1D33	3/10/2005	6.24	12.31	0.227	
2B1D31	3/21/2005	6.31	11.93	0.254	75
2B1D32	3/22/2005	6.35	12.42	0.249	
2B1D33	3/23/2005	6.32	12.28	0.253	
3B1D31	4/4/2005	6.21	12.19	0.273	80
3B1D32	4/5/2005	6.23	12.10	0.262	
3B1D33	4/6/2005	6.24	11.68	0.258	
Phase 3. Initial 3% w/w Whey Injection					
1C1D31	7/5/2005	4.97	12.75	0.815	
1C1D33	7/7/2005	5.19	12.34	0.705	
Phase 3. 10% w/w Whey Injection					
2C1D31	7/18/2005	5.45	13.01	0.536	
2C1D32	7/18/2005	5.40	12.43	2.410	
2C1D33	7/19/2005	5.36	12.86	1.670	
3C1D31	8/15/2005	5.08	13.55	0.731	
4C1D31	10/3/2005	5.13	12.87	1.339	173
4C1D32	10/4/2005	5.03	13.29	2.270	
4C1D33	10/5/2005	4.66	13.00	1.950	
Phase 3. 1% w/w Whey Injection					
5C1D31	11/7/2005	5.65	12.80	1.026	186
5C1D32	11/8/2005	5.41	12.84	1.444	

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
5C1D33	11/9/2005	5.28	12.86	1.389	
6C1D31	12/12/2005	5.87	12.41	1.270	179
6C1D32	12/13/2005	5.70	12.26	1.370	
6C1D33	12/14/2005	5.71	12.33	1.321	
7C1D31	2/22/2006	6.28	11.89	0.778	
7C1D32	2/22/2006	6.16	11.65	0.836	
7C1D33	2/23/2006	6.12	11.70	0.771	
Post- Whey Injection Sampling					
8C1D31	3/21/2006	6.18	11.81	0.801	291
9C1D31	04/17/06	6.24	11.96	0.548	203
MW1D4					
Phase 2. Baseline Sampling					
1B1D41	3/8/2005	6.42	13.21	0.253	
1B1D42	3/9/2005	6.28	12.54	0.260	
1B1D43	3/10/2005	6.28	12.41	0.232	
2B1D41	3/21/2005	6.34	12.13	0.257	69
2B1D42	3/22/2005	6.37	12.50	0.251	
2B1D43	3/23/2005	6.34	12.61	0.255	
3B1D41	4/4/2005	6.24	12.19	0.271	84
3B1D42	4/5/2005	6.24	12.30	0.262	
3B1D43	4/6/2005	6.25	11.90	0.260	
Phase 3. Initial 3% w/w Whey Injection					
1C1D41	7/5/2005	5.00	12.68	0.790	
1C1D43	7/7/2005	5.04	12.44	0.746	
Phase 3. 10% w/w Whey Injection					
2C1D41	7/18/2005	5.55	13.12	0.527	
2C1D42	7/18/2005	5.59	12.17	1.407	
2C1D43	7/19/2005	5.36	12.86	1.550	
3C1D41	8/15/2005	5.26	13.59	0.669	97
4C1D41	10/3/2005	5.28	12.18	1.240	170
4C1D42	10/4/2005	5.07	13.46	2.040	
4C1D43	10/5/2005	4.71	12.82	1.750	
Phase 3. 1% w/w Whey Injection					
5C1D41	11/7/2005	5.79	12.79	0.977	279
5C1D42	11/8/2005	5.50	12.80	1.384	
5C1D43	11/9/2005	5.40	12.75	1.382	
6C1D41	12/12/2005	5.90	12.42	1.220	210
6C1D42	12/13/2005	5.72	12.36	1.330	
6C1D43	12/14/2005	5.76	12.42	1.270	
7C1D41	2/22/2006	6.29	12.00	0.740	
7C1D42	2/22/2006	6.16	11.71	0.834	
7C1D43	2/23/2006	6.17	11.56	0.753	
Post- Whey Injection Sampling					
8C1D41	3/21/2006	6.15	12.18	0.758	388
9C1D41	04/17/06	6.24	12.2	0.56	222
MW2A1					
Phase 2. Baseline Sampling					
1B2A11	3/8/2005	6.70	12.75	0.385	

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
1B2A12	3/9/2005	6.23	11.90	0.354	
1B2A13	3/10/2005	6.19	11.69	0.279	
2B2A11	3/21/2005	6.29	11.57	0.314	94
2B2A12	3/22/2005	6.28	11.81	0.341	
2B2A13	3/23/2005	6.21	11.92	0.293	
3D2A11	4/4/2005	6.12	11.96	0.367	93
3D2A12	4/5/2005	6.11	11.77	0.372	
3D2A13	4/6/2005	6.15	11.50	0.324	
Phase 3. Initial 3% w/w Whey Injection					
1C2A11	7/5/2005	5.49	13.09	0.580	
1C2A13	7/7/2005	5.39	12.97	0.492	
Phase 3. 1% w/w Whey Injection					
2C2A11	7/18/2005	5.20	15.07	0.746	
2C2A12	7/19/2005	5.37	13.29	1.600	
2C2A13	7/20/2005	5.18	14.10	1.339	
3C2A11	8/15/2005	5.31	14.72	0.720	
3C2A12	8/16/2005	5.20	14.05	1.494	
3C2A13	8/17/2005	5.33	13.79	1.280	
4C2A11	10/3/2005	5.48	14.78	1.169	229
4C2A12	10/4/2005	5.31	14.84	1.730	
4C2A13	10/5/2005	4.55	14.68	1.800	
Phase 3. 10% w/w Whey Injection					
5C2A11	11/7/2005	5.90	14.71	1.329	220
5C2A12	11/8/2005	5.65	14.87	3.750	
5C2A13	11/9/2005	4.83	14.34	3.140	
6C2A11	12/12/2005	5.62	13.49	1.730	249
6C2A12	12/13/2005	5.63	13.58	4.480	
6C2A13	12/14/2005	5.02	13.25	2.960	
7C2A11	2/21/2006	5.42	11.57	1.073	94
7C2A12	2/22/2006	5.59	11.69	1.700	
7C2A13	2/23/2006	5.17	11.56	1.630	
Post- Whey Injection Sampling					
8C2A11	3/21/2006	5.37	11.99	0.994	192
9C2A11	04/17/06	6.04	11.62	0.703	158
MW2A2					
Phase 2. Baseline Sampling					
1B2A21	3/8/2005	6.50	12.68	0.313	
1B2A22	3/9/2005	6.16	12.11	0.320	
1B2A23	3/10/2005	6.21	11.81	0.270	
2B2A21	3/21/2005	6.31	11.78	0.292	93
2B2A22	3/22/2005	6.26	12.01	0.308	
2B2A23	3/23/2005	6.24	12.20	0.286	
3B2A21	4/4/2005	6.18	12.41	0.322	98
3B2A22	4/5/2005	6.13	11.91	0.348	
3B2A23	4/6/2005	6.17	11.76	0.315	
Phase 3. Initial 3% w/w Whey Injection					
1C2A21	7/5/2005	5.42	12.80	0.547	
1C2A23	7/7/2005	5.31	12.90	0.496	

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
Phase 3. 1% w/w Whey Injection					
2C2A21	7/18/2005	5.13	14.43	0.690	
2C2A22	7/19/2005	5.34	12.95	1.446	
2C2A23	7/20/2005	5.16	13.69	1.266	
3C2A21	8/15/2005	5.38	14.48	0.662	113
3C2A22	8/16/2005	5.23	13.76	1.520	
3C2A23	8/17/2005	5.35	13.87	1.102	
4C2A21	10/3/2005	5.45	14.36	1.130	180
4C2A22	10/4/2005	5.32	14.46	1.740	
4C2A23	10/5/2005	4.49	14.41	1.800	
Phase 3. 10% w/w Whey Injection					
5C2A21	11/7/2005	5.91	14.47	1.299	229
5C2A22	11/8/2005	5.63	14.60	4.060	
5C2A23	11/9/2005	4.81	14.32	3.090	
6C2A21	12/12/2005	5.62	13.75	1.730	271
6C2A22	12/13/2005	5.63	13.73	4.690	
6C2A23	12/14/2005	5.01	13.56	2.940	
7C2A21	2/21/2006	5.47	12.10	8.590	43
7C2A22	2/22/2006	5.60	12.13	1.710	
7C2A23	2/23/2006	5.14	12.08	1.610	
Post- Whey Injection Sampling					
8C2A21	3/21/2006	5.50	12.26	0.858	119
9C2A21	04/17/06	6.06	11.79	0.667	123
MW2A4					
Phase 2. Baseline Sampling					
1B2A41	3/8/2005	6.34	12.67	0.275	
1B2A42	3/9/2005	6.13	12.58	0.282	
1B2A43	3/10/2005	6.14	12.30	0.238	
2B2A41	3/21/2005	6.31	12.16	0.275	87
2B2A42	3/22/2005	6.24	12.66	0.276	
2B2A43	3/23/2005	6.24	12.67	0.279	
3B2A41	4/4/2005	6.15	12.50	0.318	89
3B2A42	4/5/2005	6.11	12.21	0.334	
3B2A43	4/6/2005	6.09	12.41	0.304	
Phase 3. Initial 3% w/w Whey Injection					
1C2A41	7/5/2005	5.17	13.17	0.697	
1C2A43	7/7/2005	4.96	13.53	0.708	
Phase 3. 1% w/w Whey Injection					
2C2A41	7/18/2005	5.08	13.60	0.770	
2C2A42	7/19/2005	5.15	12.99	1.480	
2C2A43	7/20/2005	5.07	13.22	1.055	
3C2A41	8/15/2005	5.43	14.83	0.672	96
3C2A42	8/16/2005	5.20	14.97	1.229	
3C2A43	8/17/2005	5.44	14.36	0.918	
4C2A41	10/3/2005	5.38	13.45	1.219	184
4C2A42	10/4/2005	5.24	13.49	1.720	
4C2A43	10/5/2005	4.87	13.45	1.250	
Phase 3. 10% w/w Whey Injection					

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
5C2A41	11/7/2005	5.95	13.53	1.335	253
5C2A42	11/8/2005	5.59	13.64	3.410	
5C2A43	11/9/2005	4.88	13.46	3.290	
6C2A41	12/12/2005	5.63	12.72	1.730	281
6C2A42	12/13/2005	5.53	13.11	4.000	
6C2A43	12/14/2005	5.07	12.94	3.380	
7C2A41	2/21/2006	5.98	12.59	0.609	113
7C2A42	2/22/2006	5.00	12.64	1.191	
7C2A43	2/23/2006	5.24	12.61	0.812	
Post- Whey Injection Sampling					
8C2A41	3/21/2006	6.03	13.01	0.757	157
9C2A41	04/17/06	6.09	12.34	0.673	136
MW2B4					
Phase 2. Baseline Sampling					
1B2B41	3/8/2005	6.17	13.46	0.232	
1B2B42	3/9/2005	6.06	13.01	0.234	
1B2B43	3/10/2005	6.09	12.70	0.219	
2B2B41	3/21/2005	6.2	12.63	0.239	77
2B2B42	3/22/2005	6.19	12.85	0.244	
2B2B43	3/23/2005	6.17	12.98	0.255	
3B2A41	4/4/2005	6.10	12.80	0.317	87
3B2A42	4/5/2005	6.10	12.55	0.304	
3B2A43	4/6/2005	6.09	12.62	0.309	
Phase 3. Initial 3% w/w Whey Injection					
1C2B41	7/5/2005	4.76	12.96	1.227	
1C2B43	7/7/2005	4.68	13.26	1.080	
Phase 3. 1% w/w Whey Injection					
2C2B41	7/18/2005	4.81	14.80	0.986	
2C2B42	7/19/2005	4.76	12.80	1.053	
2C2B43	7/20/2005	4.71	13.28	1.049	
3C2B41	8/15/2005	4.85	14.43	1.111	
3C2B42	8/16/2005	4.80	13.40	1.170	
3C2B43	8/17/2005	5.28	13.29	1.103	
4C2B41	10/3/2005	4.81	14.23	2.100	89
4C2B42	10/4/2005	5.06	13.63	1.820	
4C2B43	10/5/2005	4.75	13.59	1.860	
Phase 3. 10% w/w Whey Injection					
5C2B41	11/7/2005	5.40	13.52	1.460	150
5C2B42	11/8/2005	5.49	13.67	3.670	
5C2B43	11/9/2005	4.93	13.51	3.630	
6C2B41	12/12/2005	5.03	13.07	2.550	150
6C2B42	12/13/2005	5.30	13.21	3.930	
6C2B43	12/14/2005	5.01	13.18	3.770	
7C2B41	2/21/2006	4.86	12.30	2.360	22
7C2B42	2/22/2006	4.87	12.40	2.050	
7C2B43	2/23/2006	4.71	11.98	2.140	
Post- Whey Injection Sampling					
8C2B41	3/21/2006	4.85	12.82	2.620	100

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
9C2B41	04/17/06	5.82	12.18	0.787	106
MW2C4					
Phase 2. Baseline Sampling					
1B2C41	3/8/2005	6.55	13.47	0.335	
1B2C42	3/9/2005	6.33	13.18	0.328	
1B2C43	3/10/2005	6.35	12.96	0.293	
2B2C41	3/21/2005	6.40	12.93	0.331	95
2B2C42	3/22/2005	6.40	13.05	0.311	
2B2C43	3/23/2005	6.44	13.26	0.318	
3B2C41	4/4/2005	6.32	13.03	0.328	94
3B2C42	4/5/2005	6.28	12.71	0.322	
3B2C43	4/6/2005	6.28	12.86	0.327	
Phase 3. Initial 3% w/w Whey Injection					
1C2C41	7/5/2005	5.97	12.93	0.757	
1C2C43	7/7/2005	6.00	13.17	0.725	
Phase 3. 1% w/w Whey Injection					
2C2C41	7/18/2005	5.73	13.60	0.800	
2C2C42	7/19/2005	5.65	12.69	0.888	
2C2C43	7/20/2005	5.56	14.29	0.863	
3C2C41	8/15/2005	5.99	13.85	0.819	
3C2C42	8/16/2005	5.88	13.89	0.891	
3C2C43	8/17/2005	6.13	13.15	0.907	
4C2C41	10/3/2005	5.92	13.66	1.211	370
4C2C42	10/4/2005	5.70	13.33	1.235	
4C2C43	10/5/2005	5.67	13.25	1.230	
Phase 3. 10% w/w Whey Injection					
5C2C41	11/7/2005	6.11	13.19	1.426	372
5C2C42	11/8/2005	5.90	13.28	1.530	
5C2C43	11/9/2005	5.63	13.13	1.760	
6C2C41	12/12/2005	5.93	12.84	1.990	323
6C2C42	12/13/2005	5.82	13.06	2.030	
6C2C43	12/14/2005	5.44	12.96	2.090	
7C2C41	2/21/2006	6.07	12.68	1.600	
7C2C42	2/22/2006	6.06	12.32	1.550	
7C2C43	2/23/2006	6.04	12.56	1.550	
Post- Whey Injection Sampling					
8C2C41	3/21/2006	6.03	12.50	1.610	464
9C2C41	04/17/06	6.1	12.36	1.62	368
MW2D1					
Phase 2. Baseline Sampling					
1B2D11	3/8/2005	6.20	11.45	0.225	
1B2D12	3/9/2005	6.00	11.10	0.254	
1B2D13	3/10/2005	6.03	10.85	0.225	
2B2D11	3/21/2005	6.12	11.01	0.233	78
2B2D12	3/22/2005	6.14	10.97	0.257	
2B2D13	3/23/2005	6.12	11.38	0.256	
3B2D11	4/4/2005	5.97	11.20	0.323	95
3B2D12	4/5/2005	5.99	10.99	0.312	

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
3B2D13	4/6/2005	6.03	10.94	0.309	
Phase 3. Initial 3% w/w Whey Injection					
1C2D11	7/5/2005	5.31	13.65	0.657	
1C2D13	7/7/2005	5.38	14.75	0.516	
Phase 3. 1% w/w Whey Injection					
2C2D11	7/18/2005	5.77	14.50	0.524	
2C2D12	7/19/2005	5.54	14.19	1.490	
2C2D13	7/20/2005	5.10	14.77	1.434	
3C2D11	8/15/2005	5.36	19.83	0.669	119
3C2D12	8/16/2005	5.28	15.10	1.385	
3C2D13	8/17/2005	5.27	14.90	1.312	
4C2D11	10/3/2005	5.35	14.88	1.580	252
4C2D12	10/4/2005	5.09	15.49	1.880	
4C2D13	10/5/2005	5.05	14.97	1.610	
Phase 3. 10% w/w Whey Injection					
5C2D11	11/7/2005	5.89	15.07	0.904	110
5C2D12	11/8/2005	5.57	15.14	3.910	
5C2D13	11/9/2005	5.25	14.80	2.830	
6C2D11	12/12/2005	5.47	13.24	2.290	258
6C2D12	12/13/2005	5.54	13.38	3.920	
6C2D13	12/14/2005	5.28	13.28	3.510	
7C2D11	2/21/2006	5.94	109	0.345	56
7C2D12	2/22/2006	5.76	9.79	1.303	
7C2D13	2/23/2006	5.26	9.66	1.245	
Post- Whey Injection Sampling					
8C2D11	3/21/2006	5.74	10.38	0.472	84
9C2D11	04/17/06	6.23	10.79	0.317	98
MW2D2					
Phase 2. Baseline Sampling					
1B2D21	3/8/2005	6.31	12.63	0.246	
1B2D22	3/9/2005	6.07	12.55	0.258	
1B2D23	3/10/2005	6.06	12.30	0.231	
2B2D21	3/21/2005	6.18	12.31	0.241	71
2B2D22	3/22/2005	6.12	11.97	0.258	
2B2D23	3/23/2005	6.14	12.47	0.259	
3B2D21	4/4/2005	6.08	12.11	0.332	88
3B2D22	4/5/2005	6.02	11.86	0.312	
3B2D23	4/6/2005	6.05	12.03	0.314	
Phase 3. Initial 3% w/w Whey Injection					
1C2D21	7/5/2005	5.11	13.02	0.791	
1C2D23	7/7/2005	5.04	13.36	0.615	
Phase 3. 1% w/w Whey Injection					
2C2D21	7/18/2005	5.61	14.35	0.528	
2C2D22	7/19/2005	5.49	13.18	1.382	
2C2D23	7/20/2005	5.03	13.82	1.342	
3C2D21	8/15/2005	5.29	14.50	0.697	108
3C2D22	8/16/2005	5.25	14.23	1.271	
3C2D23	8/17/2005	5.13	13.93	1.270	

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
4C2D21	10/3/2005	5.20	14.30	1.640	137
4C2D22	10/4/2005	5.15	14.80	1.730	
4C2D23	10/5/2005	5.06	14.45	1.560	
Phase 3. 10% w/w Whey Injection					
5C2D21	11/7/2005	5.79	14.34	1.122	173
5C2D22	11/8/2005	5.57	14.50	3.410	
5C2D23	11/9/2005	5.15	14.38	2.950	
6C2D21	12/12/2005	5.28	13.45	2.500	276
6C2D22	12/13/2005	5.53	13.53	3.750	
6C2D23	12/14/2005	5.24	13.57	3.620	
7C2D21	2/21/2006	5.60	11.19	0.482	23
7C2D22	2/22/2006	5.56	11.34	1.229	
7C2D23	2/23/2006	5.25	11.02	1.334	
Post- Whey Injection Sampling					
8C2D21	3/21/2006	5.26	11.52	0.681	74
9C2D21	04/17/06	5.97	11.52	0.418	82
MW2D4					
Phase 2. Baseline Sampling					
1B2D41	3/8/2005	6.43	13.72	0.325	
1B2D42	3/9/2005	6.26	13.57	0.312	
1B2D43	3/10/2005	6.25	13.34	0.288	
2B2D41	3/21/2005	6.36	13.34	0.324	101
2B2D42	3/22/2005	6.33	13.45	0.305	
2B2D43	3/23/2005	6.34	13.61	0.318	
3B2D41	4/4/2005	6.21	13.40	0.331	87
3B2D42	4/5/2005	6.04	11.53	0.313	
3B2D43	4/6/2005	6.19	13.39	0.318	
Phase 3. Initial 3% w/w Whey Injection					
1C2D41	7/5/2005	5.22	13.17	0.911	
1C2D43	7/7/2005	5.26	13.26	0.884	
Phase 3. 1% w/w Whey Injection					
2C2D41	7/18/2005	5.52	14.98	0.793	
2C2D42	7/19/2005	5.49	12.43	0.969	
2C2D43	7/20/2005	5.45	14.50	0.938	
3C2D41	8/15/2005	5.87	23.03	0.830	177
3C2D42	8/16/2005	5.56	13.61	0.957	
3C2D43	8/17/2005	5.61	13.47	0.757	
4C2D41	10/3/2005	5.31	14.36	1.550	216
4C2D42	10/4/2005	5.35	13.54	1.580	
4C2D43	10/5/2005	5.02	13.44	1.580	
Phase 3. 10% w/w Whey Injection					
5C2D41	11/7/2005	5.85	13.44	1.416	316
5C2D42	11/8/2005	5.63	13.40	2.110	
5C2D43	11/9/2005	4.98	13.26	2.530	
6C2D41	12/12/2005	5.59	12.76	2.260	384
6C2D42	12/13/2005	5.66	13.08	2.680	
6C2D43	12/14/2005	5.19	12.95	2.720	
7C2D41	2/21/2006	5.87	12.24	1.670	

Table E-2. (continued).

Sample ID	Date	pH	Temp (°C)	Specific Conductivity (ms/cm)	Alkalinity mg/L as CaCO ₃
7C2D42	2/22/2006	5.83	12.28	1.640	
7C2D43	2/23/2006	5.69	11.84	1.425	
Post- Whey Injection Sampling					
8C2D41	3/21/2006	5.83	12.63	2.310	820
9C2D41	04/17/06	5.74	12.41	1.059	239

Table E-3. Redox Results.

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
MW1A1							
Phase 2. Baseline Sampling							
1B1A11	03/08/05	208	3.67				0.3
1B1A13	03/10/05	178	2.87				0.38
2B1A11	03/21/05	201	2.81	05			0.3
2B1A12	03/22/05	228	2.66				0.69
2B1A13	03/23/05	218	2.76		1.5	06	0.37
3B1A11	04/04/05	194	2.69	0.11			0.53
3B1A12	04/05/05	222	3.58				0.46
3B1A13	04/06/05	214	3.57		22.6	1.20	0.36
Phase 3. 10% w/w Whey Injection							
2C1A11	07/18/05	-276	1.32	2.72			2.2
2C1A12	07/19/05	-125	2.64				0.84
2C1A13	07/20/05	-215	1.94		5.50	06	0.78
3C1A1	08/15/05	8	1.7	2.49	4.80	0	66.1
4C1A11	10/03/05	-13	0.95	3.3			91
4C1A12	10/04/05	-64	0.54				38
4C1A13	10/05/05	-153	0.59				98
Phase 3. 1% w/w Whey Injection							
5C1A11	11/07/05	-106	1.33	2.77	2.80	0	320
5C1A12	11/08/05	-60	0.80				200
5C1A13	11/09/05	-113	0.87				280
6C1A11	12/12/2005	-98	0.87	2.2			
6C1A12	12/13/2005	-62	1.20				
6C1A13	12/14/2005	-138	0.69				
7C1A11	02/21/06	-85	0.8	3.3	12.50	0	9400
7C1A12	02/22/06	-34	1.51				5900
7C1A13	02/23/06	-75	0.65				9700
Post- Whey Injection Sampling							
8C1A11	03/21/06	-67	0.85	3.3	12.00	1.5	10000
9C1A11	04/17/06	-91	0.9	3.3	00	0	5700
MW1A2							
Phase 2. Baseline Sampling							
1B1A21	3/8/2005	197	2.84				0.5
1B1A22	3/9/2005	196	2.93				0.54
1B1A23	3/10/2005	192	2.86				0.41
2B1A21	3/21/2005	202	2.41	0.10			0.36
2B1A22	3/22/2005	235	2.37				0.66
2B1A23	3/23/2005	215	2.52		17.9	1.3	0.36
3B1A21	4/4/2005	199	2.58	0.11			0.43
3B1A22	4/5/2005	223	3.30				0.44

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
3B1A23	4/6/2005	219	3.30		23.6	1.2	0.38
Phase 3. 10% w/w Whey Injection							
2C1A21	7/18/2005	-106	0.80	1.66			2.6
2C1A22	7/19/2005	-139	1.44				1.3
2C1A23	7/20/2005	-214	1.97		6	03	1.1
3C1A2	8/15/2005	-13	1.16	2.41	3.8	0	2.3
4C1A2	10/03/05	-16	0.93	3.3			230
4C1A3	10/04/05	-91	0.58				77
4C1A4	10/05/05	-190	0.61				86
Phase 3. 1% w/w Whey Injection							
5C1A21	11/7/2005	-144	1.03	2.56	23.5	0	900
5C1A22	11/8/2005	-86	0.71				410
5C1A23	11/9/2005	-132	0.73				540
6C1A21	12/12/2005	-99	0.89	2.52			4900
6C1A22	12/13/2005	-90	0.65				2000
6C1A23	12/14/2005	-151	0.64				3100
7C1A21	2/22/2006	-81	1.09	3.3	2.1	0.5	12000
7C1A22	2/22/2006	-50	1.18				10000
7C1A23	2/23/2006	-98	0.65				13000
Post- Whey Injection Sampling							
8C1A21	3/21/2006	-82	0.83	3.3	8	0	11000
9C1A21	4/17/2006	-100	0.73	3.3	0	0	9000
MW1A4							
Phase 2. Baseline Sampling							
1B1A41	3/8/2005	179	4.19				0.34
1B1A42	3/9/2005	202	3.14				0.41
1B1A43	3/10/2005	204	2.95				0.36
2B1A41	3/21/2005	207	2.69	02			0.31
2B1A42	3/22/2005	241	2.51				0.57
2B1A43	3/23/2005	225	2.43		16.9	1.40	0.38
3B1A41	4/4/2005	202	2.65	08			0.44
3B1A42	4/5/2005	224	3.07				0.40
3B1A43	4/6/2005	222	3.24		29.9	1.30	0.40
Phase 3. 10% w/w Whey Injection							
2C1A41	07/18/05	80	2.08	2.72			6
2C1A42	07/19/05	-219	1.11				3.40
2C1A43	07/20/05	-197	2.07		13.9	06	13
3C1A41	08/15/05	-102	1.01	3.30	7.8	00	0
4C1A41	10/3/2005	1	1.08	2.51			67
4C1A42	10/4/2005	-123	0.58				36
4C1A43	10/5/2005	-185	0.73				64
Phase 3. 1% w/w Whey Injection							
5C1A41	11/7/2005	-125	1.00	2.46	17.7	00	480
5C1A42	11/8/2005	-73	0.75				270
5C1A43	11/9/2005	-125	0.77				360
6C1A41	12/12/2005	-73	0.76	2.07			340
6C1A42	12/13/2005	-77	0.66				2000
6C1A43	12/14/2005	-110	0.65				2100

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
7C1A41	02/22/06	-93	0.95	3.30	2.3	29.40	7100
7C1A42	02/22/06	-70	0.89				2000
7C1A43	02/23/06	-86	0.69				5200
Post- Whey Injection Sampling							
8C1A41	03/21/06	-82	0.80	3.30	1.4	0	4500
9C1A41	04/16/06	-110	0.59	3.30	0.8	0	9500
MW1B4							
Phase 2. Baseline Sampling							
1B1B41	3/8/2005	166	3.26				2.1
1B1B42	3/9/2005	201	2.99				1.5
1B1B43	3/10/2005	202	2.70				1.3
2B1B41	3/21/2005	187	2.05	03			1.5
2B1B42	3/22/2005	248	2.29				1.2
2B1B43	3/23/2005	214	2.19		16.6	1.3	0.9
3B1B41	4/4/2005	203	2.70	06			1.1
3B1B42	4/5/2005	217	2.60				0.63
3B1B43	4/6/2005	218	2.51		28.2	1.2	0.68
Phase 3. 10% w/w Whey Injection							
2C1B41	7/18/2005	-288	0.59	2.52			22
2C1B42	7/19/2005	-192	0.83				14
2C1B43	7/20/2005	-211	1.93		9.7	0.46	22
3C2B4	8/15/2005	0.72	0.96	1.98	4	0	25
4C2B4	10/3/2005	-41	0.91	2.91			160
4C2B5	10/4/2005	-133	0.58				89
4C2B6	10/5/2005	-188	0.70				180
Phase 3. 1% w/w Whey Injection							
5C1B41	11/7/2005	-172	0.77	3	10	0	1600
5C1B42	11/8/2005	-117	0.70				940
5C1B43	11/9/2005	-133	0.85				1500
6C1B41	12/12/2005	-104	0.73	2.53			7800
6C1B42	12/13/2005	-106	0.61				5700
6C1B43	12/14/2005	-134	00				5800
7C1B41	2/22/2006	-111	0.73	3.3	1.7	0.6	13000
7C1B42	2/22/2006	-105	0.77				14000
7C1B43	2/23/2006	-103	0.61				13000
Post- Whey Injection Sampling							
8C1B41	3/21/2006	-88	0.83	3.3	11.6	2.3	14000
9C1B41	4/17/2006	-79	0.68	3.3	0.8	0	7600
MW1C4							
Phase 2. Baseline Sampling							
1B1C41	3/8/2005	178	3.04				0.98
1B1C42	3/9/2005	193	2.85				0.76
1B1C43	3/10/2005	195	2.51				0.9
2B1C41	3/21/2005	193	2.36	04			1.2
2B1C42	3/22/2005	231	2.60				0.78
2B1C43	3/23/2005	192	2.47		17.5	1.4	0.62
3B1C41	4/4/2005	184	1.86	05			0.83
3B1C42	4/5/2005	206	2.48				0.56

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
3B1C43	4/6/2005	214	2.14		24.5	1.3	0.65
Phase 3. 10% w/w Whey Injection							
2C1C41	7/18/2005	-234	0.55	1.81			9.8
2C1C42	7/19/2005	-198	0.76				6.1
2C1C43	7/20/2005	-223	1.96		1.2	0.3	14
3C1C4	8/15/2005	-59	0.94	3.3	0	0	11
4C1C4	10/3/2005	-37	0.88	3.05			270
4C1C5	10/4/2005	-227	0.58				230
4C1C6	10/5/2005	-191	0.66				430
Phase 3. 1% w/w Whey Injection							
5C1C41	11/7/2005	-145	0.72	2.46	7.4	0	2400
5C1C42	11/8/2005	-104	0.72				1200
5C1C43	11/9/2005	-120	0.73				540
6C1C41	12/12/2005	-103	0.72	2.54			9800
6C1C42	12/13/2005	-106	0.68				7000
6C1C43	12/14/2005	-140	0.58				7600
7C1C41	2/22/2006	-129	0.79	3.3	1.5	0	15000
7C1C42	2/22/2006	-113	0.72				14000
7C1C43	2/23/2006	-100	0.70				14000
Post- Whey Injection Sampling							
8C1C41	3/21/2006	-104	0.73	3.3	1.4	0	12000
9C1C41	4/17/2006	-116	0.58	3.3	1.5	0	11000
MW1D2							
Phase 2. Baseline Sampling							
1B1D21	3/8/2005	192	2.52				0.39
1B1D22	3/9/2005	199	2.62				0.5
1B1D23	3/10/2004	205	2.23				0.45
2B1D21	3/21/2005	201	1.77	04			
2B1D22	3/22/2005	236	2.02				0.4
2B1D23	3/23/2005	214	1.83		18.2	1.3	0.59
3B1D21	4/4/2005	206	1.98	03			0.42
3B1D22	4/5/2005	221	3.18				
3B1D23	4/6/2005	213	2.55		34.7	1.1	0.46
Phase 3. 10% w/w Whey Injection							
2C1D121	7/18/2005	-234	1.01	06			1.6
2C1D122	7/19/2005	-149	1.14				1.5
2C1D123	7/20/2005	-181	2.05		3.6	04	1.1
3C1D2	8/15/2005	-6	1.3	2.07	1.7	0	2.2
4C1D21	10/3/2005	-31	0.96	3.3			170
4C1D22	10/4/2005	-94	0.59				38
4C1D23	10/5/2005	-175	0.60				79
Phase 3. 1% w/w Whey Injection							
5C1D21	11/7/2005	-145	1.12	1.84	12	0.9	480
5C1D22	11/8/2005	-85	0.86				250
5C1D23	11/9/2005	-131	0.74				400
6C1D21	12/12/2005	-112	0.78	2.7			3700
6C1D22	12/13/2005	-96	0.68				1900
6C1D23	12/14/2005	-150	0.67				3100

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
7C1D21	2/21/2006	-116	0.79	3.3	4.1	0	8500
7C1D22	2/22/2006	-45	0.94				5500
7C1D23	2/23/2006	-93	0.74				11000
Post- Whey Injection Sampling							
8C1D21	3/21/2006	-103	0.89	3.3	0.6	0	7900
9C1D21	4/17/2006	-73	0.81	3.3	1.1	0	13000
MW1D3							
Phase 2. Baseline Sampling							
1B1D31	3/8/2005	164	2.16				0.58
1B1D32	3/9/2005	197	2.25				0.5
1B1D33	3/10/2005	199	2.04				0.44
2B1D31	3/21/2005	194	1.72	07			0.51
2B1D32	3/22/2005	228	1.87				0.57
2B1D33	3/23/2005	208	1.94		17.1	1.3	0.48
3B1D31	4/4/2005	197	1.91	04			0.5
3B1D32	4/5/2005	218	2.33				0.45
3B1D33	4/6/2005	215	2.37		22.1	1.2	0.47
Phase 3. 10% w/w Whey Injection							
2C1D31	7/18/2005	-185	0.69	1.08			3.6
2C1D32	7/19/2005	-198	0.91				2.7
2C1D33	7/20/2005	-219	1.99		2.2	0.29	5.2
3C1D3	8/15/2005	-35	1.08	3.3	0.64	0	5.2
4C1D31	10/3/2005	-30	1.02	3.18			450
4C1D32	10/4/2005	-144	0.73				120
4C1D33	10/5/2005	-160	0.73				310
Phase 3. 1% w/w Whey Injection							
5C1D31	11/7/2005	-164	1.06	2.85	20	11	1800
5C1D32	11/8/2005	-100	0.89				1300
5C1D33	11/9/2005	-134	0.72				1500
6C1D31	12/12/2005	-121	0.80	1.77			6400
6C1D32	12/13/2005	-119	0.67				5500
6C1D33	12/14/2005	-157	0.67				5400
7C1D31	2/22/2006	-123	0.87	3.3	0.5	0.4	10000
7C1D32	2/22/2006	-87	0.92				14000
7C1D33	2/23/2006	-111	0.69				14000
Post- Whey Injection Sampling							
8C1D31	3/21/2006	-91	0.89	2.34	1.7	0	9100
9C1D31	4/17/2006	-91	0.72	3.3	1.5	0	12000
MW1D4							
Phase 2. Baseline Sampling							
1B1D41	3/8/2005	185	2.18				0.61
1B1D42	3/9/2005	183	2.02				0.55
1B1D43	3/10/2005	191	1.89				0.5
2B1D41	3/21/2005	189	1.61	00			0.66
2B1D42	3/22/2005	220	1.67				0.58
2B1D43	3/23/2005	196	1.70		16.5	1.3	0.5
3B1D41	4/4/2005	182	1.47				0.67
3B1D42	4/5/2005	216	2.00	02			0.51

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
3B1D43	4/6/2005	213	1.90		21.2	1.1	0.51
Phase 3. 10% w/w Whey Injection							
2C1D41	7/18/2005	-217	0.60	1.58			3.8
2C1D42	7/19/2005	-208	1.02				
2C1D43	7/20/2005	-233	1.98		3.1	0.36	5.5
3C1D4	8/15/2005	-56	0.93	3.30	0.11	0	4.5
4C1D41	10/3/2005	-30	0.91	3.30			210
4C1D42	10/4/2005	-182	0.53				150
4C1D43	10/5/2005	-176	0.69				230
Phase 3. 1% w/w Whey Injection							
5C1D41	11/7/2005	-176	0.84	2.50	9.2	0	2000
5C1D42	11/8/2005	-111	0.78				1300
5C1D43	11/9/2005	-139	0.75				580
6C1D41	12/12/2005	-120	0.74	2.88			6600
6C1D42	12/13/2005	-124	0.64				5000
6C1D43	12/14/2005	-155	0.62				5400
7C1D41	2/22/2006	-125	0.83	3.30	2	0	11000
7C1D42	2/22/2006	-97	0.86				11000
7C1D43	2/23/2006	-105	0.73				11000
Post- Whey Injection Sampling							
8C1D41	3/21/2006	-94	0.87	3.30	2.8	0	8100
9C1D41	4/17/2006	-103	0.69	3.30	0.86	0	3600
MW2A1							
Phase 2. Baseline Sampling							
1B2A11	3/8/2005	94	1.35				1.3
1B2A12	3/9/2005	132	1.39				1.2
1B2A13	3/10/2005	140	1.35				1.1
2B2A11	3/21/2005	139	1.01	04			0.85
2B2A12	3/22/2005	171	1.26				1.5
2B2A13	3/23/2005	174	1.24		14.0	0.91	0.87
3D2A11	4/4/2005	154	1.58				0.87
3D2A12	4/5/2005	160	1.52	08			0.96
3D2A13	4/6/2005	186	1.22		21.5	1.1	0.84
Phase 3. 1% w/w Whey Injection							
2C2A11	7/18/2005	-119	1.63	3.1			4.5
2C2A12	7/19/2005	-101	2.19				1.4
2C2A13	7/20/2005	-205	1.70		3.4	0	2.8
3C2A11	8/15/2005	-45	0.92	3.3	5.6	0	7
3C2A12	8/16/2005	-42	1.37				3.9
3C2A13	8/17/2005	-155	1.48				4.1
4C2A11	10/3/2005	-63	0.89	3.1			100
4C2A12	10/4/2005	-84	0.84				30
4C2A13	10/5/2005	-167	0.60				43
Phase 3. 10% w/w Whey Injection							
5C2A11	11/7/2005	-171	0.81	3.3	46.3	0	520
5C2A12	11/8/2005	-154	0.65				300
5C2A13	11/9/2005	-222	0.64				86
6C2A11	12/12/2005	-117	0.92	2.61			370

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
6C2A12	12/13/2005	-148	0.70				300
6C2A13	12/14/2005	-151	0.87				450
7C2A11	2/21/2006	-71	0.87	3.3	0.5	0	4900
7C2A12	2/22/2006	-117	0.92				2100
7C2A13	2/23/2006	-91	0.59				1800
Post- Whey Injection Sampling							
8C2A11	3/21/2006	-71	0.72	3.3	8.0	0	4900
9C2A11	4/17/2006	-86	0.51	3.3	0	0	13000
MW2A2							
Phase 2. Baseline Sampling							
1B2A21	3/8/2005	130	1.51				0.57
1B2A22	3/9/2005	157	1.64				0.96
1B2A23	3/10/2005	159	1.50				0.71
2B2A21	3/21/2005	149	1.25	09			0.52
2B2A22	3/22/2005	182	1.39				1.2
2B2A23	3/23/2005	173	1.09		14.0	0.9	0.78
3B2A21	4/4/2005	158	1.60				0.49
3B2A22	4/5/2005	167	1.51	06			0.81
3B2A23	4/6/2005	169	1.24		21.2	1.1	0.7
Phase 3. 1% w/w Whey Injection							
2C2A21	7/18/2005	-130	0.89	2.84			4.2
2C2A22	7/19/2005	-158	1.74				1.4
2C2A23	7/20/2005	-244	1.48		4.2	0.11	3.2
3C2A21	8/15/2005	-45	0.91	3.3	61.1	0	7.1
3C2A22	8/16/2005	-84	1.20				4.7
3C2A23	8/17/2005	-195	1.24				3.1
4C2A21	10/3/2005	-60	0.86	2.95			110
4C2A22	10/4/2005	-97	0.82				21
4C2A23	10/5/2005	-176	0.51				43
Phase 3. 10% w/w Whey Injection							
5C2A21	11/7/2005	-169	0.80	3.3	46.7	0	350
5C2A22	11/8/2005	-158	0.64				250
5C2A23	11/9/2005	-248	0.62				76
6C2A21	12/12/2005	-108	0.92	2.06			370
6C2A22	12/13/2005	-157	0.62				310
6C2A23	12/14/2005	-192	0.69				300
7C2A21	2/21/2006	-75	0.81	3.3	1.1	0	6100
7C2A22	2/22/2006	-130	0.74				1200
7C2A23	2/23/2006	-98	0.60				2100
Post- Whey Injection Sampling							
8C2A21	3/21/2006	-68	0.81	3.3	7.5	0	5500
9C2A21	4/17/2006	-79	0.48	3.3	6.0	0	12000
MW2A4							
Phase 2. Baseline Sampling							
1B2A41	3/8/2005	75	1.81				0.57
1B2A42	3/9/2005	89	1.88				0.96
1B2A43	3/10/2005	90	1.68				0.71
2B2A41	3/21/2005	81	1.29	0.23			0.52

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
2B2A42	3/22/2005	118	1.81				1.2
2B2A43	3/23/2005	110	1.11		14.4	1.1	0.78
3B2A41	4/4/2005	124	1.72				0.449
3B2A42	4/5/2005	122	2.09	0.11			0.81
3B2A43	4/6/2005	128	1.26		22.3	1.3	0.7
Phase 3. 1% w/w Whey Injection							
2C2A41	7/18/2005	-101	0.81	3.19			4.2
2C2A42	7/19/2005	-148	1.51				1.4
2C2A43	7/20/2005	-175	1.10		6.9	06	3.2
3C2A41	8/15/2005	-53	0.86	3.3	0.28	0	7.1
3C2A42	8/16/2005	-76	1.43				4.7
3C2A43	8/17/2005	-109	1.23				3.1
4C2A41	10/3/2005	-54	0.85	3.1			190
4C2A42	10/4/2005	-103	0.95				60
4C2A43	10/5/2005	-128	0.59				110
Phase 3. 10% w/w Whey Injection							
5C2A41	11/7/2005	-174	0.88	3.3	8.3	6.8	1300
5C2A42	11/8/2005	-163	0.74				440
5C2A43	11/9/2005	-235	0.60				240
6C2A41	12/12/2005	-99	0.96	1.91			1600
6C2A42	12/13/2005	-157	0.65				770
6C2A43	12/14/2005	-183	0.61				620
7C2A41	2/21/2006	-106	0.85	3.3	1.1	0.2	4400
7C2A42	2/22/2006	-73	0.81				2300
7C2A43	2/23/2006	-89	0.56				3900
Post- Whey Injection Sampling							
8C2A41	3/21/2006	-95	0.9	3.3	1.4	0	4500
9C2A41	4/17/2006	-66	0.59	3.3	1.7	0	4400
MW2B4							
Phase 2. Baseline Sampling							
1B2B41	3/8/2005	168	1.55				0.31
1B2B42	3/9/2005	186	1.78				0.36
1B2B43	3/10/2005	185	1.60				0.56
2B2B41	3/21/2005	181	1.02	04			0.33
2B2B42	3/22/2005	219	1.49				0.6
2B2B43	3/23/2005	200	1		13.6	1.1	0.65
3B2A41	4/4/2005	190	1.30				0.4
3B2A42	4/5/2005	196	1.61	03			0.42
3B2A43	4/6/2005	170	0.86		24.1	1.3	0.56
Phase 3. 1% w/w Whey Injection							
2C2B41	7/18/2005	-146	0.82	1.19			3
2C2B42	7/19/2005	-210	1.62				3
2C2B43	7/20/2005	-186	1		9.4	1.5	5.2
3C2B41	8/15/2005	80	0.69	3.3	4.3	0	4.2
3C2B42	8/16/2005	-39	1.01				3.9
3C2B43	8/17/2005	-67	0.88				3.7
4C2B41	10/3/2005	45	0.82	3.3			28
4C2B42	10/4/2005	-98	0.98				25

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
4C2B43	10/5/2005	-135	0.56				31
Phase 3. 10% w/w Whey Injection							
5C2B41	11/7/2005	-135	0.87	3.3	40.7	0	430
5C2B42	11/8/2005	-157	0.67				170
5C2B43	11/9/2005	-189	0.61				290
6C2B41	12/12/2005	-61	0.96	1.93			260
6C2B42	12/13/2005	-143	0.68				320
6C2B43	12/14/2005	-188	0.61				430
7C2B41	2/21/2006	-25	0.74	3.3	7.7	0	1500
7C2B42	2/22/2006	-39	0.80				1600
7C2B43	2/23/2006	-15	0.69				1700
Post- Whey Injection Sampling							
8C2B41	3/21/2006	-22	0.65	3.3	0	0	1800
9C2B41	4/17/2006	-61	0.44	3.3	0	0	2700
MW2C4							
Phase 2. Baseline Sampling							
1B2C41	3/8/2005	103	0.66				1.8
1B2C42	3/9/2005	144	0.75				1.8
1B2C43	3/10/2005	105	0.85				1.2
2B2C41	3/21/2005	123	0.87	0.15			1.8
2B2C42	3/22/2005	125	0.69				1.8
2B2C43	3/23/2005	102	0.54		14.6	0.97	1.3
3B2C41	4/4/2005	109	0.43				1.9
3B2C42	4/5/2005	120	0.85	07			1.3
3B2C43	4/6/2005	123	0.44		19.2	1.1	1.4
Phase 3. 1% w/w Whey Injection							
2C2C41	7/18/2005	-179	0.95	3.3			7.3
2C2C42	7/19/2005	-187	1.21				7.3
2C2C43	7/20/2005	-169	1.04		7.9	0.83	15
3C2C41	8/15/2005	-24	0.55	3.06	10.3	0	19
3C2C42	8/16/2005	-85	1.19				13
3C2C43	8/17/2005	-71	0.81				19
4C2C41	10/3/2005	-45	0.84	3.08			190
4C2C42	10/4/2005	-107	0.84				63
4C2C43	10/5/2005	-99	0.57				100
Phase 3. 10% w/w Whey Injection							
5C2C41	11/7/2005	-160	0.88	3.3	7.5	0	2800
5C2C42	11/8/2005	-147	0.79				1200
5C2C43	11/9/2005	-169	0.65				1700
6C2C41	12/12/2005	-80	0.89	1.67			3100
6C2C42	12/13/2005	-145	0.72				1600
6C2C43	12/14/2005	-138	0.62				1800
7C2C41	2/21/2006	-68	0.74	3.3	0	0	9400
7C2C42	2/22/2006	-66	0.91				4900
7C2C43	2/23/2006	-68	0.53				6000
Post- Whey Injection Sampling							
8C2C41	3/21/2006	-56	0.77	3.3	11.5	0	8000
9C2C41	4/17/2006	-32	1	3.3	8.5	0	5700

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
MW2D1							
Phase 2. Baseline Sampling							
1B2D110	3/8/2005	157	1.79				0.32
1B2D12	3/9/2005	174	1.28				0.53
1B2D13	3/10/2005	203	1.68				0.49
2B2D11	3/21/2005	180	1.12	03			0.4
2B2D12	3/22/2005	221	1.14				1.1
2B2D13	3/23/2005	209	1.15		14.8	0.99	0.69
3B2D11	4/4/2005	203	1.66				0.45
3B2D12	4/5/2005	192	1.87	04			0.63
3B2D13	4/6/2005	213	1.44		24.8	1.4	0.67
Phase 3. 1% w/w Whey Injection							
2C2D11	7/18/2005	-152	1.53	2.4			1.2
2C2D12	7/19/2005	-240	1.86				0.86
2C2D13	7/20/2005	-330	1.64		0.23	0.65	0.84
3C2D11	8/15/2005	-13	0.82	3.27	0	0	4
3C2D12	8/16/2005	-76	1.22				2.5
3C2D13	8/17/2005	-180	1.32				0
4C2D11	10/3/2005	-41	0.91	3.3			0.93
4C2D12	10/4/2005	-90	0.87				36
4C2D13	10/5/2005	-110	0.56				110
Phase 3. 10% w/w Whey Injection							
5C2D11	11/7/2005	-157	0.84	3.3	20.6	0	550
5C2D12	11/8/2005	-164	0.64				340
5C2D13	11/9/2005	-280	0.56				130
6C2D11	12/12/2005	-108	0.98	2.35			1200
6C2D12	12/13/2005	-159	0.61				440
6C2D13	12/14/2005	-174	0.75				590
7C2D11	2/21/2006	-94	0.85	3.3	0.9	0.1	1700
7C2D12	2/22/2006	-145	0.88				660
7C2D13	2/23/2006	-111	0.73				1200
Post- Whey Injection Sampling							
8C2D11	3/21/2006	-62	0.81	3.3	1	3.4	4100
9C2D11	4/17/2006	-69	0.58	3.3	0	1.2	1600
MW2D2							
Phase 2. Baseline Sampling							
1B2D21	3/8/2005	151	1.37				0.39
1B2D22	3/9/2005	179	1.46				0.61
1B2D23	3/10/2005	202	1.46	0			0.7
2B2D21	3/21/2005	179	0.96				0.42
2B2D22	3/22/2005	229	1.05				1
2B2D23	3/23/2005	181	0.94		21.7	0.96	0.74
3B2D21	4/4/2005	196	1.38				0.46
3B2D22	4/5/2005	195	1.71	03			0.61
3B2D23	4/6/2005	195	1.07		25.5	1.3	0.64
Phase 3. 1% w/w Whey Injection							
2C22D21	7/18/2005	-117	0.83	2.42			1.5
2C22D22	7/19/2005	-230	1.62				0.8

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
2C2D23	7/20/2005	-318	1.29		0.29	1.5	1.2
3C2D21	8/15/2005	-38	0.72	3.30	0	0	4.4
3C2D22	8/16/2005	-80	1.16				2.9
3C2D23	8/17/2005	-141	1.21				2.9
4C2D21	10/3/2005	-30	0.85	3.30			200
4C2D22	10/4/2005	-98	0.84				40
4C2D23	10/5/2005	-96	0.52				120
Phase 3. 10% w/w Whey Injection							
5C2D21	11/7/2005	-151	0.83	3.30	19.5	0	1900
5C2D22	11/8/2005	-167	0.64				370
5C2D23	11/9/2005	-284	0.55				170
6C2D21	12/12/2005	-89	0.98	2.82			1200
6C2D22	12/13/2005	-156	0.64				440
6C2D23	12/14/2005	-172	0.66				660
7C2D21	2/21/2006	-72	0.8	3.30	0.8	0.1	4200
7C2D22	2/22/2006	-115	0.85				1900
7C2D23	2/23/2006	-97	0.75				3000
Post- Whey Injection Sampling							
8C2D21	3/21/2006	-33	0.83	3.30	21.1	4.1	10000
9C2D21	4/17/2006	-53	0.5	3.30	1.1	0	3600
MW2D4							
Phase 2. Baseline Sampling							
1B2D41	3/8/2005	157	0.65				3.1
1B2D42	3/9/2005	174	0.86				2.2
1B2D43	3/10/2005	145	0.71				3.2
2B2D41	3/21/2005	164	0.43	04			4.1
2B2D42	3/22/2005	199	0.87				3.9
2B2D43	3/23/2005	180	0.54		16.2	0.88	3.2
3B2D41	4/4/2005	164	0.43				3.1
3B2D42	4/5/2005	170	1.51	03			0.65
3B2D43	4/6/2005	160	0.45		19.2	0.98	3.1
Phase 3. 1% w/w Whey Injection							
2C2D41	7/18/2005	5.52	0.82	2.74			5.9
2C2D42	7/19/2005	5.49	1.48				3.6
2C2D43	7/20/2005	5.45	1.10		5.3	0.18	7.4
3C2D41	8/15/2005	5.87	0.69	2.46	0	0.21	13
3C2D42	8/16/2005	5.56	1.08				5.4
3C2D43	8/17/2005	5.61	0.95				2.6
4C2D41	10/3/2005	-34	0.84	3.3			290
4C2D42	10/4/2005	-107	0.96				69
4C2D43	10/5/2005	-98	0.57				150
Phase 3. 10% w/w Whey Injection							
5C2D41	11/7/2005	-154	0.86	3.3	17.5	0	2500
5C2D42	11/8/2005	-151	0.76				740
5C2D43	11/9/2005	-166	0.67				1200
6C2D41	12/12/2005	-85	0.90	2.5			1900
6C2D42	12/13/2005	-154	0.71				1400
6C2D43	12/14/2005	-170	0.64				1300

Table E-3. (continued).

Sample ID	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
7C2D41	2/21/2006	-90	0.76	3.3	0.9	0	10000
7C2D42	2/22/2006	-81	0.89				5200
7C2D43	2/23/2006	-74	0.69				8700
Post- Whey Injection Sampling							
8C2D41	3/21/2006	-58	0.65	0.51	13	0	5700
9C2D41	4/17/2006	-42	1.08	3.3	7	0	9200

Table E-4. VOC and Dissolved Gases Results.

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
MW1A1								
Phase 2. Baseline Sampling								
1B1A11	3/8/2005	3900	490	0	0	0	0	
1B1A12	3/9/2005	10000	1800	0	0	0	0	
1B1A13	3/10/2005	8100	1100	0	0	0	0	
2B1A11	3/21/2005	3900	450	0	0	0	0	
2B1A12	3/22/2005	160	33	0	0	0	0	
2B1A13	3/23/2005	6500	1100	0	0	0	0	1.1
3B1A11	4/4/2005	9000 D	1200 D	0	0	0	0	
3B1A12	4/5/2005	17000	3500	0	0	0	0	
3B1A13	4/6/2005	20000	2100 J	0	0	0	0	4.3
3B1A13	4/6/2005	8400	1200	0	0			
Phase 3. 10% w/w Whey Injection								
2C1A11	7/18/2005	800 J, B, D	3100 B,D	0	0	0	0	
2C1A12	7/18/2005	1500 D	7700 B,D	0	0	0	0	
2C1A13	7/19/2005	810 J, D	5300 B, D	0	0	0	0	31.2
3C1A11	8/15/2005	540 D	3900 D,E	74 D	0	0	0	66.1
3C1A11	8/15/2005		4600 D					
MW1A1	9/12/2005	0	3400 D	0	0	0	0	
4C1A11	10/03/05	460 D	5300 D	47 J,D	0	0	0	
4C1A12	10/04/05	1000 B,D	8500 D	0	0	0	0	
4C1A13	10/05/05	630 D	12000 D	92 J,D	0	0	0	
Phase 3. 1% w/w Whey Injection								
5C1A11	11/7/2005	0	6500 D	0	0	1.3 J	0	
5C1A12	11/8/2005	1600 D	13000 D	1600 D	0	0	0.62 J	
5C1A13	11/9/2005	810 B,D	12000 D	100J,D	0	0.67 J	0.87 J	
6C1A11	12/12/05	290 J,D	9500 D	78 J,D	0	0	0	
6C1A12	12/13/05	1600 D	15000 D	120 J,D	120 J,D	0	0	
6C1A13	12/14/05	920 D	13000 D	95 J,D	73 J,D	0	0	
7C1A11	2/21/2006	200 D	5500 D	54 D	280 D	0	12 J,COL	58.8
7C1A12	2/22/2006	600 D	5400 D	43 J,D	270 D	0	0	
7C1A13	2/23/2006	240 J,D	3800 D	37 J,D	220 D	0	16 J,COL	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
Post- Whey Injection Sampling								
8C1A11	3/21/2006	59J,D	3200 D	0	540 D	0	47 J	31.5
9C1A11	4/17/2006	14 J,D	1200 D	0	310 D	0	26 J	11.8
MW1A2								
Phase 2. Baseline Sampling								
1B1A21	3/8/2005	3500	460	0	0	0	0	
1B1A22	3/9/2005	8900	1700	0	0	0	0	
1B1A23	3/10/2005	7300	1000	0	0	0	0	
2B1A21	3/21/2005	3700	450	0	0	0	0	
2B1A22	3/22/2005	12000	2400	0	0	0	0	
2B1A23	3/23/2005	4200	690	0	0	0	0	4.4
3B1A21	4/4/2005	5700	790	0	0	0	0	
3B1A22	4/5/2005	16000	3400	0	0	0	0	
3B1A23	4/6/2005	9900	1100 J	0	0	0	0	4.3
1C1A23	4/6/2005	7900	1300	0	0	0	0	
Phase 3. 10% w/w Whey Injection								
2C1A21	7/18/2005	600 J, B, D	3000 B, D	0	0	0	0	
2C1A22	7/18/2005	1200 D	6900 B,D	0	0	0	0	
2C1A23	7/19/2005	460 J, D	4800 B, D	0	0	0	0	25.8
3C1A21	8/15/2005	410 D	3600 D,E	76 D	0	0	0	26.7
4C1A21	10/03/05	400 J,D	5100 D	0	0	0	0	
4C1A22	10/04/05	810 D	7900 D	0	0	0	0	
4C1A23	10/05/05	530 D	11000 D	88 J,D	0	0	0	
Phase 3. 1% w/w Whey Injection								
5C1A21	11/7/2005	0	6300 D	0	0	2.4 J	0	
5C1A22	11/8/2005	1400 D	13000 D	0	0	1.8 J	0.44 J	
5C1A23	11/9/2005	470 J,B,D	12000D	0	0	1.4 J	1.3 J	
6C1A21	12/12/2005	140 J,D	8900 D	0	0	8.8 J	7.2 J	
6C1A22	12/13/2005	1300 D	13000 D	98 J,D	98 J,D	0	0	
6C1A23	12/14/2005	430 J,D	13000 D	96 J,D	78 J,D	5.3 J	4.7 J	
7C1A21	2/21/2006	170 D	4100 D	45 J,D	260 D	0	54 J	47.2
7C1A22	2/22/2006	430 D	4700 D	49 J,D	280 D	0	22 J,COL	
7C1A23	2/23/2006	150 J,D	3400 D	0	250 D	0	19 J,COL	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
Post- Whey Injection Sampling								
8C1A21	3/21/2006	120 D	2800 D	34 J,D	550 D	0	33 J	38.5
9C1A21	4/17/2006	27 J,D	1100 D	14 J,D	350 D	0	52 J	10.8
MW1A4								
Phase 2. Baseline Sampling								
1B1A41	3/8/2005	2800	370	0	0	0	0	
1B1A42	3/9/2005	7800	1300	0	0	0	0	
1B1A43	3/10/2005	7900	1100	36 J	0	0	0	
2B1A41	3/21/2005	3900	390	0	0	0	0	
2B1A42	3/22/2005	11000	2100	0	0	0	0	
2B1A43	3/23/2005	6600	1100	0	0	0	0	4.7
3B1A41	4/4/2005	7600	1500	0	0	0	0	
3B1A42	4/5/2005	16000	3200	0	0	0	0	
3B1A43	4/6/2005	11000	2000 J	0	0	0	0	5.6
3B1A43	4/6/2005	12000	1800	0	0	0	0	
Phase 3. 10% w/w Whey Injection								
2C1A41	7/18/2005	2200 B, D	2300 B, D	0	0	0	0.47 J	
2C1A42	7/18/2005	1900 D	5900 B,D	0	0	0	0	
2C1A43	7/19/2005	1800 D	4700 B,D	0	0	0	0.61 J	54.5
3C1A41	8/15/2005	1100 D	2200 D,E	0	0	0	0	77.3
4C1A41	10/03/05	300 J,D	3700 D	0	0	0	1.2 J,COL	
4C1A42	10/04/05	920 B,D	7400 D	0	0	0	0.61 J,COL	
4C1A43	10/05/05	550 D	6400 D	0	0	0	0	
Phase 3. 1% w/w Whey Injection								
5C1A41	11/7/2005	440 J,D	6400 D	0	0	1.8 J	3.1 J	
5C1A42	11/8/2005	1800 B,D	12000 D	0	0	0.88 J	1.7 J	
5C1A43	11/9/2005	690 B,D	12000 D	86 J,D	0	1.2 J	2.0 J	
6C1A41	12/12/2005	440 J,D	6500 D	0	0	6.3 J	7.1 J	
6C1A42	12/13/2005	1400 D	12000 D	84 J,D	0	0	4.2 J	
6C1A43	12/14/2005	1100 D	11000 D	0	0	0	4.1 J	
7C1A41	2/21/2006	18 J,D	2900 D	18 J,D	310 D	0	33 J	29.4
7C1A42	2/22/2006	240 J,D	4100 D	44 J,D	280 D	0	0	
7C1A43	2/23/2006	59 J,D	2800 D	0	270 D	0	14 J,COL	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
Post- Whey Injection Sampling								
8C1A41	3/21/2006	0	2100 D	27 J,D	360 D	0	8.5 J	20.4
9C1A41	4/17/2006	0	980 D	14 J,D	300 D	0	33 J, COL	9.1
MW1B4								
Phase 2. Baseline Sampling								
1B1B41	3/8/2005	3900	630	0	0	0	0	
1B1B42	3/9/2005	5000	1000	0	0	0	0	
1B1B43	3/10/2005	8600	1200	0	0	0	0	
2B1B41	3/21/2005	4200	580	0	0	0	0	
2B1B42	3/22/2005	9400	1600	0	0	0	0	
2B1B43	3/23/2005	5500	900	0	0	0	0	4.4
3B1B41	4/4/2005	7100	1500	0	0	0	0	
3B1B42	4/5/2005	12000	2400	0	0	0	0	
3B1B43	4/6/2005	9500	1800	0	0	0	0	4.9
Phase 3. 10% w/w Whey Injection								
2C1B41	7/18/2005	1500 B, D	4400 B,D	0	0	0	0.72 J	
2C1B42	7/18/2005	1100 D	6300 B,D	0	0	0	0	
2C1B43	7/19/2005	920 J, D	6200 B, D	0	0	0	0.46 J	18.8
3C1B41	8/15/2005	710 J,D	5400 D	0	0	0	1.2 J	27.4
3C1B41	8/15/2005	500 D	4700 D,E	91 D	9.1 J,D			
4C1B41	10/03/05	89 J,D	5300 D	0	0	0.45 J	1.1 J	
4C1B42	10/04/05	200 J,D	6300 D	0	0	0	0	
4C1B43	10/05/05	180 J,D	8100 D	0	0	0	0	
Phase 3. 1% w/w Whey Injection								
5C1B41	11/7/2005	95 J,D	6700 D	0	0	4.0 J	3.8 J	
5C1B42	11/8/2005	500 J,D	9500 D	0	0	0	2.0 J	
5C1B43	11/9/2005	200 J,D	9100 J,D	71 D	0	3.7 J	0	
6C1B41	12/12/2005	110 J,D	6700 D	0	160 J,D	10	16 J	
6C1B42	12/13/2005	600 D	9600 D	81 J,D	170 J,D	8.6 J	10 J	
6C1B43	12/14/2005	350 J,D	9400 D	82 J,D	200 D	12 J	11 J	
7C1B41	2/22/2006	90 D	3000 D	50 D	1900 D	0	150	35
7C1B42	2/22/2006	0	3400 D	66 J,D	1900 D	0	140	
7C1B43	2/23/2006	60 J,D	2700 D	0	2200 D	0	150	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
Post- Whey Injection Sampling								
8C1B41	3/21/2006	13 J,D	1500 D	22 J,D	740 D	0	58 J	23.6
9C1B41	4/17/2006	15 J,D	640 D	5.1 J,D	740 D	0	180	13.3
MW1C4								
Phase 2. Baseline Sampling								
1B1C41	3/8/2005	6200	1000	0	0	0	0	
1B1C42	3/9/2005	6000	980	0	0	0	0	
1B1C43	3/10/2005	8000	1300	0	0	0	0	
2B1C41	3/21/2005	5800	890	0	0	0	0	
2B1C42	3/22/2005	8800	1400	0	0	0	0	
2B1C43	3/23/2005	6800	1100	0	0	0	0	4.8
3B1C41	4/4/2005	9300	2200	0	0	0	0	
3B1C42	4/5/2005	11000	2100	0	0	0	0	
3B1C43	4/6/2005	9200	1700	0	0	0	0	5.6
Phase 3. 10% w/w Whey Injection								
2C1C41	7/18/2005	210 J, B, D	2900 B, D	0	0	0	0	
2C1C42	7/18/2005	530 J,D	4300 B,D	0	0	0	0	
2C1C43	7/19/2005	85 J, D	3600 D	0	0	0	0	12.5
2C1C43	7/19/2005		3900 B,D	0	0	0	0	
3C1C41	8/15/2005	22 J,D	2300 D,E	0	0	0	0	16.6
4C1C41	10/03/05	0	4600 D	0	0	0	1.5 J	
4C1C42	10/04/05	330 J,D	7600 D	0	0	0	1.3 J	
4C1C43	10/05/05	46 J,D	5900 D	0	0	0	0	
Phase 3. 1% w/w Whey Injection								
5C1C41	11/7/2005	250 J, D	6800 D	0	0	4.5 J	6.3 J	
5C1C42	11/8/2005	450 J,D	8800 D	70 J,D	0	4.1 J	7.2 J	
5C1C43	11/9/2005	190 J,B,D	8400 D	0	0	0	1.7 J	
6C1C41	12/12/2005	0	5000 D	0	0	0	22 J	
6C1C42	12/13/2005	350 J,D	7200 D	0	0	0	11 J	
6C1C43	12/14/2005	110 J,D	6700 D	58 J,D	70 J,D	0	30 J	
7C1C41	2/22/2006	30 J,D	2500 D	30 J,D	590 D	0	48 J, COL	23.1
7C1C42	2/22/2006	0	3100 D	38 J,D	460 D	0	69 J	
7C1C43	2/23/2006	0	2300 D	0	430 D	0	42 J,COL	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
Post- Whey Injection Sampling								
8C1C41	3/21/2006	66 J,D	1600 J,D	36 J,D	2400 D	0	290	33
9C1C41	4/17/2006	0	1300 D	23 J,D	750 D	0	100 J	12
MW1D2								
Phase 2. Baseline Sampling								
1B1D21	3/8/2005	9100	1800	0	0	0	0	
1B1D22	3/9/2005	9900	1800	0	0	0	0	
1B1D23	3/10/2004	9900	1700	0	0	0	0	
2B1D21	3/21/2005	9100	1500	0	0	0	0	
2B1D22	3/22/2005	16000	3000	0	0	0	0	
2B1D23	3/23/2005	9400	2000	0	0	0	0	5.0
3B1D21	4/4/2005	13000 D	4500 D	0	0	0	0	
3B1D22	4/5/2005	16000	3500	0	0	0	0	
3B1D23	4/6/2005	12000	3400	0	0	0	0	6.1
3B1D23	4/6/2005	14000	3500	0	0	0	0	
Phase 3. 10% w/w Whey Injection								
2C1D21	7/18/2005	320 J, B, D	5800 B, D,	0	0	0	0	
2C1D22	7/18/2005	1100 D	7500 B,D	0	0	0	0	
2C1D23	7/19/2005	350 J, D	7100 B,D	0	0	0	0	21.9
3C1D21	8/15/2005	140 D	5000 D,E	110 D	0	0	0	42.9
4C1D21	10/03/05	140 J,D	8100 D	0	0	0	0	
4C1D22	10/04/05	570 B,D	9600 D	0	0	0	0	
4C1D23	10/05/05	620 D	11000 D	87 J,D	0	0	0	
Phase 3. 1% w/w Whey Injection								
5C1D21	11/7/2005	0	18000 D	210 J,D	0	2.2 J	0	
5C1D22	11/8/2005	1600 B,D	16000 D	0	0	0	0	
5C1D23	11/9/2005	0	34000 D	180 J,D	0	1.3 J	1.4 J	
6C1D21	12/12/2005	0	19000 D	130J,D	0	6.8 J	5.5 J	
6C1D22	12/13/2005	1500 D	17000 D	140 J,D	120 J,D	3.9 J	0	
6C1D23	12/14/2005	280 J,D	20000 D	130 J,D	95 J,D	0	0	
7C1D21	2/21/2006	1100 D	8400 D	68 D	870 D	0	45 J,COL	21.7
7C1D22	2/22/2006	580 D	6600 D	66 J,D	320 D	0	18 J,COL	
7C1D23	2/23/2006	0	8100	88 J,D	480 D	0	32 J,COL	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
Post- Whey Injection Sampling								
8C1D21	3/21/2006	840 D	7100 D	64 J,D	1100 D	0	110	22.2
9C1D21	4/17/2006	190 J,D	3900 D	43 J,D	780 D	0	110	12.3
MW1D3								
Phase 2. Baseline Sampling								
1B1D31	3/8/2005	9100	2100	0	0	0	0	
1B1D32	3/9/2005	8100	1700	0	0	0	0	
1B1D33	3/10/2005	11000	1900	0	0	0	0	
2B1D31	3/21/2005	11000 E	1900	0	0	0	0	
2B1D31	3/21/2005	11000 D		0	0	0	0	
2B1D32	3/22/2005	17000	3000	0	0	0	0	
2B1D33	3/23/2005	10000	1900	0	0	0	0	5.5
3B1D31	4/4/2005	12000 D	2600 D	0	0	0	0	
3B1D32	4/5/2005	15000	2800	0	0	0	0	
3B1D33	4/6/2005	11000	2300 J	0	0	0	0	5.5
3B1D33	4/6/2005	12000	2100	0	0	0	0	
Phase 3. 10% w/w Whey Injection								
2C1D31	7/18/2005	400 J, B, D	6000 B, D	0	0	0	0	
2C1D32	7/18/2005	680 J, D	7100 B,D	0	0	0	0	
2C1D33	7/19/2005	260 J,D	6900 B,D	0	0	0	0	17.3
3C1D31	8/15/2005	200 D	5800 D, E	120 D	0	0	0	29
4C1D31	10/03/05	130 J,D	7400 D	94 J,D	0	0.81 J,COL	2.6 J	
4C1D32	10/04/05	360 J,B,D	7800 D	0	0	0	0.42 J	
4C1D33	10/05/05	200 J,D	11000 D	0	0	0	0.48 J	
Phase 3. 1% w/w Whey Injection								
5C1D31	11/7/2005	0	10000 D	190 J, D	0	4.2 J	7.7 J	
5C1D32	11/8/2005	710 D	10000 D	0	0	0	5.3 J,COL	
5C1D33	11/9/2005	210 J,B,D	18000 D	0	0	0	5.9 J	
6C1D31	12/12/2005	120 J,D	12000 D	100 J,D	390 D	0	18 J	
6C1D32	12/13/2005	1100 D	11000 D	86 J,D	310 D	0	11 J	
6C1D33	12/14/2005	220 J,D	15000 D	120 J,D	370 D	0	12 J	
7C1D31	2/22/2006	350 D	6100 D	64 D	2100 D	0	130 J	26
7C1D32	2/23/2006	480 D	4100 D	51 J,D	1100 D	0	150 COL	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
7C1D33	2/24/2006	150 J,D	5000 D	0	1300 D	0	160	
Post- Whey Injection Sampling								
8C1D31	3/21/2006	670 D	4600 D	52 J,D	2000 D	0	250	23.8
9C1D31	4/17/2006	42 J,D	3300 D	98 J,D	1500 D	0	230	16.1
MW1D4								
Phase 2. Baseline Sampling								
1B1D41	3/8/2005	5000	1000	0	0	0	0	
1B1D42	3/9/2005	10000	1900	0	0	0	0	
1B1D43	3/10/2005	12000	2000	0	0	0	0	
2B1D41	3/21/2005	12000	1900	0	0	0	0	
2B1D42	3/22/2005	16000	2500	0	0	0	0	
2B1D43	3/23/2005	9900	1700	0	0	0	0	5.8
3B1D41	4/4/2005	13000 D	2300 D	0	0	0	0	
3B1D42	4/5/2005	16000	2900	0	0	0	0	
3B1D43	4/6/2005	13000	2500	0	0	0	0	5.7
Phase 3. 10% w/w Whey Injection								
2C1D41	7/18/2005	400 J, B, D	5900 B,D	0	0	0	0	
2C1D42	7/18/2005			0	0	0	0	
2C1D43	7/19/2005	300 J, D	7100 B,D	0	0	0	0	15.9
3C1D41	8/15/2005	260 D	5900 D,E	110 D	0	0	0	23.8
MW104	9/12/2005	0	4300 D	0	0	0	0.72	
4C1D41	10/03/05	100 J,D	6800 D	82 J,D	0	0	0.69 J	
4C1D42	10/04/05	300 J,B,D	8200 D	0	0	0	0	
4C1D43	10/05/05	130 J,D	7500 D	80 J,D	0	0	0.55 J,COL	
Phase 3. 1% w/w Whey Injection								
5C1D41	11/7/2005	130 J, D	13000 D	190 J,D	0	4.3 J	7.5 J	
5C1D42	11/8/2005	530 D	10000 D	74 J,D	0	0	3.7 J	
5C1D43	11/9/2005	270 J,B,D	15000 D	0	0	0	2.1 J,COL	
6C1D41	12/12/2005	190 J,D	12000 D	0	380 D	12 J	18 J	
6C1D42	12/13/2005	980 D	10000 D	97 J,D	250 D	0	12 J	
6C1D43	12/14/2005	370 J,D	13000 D	110 J,D	360 D	9.6 J	12 J	
7C1D41	2/22/2006	320 D	4400 D	58 D	2000 D	0	160	24.9
7C1D42	2/22/2006	410 D	3800 D	62 J,D	1200 D	0	120	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
7C1D43	2/23/2006	440 J,D	3700 D	41 J,D	1400 D	0	120	
Post- Whey Injection Sampling								
8C1D41	3/21/2006	560 D	4100 D	44, J,D	1700 D	0	210	24.4
9C1D41	4/17/2006	33 J,D	3100 D	77 J,D	1500 D	0	91 J	17.6
MW2A1								
Phase 2. Baseline Sampling								
1B2A11	3/8/2005	23000	8400	0	0	0.51 J	0	
1B2A12	3/9/2005	21000	7800	0	0	0.56 J	0	
1B2A12	3/9/2005	30000	9200	0	0			
1B2A13	3/10/2005	21000	6900	0	0	0.52 J	0	
2B2A11	3/21/2005	17000 E	5600	44 J	0	0.41 J	0	
2B2A11	3/21/2005	18000 D			0			
2B2A12	3/22/2005	35000 E	12000	0	0	0.58 J	0	
2B2A12	3/22/2005	24000 D		0	0			
2B2A13	3/23/2005	17000	6100	0	0	0	0	8.0
3B1A11	4/4/2005	21000 D	6500 D	0	0	0	0	
3B1A12	4/5/2005	33000	12000	0	0	0.40 J	0	
3B1A13	4/6/2005	19000	6600	0	0	0	0	8.6
Phase 3. 1% w/w Whey Injection								
2C2A11	7/18/2005	320	21000 B, D, E	0	0	0.44 J	1.0 J	
2C2A11	7/18/2005		24000 D	0	0			
2C2A12	7/19/2005	1600 D	40000 B, D, E	0	0	0.46 J	0.98 J	
2C2A12	7/19/2005		28000 D	0	0			
2C2A13	7/20/2005	140 J, D	32000 D, E	0	0	0.62 J	1.2 J	30.1
2C2A13	7/20/2005		34000 D	0	0			
3C2A11	8/15/2005	370 J,D	18000 D	0	0	0.48 J	1.4 J	28.6
3C2A12	8/16/2005	1700 D	42000 B,D,E	570 D	0	0	1.7 J	
3C2A13	8/17/2005	300 J, D	26000 B, D, E	0	0	0	1.1 J	
MW2A1	9/12/2005	0	26000 D,E	0	0	0.72 J	2.7 J	
4C2A11	10/03/05	87 J,D	20000 D	150 J,D	0	0.47 J, COL	0.99 J	
4C2A12	10/04/05	770 D	29000 D,E	180 J,D	0	0	0.64 J, COL	
4C2A12	10/04/05	970 J,B,D	38000 D	0	0			
4C2A12	10/04/05	890 J,D	30000 D	210 J,D	0			

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
4C2A13	10/05/05	320 D	39000 D,E	360 D	76 J,D	0.39 J	0.67 J	
Phase 3. 10% w/w Whey Injection								
5C2A11	11/7/2005	350 J,D	63000 D,E	390 J,D	0	1.7 J	6	
5C2A11	11/7/2005		75000 D					
5C2A12	11/8/2005	1500 D	58000 D,E	300 J,D	330 J,D	0.74 J	3.2 J	
5C2A12	11/8/2005		52000 D					
5C2A13	11/9/2005	2000 J,B,D	66000 D	0	0	0	0.99 J	
6C2A11	12/12/2005	0	110000 D	0	0	1.5 J	6	
6C2A12	12/13/2005	1200 J,D	69000 D	0	0	0	9.5	
6C2A13	12/14/2005	0	59000 D	0	0	0	0	
7C2A11	2/21/2006	170 D	19000 D	150 D	1900 D	9.8 J	53	54.9
7C2A12	2/22/2006	390 D	20000 D	140 J,D	910 D	0	29 J	
7C2A13	2/23/2006	160 J,D	22000 D	160 D	1400 D	3.2 J	22 J	
Post- Whey Injection Sampling								
8C2A11	3/21/2006	150 J,D	15000 D	100 J,D	2600 D	0	72	46.5
9C2A11	4/17/2006	77 J,D	8000 D	83 J, D	2500 D	0	180	20.9
MW2A2								
Phase 2. Baseline Sampling								
1B2A21	3/8/2005	19000	6300	0	0	0	0	
1B2A22	3/9/2005	31000	10000	0	0	0.52 J	0	
1B2A23	3/10/2005	23000	5900	0	0	0	0	
2B2A21	3/21/2005	17000 E	5200	44 J	0	0	0	
2B2A21	3/21/2005	18000 D			0		0	
2B2A22	3/22/2005	25000 E	8500	0	0	0.47 J	0	
2B2A22	3/22/2005	20000 D		0	0		0	
2B2A23	3/23/2005	17000	6400	0	0	0	0	8.3
3B2A21	4/4/2005	23000 D	5700 D	0	0	0	0	
3B2A22	4/5/2005	30000	12000	0	0	0	0	
3B2A23	4/6/2005	21000	6300	0	0	0	0	8.9
Phase 3. 1% w/w Whey Injection								
2C2A21	7/18/2005	450 J, D	17000 B,D	0	0	0	0.93 J	
2C2A22	7/19/2005	1600 D	40000 B, D, E	0	0	0.40 J	2.0 J	
2C2A23	7/20/2005	170 J, D	31000 D, E	0	0	0.62 J	2.5 J	28.1

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
2C2A23	7/20/2005		30000 D					
3C2A21	8/15/2005	500 J,D	19000 D	0	0	0.41 J	1.1 J	23
3C2A22	8/16/2005	1600 D	38000 B,D,E	400 J,D	0	0.41 J	1.1 J	
3C2A23	8/17/2005	250 J, D	17000 B, D	0	0	0	0.77 J	
4C2A21	10/03/05	180 J,D	19000 D	150 J,D	0	0.48 J	0.67 J,COL	
4C2A22	10/04/05	860 D	30000 D,E	180 J,D	0	0	0.87 J	
4C2A22	10/04/05	930 J,B,D	36000 D	0	0			
4C2A23	10/05/05	400 D	36000 D,E	320 D	52 J,D	0	0.62 J,COL	
Phase 3. 10% w/w Whey Injection								
5C2A21	11/7/2005	200 J,D	64000 D,E	460 J,D	0	1.5 J	5.8	
5C2A21	11/7/2005		78000 D					
5C2A22	11/8/2005	1500 D	58000 D,E	300 J,D	170 J,D	0	2.8 J	
5C2A22	11/8/2005		52000 D					
5C2A23	11/9/2005	940 J,B,D	71000 D	0	0	0	1.0 J,COL	
6C2A21	12/12/2005	0	100000 D	0	0	0	4.2 J	
6C2A22	12/13/2005	1300 J,D	63000 D	0	0	0	5.7	
6C2A23	12/14/2005	0	69000 D	0	0	0	3.8 J	
7C2A21	2/21/2006	110 D	21000 D	140 D	1400 D	14 J	37 J	47.2
7C2A22	2/22/2006	290 D	19000 D	150 J,D	750 D	0	10 J	
7C2A23	2/23/2006	120 J,D	20000 D	140 J,D	990 D	2.4 J	14 J	
Post- Whey Injection Sampling								
8C2A21	3/21/2006	190 J,D	14000 D	82 J,D	2300 D	0	55	43.5
9C2A21	4/17/2006	67 J,D	7200 D	0	2300 D	0	170	25.5
MW2A4								
Phase 2. Baseline Sampling								
1B2A41	3/8/2005	17000	6100	0	0	0.46 J	2.0 J	
1B2A42	3/9/2005	26000	4600	0	0	0.42 J	1.3 J	
1B2A43	3/10/2005	14000	5500	0	0	0	0.53 J	
2B2A41	3/21/2005	15000	5000	0	0	0.41 J	1.6 J	
2B2A42	3/22/2005	21000 E	7700	0	0	0.45 J	0.82 J	
2B2A42	3/22/2005	16000 D		0	0			
2B2A43	3/23/2005	16000	6200	0	0	0	0.54 J	8.1
3B2A41	4/4/2005	20000 D	5000 D	0	0	0	0	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
3B2A42	4/5/2005	24000	10000	0	0	0	0	
3B2A43	4/6/2005	18000	5700	0	0	0	0	8.7
Phase 3. 1% w/w Whey Injection								
2C2A41	7/18/2005	1600 D	12000 B,D	0	0	0	1.6 J	
2C2A42	7/19/2005	1200 D	18000 B,D	0	0	0	1.7 J	
2C2A43	7/20/2005	920 J, D	19000 D	0	0	0.48 J	1.2 J	31.6
3C2A41	8/15/2005	29 J,D	6600 D,E	100 D	41 D	0	2.3 J	22.0
3C2A41	8/15/2005		8200 D					
3C2A42	8/16/2005	590 D	19000 B,D	0	0	0	2.8 J	
3C2A43	8/17/2005	140 J, D	12000 B, D	0	0	0	2.3 J	
4C2A41	10/03/05	0	1600 D	0	0	0.67 J	7	
4C2A42	10/04/05	590 D	24000 D,E	160 J,D	89 J,D	0	3.7 J	
4C2A42	10/04/05	720 J,B,D	33000 D	0	0	0		
4C2A43	10/05/05	110 J,D	21000 D,E	200 J,D	96 J,D	0	4.1 J	
4C2A43	10/05/05		20000 D					
Phase 3. 10% w/w Whey Injection								
5C2A41	11/7/2005	0	59000 D,E	400 J,D	0	3.4 J	25	
5C2A41	11/7/2005		70000 D					
5C2A42	11/8/2005	790 J,D	55000 D,E	260 J,D	310 J,D	0	12	
5C2A42	11/8/2005		49000 D					
5C2A43	11/9/2005	990 J,B,D	52000 D	0	0	0.55 J	6.5	
6C2A41	12/12/2005	0	40000 D	170 J,D	1100 D	0	44 J	
6C2A42	12/13/2005	0	55000 D	0	0	0	23 J	
6C2A43	12/14/2005	0	59000 D	0	620 J,D	0	20 J	
7C2A41	2/21/2006	9.0 J,D	5900 D	51 D	1100 D	11 J	43 J	27.6
7C2A42	2/22/2006	0	9700 D	79 J,D	610 D	0	23 J	
7C2A43	2/23/2006	40 J,D	7200 D	0	870 D	0	35 J	
Post- Whey Injection Sampling								
8C2A41	3/21/2006	0	7000 D	51 J,D	1900 D	0	80 J	28.4
9C2A41	4/17/2006	0	4400 D	45 J,D	2000 D	0	81 J	23.6
MW2B4								
Phase 2. Baseline Sampling								
1B2B41	3/8/2005	19000	4800	0	0	0	0	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
1B2B42	3/9/2005	13000	4000	0	0	0	0	
1B2B43	3/10/2005	16000	5300	0	0	0	0	
2B2B41	3/21/2005	14000 E	4100	36 J	0	0	0	
2B2B41	3/21/2005	14000 D			0	0	0	
2B2B42	3/22/2005	18000	5800	0	0	0	0	
2B2B43	3/23/2005	14000	5300	0	0	0	0	7.1
3B2B41	4/4/2005	24000 D	5800 D	0	0	0	0	
3B2B41	4/4/2005	17000	8300	0	0			
3B2B42	4/5/2005	26000	6900	0	0	0	0	
3B2B43	4/6/2005	20000	6100	0	0	0	0	9.0
Phase 3. 1% w/w Whey Injection								
2C2B41	7/8/2005	3900 D	16000 B,D	0	0	0	0	
2C2B42	7/19/2005	4100 D	18000 D	0	0	0	0	
2C2B43	7/20/2005	3500 D	18000 D	0	0	0	0	50.6
3C2B41	8/15/2005	1300 D	22000 D,E	0	0	0	0.60 J	53.1
3C2B41	8/15/2005		18000 D					
3C2B42	8/16/2005	1500 D	21000 B, D, E	0	0	0	0.55 J	
3C2B42	8/16/2005		24000 D					
3C2B43	8/17/2005	970 D	24000 B, D, E	0	0	0	0.55 J	
3C2B43	8/17/2005		22000 D,E					
4C2B41	10/03/05	97 J,D	2300 D	0	0	0	0	
4C2B42	10/04/05	600 D	26000 D,E	160 J,D	0	0	0	
4C2B42	10/04/05	650 J,B,D	32000 D	0	0			
4C2B43	10/05/05	600 J,D	40000 D,E	0	0	0	0	
4C2B43	10/05/05		35000 D					
Phase 3. 10% w/w Whey Injection								
5C2B41	11/7/2005	490 J,D	62000 D,E	410 J,D	0	2.4 J	1.6 J	
5C2B41	11/7/2005		74000 D					
5C2B42	11/8/2005	1300 D	62000 D,E	280 J,D	0	0.78 J	0.96 J	
5C2B42	11/8/2005		60000 D					
5C2B43	11/9/2005	1200 J,D	54000 D	0	0	1.0 J	1.2 J,COL	
6C2B41	12/12/2005	1200 J,D	110000 D	0	0	0	0.44 J,COL	
6C2B42	12/13/2005	780 J,D	81000 D	390 J,D	0	0	0	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
6C2B43	12/14/2005	0	80000 D	340 J,D	0	0	0	
7C2B41	2/21/2006	1300 D	43000 D	240 D	450 D	3.1 J,COL	6.6 J	191.0
7C2B42	2/22/2006	570 D	38000 D	220 J,D	530 D	0	6.1 J	
7C2B43	2/23/2006	0	35000 D	0	540 D	0	5.4 J	
Post- Whey Injection Sampling								
8C2B41	3/21/2006	1000 J,D	49000 D	280 J,D	1000 D	0	7.8 J,COL	
9C2B41	4/17/2006	65 J,D	8300 D	72 J,D	1100 D	0	0	229.0
MW2C4								
Phase 2. Baseline Sampling								
1B2C41	3/8/2005	19000	5500	0	0	0	0.44 J	
1B2C42	3/9/2005	20000	5400	0	0	0.43 J	0.46 J	
1B2C43	3/10/2005	20000	5300	0	0	0	0	
2B2C41	3/21/2005	14000 E	4100	0	0	0	0	
2B2C41	3/21/2005	15000 D						
2B2C42	3/22/2005	20000 E	5200	0	0	0	0	
2B2C42	3/22/2005	14000 D						
2B2C43	3/23/2005	14000	4400	0	0	0	0	10.4
3B2C41	4/4/2005	19000 D	5800 D	0	0	0	0	
3B2C42	4/5/2005	19000	5800	0	0	0	0	
3B2C43	4/6/2005	17000	5400	0	0	0	0	9.4
Phase 3. 1% w/w Whey Injection								
2C2C41	7/18/2005	1800 D	14000 B,D	0	0	0	0.43 J	
2C2C42	7/19/2005	1100 D	14000 D	0	0	0	0	
2C2C43	7/20/2005	510 J, D	14000 D	0	0	0.50 J	0.76 J	27.4
3C2C41	8/15/2005	780 J,D	13000 D	0	0	0	0.78 J	26.0
3C2C42	8/16/2005	510 D	15000 B,D	0	0	0	0.70 J	
3C2C43	8/17/2005	570 D	13000 B, D	0	0	0	0.64 J	
4C2C41	10/03/05	0	1300 D	0	0	0.55 J,COL	2.2 J	
4C2C42	10/04/05	290 J,D	17000 D	130 J,D	160 J,D	0	0.95 J	
4C2C43	10/05/05	250 J,D	20000 D	0	170 J,D	0	1.3 J	
Phase 3. 10% w/w Whey Injection								
5C2C41	11/7/2005	170 J,D	22000 D	220 J,D	710 D	5.1 J	15 J	
5C2C42	11/8/2005	0	29000 D	230 J,D	450 D	2.4 J	6.3 J	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
5C2C43	11/9/2005	440 J,B,D	27000 D	0	540 D	4.0 J	8.6 J,COL	
6C2C41	12/12/2005	220 J,D	33000 D	0	1200 D	0	24 J	
6C2C42	12/13/2005	460 J,D	34000 D	0	1200 D	0	6.9 J	
6C2C43	12/14/2005	290 J,D	34000 D	180 J,D	930 D	0	10 J	
7C2C41	2/21/2006	60 D	15000 D	140 D	8100 D	0	170	75.7
7C2C42	2/22/2006	0	11000 D	71 J,D	5900 D	0	120	
7C2C43	2/23/2006	0	12000 D	72 J,D	5800 D	0	110	
Post- Whey Injection Sampling								
8C2C41	3/21/2006	0	8000 D	130 J,D	8400 D	0	190	67.5
9C2C41	4/17/2006	0	3900 D	90 J,D	7800 D	0	450	68.0
MW2D1								
Phase 2. Baseline Sampling								
1B2D110	3/8/2005	12000	4900	0	0	0	0	
1B2D12	3/9/2005	22000	13000	0	0	0	0	
1B2D13	3/10/2005	16000	8100	98 J	0	0	0	
2B2D11	3/21/2005	13000 E	5400	48 J	0	0	0	
2B2D11	3/21/2005	14000 D						
2B2D12	3/22/2005	17000	10000	0	0	0.49 J	0	
2B2D13	3/23/2005	16000	8500	0	0	0	0	9.0
3B2D11	4/4/2005	20000 D	6700 D	0	0	0	0	
3B2D12	4/5/2005	23000	10000	0	0	0	0	
3B2D13	4/6/2005	19000	7800	0	0	0	0	10.3
Phase 3. 1% w/w Whey Injection								
2C2D11	7/18/2005	110 J, D	25000 B,D,E	0	0	0.41 J	0.52 J	
2C2D11	7/18/2005		31000 D					
2C2D12	7/19/2005	0	32000 B, D, E,	0	0	0	0	
2C2D12	7/19/2005		29000 D					
2C2D13	7/20/2005	100 J, D	32000 D, E	0	0	0	0	15.0
2C2D13	7/20/2005		29000 D					
3C2D11	8/15/2005	0	32000 D,E	0	0	0	0.60 J	23.6
3C2D11	8/15/2005		14000 D,E					
3C2D12	8/16/2005	560 D	43000 B,D,E	530 D	0	0	0	
3C2D12	8/16/2005		39000 D					

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
3C2D13	8/17/2005	0	35000 B, D, E	500 D	0	0	0	
3C2D13	8/17/2005		35000 D					
4C2D11	10/03/05	0	25000 E,D	220 J,D	0	0	0	
4C2D11	10/03/05		26000 D					
4C2D12	10/04/05	810 D	44000 D,E	220 J,D	0	0	0	
4C2D12	10/04/05	990 J,B,D	62000 D	0	0			
4C2D13	10/05/05	390 D	46000 D,E	350 D	0	0	0 COL	
4C2D13	10/05/05		49000 D					
Phase 3. 10% w/w Whey Injection								
5C2D11	11/7/2005	370 J,D	33000 D	320 J,D	0	1.3	1.1	
5C2D12	11/8/2005	1300 D	73000 D,E	330 J,D	0	1.3 J	1.1 J	
5C2D12	11/8/2005		60000 D					
5C2D13	11/9/2005	0	61000 D	0	0	0	0	
6C2D11	12/12/2005	0	110000 D	0	0	0	0	
6C2D12	12/13/2005	1200 J,D	74000 D	0	0	1.3 J	1.6 J	
6C2D13	12/14/2005	0	71000 D	0	0	1.6 J	1.8 J	
7C2D11	2/21/2006	11 J,D	24000 D	190 D	130 D	3.7 J	0	19.5
7C2D12	2/22/2006	0	16000 D	120 J,D	160 D	1.5 J	1.9 J	
7C2D13	2/23/2006	0	21000 D	160 J,D	220 D	0	0	
Post- Whey Injection Sampling								
8C2D11	3/21/2006	0	15000 D	120 J,D	370 J,D	0	8.1 J,COL	18.7
9C2D11	4/17/2006	0	2600 D	0	220 D	0	5.1 J	7.0
MW2D2								
Phase 2. Baseline Sampling								
1B2D21	3/8/2005	19000	7400	0	0	0	0	
1B2D22	3/9/2005	15000	8500	0	0	0	0	
1B2D23	3/10/2005	16000	8700	0	0	0.47 J	0	
2B2D21	3/21/2005	13000 E	5600	48 J	0	0	0	
2B2D21	3/21/2005	14000 D						
2B2D22	3/22/2005	16000	9800	0	0	0.49 J	0	
2B2D23	3/23/2005	16000	8400	0	0	0	0	8.8
3B2D21	4/4/2005	21000 D	8000 D	0	0	0	0	
3B2D22	4/5/2005	22000	10000	0	0	0	0	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
3B2D23	4/6/2005	19000	7700	0	0	0	0	10.3
Phase 3. 1% w/w Whey Injection								
2C2D21	7/18/2005	170 J, D	25000B, D, E	0	0	0.43 J	0.64 J	
2C2D21	7/18/2005		29000 D					
2C2D22	7/19/2005	530 J, D	30000 B, D, E	0	0	0	0	
2C2D22	7/19/2005		27000 D					
2C2D23	7/20/2005	180 J, D	30000 D,E	0	0	0	0	18.7
2C2D23	7/20/2005		27000 D					
3C2D21	8/15/2005	220 J,D	31000 D,E	0	0	0.43 J	0.88 J	27.0
3C2D21	8/15/2005		37000 B,D					
3C2D22	8/16/2005	1500 D	36000 B,D,E	410 J,D	0	0	0	
3C2D22	8/16/2005		35000 D					
3C2D23	8/17/2005	180 J, D	33000 B, D, E	500 D	0	0	0	
3C2D23	8/17/2005		35000 D					
4C2D21	10/03/05	470 J,D	24000 E,D	200 J,D	0	0	0.56 J	
4C2D21	10/03/05		27000 D					
4C2D22	10/04/05	1700 D	42000 D,E	240 J,D	0	0	0	
4C2D22	10/04/05	2100 J,B,D	57000 D	0	0			
4C2D23	10/05/05	500 D	44000 D,E	350 D	0 D	0	0.49 J,COL	
4C2D23	10/05/05		47000 D					
Phase 3. 10% w/w Whey Injection								
5C2D21	11/7/2005	0	37000 D	320 J,D	0	4.3 J	3.3 J	
5C2D22	11/8/2005	780 J,D	57000 D,E	300 J,D	0	1.1 J	1.1 J	
5C2D22	11/8/2005		54000 D					
5C2D23	11/9/2005	0	53000 D	0	0	0.41 J	0.53 J,COL	
6C2D21	12/12/2005	0	97000 D	0	0	0	0	
6C2D22	12/13/2005	1000 J,D	68000 D	0	0	1.3 J	1.7 J	
6C2D23	12/14/2005	350 J,D	74000 D	0	0	0	0	
7C2D21	2/21/2006	250 D	26000 D	200 D	190 D	8.4 J	9.2 J	26.5
7C2D22	2/22/2006	170 J,D	20000 D	130 J,D	230 D	0	5.0 J	
7C2D23	2/23/2006	390 J,D	21000 D	330 J,D	920 D	5.6 J	7.8 J	
Post- Whey Injection Sampling								
8C2D21	3/21/2006	0	16000 D	100 J,D	720 D	0	22 J	35.8

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
9C2D21	4/17/2006	45 J,D	3900 D	36 J,D	500 D	0	12 J	10.3
MW2D4								
Phase 2. Baseline Sampling								
1B2D41	3/8/2005	19000	8700	0	0	0	0	
1B2D42	3/9/2005	16000	7300	0	0	0	0	
1B2D43	3/10/2005	17000	8600	0	0	0	0	
2B2D41	3/21/2005	16000 E	7500	59 J	0	0.44 J	0.51 J	
2B2D41	3/21/2005	17000 D						
2B2D42	3/22/2005	15000	6800	0	0	0.45 J	0	
2B2D43	3/23/2005	14000	7900	0	0	0	0	11.9
3B2D41	4/4/2005	18000 D	9200 D	0	0	0	0	
3B2D42	4/5/2005	22000	11000	0	0	0	0	
3B2D43	4/6/2005	17000	8000	0	0	0	0	10.6
Phase 3. 1% w/w Whey Injection								
2C2D41	7/18/2005	1400 D	18000 B,D	0	0	0.41 J	1.2 J	
2C2D42	7/19/2005	830 J, D	18000 B, D	0	0	0	0	
2C2D43	7/20/2005	350 J,D	17000	0	0	0	0.45 J	28.1
3C2D41	8/15/2005	490 J,D	17000 D	0	0	0	1.9 J	27.2
3C2D42	8/16/2005	1000 D	18000 B,D	0	0	0	0.95 J	
3C2D43	8/17/2005	7800 D	29000 B, D, E	0	0	0.39 J	0.48 J	
3C2D43	8/17/2005		31000 D					
MW2D4	9/12/2005	0	12000 D	0	0	0.53 J	4.1J	
4C2D41	10/03/05	0	2300 D	0	0	0	1.8 J	
4C2D42	10/04/05	240 J,D	21000 D,E	150 J,D	0	0	1.1 J,COL	
4C2D42	10/04/05	270 J,B,D	26000 D	0	0			
4C2D43	10/05/05	0	25000 D	0	0			
4C2D43	10/05/05	0 D	24000 D,E	260 D	42 J,D	0	3.3 J	
Phase 3. 10% w/w Whey Injection								
5C2D41	11/7/2005	0	41000 D	400 J,D	0	6.6 J	12 J	
5C2D42	11/8/2005	0	42000 D	0	0	0	5.0 J	
5C2D43	11/9/2005	590 J,B,D	47000 D	0	0	2.5 J	6.2 J	
6C2D41	12/12/2005	0	66000 D	360 J,D	0	3.9 J	13 J	
6C2D42	12/13/2005	640 J,D	47000 D	0	0	0	5.2 J	

Table E-4. (continued).

Sample ID	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	VC (ug/L)	Ethane (ug/L)	Ethene (ug/L)	Chloride (ug/L)
6C2D43	12/14/2005	0	52000 D	0	0	0	8.9 J	
7C2D41	2/21/2006	23 J,D	22000 D	190 D	1800 D	0	100	81.8
7C2D42	2/22/2006	0	21000 D	150 J,D	1500 D	0	53	
7C2D43	2/23/2006	0	17000 D	86 J,D	1300 D	0	73 J	
Post- Whey Injection Sampling								
8C2D41	3/21/2006	0	30000 D	0	3600	0	53	104
9C2D41	4/17/2006	0	10000 D	110 J,D	2600 D	0	56 J	42

0 = Analyte sampled, not detected

Blank = Analyte not sampled

J=Estimated result. Result is less than RL

D= Result obtained from analysis of a dilution

B= Method blank contamination. Associated method blank contains target analyte at a reportable level

E= Estimated result. Result concentration exceeds the calibration range.

COL=

Table E-5. Molar VOC and Dissolved Gases Results.

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethene, Ethane (umol/L)
MW1A1								
Phase 2. Baseline Sampling								
1B1A11	3/8/2005	26.3	4.6	0	0	0	0	30.8
1B1A12	3/9/2005	76.1	18.6	0	0	0	0	94.7
1B1A13	3/10/2005	61.6	11.3	0	0	0	0	73
2B1A11	3/21/2005	29.7	4.6	0	0	0	0	34.3
2B1A12	3/22/2005	1.2	0.3	0	0	0	0	1.6
2B1A13	3/23/2005	49.5	11.3	0	0	0	0	60.8
3B1A11	4/4/2005	68.5	12.4	0	0	0	0	80.9
3B1A12	4/5/2005	129.4	36.1	0	0	0	0	165.5
3B1A13	4/6/2005	108.1	17.0	0	0	0	0	125.1
Phase 3. 10% w/w Whey Injection								
2C1A11	7/18/2005	6.1	32.0	0	0	0	0	38.1
2C1A12	7/18/2005	11.4	79.4	0	0	0	0	90.8
2C1A13	7/19/2005	6.2	54.7	0	0	0	0	60.8
3C1A11	8/15/2005	4.1	47.5	0.8	0	0	0	52.3
MW1A1	9/12/2005	0	35.1	0	0	0	0	35.1
4C1A11	10/03/05	3.5	54.7	0.5	0	0	0	58.7
4C1A12	10/04/05	7.6	87.7	0	0	0	0	95.3
4C1A13	10/05/05	4.8	123.8	0.9	0	0	0	129.5
Phase 3. 1% w/w Whey Injection								
5C1A11	11/7/2005	0	67.1	0	0	0	0	67.1
5C1A12	11/8/2005	12.2	134.1	16.5	0	0	0	162.8
5C1A13	11/9/2005	6.2	123.8	1.0	0	0	0	131
6C1A11	12/12/05	2.2	154.7	0.8	0	0	0	157.7
6C1A12	12/13/05	12.2	154.7	1.2	0.3	0	0	168.5
6C1A13	12/14/05	7.0	134.1	1.0	1.2	0	0	143.3
7C1A11	2/21/2006	1.5	56.7	0.6	4.5	0.4	0	63.7
7C1A12	2/22/2006	4.6	55.7	0.4	4.3	0	0	65
7C1A13	2/23/2006	1.8	39.2	0.4	3.5	0.6	0	45.5

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
Post- Whey Injection Sampling								
8C1A11	3/21/2006	0.4	33.0	0	8.6	1.7	0	43.8
9C1A11	4/17/2006	0.1	12.4	0	5.0	0.9	0	18.4
MW1A2								
Phase 2. Baseline Sampling								
1B1A21	3/8/2005	26.6	4.7	0	0	0	0	31.4
1B1A22	3/9/2005	67.7	17.5	0	0	0	0	85.3
1B1A23	3/10/2005	55.6	10.3	0	0	0	0	65.9
2B1A21	3/21/2005	28.2	4.6	0	0	0	0	32.8
2B1A22	3/22/2005	91.3	24.8	0	0	0	0	116.1
2B1A23	3/23/2005	32.0	7.1	0	0	0	0	39.1
3B1A21	4/4/2005	43.4	8.1	0	0	0	0	51.5
3B1A22	4/5/2005	121.8	35.1	0	0	0	0	156.8
3B1A23	4/6/2005	67.7	12.4	0	0	0	0	80.1
Phase 3. 10% w/w Whey Injection								
2C1A21	7/18/2005	4.6	30.9	0	0	0	0	35.5
2C1A22	7/18/2005	9.1	71.2	0	0	0	0	80.3
2C1A23	7/19/2005	3.5	49.5	0	0	0	0	53
3C1A21	8/15/2005	3.1	43.3	0.8	0	0	0	47.2
4C1A21	10/03/05	3.0	52.6	0	0	0	0	55.7
4C1A22	10/04/05	6.2	81.5	0	0	0	0	87.7
4C1A23	10/05/05	4.0	113.5	0.9	0	0	0	118.4
Phase 3. 1% w/w Whey Injection								
5C1A21	11/7/2005	0	65.0	0	0	0	0.1	65
5C1A22	11/8/2005	10.7	134.1	0	0	0	0.1	144.8
5C1A23	11/9/2005	3.6	123.8	0	0	0	0	127.4
6C1A21	12/12/2005	1.1	91.8	0	0	0.3	0.3	93.1
6C1A22	12/13/2005	9.9	134.1	1.0	1.6	0	0	146.6
6C1A23	12/14/2005	3.3	134.1	1.0	1.2	0.2	0.2	139.8
7C1A21	2/21/2006	1.3	42.3	0.5	4.2	1.9	0	50.1
7C1A22	2/22/2006	3.3	48.5	0.5	4.5	0.8	0	57.5
7C1A23	2/23/2006	1.1	35.1	0	4.0	0.7	0	40.9

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
Post- Whey Injection Sampling								
8C1A21	3/21/2006	0.9	28.9	0.4	8.8	1.2	0	40.1
9C1A21	4/17/2006	0.2	11.3	0.1	5.6	1.9	0	19.2
MW1A4								
Phase 2. Baseline Sampling								
1B1A41	3/8/2005	21.3	3.8	0	0	0	0	25.1
1B1A42	3/9/2005	59.4	13.4	0	0	0	0	72.8
1B1A43	3/10/2005	60.1	11.3	0.4	0	0	0	71.8
2B1A41	3/21/2005	29.7	4.0	0	0	0	0	33.7
2B1A42	3/22/2005	83.7	21.7	0	0	0	0	105.4
2B1A43	3/23/2005	50.2	11.3	0	0	0	0	61.6
3B1A41	4/4/2005	68.5	12.4	0	0	0	0	80.9
3B1A42	4/5/2005	129.4	36.1	0	0	0	0	165.5
3B1A43	4/6/2005	87.5	19.6	0	0	0	0	107.1
Phase 3. 10% w/w Whey Injection								
2C1A41	7/18/2005	16.7	23.7	0	0	0	0	40.5
2C1A42	7/18/2005	14.5	60.9	0	0	0	0	75.3
2C1A43	7/19/2005	13.7	48.5	0	0	0	0	62.2
3C1A41	8/15/2005	8.4	24.8	0	0	0	0	33.1
4C1A41	10/03/05	2.3	38.2	0	0	0	0	40.5
4C1A42	10/04/05	7.0	76.3	0	0	0	0	83.4
4C1A43	10/05/05	4.2	66.0	0	0	0	0	70.2
Phase 3. 1% w/w Whey Injection								
5C1A41	11/7/2005	3.3	66.0	0	0	0.1	0.1	69.5
5C1A42	11/8/2005	13.7	123.8	0	0	0.1	0	137.5
5C1A43	11/9/2005	5.3	123.8	0.9	0	0.1	0	130
6C1A41	12/12/2005	3.3	67.1	0	0	0.3	0.2	70.7
6C1A42	12/13/2005	10.7	123.8	0.9	0	0.1	0	135.5
6C1A43	12/14/2005	8.4	113.5	0	0	0.1	0	122
7C1A41	2/21/2006	0.1	29.9	0.2	5.0	1.2	0	36.4
7C1A42	2/22/2006	1.8	42.3	0.5	4.5	0	0	49.1
7C1A43	2/23/2006	0.4	28.9	0	4.3	0.5	0	34.2

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
Post- Whey Injection Sampling								
8C1A41	3/21/2006	0	21.7	0.3	5.8	0.3	0	28
9C1A41	4/17/2006	0	10.1	0.1	4.8	1.2	0	16.2
MW1B4								
Phase 2. Baseline Sampling								
1B1B41	3/8/2005	29.7	6.5	0	0	0	0	36.2
1B1B42	3/9/2005	38.1	10.3	0	0	0	0	48.4
1B1B43	3/10/2005	65.5	12.4	0	0	0	0	77.8
2B1B41	3/21/2005	32.0	6.0	0	0	0	0	37.9
2B1B42	3/22/2005	71.5	16.5	0	0	0	0	88
2B1B43	3/23/2005	41.9	9.3	0	0	0	0	51.1
3B1B41	4/4/2005	54.0	15.5	0	0	0	0	69.5
3B1B42	4/5/2005	91.3	24.8	0	0	0	0	116.1
3B1B43	4/6/2005	72.3	18.6	0	0	0	0	90.9
Phase 3. 10% w/w Whey Injection								
2C1B41	7/18/2005	11.4	45.4	0	0	0	0	56.8
2C1B42	7/18/2005	8.4	65.0	0	0	0	0	73.4
2C1B43	7/19/2005	7.0	64.0	0	0	0	0	71
3C1B41	8/15/2005	3.8	55.7	0.9	0.1	0	0	60.6
4C1B41	10/03/05	0.7	54.7	0	0	0	0	55.4
4C1B42	10/04/05	1.5	65.0	0	0	0	0	66.5
4C1B43	10/05/05	1.4	83.6	0	0	0	0	84.9
Phase 3. 1% w/w Whey Injection								
5C1B41	11/7/2005	0.7	69.1	0	0	0.1	0.1	70
5C1B42	11/8/2005	3.8	98.0	0	0	0.1	0	101.9
5C1B43	11/9/2005	1.5	93.9	0.7	0	0	0.1	96.1
6C1B41	12/12/2005	0.8	69.1	0	2.6	0.6	0	73.1
6C1B42	12/13/2005	4.6	99.0	0.8	2.7	0.4	0.3	107.5
6C1B43	12/14/2005	2.7	97.0	0.8	3.2	0.4	0.4	104.1
7C1B41	2/22/2006	0.7	30.9	0.5	30.4	5.3	0	67.9
7C1B42	2/22/2006	0	35.1	0.7	30.4	5.0	0	71.1
7C1B43	2/23/2006	0.5	27.9	0	35.2	5.3	0	68.9

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
Post- Whey Injection Sampling								
8C1B41	3/21/2006	0.1	15.5	0.2	11.8	2.1	0	29.7
9C1B41	4/17/2006	0.1	6.6	0.1	11.8	6.4	0	25
MW1C4								
Phase 2. Baseline Sampling								
1B1C41	3/8/2005	47.2	10.3	0	0	0	0	57.5
1B1C42	3/9/2005	45.7	10.1	0	0	0	0	55.8
1B1C43	3/10/2005	60.9	13.4	0	0	0	0	74.3
2B1C41	3/21/2005	44.1	9.2	0	0	0	0	53.3
2B1C42	3/22/2005	67.0	14.4	0	0	0	0	81.4
2B1C43	3/23/2005	51.8	11.3	0	0	0	0	63.1
3B1C41	4/4/2005	70.8	22.7	0	0	0	0	93.5
3B1C42	4/5/2005	83.7	21.7	0	0	0	0	105.4
3B1C43	4/6/2005	70	17.5	0	0	0	0	87.6
Phase 3. 10% w/w Whey Injection								
2C1C41	7/18/2005	1.6	29.9	0	0	0	0	31.5
2C1C42	7/18/2005	4.0	44.4	0	0	0	0	48.4
2C1C43	7/19/2005	0.6	37.1	0	0	0	0	37.8
3C1C41	8/15/2005	0.2	30.9	0	0	0	0	31.1
4C1C41	10/03/05	0	47.5	0	0	0.1	0	47.5
4C1C42	10/04/05	2.5	78.4	0	0	0	0	81
4C1C43	10/05/05	0.4	60.9	0	0	0	0	61.2
Phase 3. 1% w/w Whey Injection								
5C1C41	11/7/2005	1.9	70.1	0	0	0.2	0.1	72.3
5C1C42	11/8/2005	3.4	90.8	0.7	0	0.3	0.1	95.2
5C1C43	11/9/2005	1.4	86.7	0	0	0.1	0	88.2
6C1C41	12/12/2005	0	51.6	0	0	0.8	0	52.4
6C1C42	12/13/2005	2.7	74.3	0	0	0.4	0	77.3
6C1C43	12/14/2005	0.8	69.1	0.6	1.1	1.1	0	72.7
7C1C41	2/22/2006	0.2	25.8	0.3	9.4	1.7	0	37.5
7C1C42	2/22/2006	0	32.0	0.4	7.4	2.5	0	42.2
7C1C43	2/23/2006	0	23.7	0	6.9	1.5	0	32.1

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
Post- Whey Injection Sampling								
8C1C41	3/21/2006	0.5	16.5	0.4	38.4	10.3	0	66.1
9C1C41	4/17/2006	0	13.4	0.2	12.0	3.6	0	29.2
MW1D2								
Phase 2. Baseline Sampling								
1B1D21	3/8/2005	69.3	18.6	0	0	0	0	87.8
1B1D22	3/9/2005	75.3	18.6	0	0	0	0	93.9
1B1D23	3/10/2004	75.3	17.5	0	0	0	0	92.9
2B1D21	3/21/2005	69.3	15.5	0	0	0	0	84.7
2B1D22	3/22/2005	121.8	30.9	0	0	0	0	152.7
2B1D23	3/23/2005	71.5	20.6	0	0	0	0	92.2
3B1D21	4/4/2005	98.9	46.4	0	0	0	0	145.4
3B1D22	4/5/2005	121.8	36.1	0	0	0	0	157.9
3B1D23	4/6/2005	98.9	35.6	0	0	0	0	134.5
Phase 3. 10% w/w Whey Injection								
2C1D21	7/18/2005	2.4	59.8	0	0	0	0	62.3
2C1D22	7/18/2005	8.4	77.4	0	0	0	0	85.7
2C1D23	7/19/2005	2.7	73.2	0	0	0	0	75.9
3C1D21	8/15/2005	1.1	68.1	1.1	0	0	0	70.3
4C1D21	10/03/05	1.1	83.6	0	0	0	0	84.6
4C1D22	10/04/05	4.3	99	0	0	0	0	103.4
4C1D23	10/05/05	4.7	113.5	0.9	0	0	0	119.1
Phase 3. 1% w/w Whey Injection								
5C1D21	11/7/2005	0	185.7	2.2	0	0	0.1	187.8
5C1D22	11/8/2005	12.2	165.1	0	0	0	0	177.2
5C1D23	11/9/2005	0	350.7	1.9	0	0	0	352.6
6C1D21	12/12/2005	0	196	1.3	0	0.2	0.2	197.5
6C1D22	12/13/2005	11.4	175.4	1.4	1.9	0	0.1	190.1
6C1D23	12/14/2005	2.1	206.3	1.3	1.5	0	0	211.3
7C1D21	2/21/2006	8.4	86.7	0.7	13.9	1.6	0	111.2
7C1D22	2/22/2006	4.4	68.1	0.7	5.1	0.6	0	78.9
7C1D23	2/23/2006	0	83.6	0.9	7.7	1.1	0	93.3

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
Post- Whey Injection Sampling								
8C1D21	3/21/2006	6.4	73.2	0.7	17.6	3.9	0	101.8
9C1D21	4/17/2006	1.4	40.2	0.4	12.5	3.9	0	58.5
MW1D3								
Phase 2. Baseline Sampling								
1B1D31	3/8/2005	69.3	21.7	0	0	0	0	90.9
1B1D32	3/9/2005	61.6	17.5	0	0	0	0	79.2
1B1D33	3/10/2005	83.7	19.6	0	0	0	0	103.3
2B1D31	3/21/2005	83.7	19.6	0	0	0	0	103.3
2B1D32	3/22/2005	129.4	30.9	0	0	0	0	160.3
2B1D33	3/23/2005	76.1	19.6	0	0	0	0	95.7
3B1D31	4/4/2005	91.3	26.8	0	0	0	0	118.2
3B1D32	4/5/2005	114.2	28.9	0	0	0	0	143.0
3B1D33	4/6/2005	87.5	22.7	0	0	0	0	110.2
Phase 3. 10% w/w Whey Injection								
2C1D31	7/18/2005	3.0	61.9	0	0	0	0	64.9
2C1D32	7/18/2005	5.2	73.2	0	0	0	0	78.4
2C1D33	7/19/2005	2.0	71.2	0	0	0	0	73.2
3C1D31	8/15/2005	1.5	65.0	1.2	0	0	0	67.7
4C1D31	10/03/05	1.0	76.3	1.0	0	0.1	0	78.4
4C1D32	10/04/05	2.7	80.5	0	0	0	0	83.2
4C1D33	10/05/05	1.5	113.5	0	0	0	0	115.0
Phase 3. 1% w/w Whey Injection								
5C1D31	11/7/2005	0	103.2	2.0	0	0.3	0.1	105.4
5C1D32	11/8/2005	5.4	103.2	0	0	0.2	0	108.7
5C1D33	11/9/2005	1.6	185.7	0	0	0.2	0	187.5
6C1D31	12/12/2005	0.9	123.8	1.0	6.2	0.6	0	132.6
6C1D32	12/13/2005	8.4	113.5	0.9	5.0	0.4	0	128.1
6C1D33	12/14/2005	1.7	154.7	1.2	5.9	0.4	0	164.0
7C1D31	2/22/2006	2.7	62.9	0.7	33.6	4.6	0	104.5
7C1D32	2/23/2006	3.7	42.3	0.5	17.6	5.3	0	69.4
7C1D33	2/24/2006	1.1	51.6	0	20.8	5.7	0	79.2

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
Post- Whey Injection Sampling								
8C1D31	3/21/2006	5.1	47.5	0.5	32.0	8.9	0	94.0
9C1D31	4/17/2006	0.3	34.0	1.0	24.0	8.2	0	67.6
MW1D4								
Phase 2. Baseline Sampling								
1B1D41	3/8/2005	38.1	10.3	0	0	0	0	48.4
1B1D42	3/9/2005	76.1	19.6	0	0	0	0	95.7
1B1D43	3/10/2005	91.3	20.6	0	0	0	0	112
2B1D41	3/21/2005	91.3	19.6	0	0	0	0	110.9
2B1D42	3/22/2005	121.8	25.8	0	0	0	0	147.6
2B1D43	3/23/2005	75.3	17.5	0	0	0	0	92.9
3B1D41	4/4/2005	98.9	23.7	0	0	0	0	122.7
3B1D42	4/5/2005	121.8	29.9	0	0	0	0	151.7
3B1D43	4/6/2005	98.9	25.8	0	0	0	0	124.7
Phase 3. 10% w/w Whey Injection								
2C1D41	7/18/2005	3.0	60.9	0	0	0	0	63.9
2C1D42	7/19/2005	2.3	73.2	0	0	0	0	75.5
3C1D41	8/15/2005	2.0	61.9	1.1	0	0	0	65
MW1D4	9/12/2005	0	44.4	0	0	0	0	44.4
4C1D41	10/03/05	0.8	70.1	0.8	0	0	0	71.8
4C1D42	10/04/05	2.3	84.6	0	0	0	0	86.9
4C1D43	10/05/05	1.0	77.4	0.8	0	0	0	79.2
Phase 3. 1% w/w Whey Injection								
5C1D41	11/7/2005	1.0	134.1	2.0	0	0.3	0.1	137.3
5C1D42	11/8/2005	4.0	103.2	0.8	0	0.1	0	108.1
5C1D43	11/9/2005	2.1	154.7	0	0	0.1	0	156.9
6C1D41	12/12/2005	1.4	123.8	0	6.1	0.6	0.4	132
6C1D42	12/13/2005	7.5	103.2	1.0	4.0	0.4	0	116
6C1D43	12/14/2005	2.8	134.1	1.1	5.8	0.4	0.3	144.2
7C1D41	2/22/2006	2.4	45.4	0.6	32.0	5.7	0	86.1
7C1D42	2/22/2006	3.1	39.2	0.6	19.2	4.3	0	66.4
7C1D43	2/23/2006	3.3	38.2	0.4	22.4	4.3	0	68.6

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
Post- Whey Injection Sampling								
8C1D41	3/21/2006	4.3	42.3	0.5	27.2	7.5	0	81.7
9C1D41	4/17/2006	0.3	32.0	0.8	24.0	3.2	0	60.3
MW2A1								
Phase 2. Baseline Sampling								
1B2A11	3/8/2005	175.1	86.7	0	0	0	0	261.7
1B2A12	3/9/2005	228.3	94.9	0	0	0	0	323.3
1B2A12	3/10/2005	159.8	71.2	0	0	0	0	231
2B2A11	3/21/2005	137.0	57.8	0.5	0	0	0	195.2
2B2A12	3/22/2005	182.7	123.8	0	0	0	0	306.5
2B2A13	3/23/2005	129.4	62.9	0	0	0	0	192.3
3B1A11	4/4/2005	159.8	67.1	0	0	0	0	226.9
3B1A12	4/5/2005	251.2	123.8	0	0	0	0	375
3B1A13	4/6/2005	144.6	68.1	0	0	0	0	212.7
Phase 3. 1% w/w Whey Injection								
2C2A11	7/18/2005	2.4	247.6	0	0	0	0	250.1
2C2A12	7/19/2005	12.2	288.8	0	0	0	0	301.1
2C2A13	7/20/2005	1.1	350.7	0	0	0	0	351.9
3C2A11	8/15/2005	2.8	185.7	0	0	0	0	188.6
3C2A12	8/16/2005	12.9	433.3	5.9	0	0	0.1	452.1
3C2A13	8/17/2005	2.3	268.2	0	0	0	0	270.5
MW2A1	9/12/2005	0	252.7	0	0	0.1	0	252.9
4C2A11	10/03/05	0.7	206.3	1.5	0	0	0	208.6
4C2A12	10/04/05	6.8	309.5	2.2	0	0	0	318.4
4C2A13	10/05/05	2.4	453.9	3.7	1.2	0	0	461.3
Phase 3. 10% w/w Whey Injection								
5C2A11	11/7/2005	2.7	773.7	4.0	0	0.2	0.1	780.6
5C2A12	11/8/2005	11.4	536.4	3.1	5.3	0.1	0	556.3
5C2A13	11/9/2005	15.2	680.8	0	0	0	0	696.1
6C2A11	12/12/2005	0	1134.7	0	0	0.2	0	1135
6C2A12	12/13/2005	9.1	711.8	0	0	0.3	0	721.3
6C2A13	12/14/2005	0	608.6	0	0	0	0	608.6

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
7C2A11	2/21/2006	1.3	196.0	1.5	30.4	1.9	0.3	231.5
7C2A12	2/22/2006	3.0	206.3	1.4	14.6	1.0	0	226.3
7C2A13	2/23/2006	1.2	226.9	1.7	22.4	0.8	0.1	253.1
Post- Whey Injection Sampling								
8C2A11	3/21/2006	1.1	154.7	1.0	41.6	2.6	0	201.1
9C2A11	4/17/2006	0.6	82.5	0.9	40	6.4	0	130.4
MW2A2								
Phase 2. Baseline Sampling								
1B2A21	3/8/2005	144.6	65.0	0	0	0	0	209.6
1B2A22	3/9/2005	235.9	103.2	0	0	0	0	339.1
1B2A23	3/10/2005	175.1	60.9	0	0	0	0	235.9
2B2A21	3/21/2005	137.0	53.6	0.5	0	0	0	191.1
2B2A22	3/22/2005	152.2	87.7	0	0	0	0	239.9
2B2A23	3/23/2005	129.4	66.0	0	0	0	0	195.4
3B2A21	4/4/2005	175.1	58.8	0	0	0	0	233.9
3B2A22	4/5/2005	228.3	123.8	0	0	0	0	352.1
3B2A23	4/6/2005	159.8	65.0	0	0	0	0	224.8
Phase 3. 1% w/w Whey Injection								
2C2A21	7/18/2005	3.4	175.4	0	0	0	0	178.8
2C2A22	7/19/2005	12.2	340.4	0	0	0.1	0	352.7
2C2A23	7/20/2005	1.3	309.5	0	0	0.1	0	310.9
3C2A21	8/15/2005	3.8	196.0	0	0	0	0	199.9
3C2A22	8/16/2005	12.2	412.6	4.1	0	0	0	429
3C2A23	8/17/2005	1.9	72.2	0	0	0	0	74.1
4C2A21	10/03/05	1.4	196.0	1.5	0	0	0	199
4C2A22	10/04/05	6.5	309.5	1.9	0	0	0	317.9
4C2A23	10/05/05	3.0	402.3	3.3	0.8	0	0	409.5
Phase 3. 10% w/w Whey Injection								
5C2A21	11/7/2005	1.5	804.6	4.7	0	0.2	0	811.1
5C2A22	11/8/2005	11.4	536.4	3.1	2.7	0.1	0	553.7
5C2A23	11/9/2005	7.2	732.4	0	0	0	0	739.6
6C2A21	12/12/2005	0	1031.6	0	0	0.1	0	1031.7

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
6C2A22	12/13/2005	9.9	649.9	0	0	0.2	0	660
6C2A23	12/14/2005	0	711.8	0	0	0.1	0	711.9
7C2A21	2/21/2006	0.8	216.6	1.4	22.4	1.3	0.5	243.1
7C2A22	2/22/2006	2.2	196	1.5	12	0.4	0	212.1
7C2A23	2/23/2006	0.9	206.3	1.4	15.8	0.5	0.1	225.1
Post- Whey Injection Sampling								
8C2A21	3/21/2006	1.4	144.4	0.8	36.8	2.0	0	185.5
9C2A21	4/17/2006	0.5	74.3	0	36.8	6.1	0	117.6
MW2A4								
Phase 2. Baseline Sampling								
1B2A41	3/8/2005	129.4	62.9	0	0	0.1	0	192.4
1B2A42	3/9/2005	197.9	47.5	0	0	0	0	245.4
1B2A43	3/10/2005	106.6	56.7	0	0	0	0	163.3
2B2A41	3/21/2005	114.2	51.6	0	0	0.1	0	165.8
2B2A42	3/22/2005	121.8	79.4	0	0	0	0	201.2
2B2A43	3/23/2005	121.8	64.0	0	0	0	0	185.8
3B2A41	4/4/2005	152.2	51.6	0	0	0	0	203.8
3B2A42	4/5/2005	182.7	103.2	0	0	0	0	285.8
3B2A43	4/6/2005	137.0	58.8	0	0	0	0	195.8
Phase 3. 1% w/w Whey Injection								
2C2A41	7/18/2005	12.2	123.8	0	0	0.1	0	136
2C2A42	7/19/2005	9.1	185.7	0	0	0.1	0	194.9
2C2A43	7/20/2005	7.0	196.0	0	0	0	0	203.1
3C2A41	8/15/2005	0.2	84.6	1.0	0.7	0	0.1	86.6
3C2A42	8/16/2005	4.5	196.0	0	0	0	0.1	200.6
3C2A43	8/17/2005	1.1	20.6	0	0	0	0.1	21.8
4C2A41	10/03/05	0	16.5	0	0	0.2	0	16.8
4C2A42	10/04/05	5.5	340.4	0	0	0.1	0	346
4C2A43	10/05/05	0.8	206.3	2.1	1.5	0.1	0	210.9
Phase 3. 10% w/w Whey Injection								
5C2A41	11/7/2005	0	722.1	4.1	0	0.9	0.1	727.2
5C2A42	11/8/2005	6.0	505.5	2.7	5.0	0.4	0	519.5

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
5C2A43	11/9/2005	7.5	536.4	0	0	0.2	0	544.2
6C2A41	12/12/2005	0	412.6	1.8	17.6	1.6	0	433.5
6C2A42	12/13/2005	0	567.4	0	0	0.8	0	568.2
6C2A43	12/14/2005	0	608.6	0	9.9	0.7	0	619.3
7C2A41	2/21/2006	0.1	60.9	0.5	17.6	1.5	0.4	81
7C2A42	2/22/2006	0	100.1	0.8	9.8	0.8	0	111.5
7C2A43	2/23/2006	0.3	74.3	0	13.9	1.2	0	89.7
Post- Whey Injection Sampling								
8C2A41	3/21/2006	0	72.2	0.5	30.4	2.9	0	102
9C2A41	4/17/2006	0	45.4	0.5	32	2.9	0	80.7
MW2B4								
Phase 2. Baseline Sampling								
1B2B41	3/8/2005	144.6	49.5	0	0	0	0	194.1
1B2B42	3/9/2005	98.9	41.3	0	0	0	0	140.2
1B2B43	3/10/2005	121.8	54.7	0	0	0	0	176.4
2B2B41	3/21/2005	106.6	42.3	0.4	0	0	0	149.2
2B2B42	3/22/2005	137.0	59.8	0	0	0	0	196.8
2B2B43	3/23/2005	106.6	54.7	0	0	0	0	161.2
3B2B41	4/4/2005	156.0	72.7	0	0	0	0	228.7
3B2B42	4/5/2005	197.9	71.2	0	0	0	0	269.1
3B2B43	4/6/2005	152.2	62.9	0	0	0	0	215.1
Phase 3. 1% w/w Whey Injection								
2C2B41	7/8/2005	29.7	165.1	0	0	0	0	194.7
2C2B42	7/19/2005	31.2	185.7	0	0	0	0	216.9
2C2B43	7/20/2005	26.6	185.7	0	0	0	0	212.3
3C2B41	8/15/2005	9.9	185.7	0	0	0	0	195.6
3C2B42	8/16/2005	11.4	247.6	0	0	0	0	259.0
3C2B43	8/17/2005	7.4	226.9	0	0	0	0	234.3
4C2B41	10/03/05	0.7	23.7	0	0	0	0	24.5
4C2B42	10/04/05	4.9	330.1	0	0	0	0	335.0
4C2B43	10/05/05	4.6	361.0	0	0	0	0	365.6
Phase 3. 10% w/w Whey Injection								

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
5C2B41	11/7/2005	3.7	763.4	4.2	0	0.1	0.1	771.5
5C2B42	11/8/2005	9.9	618.9	2.9	0	0	0	631.8
5C2B43	11/9/2005	9.1	557.0	0	0	0	0	566.3
6C2B41	12/12/2005	9.1	1134.7	0	0	0	0	1143.9
6C2B42	12/13/2005	5.9	835.6	4.0	0	0	0	845.5
6C2B43	12/14/2005	0	825.3	3.5	0	0	0	828.8
7C2B41	2/21/2006	9.9	443.6	2.5	7.2	0.2	0.1	463.5
7C2B42	2/22/2006	4.3	392.0	2.3	8.5	0.2	0	407.3
7C2B43	2/23/2006	0	361.0	0	8.6	0.2	0	369.9
Post- Whey Injection Sampling								
8C2B41	3/21/2006	7.6	505.5	2.9	16.0	0.3	0	532.2
9C2B41	4/17/2006	0.5	85.6	0.7	17.6	0	0	104.5
MW2C4								
Phase 2. Baseline Sampling								
1B2C41	3/8/2005	144.6	56.7	0	0	0	0	201.4
1B2C42	3/9/2005	152.2	55.7	0	0	0	0	208.0
1B2C43	3/10/2005	152.2	54.7	0	0	0	0	206.9
2B2C41	3/21/2005	114.2	42.3	0	0	0	0	156.5
2B2C42	3/22/2005	106.6	53.6	0	0	0	0	160.2
2B2C43	3/23/2005	106.6	45.4	0	0	0	0	151.9
3B2C41	4/4/2005	144.6	59.8	0	0	0	0	204.4
3B2C42	4/5/2005	144.6	59.8	0	0	0	0	204.4
3B2C43	4/6/2005	129.4	55.7	0	0	0	0	185.1
Phase 3. 1% w/w Whey Injection								
2C2C41	7/18/2005	13.7	144.4	0	0	0	0	158.1
2C2C42	7/19/2005	8.4	144.4	0	0	0	0	152.8
2C2C43	7/20/2005	3.9	144.4	0	0	0	0	148.3
3C2C41	8/15/2005	5.9	134.1	0	0	0	0	140.1
3C2C42	8/16/2005	3.9	154.7	0	0	0	0	158.6
3C2C43	8/17/2005	4.3	134.1	0	0	0	0	138.5
4C2C41	10/03/05	0	13.4	0	0	0.1	0	13.5
4C2C42	10/04/05	2.2	175.4	1.3	2.6	0	0	181.5

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
4C2C43	10/05/05	1.9	206.3	0	2.7	0	0	211.0
Phase 3. 10% w/w Whey Injection								
5C2C41	11/7/2005	13.5	226.9	2.3	11.4	0.5	0.2	254.7
5C2C42	11/8/2005	0	299.2	2.4	7.2	0.2	0.1	309.0
5C2C43	11/9/2005	3.3	278.5	0	8.6	0.3	0.1	291.0
6C2C41	12/12/2005	1.7	340.4	0	19.2	0.9	0	362.1
6C2C42	12/13/2005	3.5	350.7	0	19.2	0.2	0	373.7
6C2C43	12/14/2005	2.2	350.7	1.9	14.9	0.4	0	370
7C2C41	2/21/2006	0.5	154.7	1.4	129.6	6.1	0	292.3
7C2C42	2/22/2006	0	113.5	0.7	94.4	4.3	0	212.9
7C2C43	2/23/2006	0	123.8	0.7	92.8	3.9	0	221.3
Post- Whey Injection Sampling								
8C2C41	3/21/2006	0	82.5	1.3	134.4	6.8	0	225.0
9C2C41	4/17/2006	0	40.2	0.9	124.8	16.0	0	182.0
MW2D1								
Phase 2. Baseline Sampling								
1B2D110	3/8/2005	91.3	50.5	0	0	0	0	141.9
1B2D12	3/9/2005	167.4	134.1	0	0	0	0	301.5
1B2D13	3/10/2005	121.8	83.6	1.0	0	0	0	206.3
2B2D11	3/21/2005	106.6	55.7	0.5	0	0	0	162.8
2B2D12	3/22/2005	129.4	103.2	0	0	0	0	232.6
2B2D13	3/23/2005	121.8	87.7	0	0	0	0	209.5
3B2D11	4/4/2005	152.2	69.1	0	0	0	0	221.3
3B2D12	4/5/2005	175.1	103.2	0	0	0	0	278.2
3B2D13	4/6/2005	144.6	80.5	0	0	0	0	225.1
Phase 3. 1% w/w Whey Injection								
2C2D11	7/18/2005	0.8	319.8	0	0	0	0	320.7
2C2D12	7/19/2005	0	299.2	0	0	0	0	299.2
2C2D13	7/20/2005	0.8	299.2	0	0	0	0	299.9
3C2D11	8/15/2005	0	144.4	0	0	0	0	144.4
3C2D12	8/16/2005	4.3	402.3	5.5	0	0	0	412.0
3C2D13	8/17/2005	0	361.0	5.2	0	0	0	366.2

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
4C2D11	10/03/05	0	268.2	2.3	0	0	0	270.5
4C2D12	10/04/05	7.5	639.6	0	0	0	0	647.1
4C2D13	10/05/05	3.0	505.5	3.6	0	0	0	512.0
Phase 3. 10% w/w Whey Injection								
5C2D11	11/7/2005	2.8	340.4	3.3	0	0	0	346.6
5C2D12	11/8/2005	9.9	618.9	3.4	0	0	0	632.3
5C2D13	11/9/2005	0	629.3	0	0	0	0	629.3
6C2D11	12/12/2005	0	1134.7	0	0	0	0	1134.7
6C2D12	12/13/2005	9.1	763.4	0	0	0.1	0	772.6
6C2D13	12/14/2005	0	732.4	0	0	0.1	0.1	732.5
7C2D11	2/21/2006	0.1	247.6	2.0	2.1	0	0.1	251.8
7C2D12	2/22/2006	0	165.1	1.2	2.6	0.1	0	169.0
7C2D13	2/23/2006	0	216.6	1.7	3.5	0	0	221.8
Post- Whey Injection Sampling								
8C2D11	3/21/2006	0	154.7	1.2	5.9	0.3	0	162.2
9C2D11	4/17/2006	0	26.8	0	3.5	0.2	0	30.5
MW2D2								
Phase 2. Baseline Sampling								
1B2D21	3/8/2005	144.6	76.3	0	0	0	0	220.9
1B2D22	3/9/2005	114.2	87.7	0	0	0	0	201.8
1B2D23	3/10/2005	121.8	89.7	0	0	0	0	211.5
2B2D21	3/21/2005	106.6	57.8	0.5	0	0	0	164.8
2B2D22	3/22/2005	121.8	101.1	0	0	0	0	222.9
2B2D23	3/23/2005	121.8	86.7	0	0	0	0	208.4
3B2D21	4/4/2005	159.8	82.5	0	0	0	0	242.4
3B2D22	4/5/2005	167.4	103.2	0	0	0	0	270.6
3B2D23	4/6/2005	144.6	79.4	0	0	0	0	224.0
Phase 3. 1% w/w Whey Injection								
2C2D21	7/18/2005	1.3	299.2	0	0	0	0	300.5
2C2D22	7/19/2005	4.0	278.5	0	0	0	0	282.6
2C2D23	7/20/2005	1.4	278.5	0	0	0	0	279.9
3C2D21	8/15/2005	1.7	381.7	0	0	0	0	383.4

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
3C2D22	8/16/2005	11.4	361.0	4.2	0	0	0	376.7
3C2D23	8/17/2005	1.4	361.0	5.2	0	0	0	367.6
4C2D21	10/03/05	3.6	278.5	2.1	0	0	0	284.2
4C2D22	10/04/05	16.0	588.0	0	0	0	0	604.0
4C2D23	10/05/05	3.8	484.8	3.6	0	0	0	492.3
Phase 3. 10% w/w Whey Injection								
5C2D21	11/7/2005	0	381.7	3.3	0	0.1	0.1	385.2
5C2D22	11/8/2005	5.9	557.0	3.1	0	0	0	566.2
5C2D23	11/9/2005	0	546.7	0	0	0	0	546.8
6C2D21	12/12/2005	0	1000.6	0	0	0	0	1000.6
6C2D22	12/13/2005	7.6	701.5	0	0	0.1	0	709.2
6C2D23	12/14/2005	2.7	763.4	0	0	0	0	766.0
7C2D21	2/21/2006	1.9	268.2	2.1	3.0	0.3	0.3	275.8
7C2D22	2/22/2006	1.3	206.3	1.3	3.7	0.2	0	212.8
7C2D23	2/23/2006	3.0	216.6	3.4	14.7	0.3	0.2	238.2
Post- Whey Injection Sampling								
8C2D21	3/21/2006	0	165.1	1.0	11.5	0.8	0	178.4
9C2D21	4/17/2006	0.3	40.2	0.4	8.0	0.4	0	49.4
MW2D4								
Phase 2. Baseline Sampling								
1B2D41	3/8/2005	144.6	89.7	0	0	0	0	234.4
1B2D42	3/9/2005	121.8	75.3	0	0	0	0	197.1
1B2D43	3/10/2005	129.4	88.7	0	0	0	0	218.1
2B2D41	3/21/2005	129.4	77.4	0.6	0	0	0	207.4
2B2D42	3/22/2005	114.2	70.1	0	0	0	0	184.3
2B2D43	3/23/2005	106.6	81.5	0	0	0	0	188.0
3B2D41	4/4/2005	137.0	94.9	0	0	0	0	231.9
3B2D42	4/5/2005	167.4	113.5	0	0	0	0	280.9
3B2D43	4/6/2005	129.4	82.5	0	0	0	0	211.9
Phase 3. 1% w/w Whey Injection								
2C2D41	7/18/2005	10.7	185.7	0	0	0	0	196.4
2C2D42	7/19/2005	6.3	185.7	0	0	0	0	192.0

Table E-5. (continued).

Sample ID	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	VC (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
2C2D43	7/20/2005	2.7	175.4	0	0	0	0	178.0
3C2D41	8/15/2005	3.7	175.4	0	0	0	0.1	179.2
3C2D42	8/16/2005	7.6	185.7	0	0	0	0	193.3
3C2D43	8/17/2005	59.4	319.8	0	0	0	0	379.2
MW2D4	9/12/2005	0	123.8	0	0	0.1	0	124.0
4C2D41	10/03/05	0	23.7	0	0	0.1	0	23.8
4C2D42	10/04/05	2.1	268.2	0	0	0	0	270.3
4C2D43	10/05/05	0	247.6	2.7	0.7	0.1	0	251.0
Phase 3. 10% w/w Whey Injection								
5C2D41	11/7/2005	0	422.9	4.1	0	0.4	0.2	427.7
5C2D42	11/8/2005	0	433.3	0	0	0.2	0	433.4
5C2D43	11/9/2005	4.5	484.8	0	0	0.2	0.1	489.6
6C2D41	12/12/2005	0	680.8	3.7	0	0.5	0.1	685.1
6C2D42	12/13/2005	4.9	484.8	0	0	0.2	0	489.9
6C2D43	12/14/2005	0	536.4	0	0	0.3	0	536.7
7C2D41	2/21/2006	0.2	226.9	2.0	28.8	3.6	0	261.4
7C2D42	2/22/2006	0	216.6	1.5	24.0	1.9	0	244.1
7C2D43	2/23/2006	0	175.4	0.9	20.8	2.6	0	199.7
Post- Whey Injection Sampling								
8C2D41	3/21/2006	0	309.5	0	57.6	1.9	0	369.0
9C2D41	4/17/2006	0	103.2	1.1	41.6	2.0	0	147.9

Table E-6. Flux Meter Carbon Results.

Well	Date	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)	COD (mg/L)
FX1									
FX1	12/12/06	0	0	0	0	0	0	0	380
FX1	1/18/2006	0	0	0	0	0	0	0	470
FX1	2/23/2006	0	0	0	0	0.1	0	0	27
FX1	3/21/2006	0	0	0	0	0	0	0	
FX1	4/17/2006	0	0	0	0	0	0	0	13
FX1	5/17/2006	0	0	0	0	0	0	0	12
FX2									
FX2	12/12/06	0	0	0	0	0	0	0	1020
FX2	1/18/2006	0	0	0	0	0	0	0	200
FX2	2/23/2006	0	0	0	0	0	0	0	
FX2	3/21/2006	0	0	0	0	0	0	0	
FX2	4/17/2006	0	0	0	0	0	0	0	
FX2	5/17/2006	0	0	0	0	0	0	0	53
FX3									
FX3	12/12/06	0	0	0	0	0	0	0	280
FX3	1/18/2006	0	0	0	0	0	0	0	330
FX3	2/23/2006	0	0	0	0	0	0	0	
FX3	3/21/2006	0.21	0	0	0	0	0	0	
FX3	4/17/2006	0	0	0	0	0	0	0	13
FX3	5/17/2006	0	0	0	0	0	0	0	415
FX4									
FX4	12/12/06	0	0	0	0	0	0	0	
FX4	1/18/2006	0	0.55	0	0	0	0	0	170
FX4	2/23/2006	0	0	0	0	0	0	0	90
FX4	3/21/2006	0	0	0	0	0	0	0	
FX4	4/17/2006	0	0	0	0	0	0	0	
FX4	5/17/2006	0	0	0	0	0	0	0	20

Table E-6. (continued).

Well	Date	Lactate (mg/L)	Acetate (mg/L)	Propionate (mg/L)	IsoButyrate (mg/L)	Butyrate (mg/L)	IsoValerate (mg/L)	Valerate (mg/L)	COD (mg/L)
FX5									
FX5	12/12/06	0	37	9.5	4.5	27.5	0	0	380
FX5	1/18/2006	0	0	0	0	0	0	0	370
FX5	2/23/2006	0.19	0	0	0.3	08	0.15	0	22
FX5	3/21/2006	0	0	0	0	0	0	0	
FX5	4/17/2006	0	0	0	0	0	0	0	
FX5	5/17/2006	0	0	0	0	0	0	0	53
FX6									
FX6	12/12/06	0	0	0	0	0	0	0	
FX6	1/18/2006	0	0	0	0	0	0	0	330
FX6	2/23/2006	0	0	0	0	0	0	0	10
FX6	3/21/2006	0	0	0	0	0	0	0	
FX6	4/17/2006	0	0	0	0	0	0	0	
FX6	5/17/2006	0	0	0	0	0	0	0	
FX7									
FX7	12/12/06	10.5	5	8	9	10.5	8	5.5	
FX7	1/18/2006	0	0	0	0	0	0	0	330
FX7	2/23/2006	0	0	0	0	0	0	0	52
FX7	3/21/2006	0	10.3	3.1	1.7	4.3	1.9	2	
FX7	4/17/2006	0	0	0	0	0	0	0	19
FX7	5/17/2006	0	0	0	0	0	0	0	24
FX8									
FX8	12/12/06	0	0	0	0	0	0	0	320
FX8	1/18/2006	0	0	0	0	0	0	0	580
FX8	2/23/2006	0	0	0	0	0	0	0	16
FX8	3/21/2006	0	12.5	4.3	2.8	4.7	2.5	3.1	
FX8	4/17/2006	0	1.3	0	0	0	0	0	20
FX8	5/17/2006	0	1.6	05	0.16	0	0	0	335

Table E-7. Flux Meter Well Geochemistry Results.

Well	Date	pH	Temperature (°C)	Specific Conductivity (ms/cm)	Alkalinity (mg/L as CaCO ₃)
FX1					
FX1	12/12/06	6.19	12.57	0.4	172
FX1	1/18/2006	5.87	10.64	0.186	48
FX1	2/23/2006	6.39	108	0.329	
FX1	3/21/2006	6.09	10.15	0.143	50
FX1	4/17/2006	6.02	12.06	0.126	33
FX1	5/17/2006	5.96	11.28	0.102	54
FX1	6/26/2006	5.81	14.68	0.101	44
FX2					
FX2	12/12/06	6.21	12.79	0.45	140
FX2	1/18/2006	5.5	10.6	099	14
FX2	2/23/2006	5.86	9.87	082	
FX2	3/21/2006	6.15	10.69	0.162	55
FX2	4/17/2006	5.81	11.43	0.102	31
FX2	5/17/2006	5.9	11.69	082	40
FX2	6/26/2006	5.77	13.72	093	40
FX3					
FX3	12/12/06	5.9	12.82	0.3	66
FX3	1/18/2006	5.38	11.25	0.108	13
FX3	2/23/2006	5.93	9.96	0.11	
FX3	3/21/2006	6.16	10.39	0.214	68
FX3	4/17/2006	5.78	11.23	095	24
FX3	5/17/2006	5.92	11.71	079	32
	6/26/2006	5.72	13.43	091	38
FX4					
FX4	12/12/06	6.24	11.81	0.37	119
FX4	1/18/2006	6.01	10.82	0.3	74
FX4	2/23/2006	6.09	10.25	0.169	
FX4	3/21/2006	5.92	102	0.128	44
FX4	4/17/2006	5.91	11.08	0.13	39
FX4	5/17/2006	6.05	11.47	0.113	45
FX4	6/26/2006	5.85	13.99	0.134	51
FX5					
FX5	12/12/06	6.05	12.28	0.35	69
FX5	1/18/2006	5.38	10.45	085	17
FX5	2/23/2006	5.69	9.15	064	
FX5	3/21/2006	5.65	9.54	082	26
FX5	4/17/2006	5.77	10.75	0.88	24
FX5	5/17/2006	5.87	12.02	079	60
FX5	6/26/2006	5.53	13.11	091	27
FX6					
FX6	12/12/06	6.02	12.25	0.2	73
FX6	1/18/2006	5.94	10.72	0.281	84
FX6	2/23/2006	6.03	9.64	0.154	
FX6	3/21/2006	5.95	9.82	0.145	56

Table E-7. (continued).

Well	Date	pH	Temperature (°C)	Specific Conductivity (ms/cm)	Alkalinity (mg/L as CaCO₃)
FX6	4/17/2006	5.9	11	0.156	46
FX6	5/17/2006	5.88	12.37	0.109	40
FX6	6/26/2006	6.23	14.2	0.237	97
FX7					
FX7	12/12/06	6.55	11.41	0.29	120
FX7	1/18/2006	5.72	10.23	0.25	70
FX7	2/23/2006	6.48	11.16	0.36	
FX7	3/21/2006	6.27	10.13	0.39	152
FX7	4/17/2006	6.01	11.3	0.21	79
FX7	5/17/2006	6	13.2	0.125	61
FX7	6/26/2006	6.06	14.68	0.224	97
FX8					
FX8	12/12/06	6.02	11.69	0.15	49
FX8	1/18/2006	5.84	10.14	0.277	89
FX8	2/23/2006	6.39	10.44	0.259	
FX8	3/21/2006	6.24	9.97	0.43	164
FX8	4/17/2006	6.13	10.99	0.297	124
FX8	5/17/2006	6.23	12.87	0.268	140
FX8	6/26/2006	6.2	14.78	0.297	131

Table E-8. Flux Meter Well Redox Results.

Well	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
FX1							
FX1	12/12/06	-117	5.18	1.3	48.5	0.5	340
FX1	1/18/2006	2	5.38	2.27	7.1	4.9	120
FX1	2/23/2006	-33	1.03		20.7	0.39	340
FX1	3/21/2006	34	4.39		8.1	1.2	44
FX1	4/17/2006	121	4.31	0.24	6.1	1	38
FX1	5/17/2006	162	3.89	04	5	0.67	9.6
FX1	6/26/2006	123	3.41	01			4.7
FX2							
FX2	12/12/06	-43	0.84	1.67	14	2	440
FX2	1/18/2006	161	6.45	0.13	12.3	3.8	0.41
FX2	2/23/2006	141	5.6		6	1.7	97
FX2	3/21/2006	32	3.2		5.5	1	140
FX2	4/17/2006	171	5.76	0.16	5.7	1.2	0.79
FX2	5/17/2006	201	5.15	02	4.5	0.72	0
FX2	6/26/2006	167	3.81	01			0
FX3							
FX3	12/12/06	-155	5.12	0.27	12	2	74
FX3	1/18/2006	256	5.05	09	4.8	6.5	0.31
FX3	2/23/2006	61	5.45		0.61	0.17	100
FX3	3/21/2006	3	2.83		6.2	0.81	170
FX3	4/17/2006	188	5.36	07	5.4	1.3	0.41
FX3	5/17/2006	222	5.92	06	4.5	0.74	0
	6/26/2006	184	4.39	0			0
FX4							
FX4	12/12/06	26	1.53	1.28	7	3	26
FX4	1/18/2006	-59	1.67	2.01	16.6	1.7	120
FX4	2/23/2006	-19	2.2		11.8	1.5	410
FX4	3/21/2006	55	3.18		10.2	1.1	130
FX4	4/17/2006	137	2.5	06	8.3	0.74	6
FX4	5/17/2006	133	1.74	0.18	5.5	0.43	11
FX4	6/26/2006	91	1.12	04			42
FX5							
FX5	12/12/06	-69	2.08	1.95	12.5	4.5	480
FX5	1/18/2006	240	5.48	06	3.7	4.9	0
FX5	2/23/2006	70	7.41		0.49	0.49	8.7
FX5	3/21/2006	48	6.34		7	1.8	11
FX5	4/17/2006	199	7.05	05	5.7	1.4	0
FX5	5/17/2006	216	6.04		4.9	0.77	0
FX5	6/26/2006	204	4.46	0			480
FX6							
FX6	12/12/06	112	4.52	0.12	7.5	3	1.8
FX6	1/18/2006	-111	0.97	3.3	11.5	0	160
FX6	2/23/2006	-7	0.87		13.1	0.85	63
FX6	3/21/2006	61	0.8		9.7	0.4	64

Table E-8. (continued).

Well	Date	ORP (mV)	DO (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Nitrate (mg/L)	Methane (ug/L)
FX6	4/17/2006	91	0.77	0.18	9.5	0.42	50
FX6	5/17/2006	122	1.32	0.1	5.8	0.3	6
FX6	6/26/2006	-161	0.66	3.3			380
FX7							
FX7	12/12/06	41	1.07	08	53	11	7.1
FX7	1/18/2006	62	1.13	0.25	2	0	71
FX7	2/23/2006	-60	0.69		5.1	05	42
FX7	3/21/2006	-7	2.45		0.7	0	470
FX7	4/17/2006	17	0.82	2.26	9.2	0.11	250
FX7	5/17/2006	12	0.81	1	1.1	0	17
FX7	6/26/2006	-171	0.87	2.32			740
FX8							
FX8	12/12/06	140	5.33	02	9.5	3.5	0.32
FX8	1/18/2006	-62	1.01	0.62	3	0	83
FX8	2/23/2006	-67	0.7		0.69	0	240
FX8	3/21/2006	-48	0.74		0.2	0	1100
FX8	4/17/2006	-33	0.91	3.3	5.5	0	480
FX8	5/17/2006	-130	0.94	3.3	1.1	0	620
FX8	6/26/2006	-184	1.04	3.3			3000

Table E-9. Flux Meter Well VOC and Dissolved Gases Results.

Well	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	Vinyl Chloride (ug/L)	Ethane (ug/L)	Ethene (ug/L)
FX1							
FX1	7/12/2005	4.5	6650	60	0		
FX1	11/01/2005	10.2	17590	161	1505	0.9	2.1
FX1	12/12/06	260	21000	140	310	0	0.75
FX1	1/18/2006	230	5600	0	380	0	0.47
FX1	2/23/2006	1100	10000	74	850	0.94	2.6
FX1	3/21/2006	290	1200	9.5	230	0	0.88
FX1	4/17/2006	64	510	13	99	0	0
FX1	5/17/2006	85	140	2.6	74	0	0
FX1	6/26/2006	120	190	4.2	30	0	0
FX1	8/7/2006	817	1750	15	19	0.3	0.4
FX2							
FX2	7/12/2005	7.8	7110	57	0		
FX2	11/01/2005	21.3	19252	149	1466	0.7	3.2
FX2	12/12/06	410	22000	170	500	1.1	1.3
FX2	1/18/2006	130	210	8.9	8.5	0	0
FX2	2/23/2006	82	380	0	36	0	0.75
FX2	3/21/2006	120	1100	9.7	180	0	3.9
FX2	4/17/2006	48	130	4.9	4.9	0	0
FX2	5/17/2006	74	25	0.96	0	0	0
FX2	6/26/2006	99	91	2.1	0	0	0
FX2	8/7/2006	232	368	3.4	19	0.2	1.5
FX3							
FX3	7/12/2005	177	4000	32	0		
FX3	11/01/2005	17.3	34015	234	119	0.7	0.3
FX3	12/12/06	1000	22000	170	140	0	0
FX3	1/18/2006	210	420	12	0	0	0
FX3	2/23/2006	120	1300	13	42	0	0
FX3	3/21/2006	210	4300	28	150	0	1
FX3	4/17/2006	49	61	1.2	0	0	0

Table E-9. (continued).

Well	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	Vinyl Chloride (ug/L)	Ethane (ug/L)	Ethene (ug/L)
FX3	5/17/2006	74	9	0	0	0	0
FX3	6/26/2006	110	170	4.1	0	0	0
FX4							
FX4	7/12/2005	14	11900	93	0		
FX4	11/01/2005	15.5	14711	148	465	0.5	0.7
FX4	12/12/06	300	13000	110	120	0	0
FX4	1/18/2006	740	10000	0	320	0	1.2
FX4	2/23/2006	2400	9800	91	2800	0	6.3
FX4	3/21/2006	560	560	5.2	110	0	2.5
FX4	4/17/2006	220	600	12	22	0	0
FX4	5/17/2006	280	440	4.7	83	0	0
FX4	6/26/2006	200	720	6.8	110	0	2.1
FX4	8/7/2006	1170	2040	23	85	0.2	0.9
FX5							
FX5	7/12/2005	2600	4700	20	0		
FX5	11/01/2005	93.3	3641	34.0	36.40	0.2	0.4
FX5	12/12/06	1400	8800	87	0	0	0.78
FX5	1/18/2006	78	47	2	0	0	0
FX5	2/23/2006	130	98	2.2	6.7	0	0
FX5	3/21/2006	200	220	2.9	36	0	0.44
FX5	4/17/2006	84	29	1.3	0	0	0
FX5	5/17/2006	110	9	0.84	0	0	0
FX5	6/26/2006	110	76	3.2	0	0	0
FX6							
FX6	7/12/2005	46	10300	112	0		
FX6	11/01/2005	34.6	11984	118	33.5	0.7	0.7
FX6	12/12/06	930	5000	61	0	0	0
FX6	1/18/2006	240	16000	120	0	0.4	0.72
FX6	2/23/2006	280	2800	0	130	0	0.91
FX6	3/21/2006	350	800	5.5	44	0	0.67
FX6	4/17/2006	160	930	9.1	62	0	0.6
FX6	5/17/2006	160	350	3.3	14	0	0
FX6	6/26/2006	150	5000	41	1200	2.5	31

Table E-9. (continued).

Well	Date	TCE (ug/L)	cis-DCE (ug/L)	trans-DCE (ug/L)	Vinyl Chloride (ug/L)	Ethane (ug/L)	Ethene (ug/L)
FX6	8/7/2006	151	1420	17	264	1.0	11
FX7							
FX7	7/12/2005	18700	2650	22	0		
FX7	11/01/2005	808	19097	153	4.93	2.8	2.4
FX7	12/12/06	4000	5400	44	0	0	0
FX7	1/18/2006		21000	150	0	0	0
FX7	2/23/2006	2500	9200	95	0	0.29	0
FX7	3/21/2006	56	11000	75	280	1.2	3
FX7	4/17/2006	100	2500	25	160	0	2.4
FX7	5/17/2006	110	480	4.6	4	0	0
FX7	6/26/2006	160	6200	64	1400	1	33
FX8							
FX8	7/12/2005	886	548	5.3	0		
FX8	11/01/2005	519	513	11.6	1.16	0.3	0.2
FX8	12/12/06	610	1800	38	0	0	0
FX8	1/18/2006	0	19000	0	0		0.42
FX8	2/23/2006	1600	7000	77	0	0.66	0.84
FX8	3/21/2006	0	11000	84	250	0	0
FX8	4/17/2006	0	4600	37	260	0	0
FX8	5/17/2006	50	5900	45	570	0	7.9
FX8	6/26/2006	46	4500	40	1500	3.1	52

Table E-10. Flux Meter Well Molar VOC and Dissolved Gases Results.

Well	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	Vinyl Chloride (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total TCE, DCE, VC, Ethane, Ethene (umol/L)
FX1								
FX1	7/12/2005	0.03	68.60	0.62	0	0	0	69.25
FX1	11/01/2005	0.08	181.45	1.66	24.08	0.03	0.08	207.35
FX1	12/12/06	1.98	216.63	1.44	4.96	0	0.03	225.04
FX1	1/18/2006	1.75	57.77	0	6.08	0	0.02	65.61
FX1	2/23/2006	8.37	103.16	0.76	13.60	0.03	0.09	125.98
FX1	3/21/2006	2.21	12.38	0.10	3.68	0	0.03	18.40
FX1	4/17/2006	0.49	5.26	0.13	1.58	0	0	7.47
FX1	5/17/2006	0.65	1.44	0.03	1.18	0	0	3.30
FX1	6/26/2006	0.91	1.96	0.04	0.48	0	0	3.40
FX1	8/7/2006	6.22	18.05	0.15	0.30	0.01	0.01	24.74
FX2								
FX2	7/12/2005	0.06	73.34	0.59	0	0	0	73.99
FX2	11/01/2005	0.16	198.60	1.54	23.46	0.02	0.11	223.87
FX2	12/12/06	3.12	226.94	1.75	8.00	0.04	0.05	239.86
FX2	1/18/2006	0.99	2.17	0.09	0.14	0	0	3.38
FX2	2/23/2006	0.62	3.92	0	0.58	0	0.03	5.15
FX2	3/21/2006	0.91	11.35	0.10	2.88	0	0.14	15.38
FX2	4/17/2006	0.37	1.34	0.05	0.08	0	0	1.84
FX2	5/17/2006	0.56	0.26	0.01	0	0	0	0.83
FX2	6/26/2006	0.75	0.94	0.02	0	0	0	1.71
FX2	8/7/2006	1.77	3.80	0.04	0.30	0.01	0.05	5.95
FX3								
FX3	7/12/2005	1.35	41.26	0.33	0	0	0	42.94
FX3	11/01/2005	0.13	350.89	2.41	1.90	0.02	0.01	355.35
FX3	12/12/06	7.61	226.94	1.75	2.24	0	0	238.55
FX3	1/18/2006	1.60	4.33	0.12	0	0	0	6.05
FX3	2/23/2006	0.91	13.41	0.13	0.67	0	0	15.13

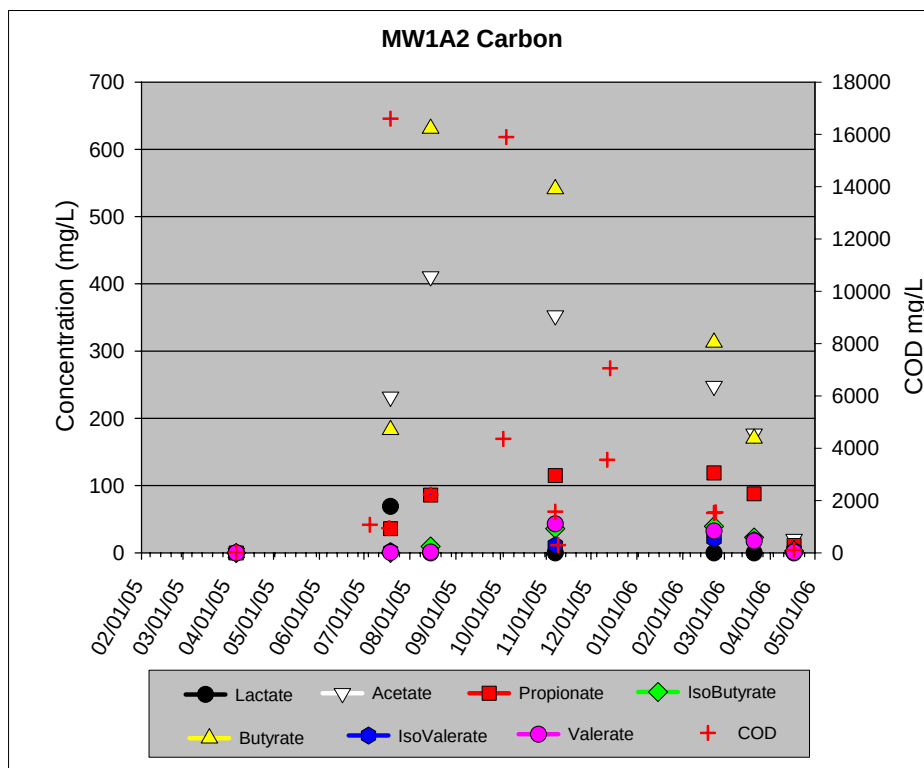
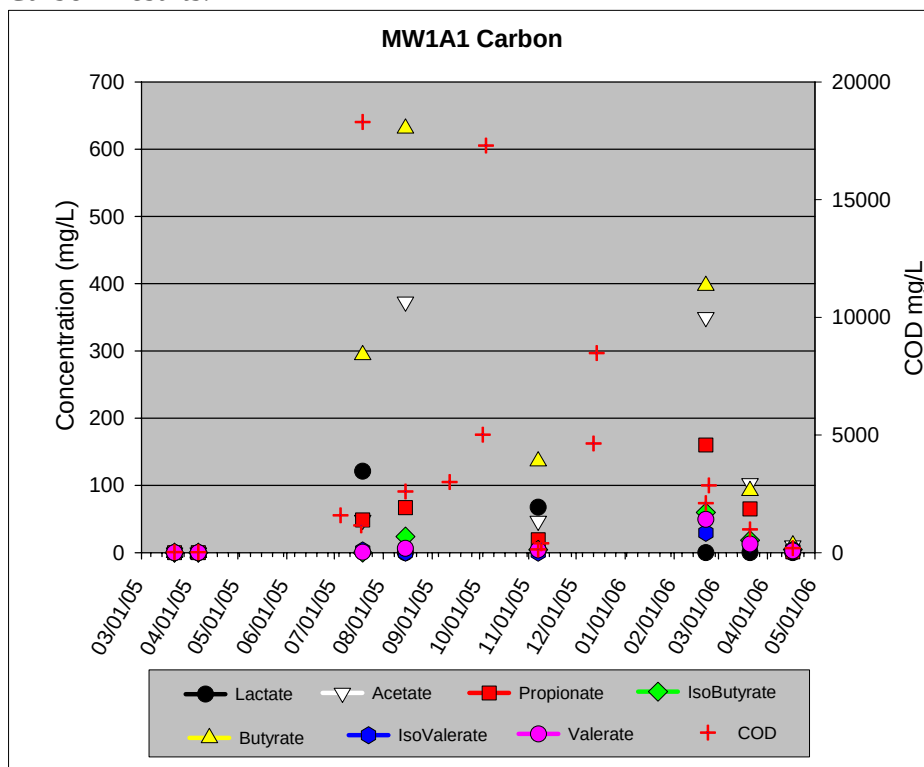
Table E-10. (continued).

Well	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	Vinyl Chloride (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total (umol/L)
FX3	3/21/2006	1.60	44.36	0.29	2.40	0	0.04	48.68
FX3	4/17/2006	0.37	0.63	0.01	0	0	0	1.01
FX3	5/17/2006	0.56	0.09	0	0	0	0	0.66
FX3	6/26/2006	0.84	1.75	0.04	0	0	0	2.63
FX4								
FX4	7/12/2005	0.11	122.76	0.96	0	0	0	123.82
FX4	11/01/2005	0.12	151.75	1.53	7.44	0.02	0.02	160.86
FX4	12/12/06	2.28	134.10	1.13	1.92	0	0	139.44
FX4	1/18/2006	5.63	103.16	0	5.12	0	0.04	113.95
FX4	2/23/2006	18.27	101.09	0.94	44.80	0	0.22	165.32
FX4	3/21/2006	4.26	5.78	0.05	1.76	0	0.09	11.94
FX4	4/17/2006	1.67	6.19	0.12	0.35	0	0	8.34
FX4	5/17/2006	2.13	4.54	0.05	1.33	0	0	8.05
FX4	6/26/2006	1.52	7.43	0.07	1.76	0	0.07	10.85
FX4	8/7/2006	8.90	21.04	0.24	1.36	0.01	0.03	31.58
FX5								
FX5	7/12/2005	19.79	48.48	0.21	0	0	0	68.48
FX5	11/01/2005	0.71	37.56	0.35	0.58	0.01	0.02	39.22
FX5	12/12/06	10.66	90.78	0.90	0	0	0.03	102.36
FX5	1/18/2006	0.59	0.48	0.02	0	0	0	1.10
FX5	2/23/2006	0.99	1.01	0.02	0.11	0	0	2.13
FX5	3/21/2006	1.52	2.27	0.03	0.58	0	0.02	4.41
FX5	4/17/2006	0.64	0.30	0.01	0	0	0	0.95
FX5	5/17/2006	0.84	0.09	0.01	0	0	0	0.94
FX5	6/26/2006	0.84	0.78	0.03	0	0	0	1.65
FX6								
FX3	7/12/2005	0.35	106.25	1.16	0	0	0	107.76
FX3	11/01/2005	0.26	123.62	1.22	0.54	0.02	0.02	125.66
FX3	12/12/06	7.08	51.58	0.63	0	0	0	59.29
FX3	1/18/2006	1.83	165.05	1.24	0	0.01	0.03	168.14
FX3	2/23/2006	2.13	28.88	0	2.08	0	0.03	33.13

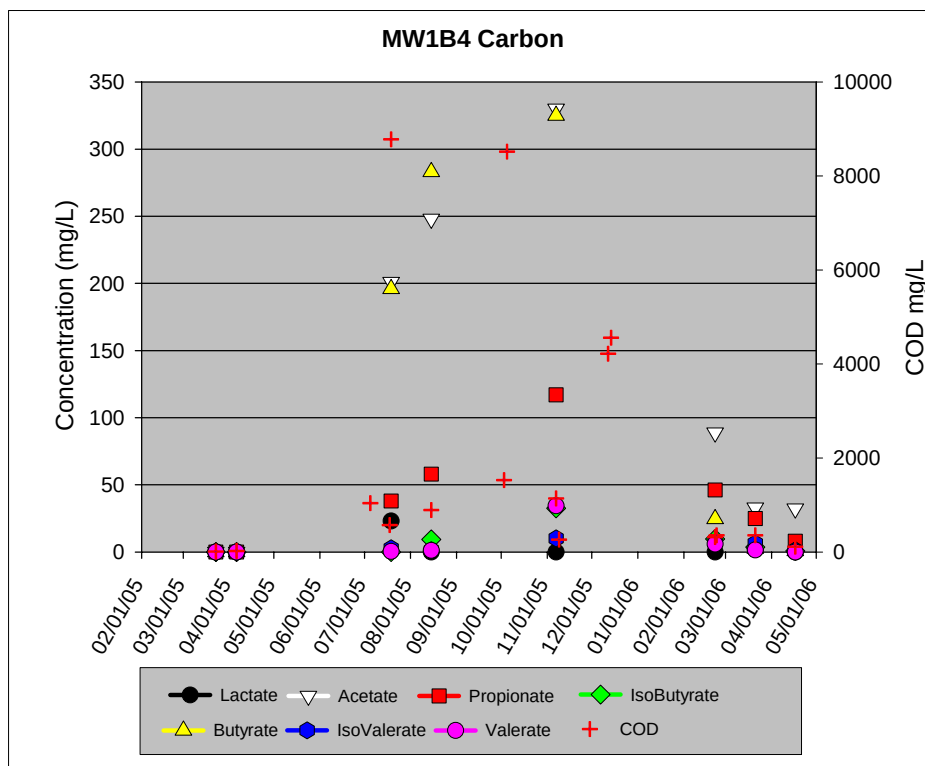
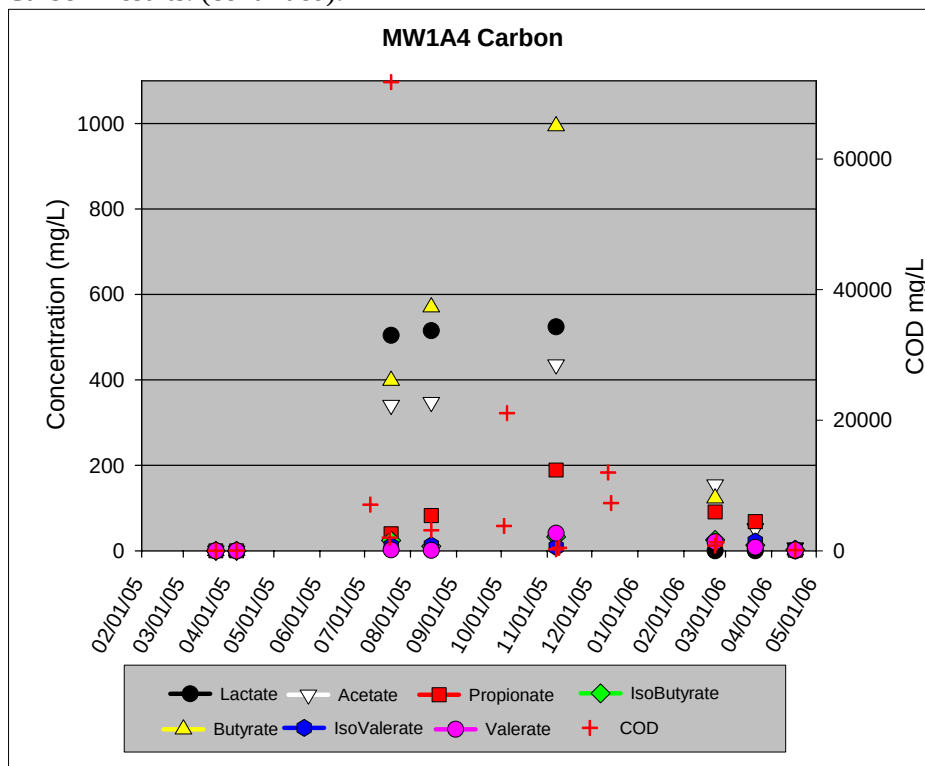
Table E-10. (continued).

Well	Date	TCE (umol/L)	cis-DCE (umol/L)	trans-DCE (umol/L)	Vinyl Chloride (umol/L)	Ethane (umol/L)	Ethene (umol/L)	Total (umol/L)
FX6	3/21/2006	2.66	8.25	0.06	0.70	0	0.02	11.70
FX6	4/17/2006	1.22	9.59	0.09	0.99	0	0.02	11.92
FX6	5/17/2006	1.22	3.61	0.03	0.22	0	0	5.09
FX6	6/26/2006	1.14	51.58	0.42	19.20	0.08	1.11	73.45
FX6	8/7/2006	1.15	14.65	0.18	4.22	0.03	0.39	20.59
FX7								
FX7	7/12/2005	142.32	27.34	0.23	0	0	0	169.89
FX7	11/01/2005	6.15	197.00	1.58	0.08	0.09	0.08	204.89
FX7	12/12/06	30.44	55.70	0.45	0	0	0	86.60
FX7	1/18/2006	0	216.63	1.55	0	0	0	218.18
FX7	2/23/2006	19.03	94.90	0.98	0	0.01	0	114.91
FX7	3/21/2006	0.43	113.47	0.77	4.48	0.04	0.11	119.26
FX7	4/17/2006	0.76	25.79	0.26	2.56	0	0.09	29.45
FX7	5/17/2006	0.84	4.95	0.05	0.06	0	0	5.90
FX7	6/26/2006	1.22	63.96	0.66	22.40	0.03	1.18	89.41
FX8								
FX8	7/12/2005	6.74	5.65	0.05	0	0	0	12.45
FX8	11/01/2005	3.95	5.29	0.12	0.02	0.01	0.01	9.39
FX8	12/12/06	4.64	18.57	0.39	0	0	0	23.60
FX8	1/18/2006	0	196.00	0	0	0	0.01	196.01
FX8	2/23/2006	12.18	72.21	0.79	0	0.02	0.03	85.21
FX8	3/21/2006	0	113.47	0.87	4.00	0	0	118.34
FX8	4/17/2006	0	47.45	0.38	4.16	0	0	51.99
FX8	5/17/2006	0.38	60.86	0.46	9.12	0	0.28	71.11
FX8	6/26/2006	0.35	46.42	0.41	24.00	0.10	1.85	73.04

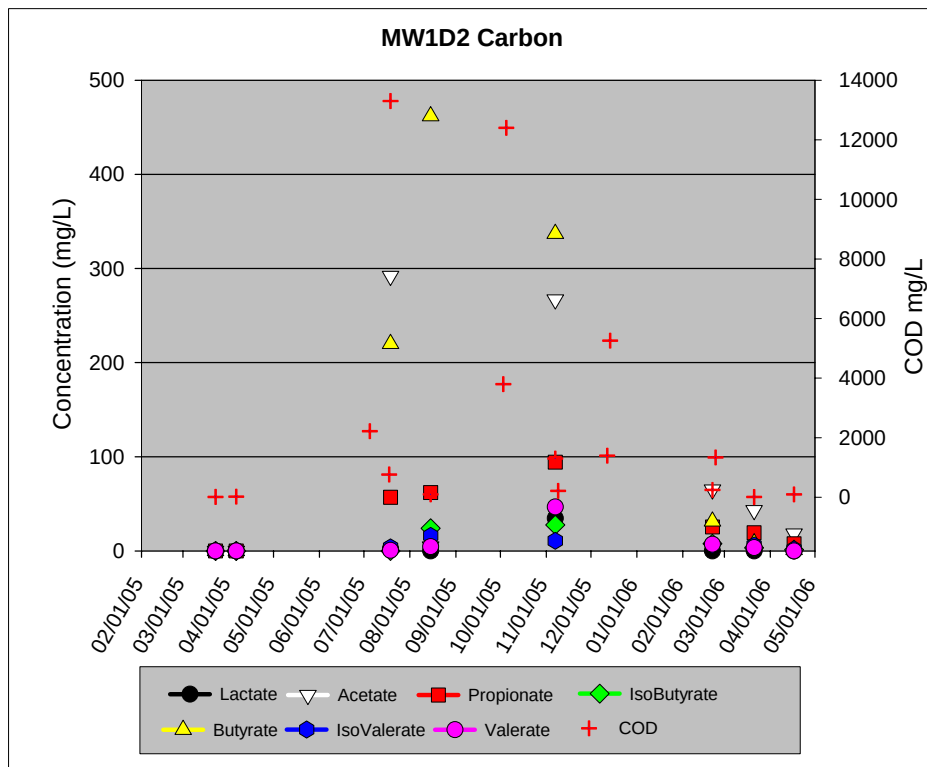
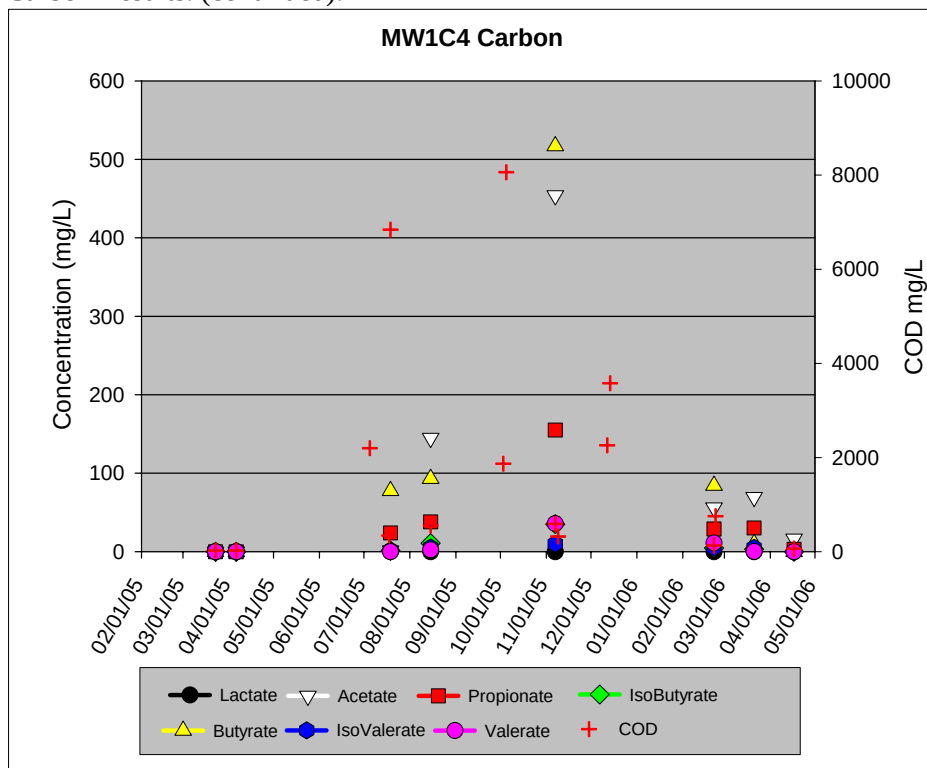
Carbon Results.



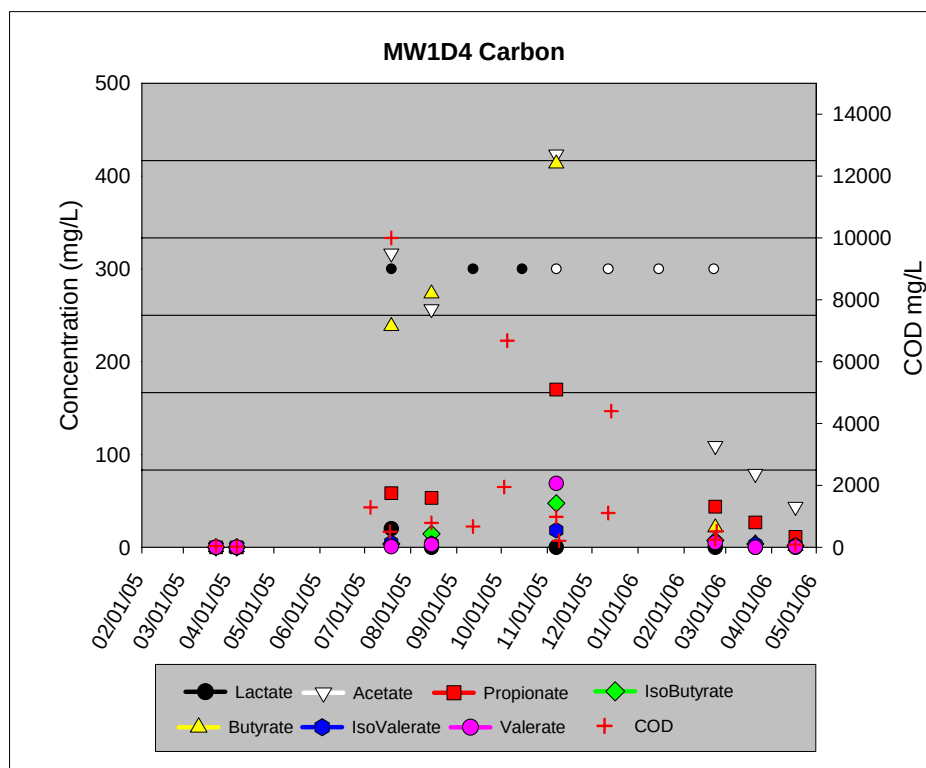
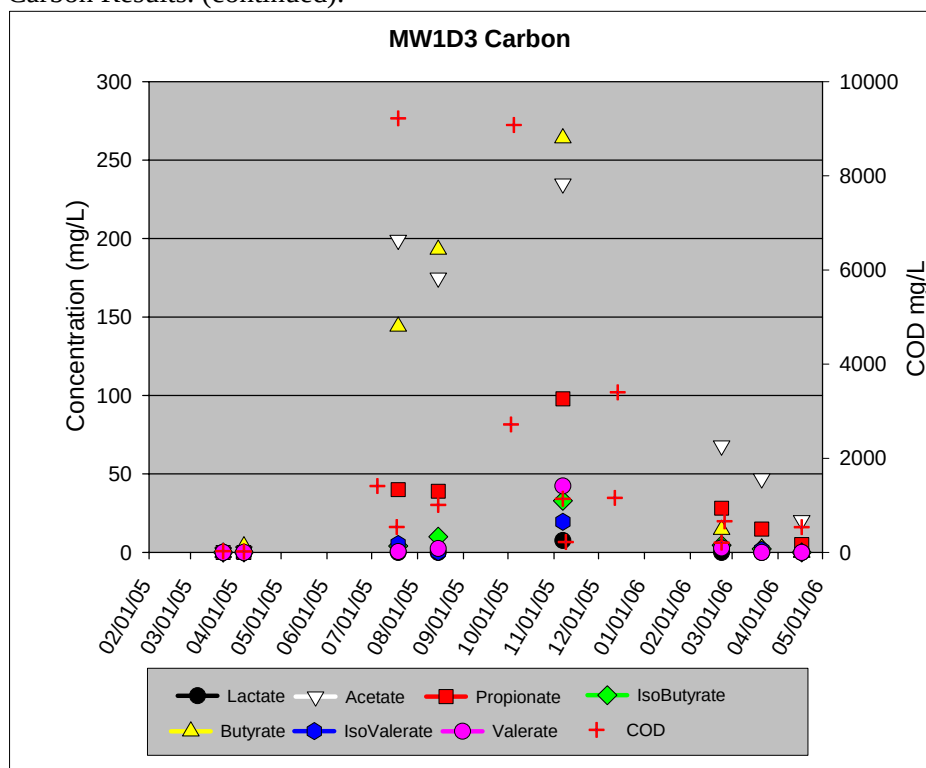
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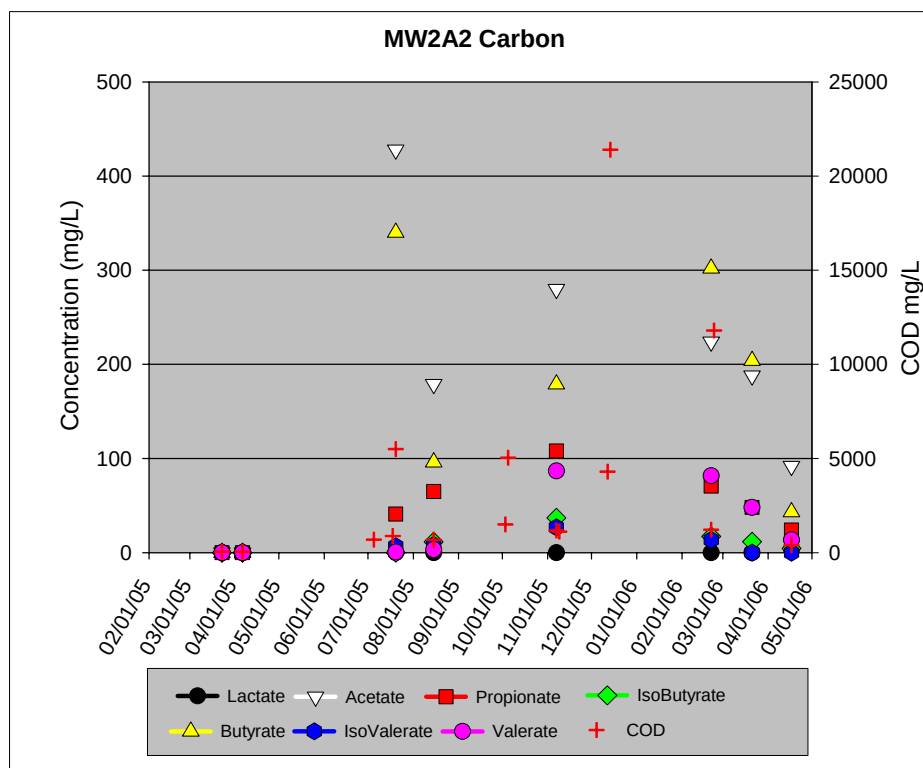
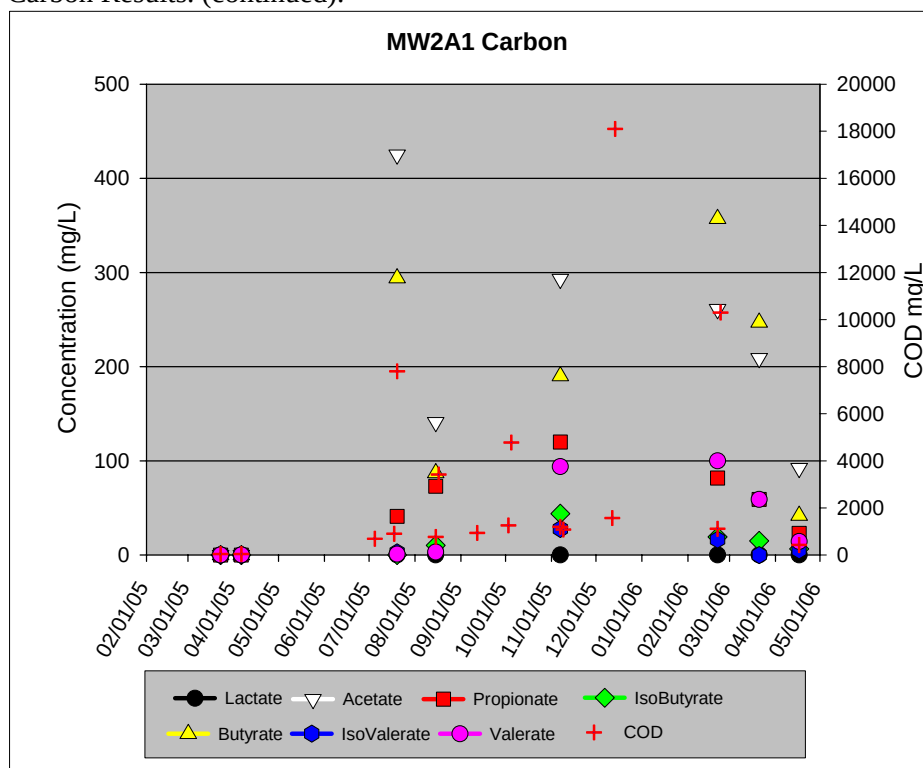
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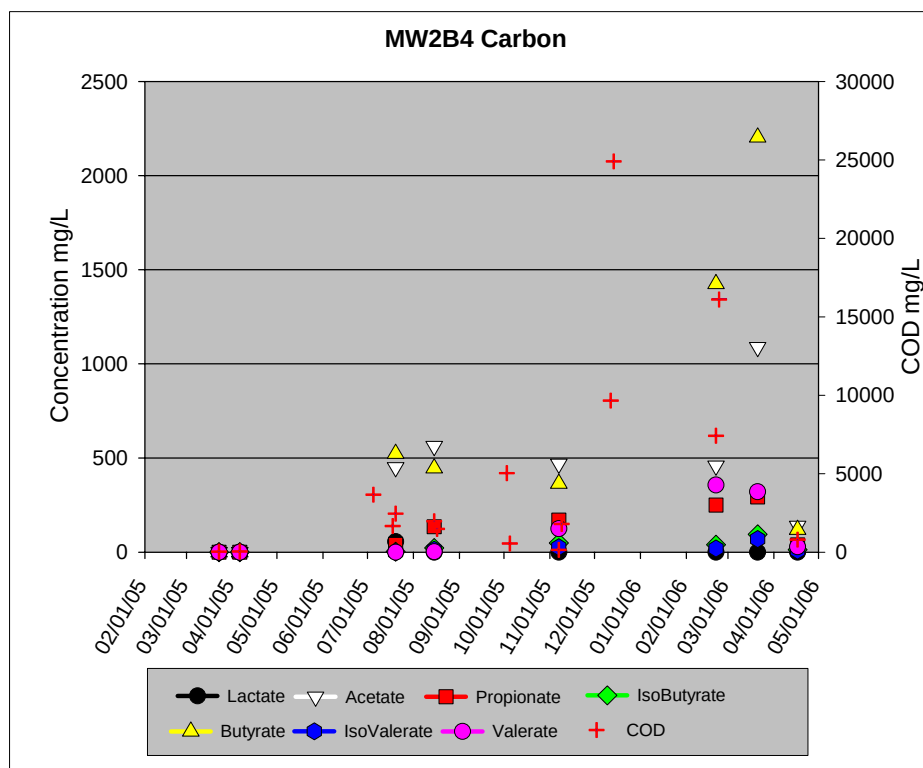
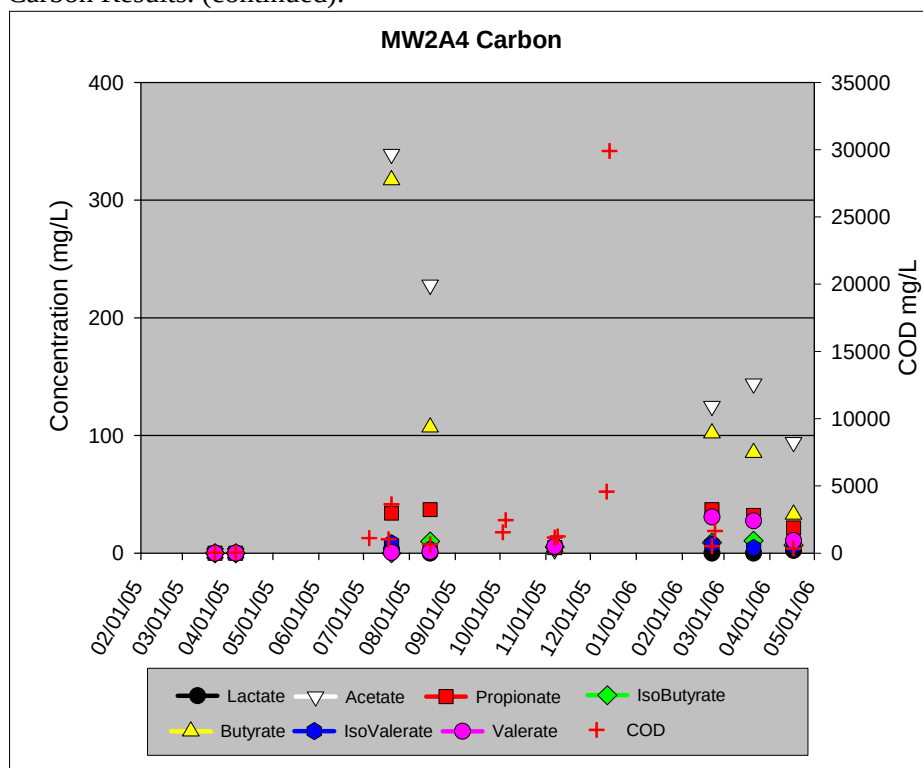
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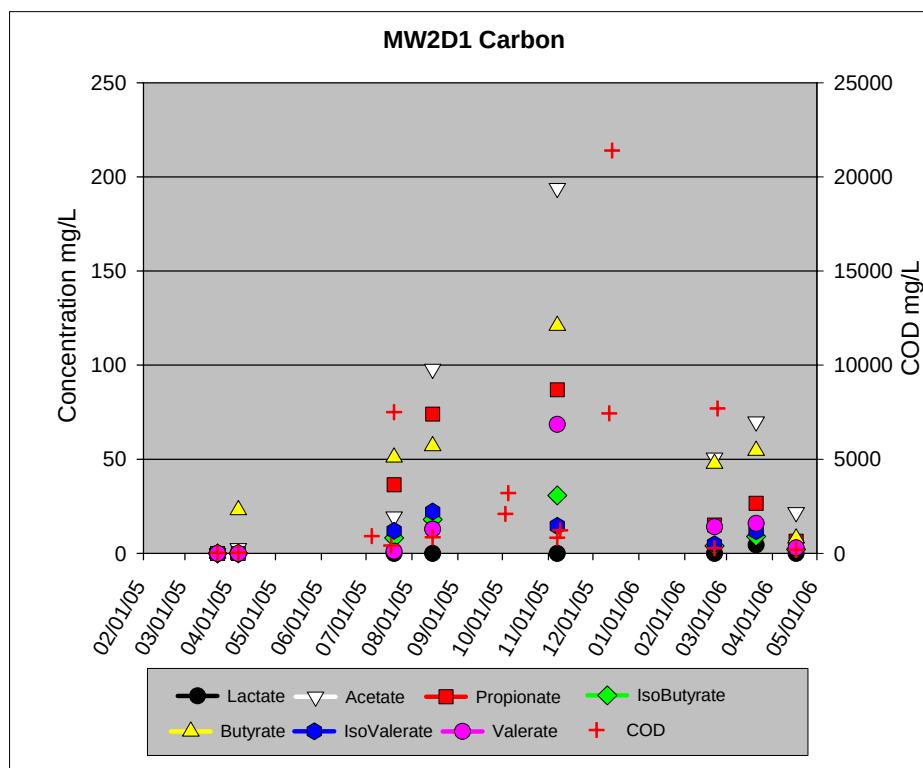
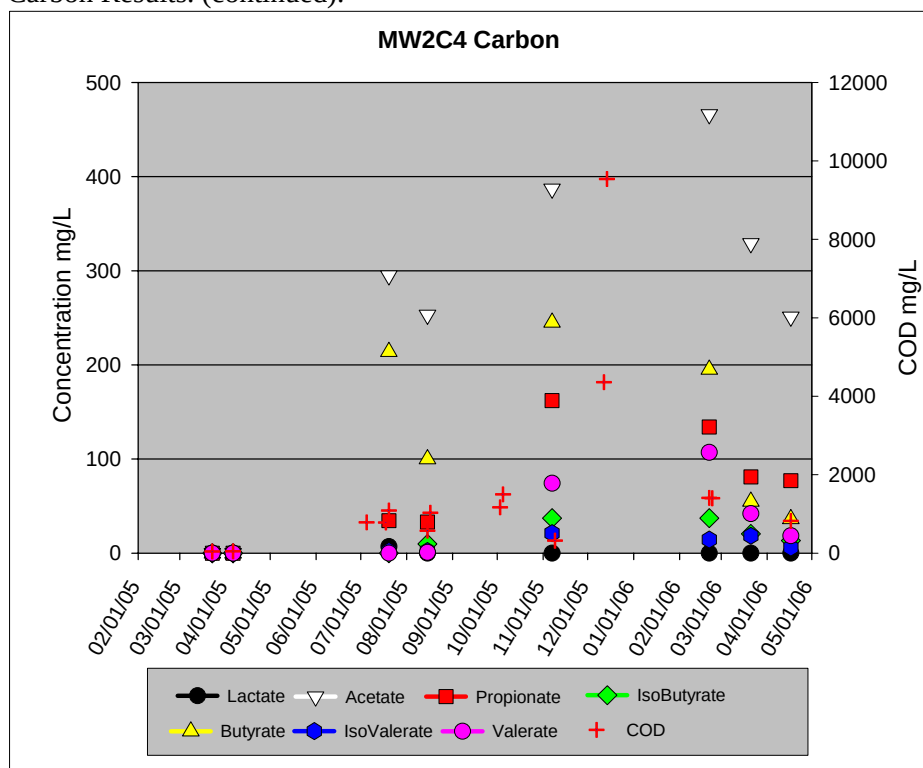
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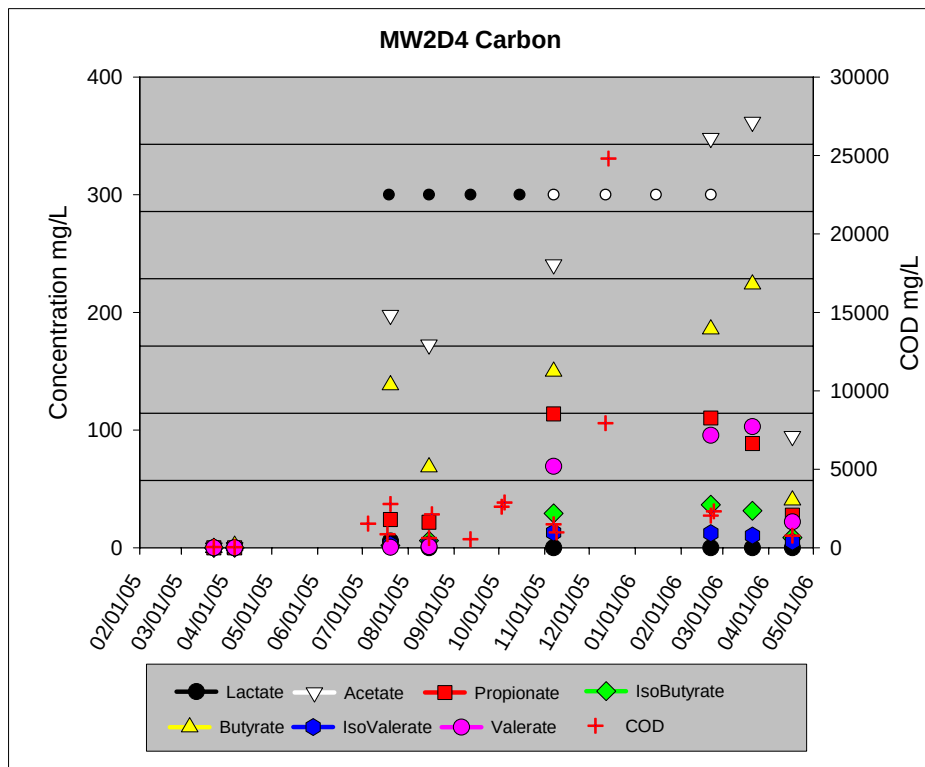
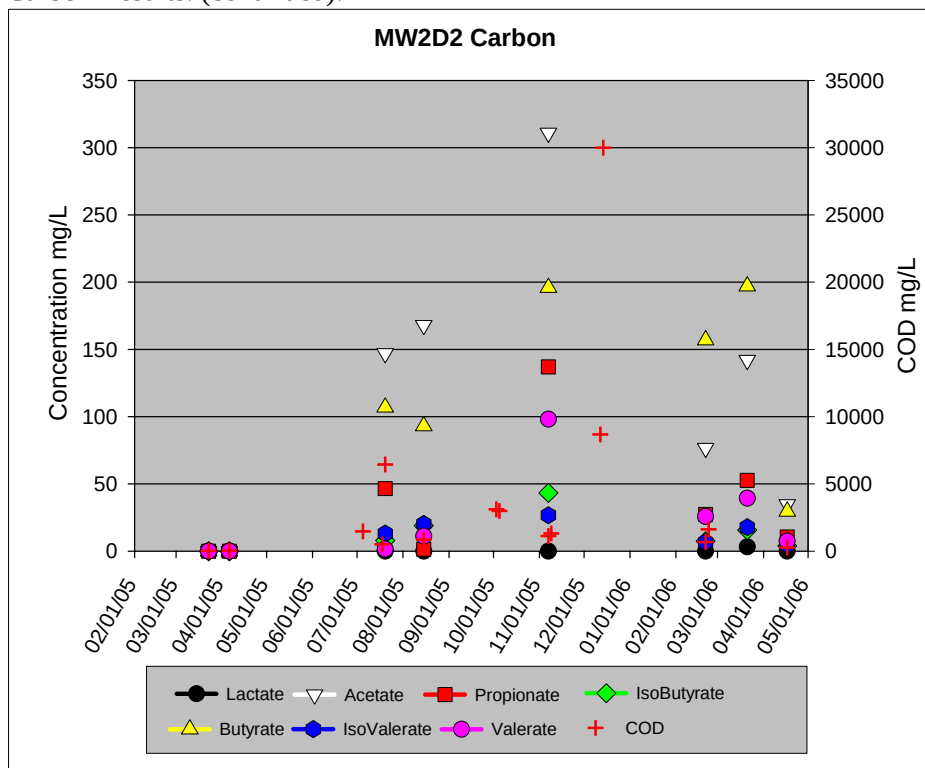
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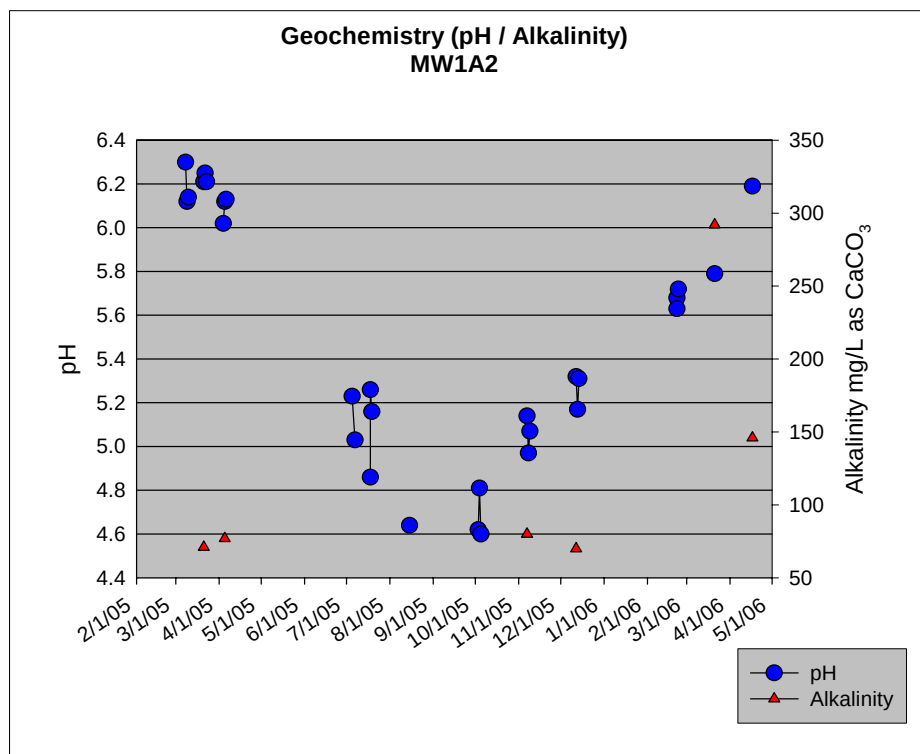
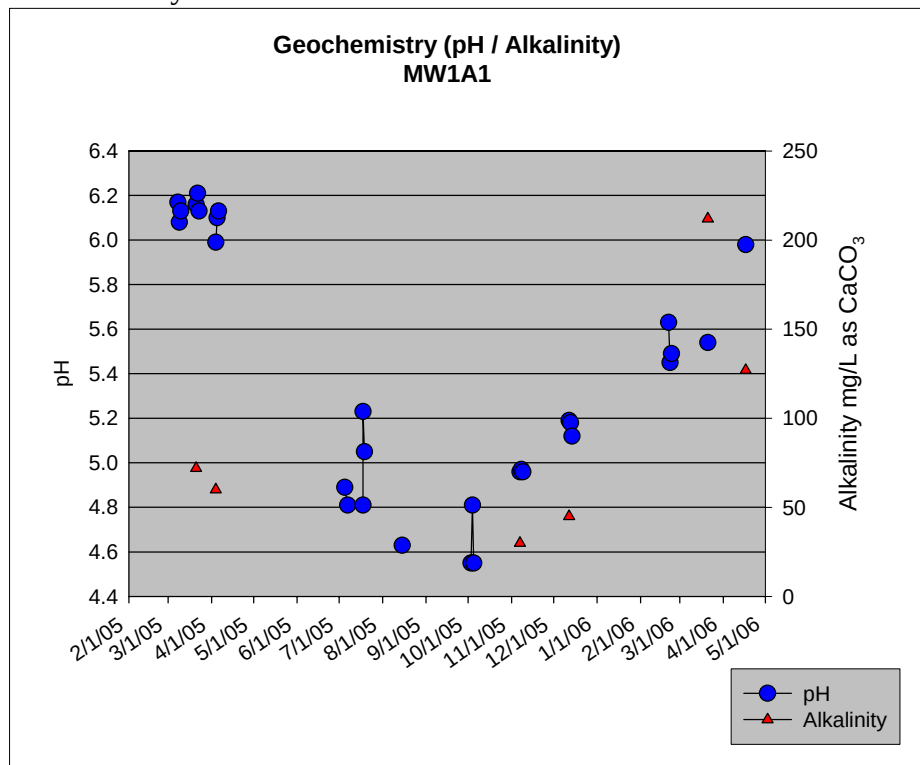
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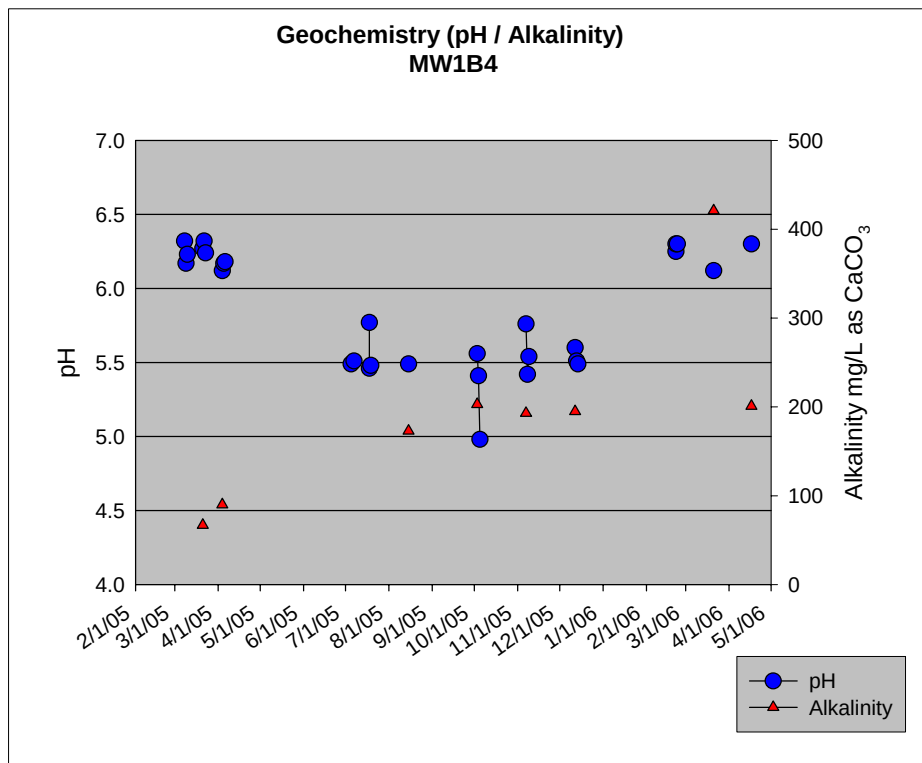
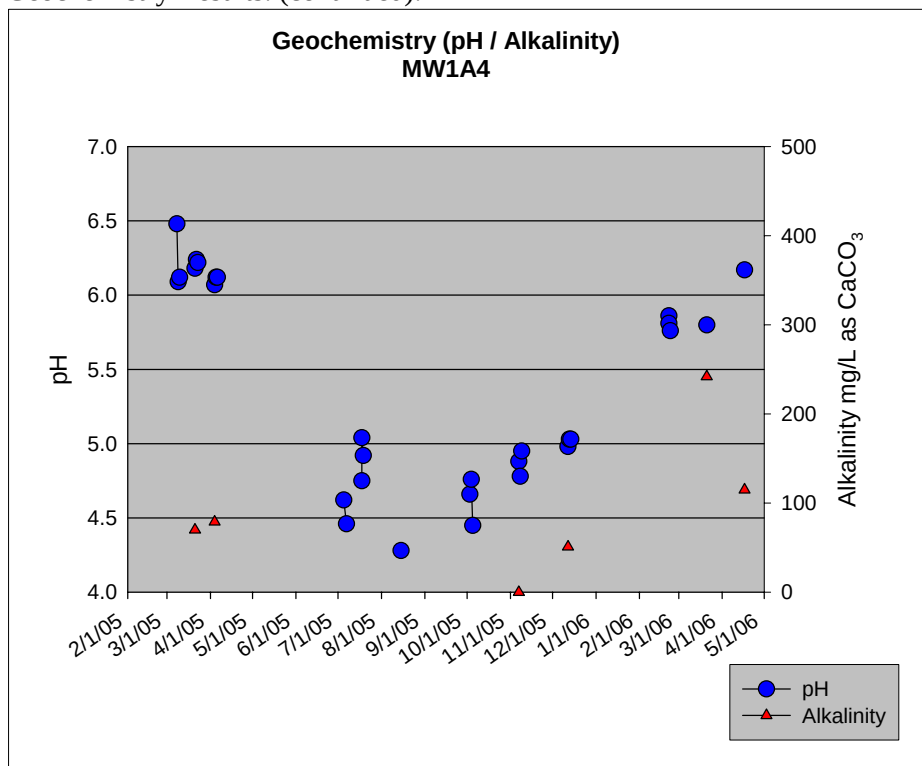
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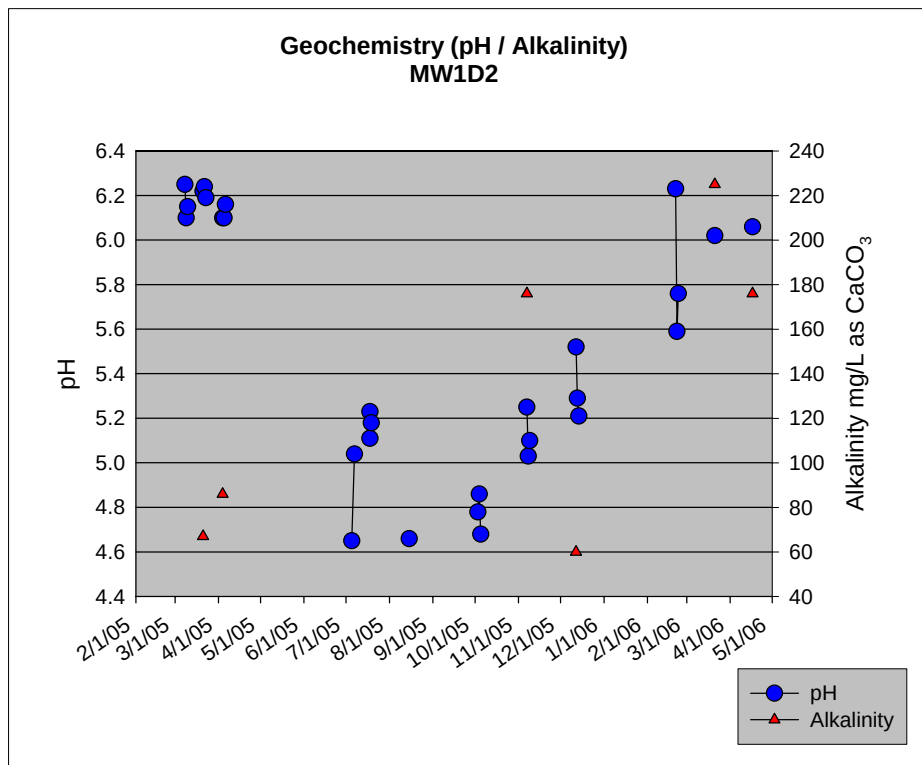
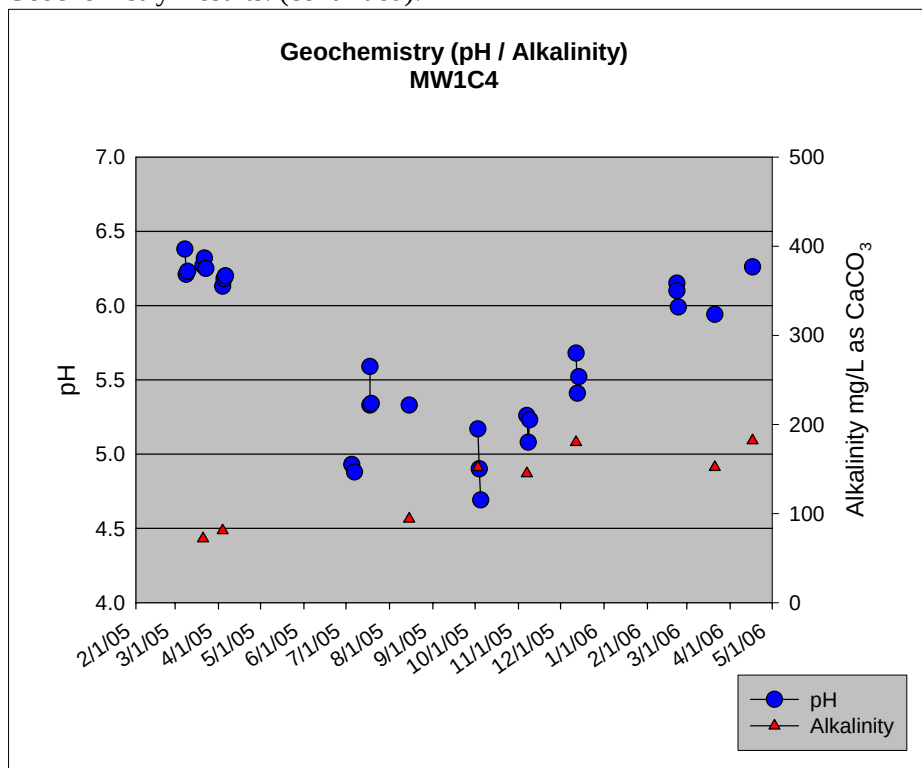
Geochemistry Results.



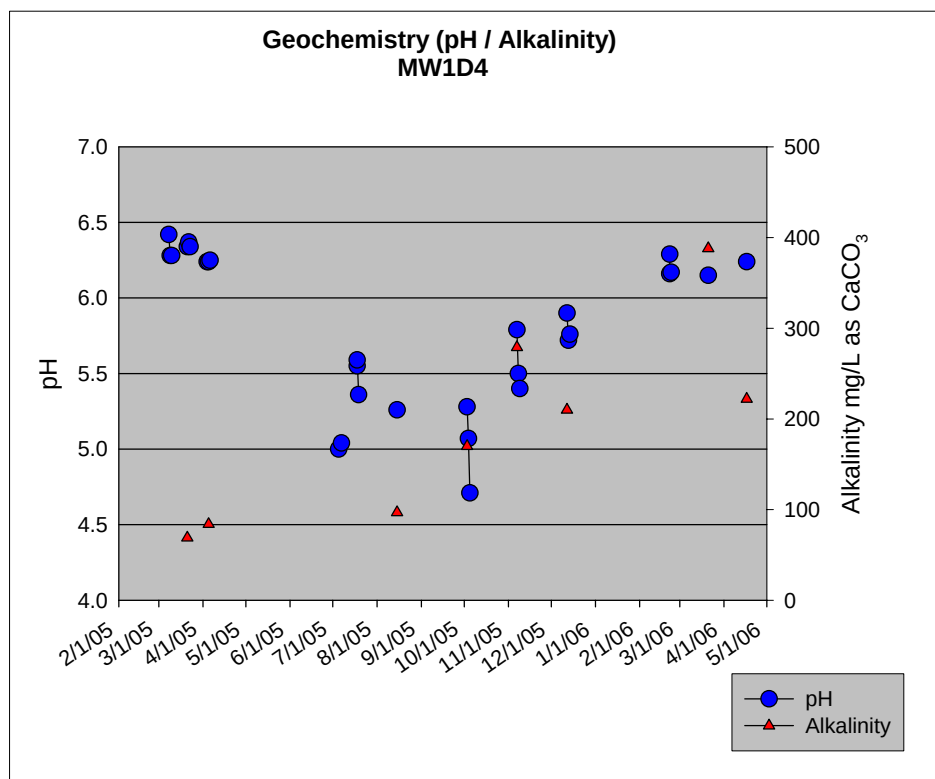
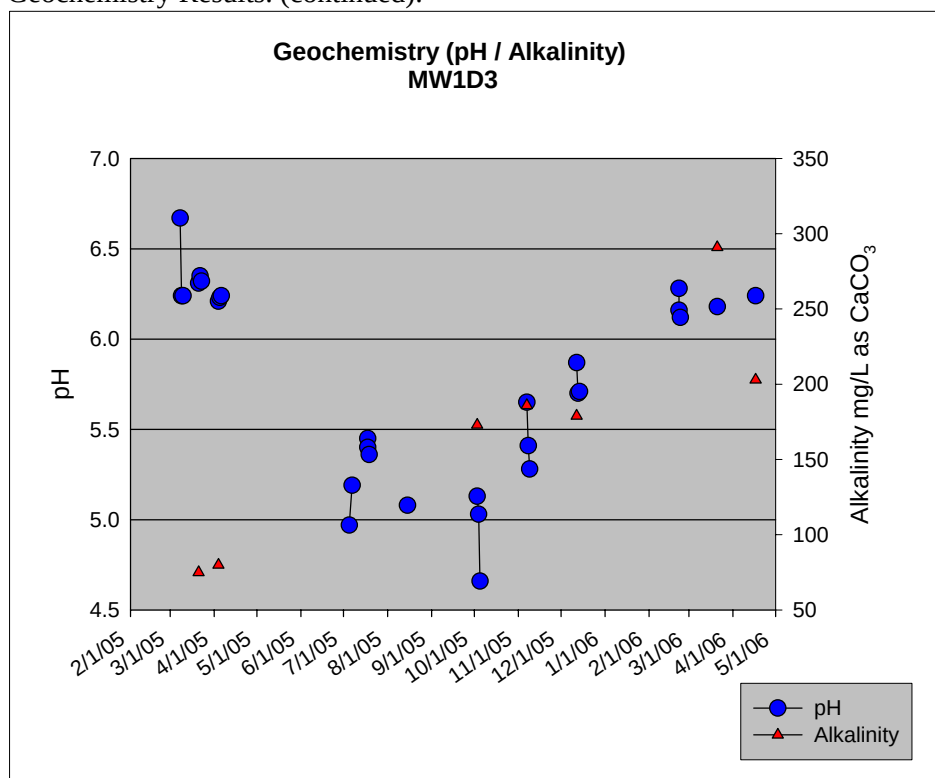
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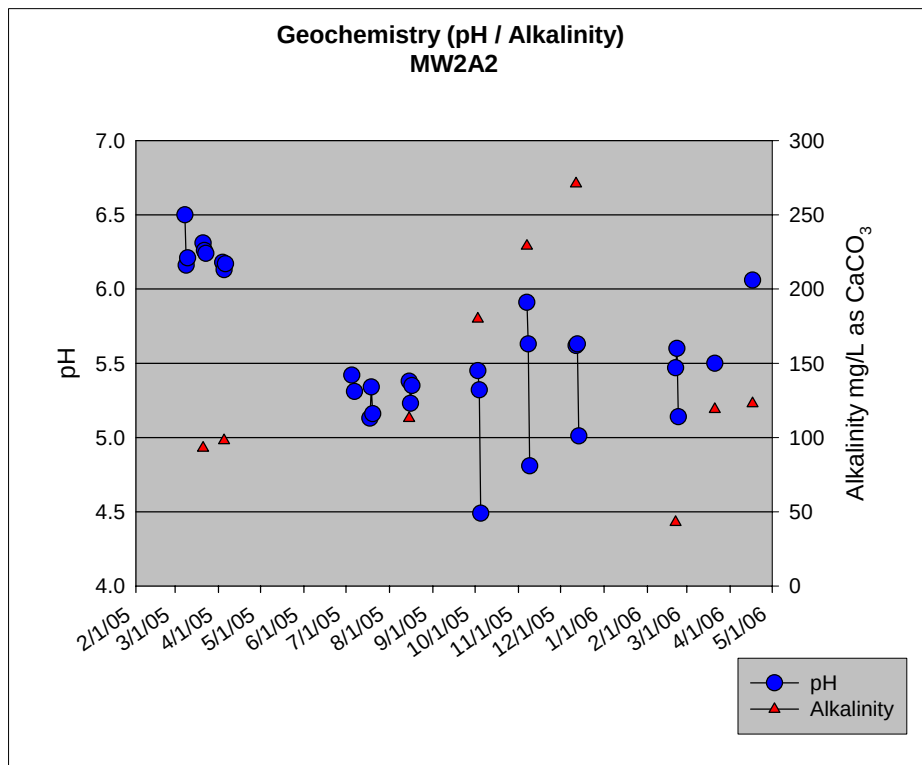
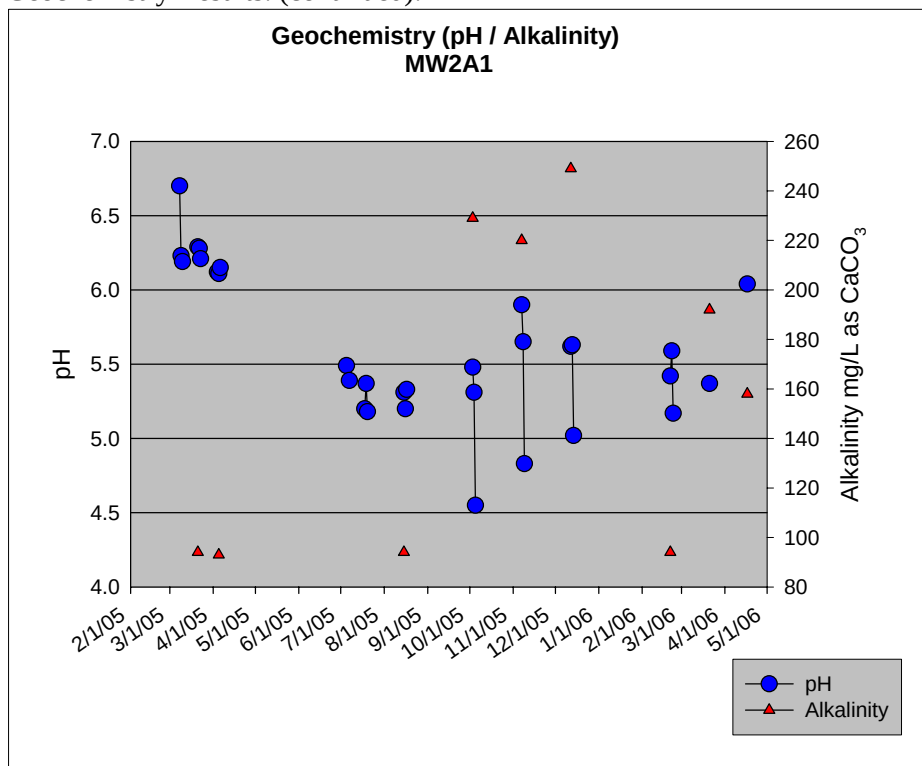
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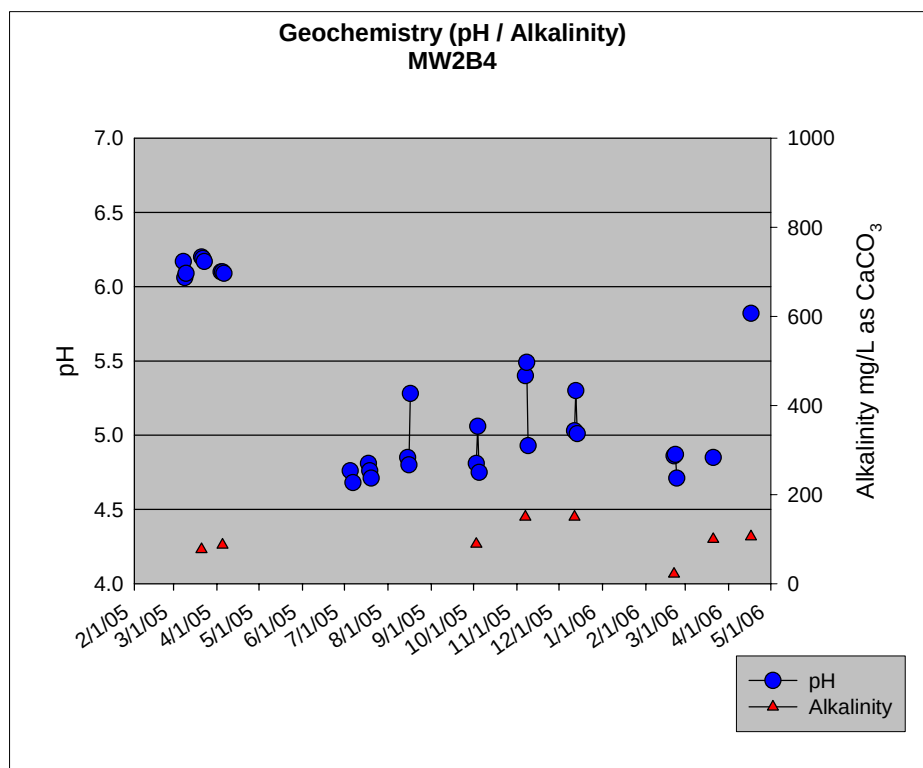
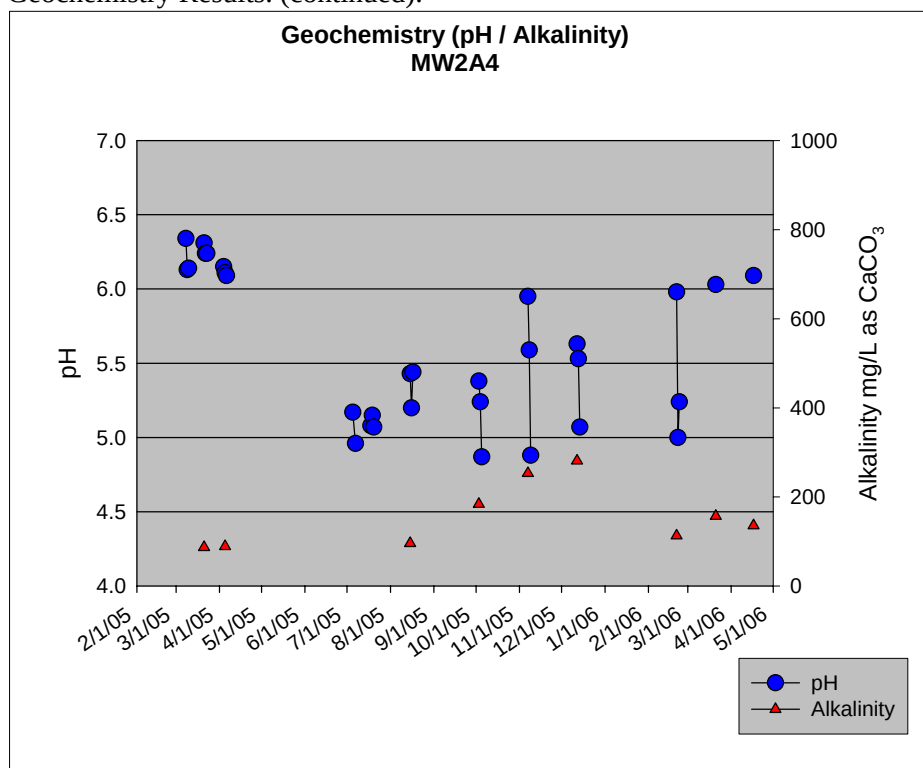
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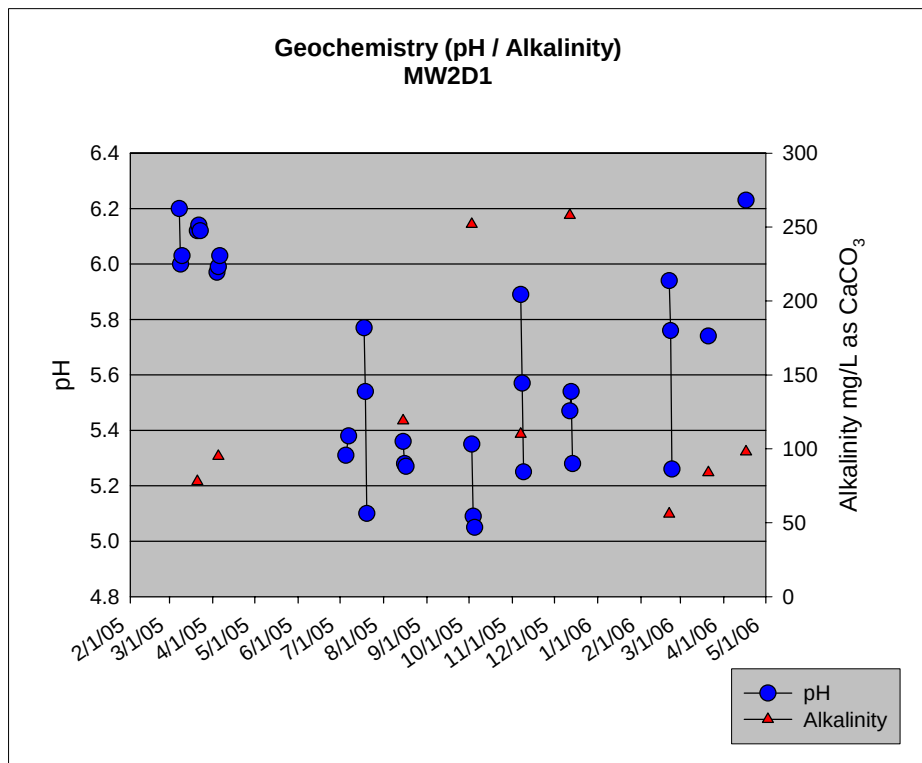
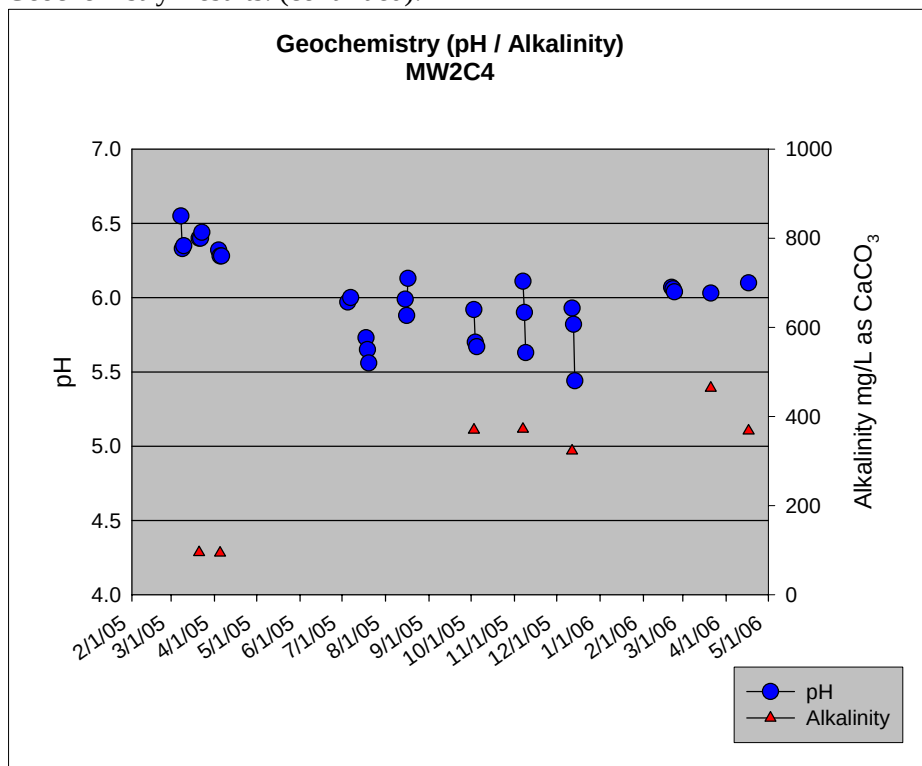
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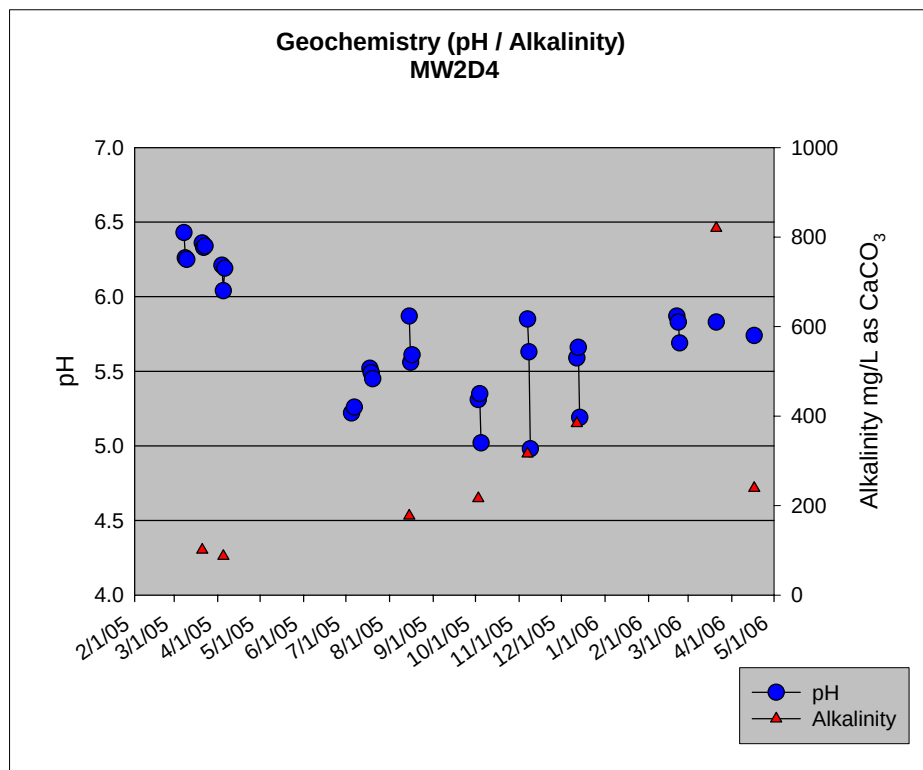
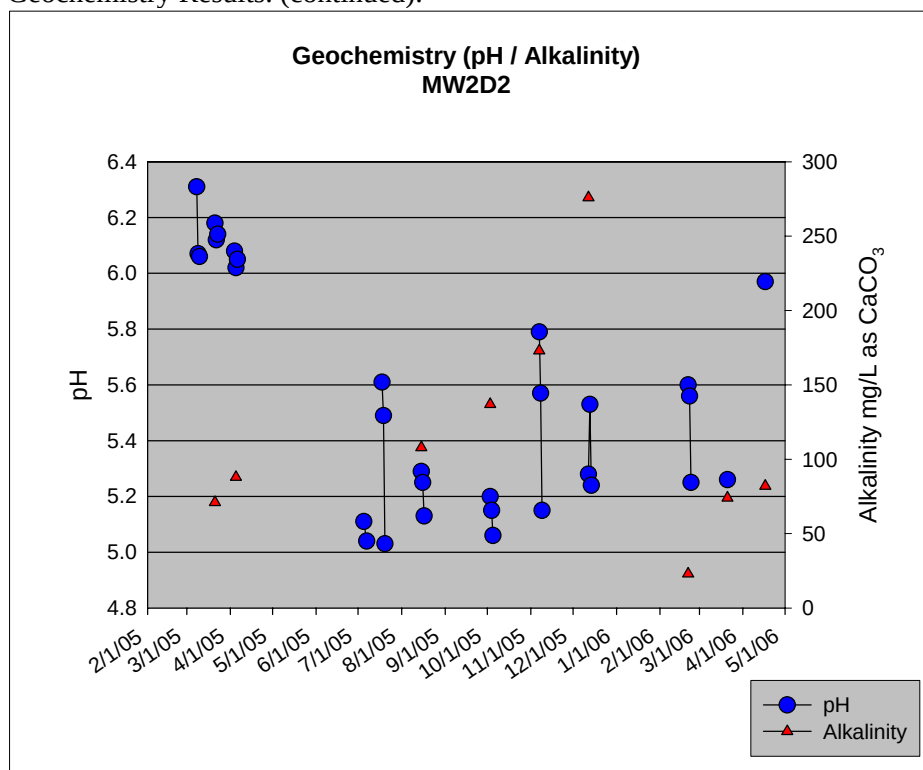
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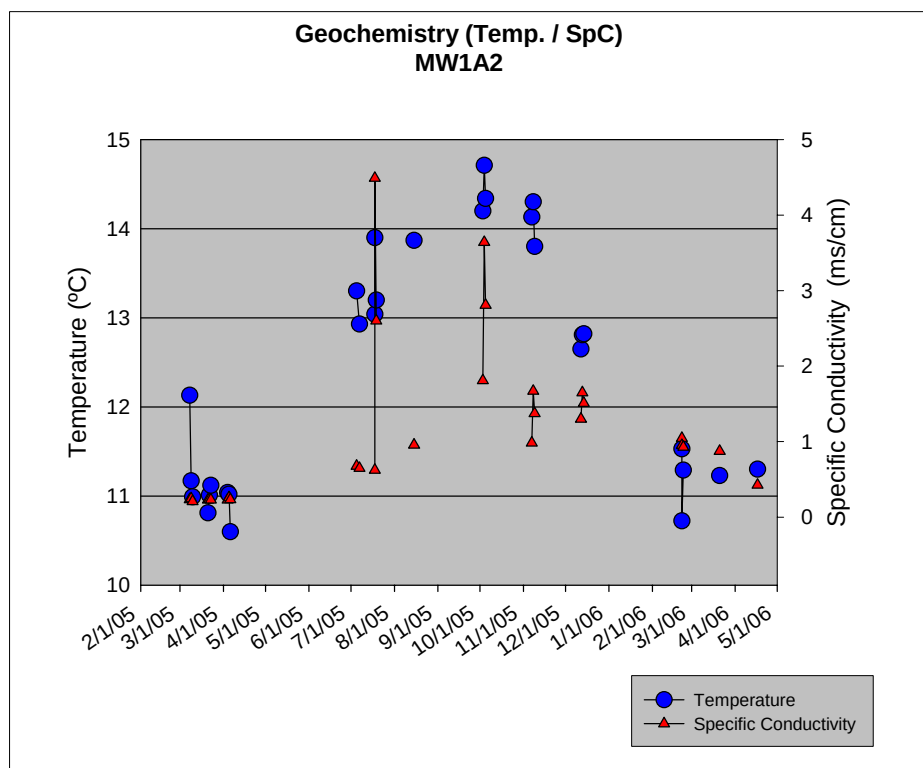
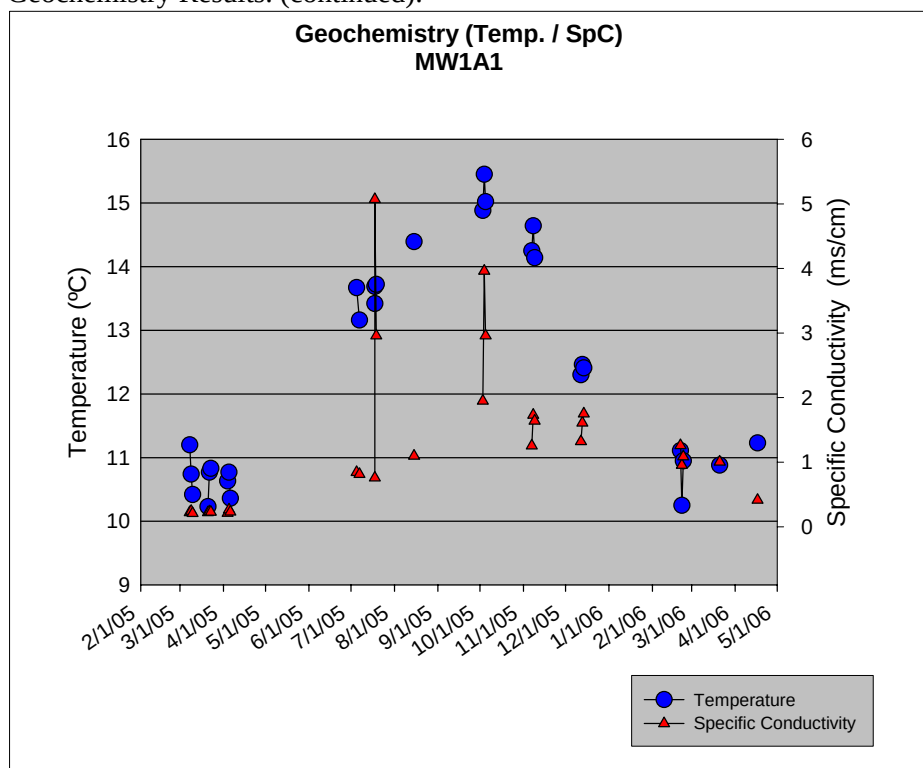
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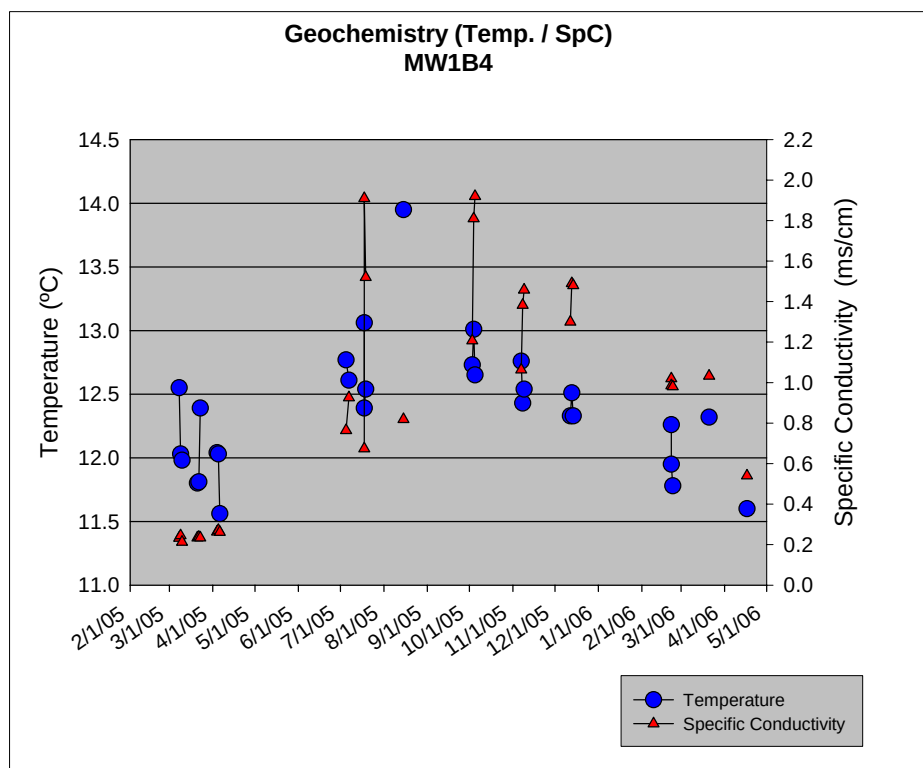
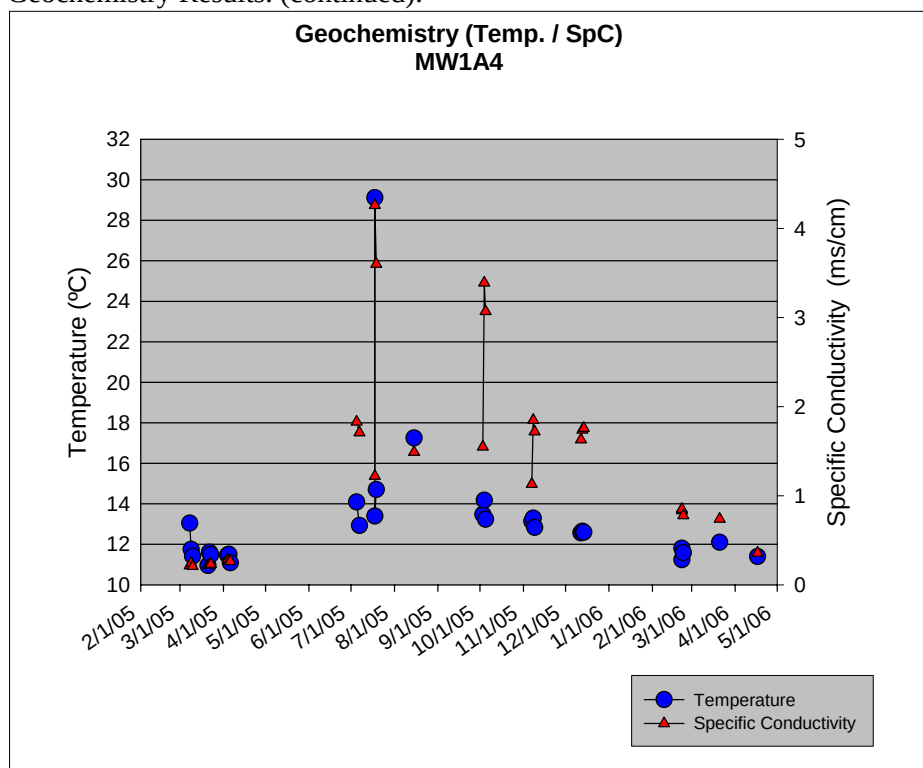
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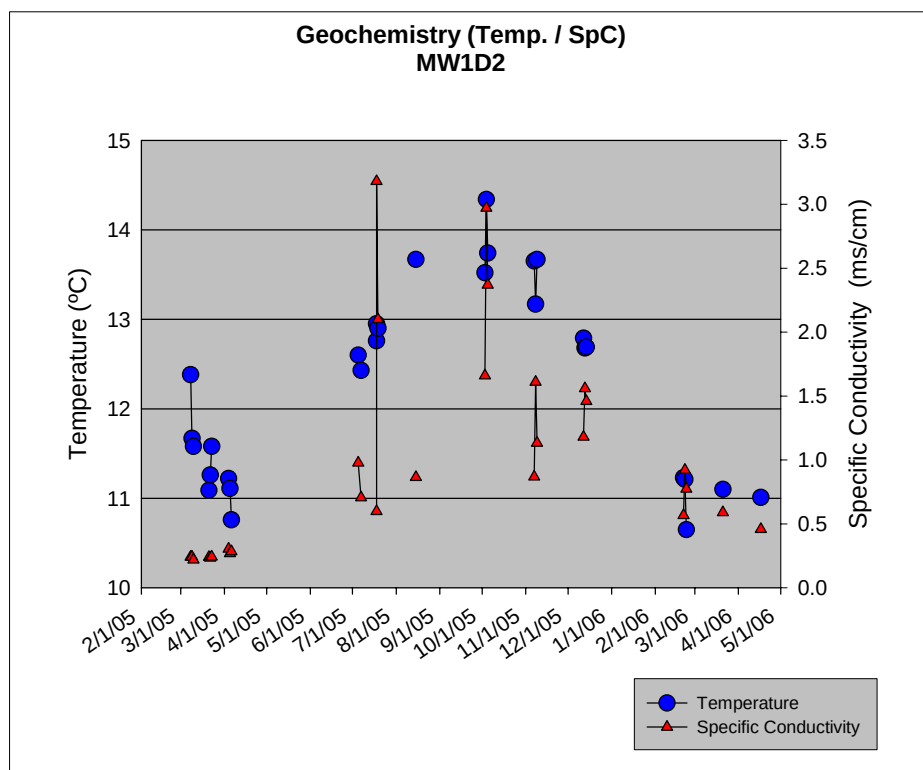
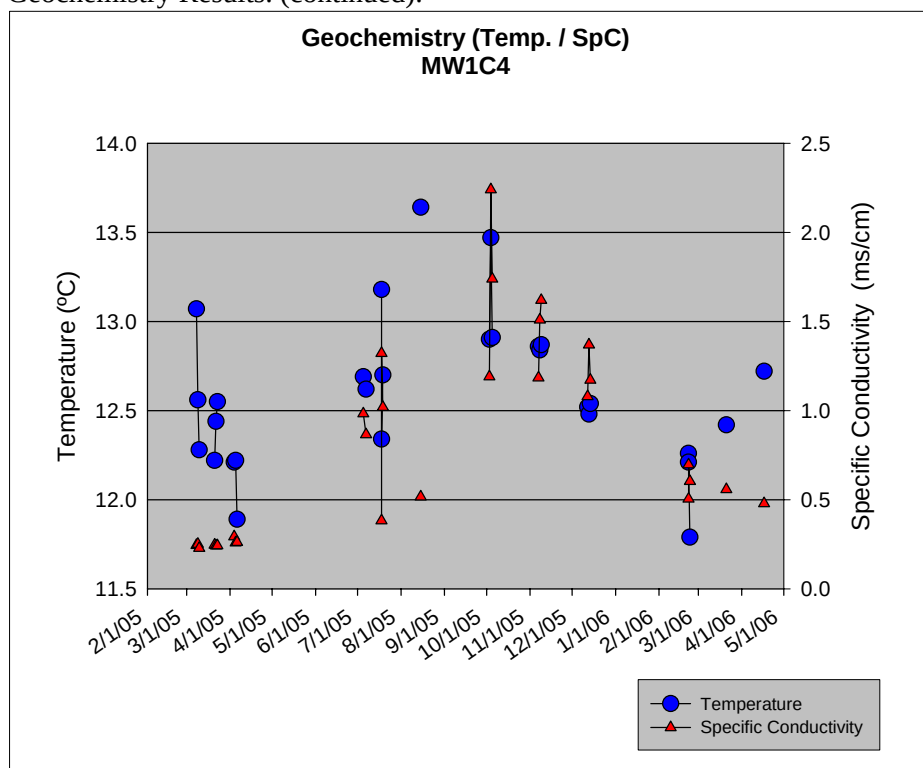
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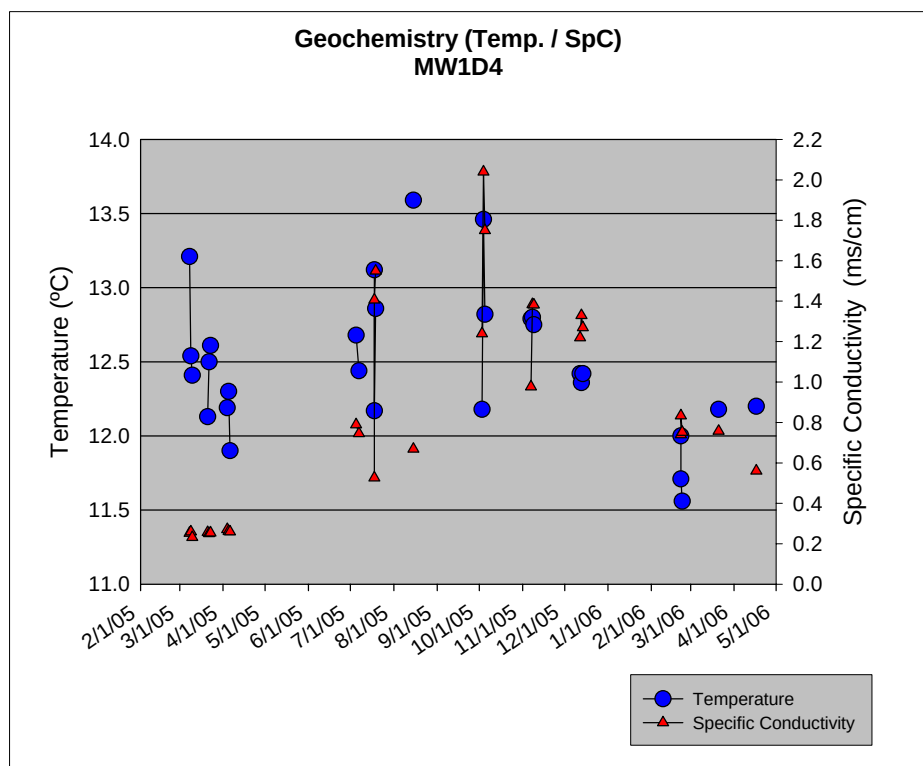
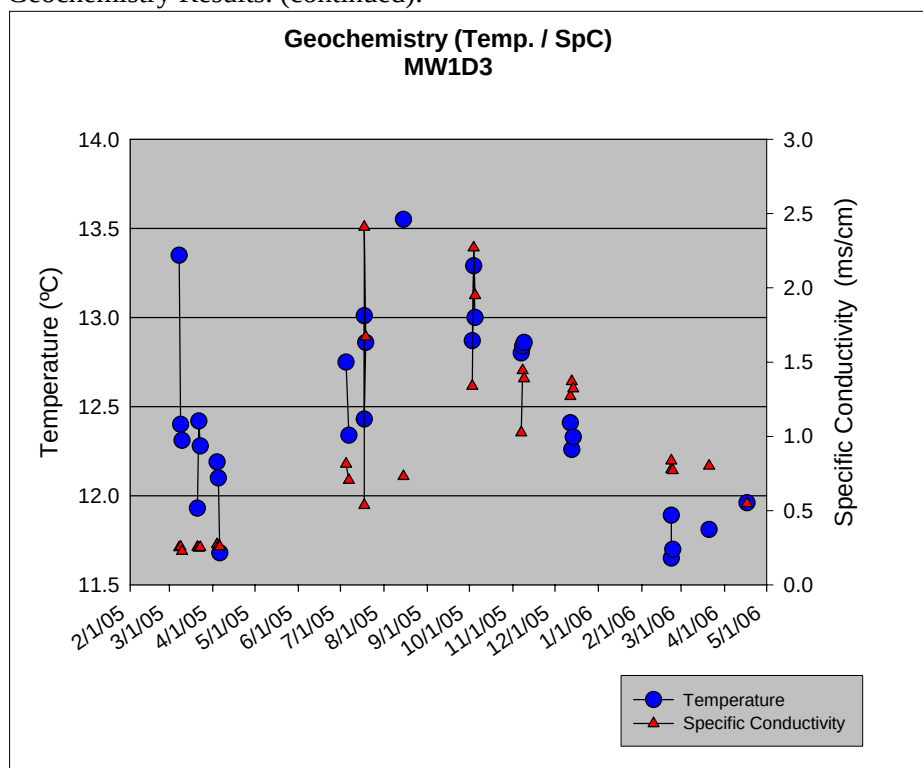
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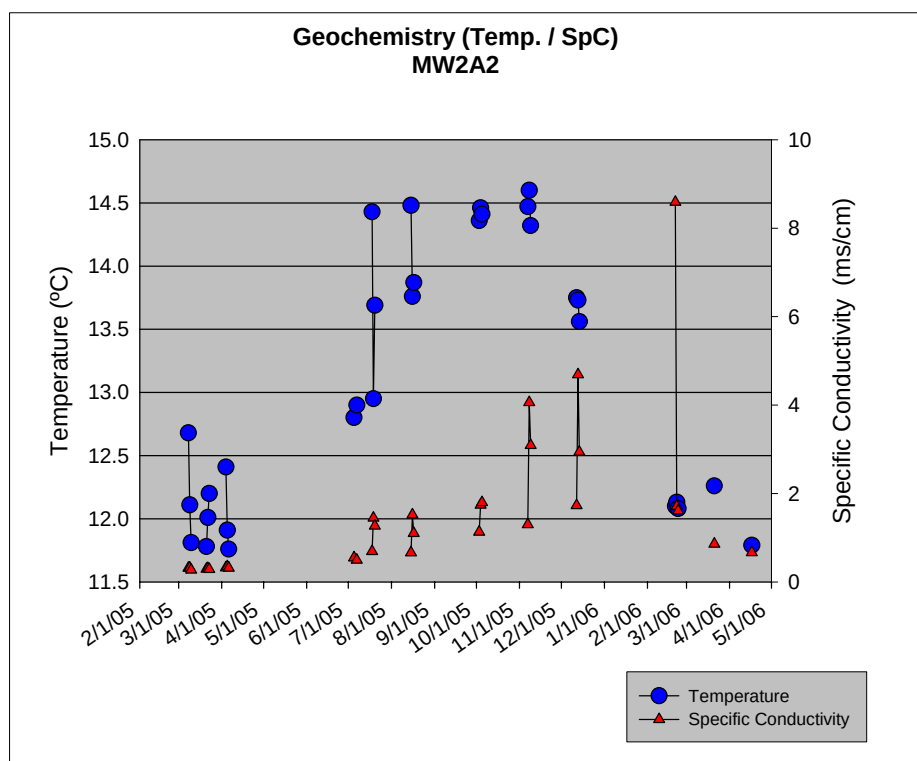
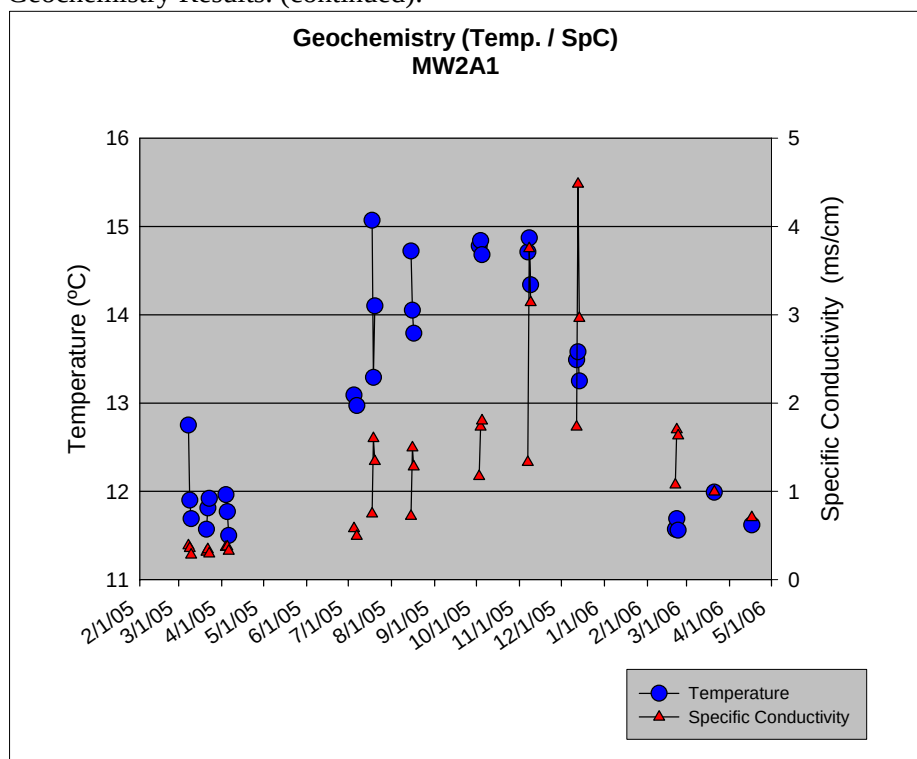
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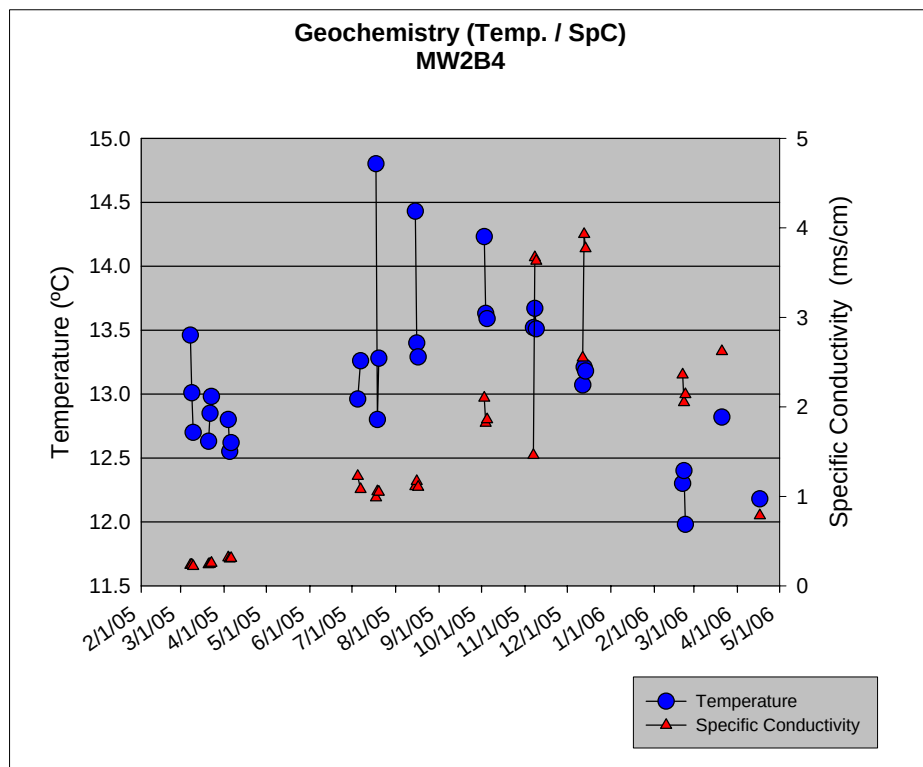
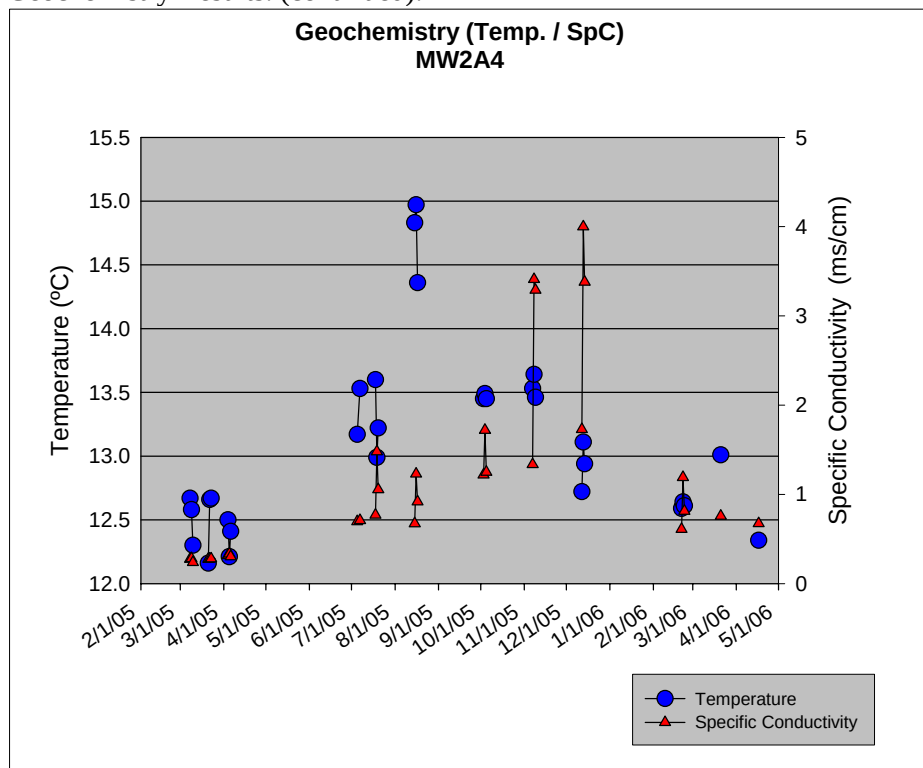
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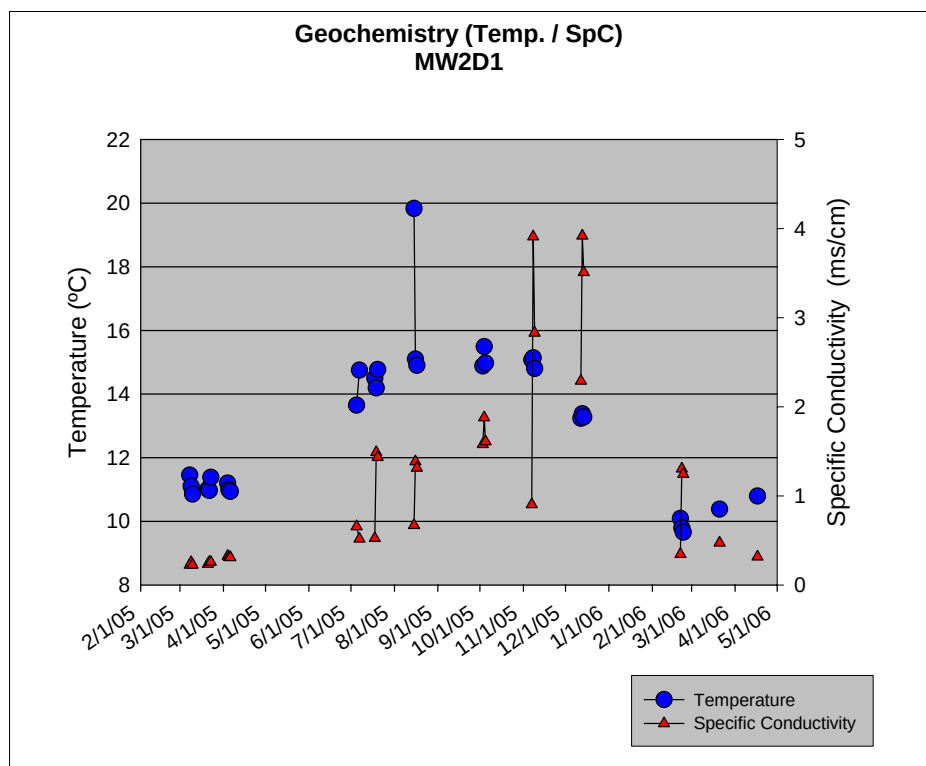
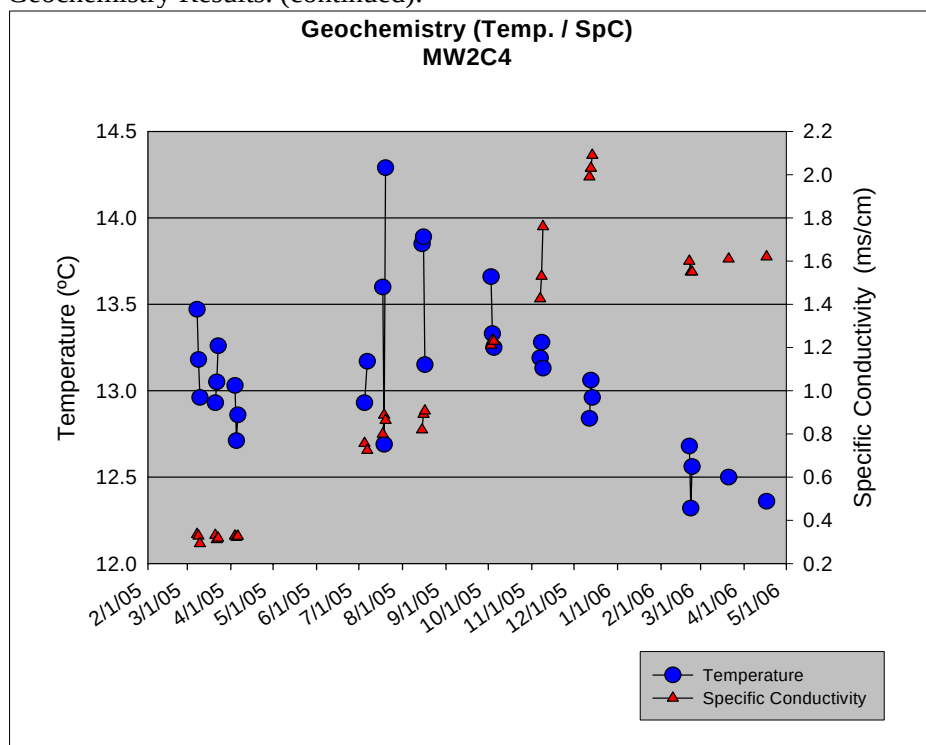
Geochemistry Results. (continued).



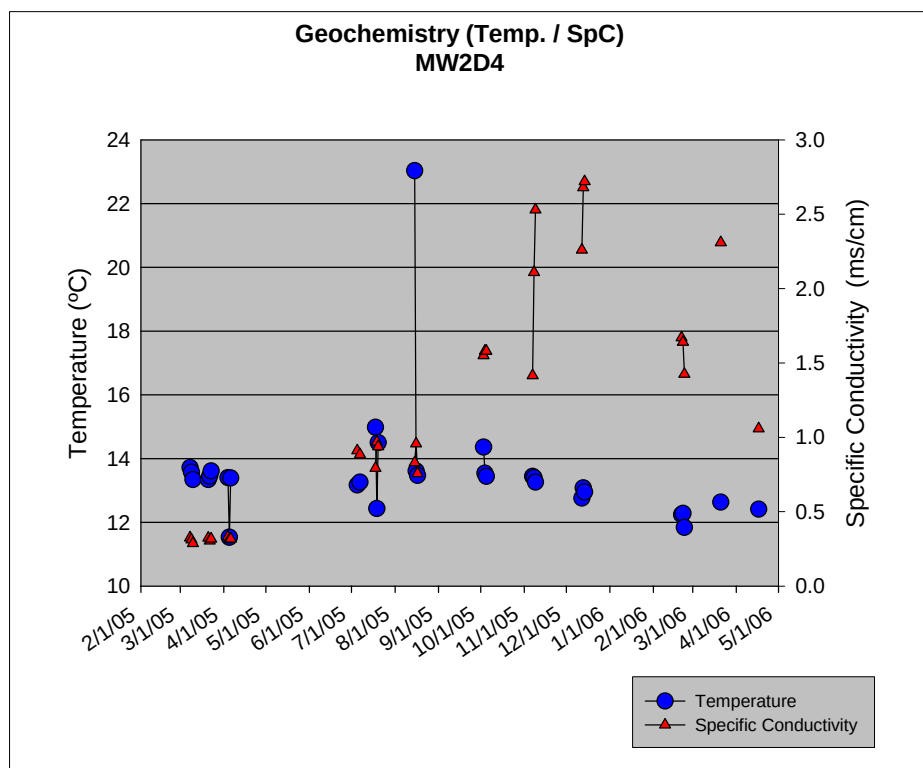
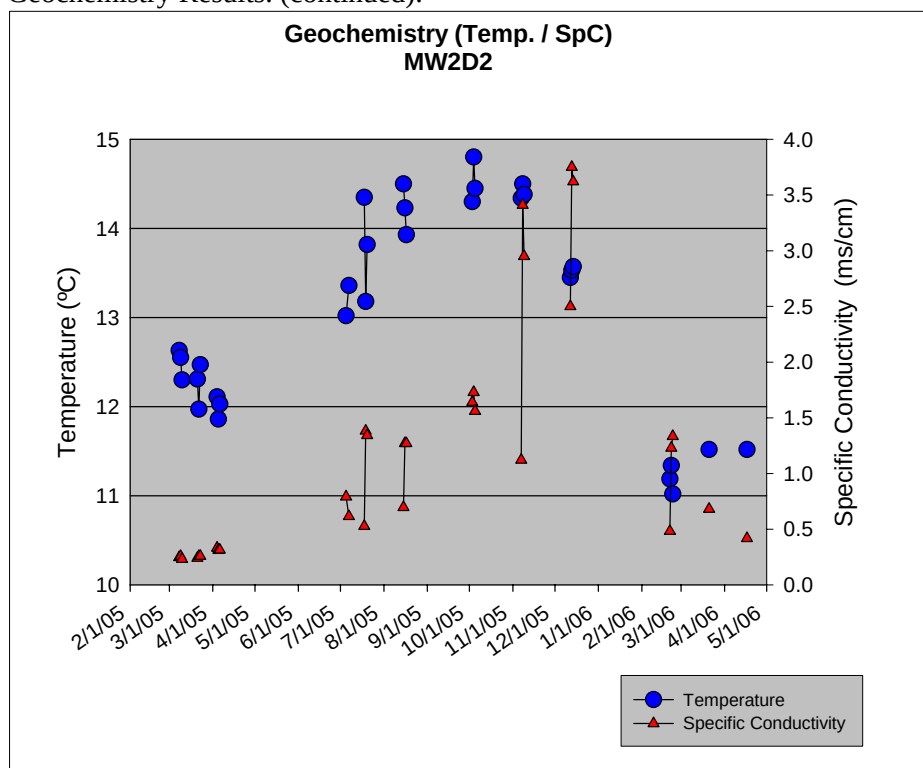
Geochemistry Results. (continued).



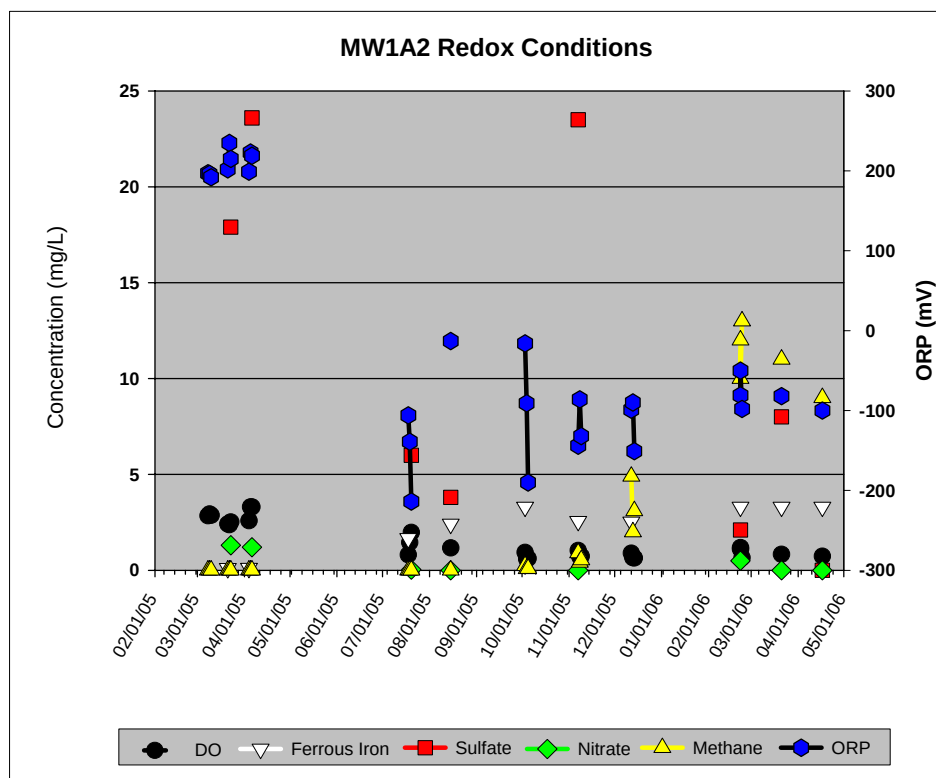
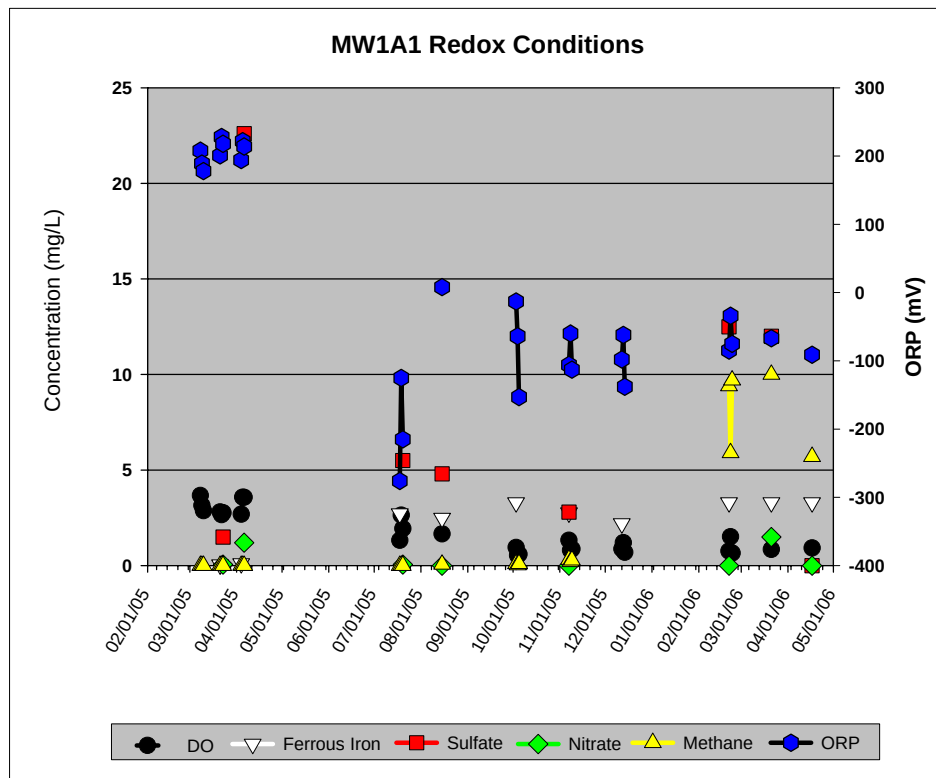
Geochemistry Results. (continued).



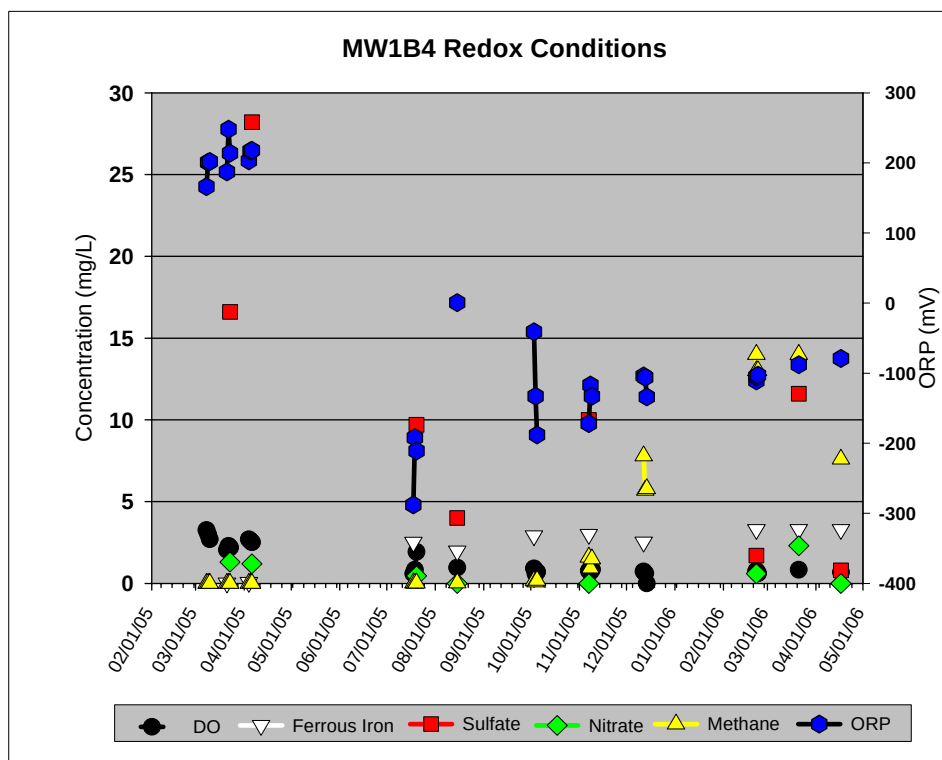
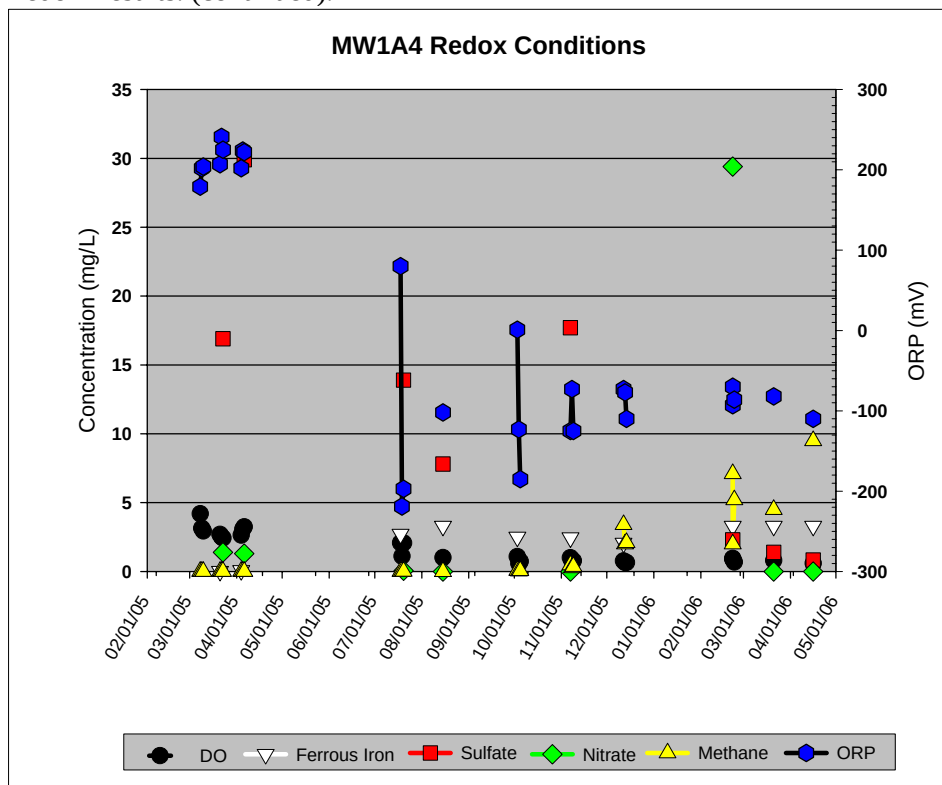
Geochemistry Results. (continued).



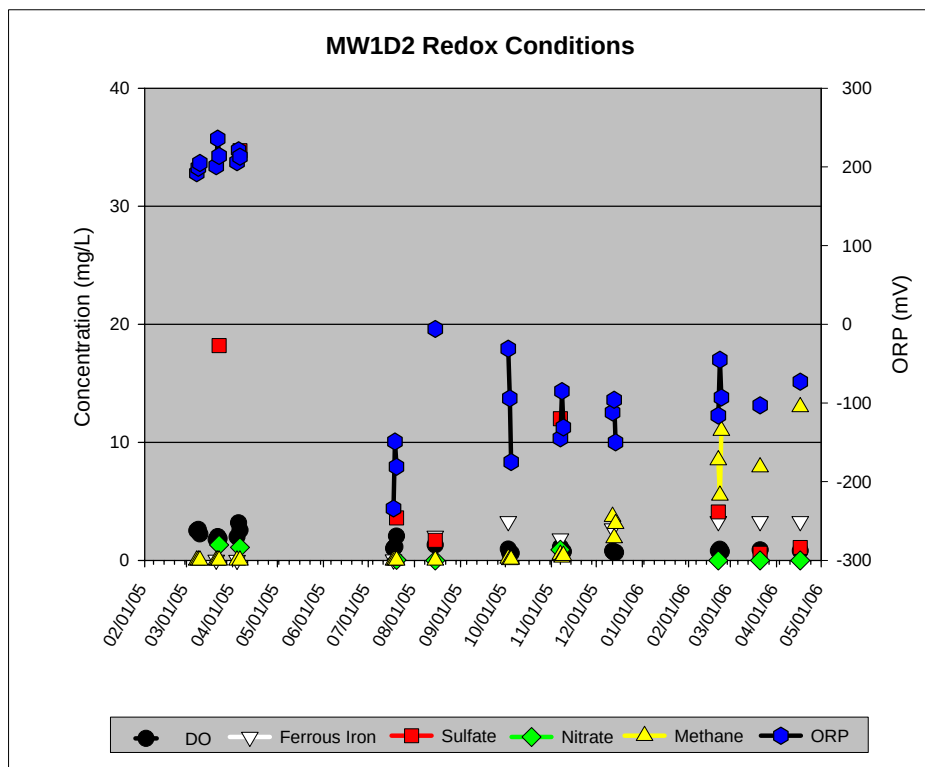
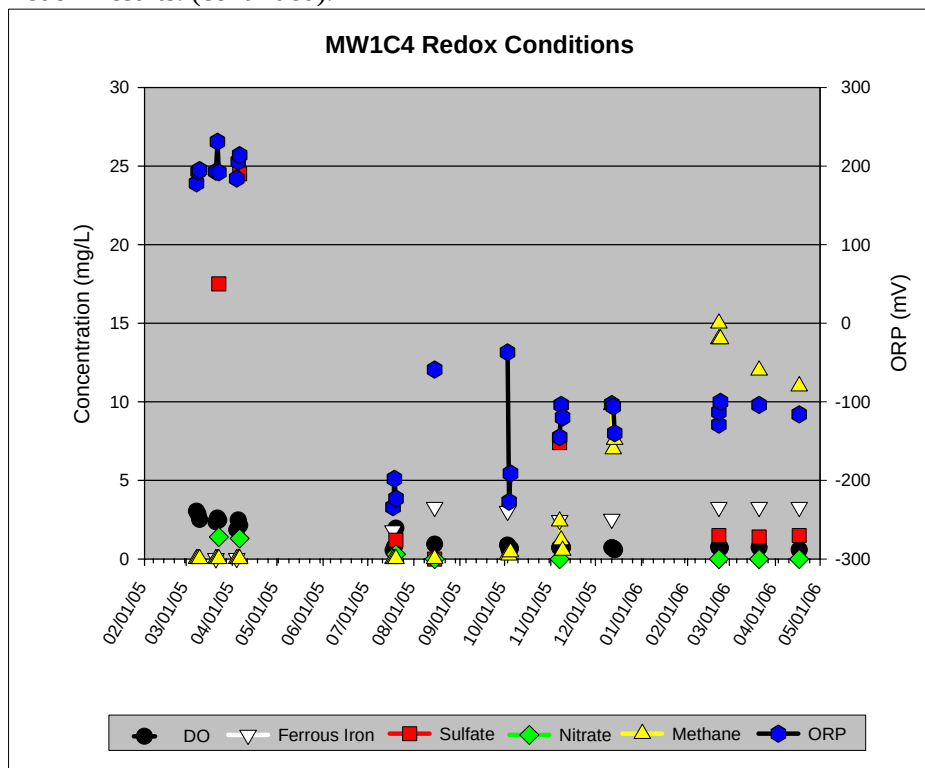
Redox Results.



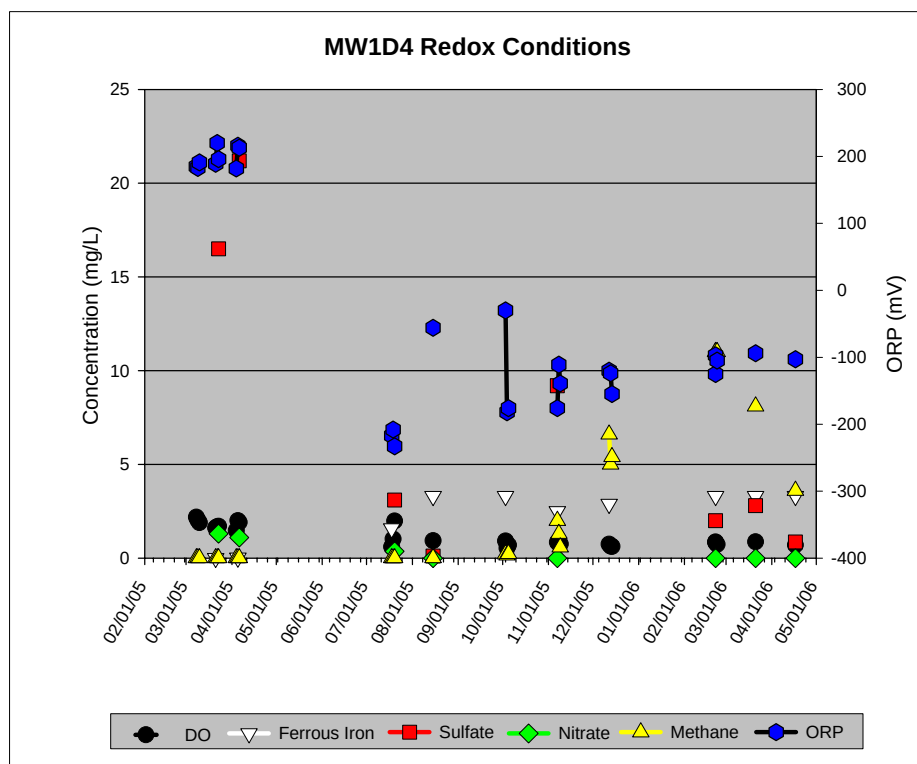
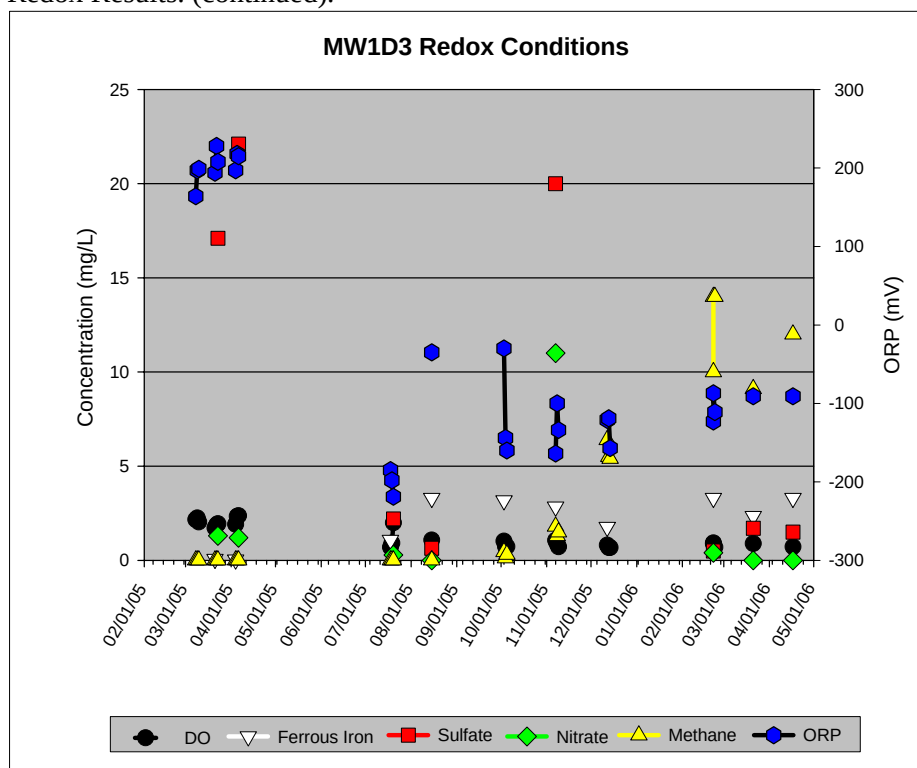
Redox Results. (continued).



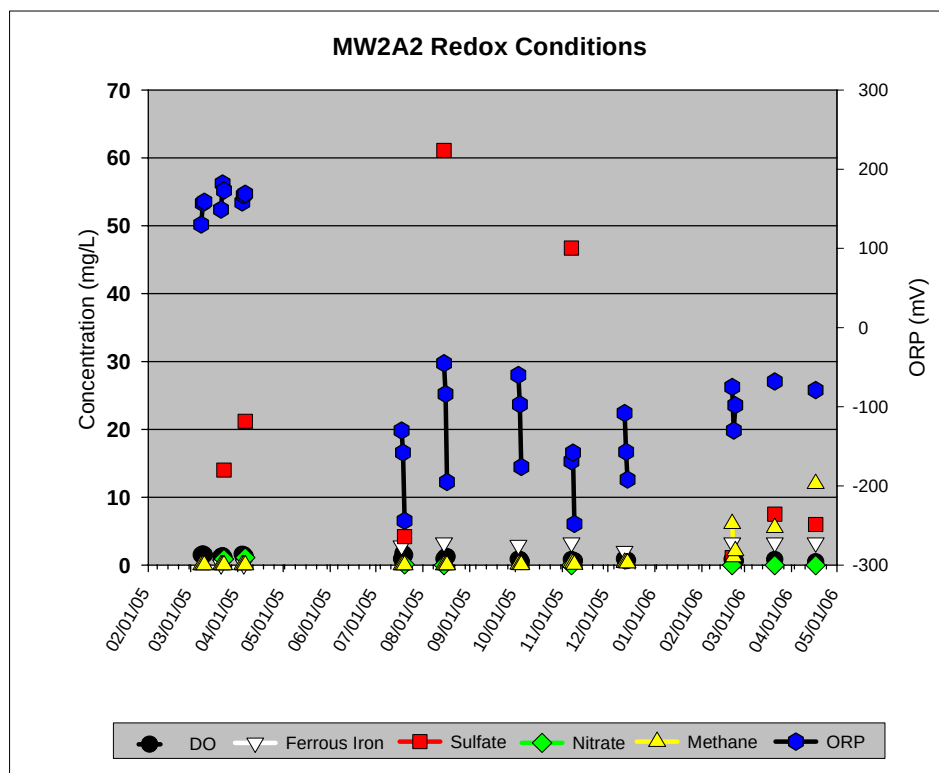
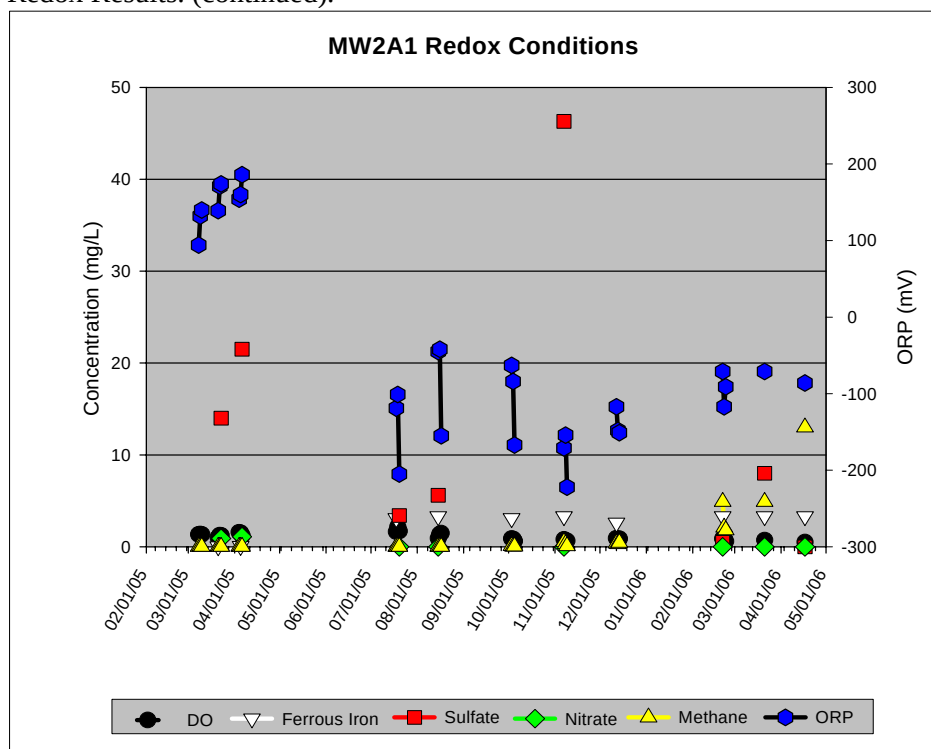
Redox Results. (continued).



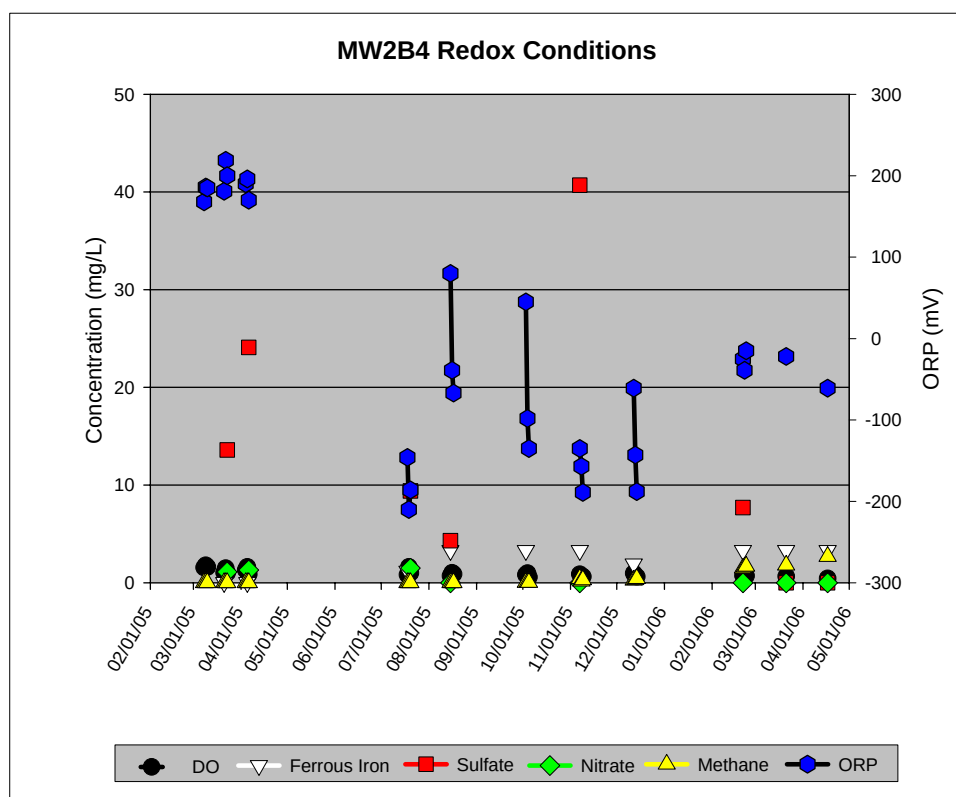
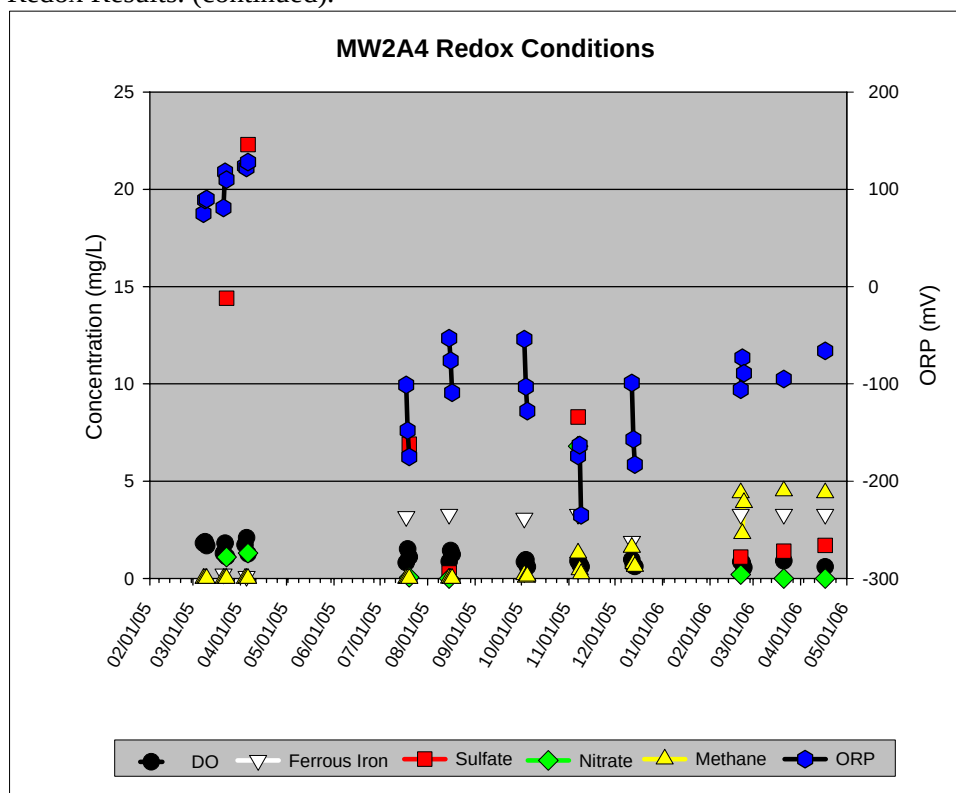
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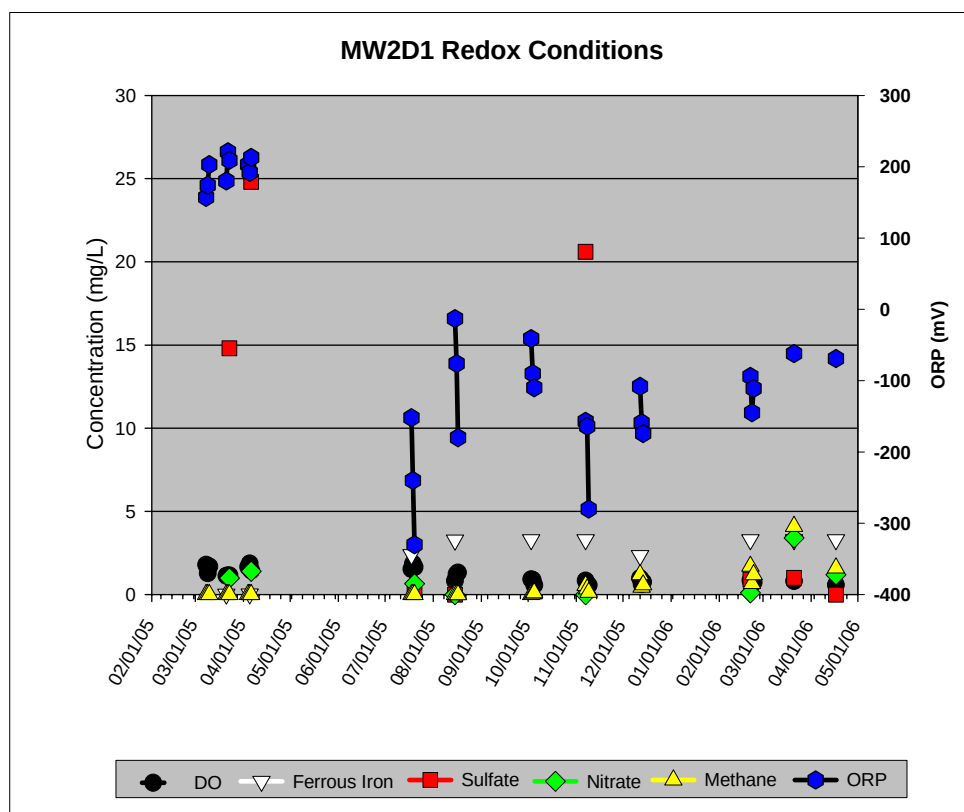
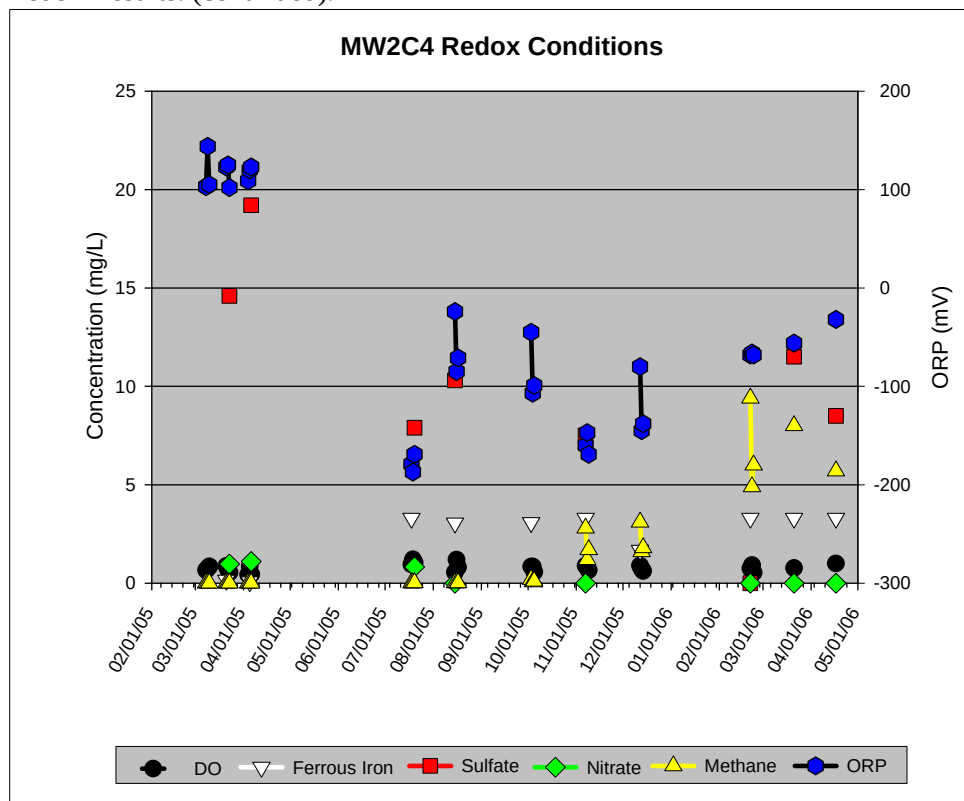
Redox Results. (continued).



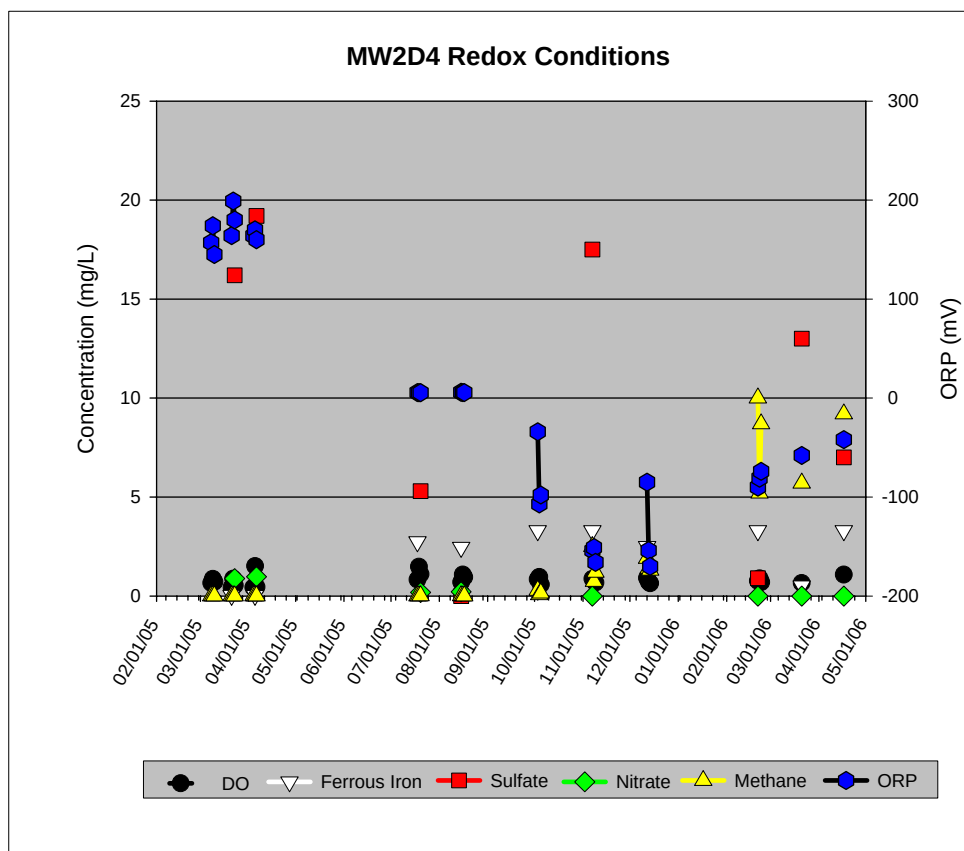
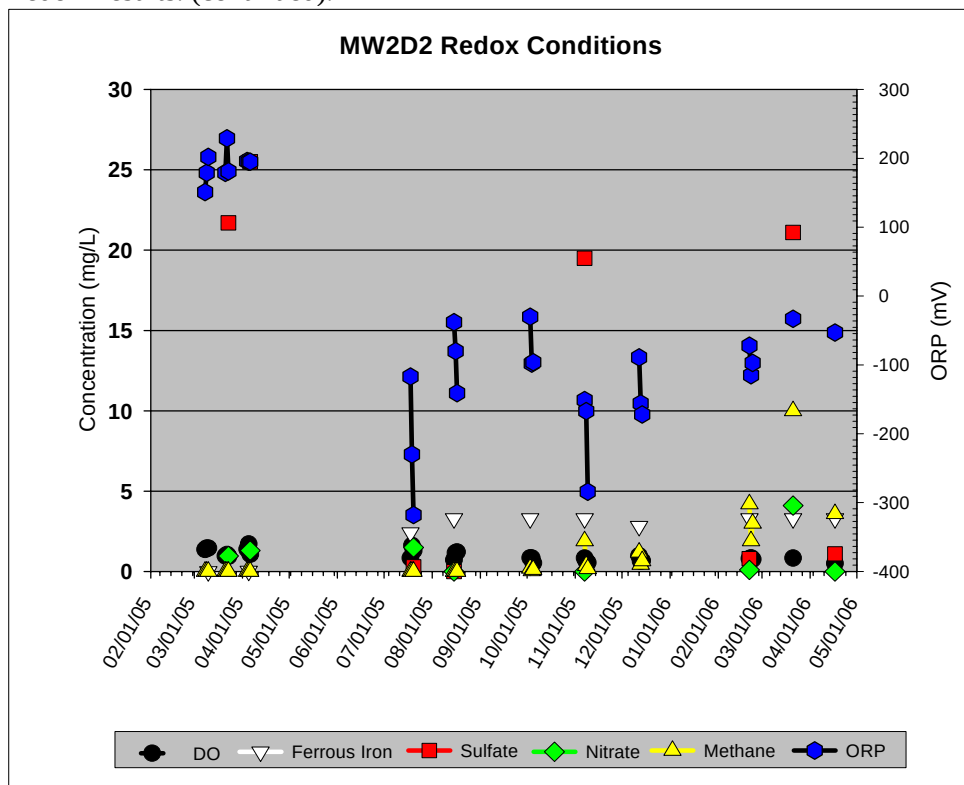
Redox Results. (continued).



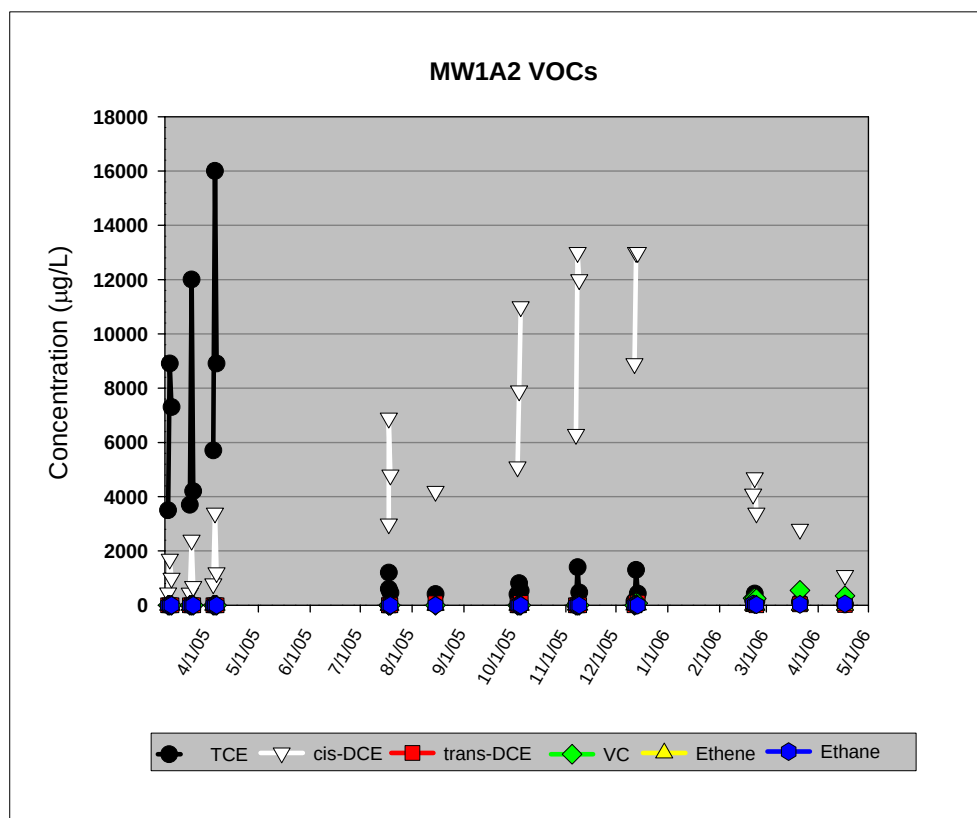
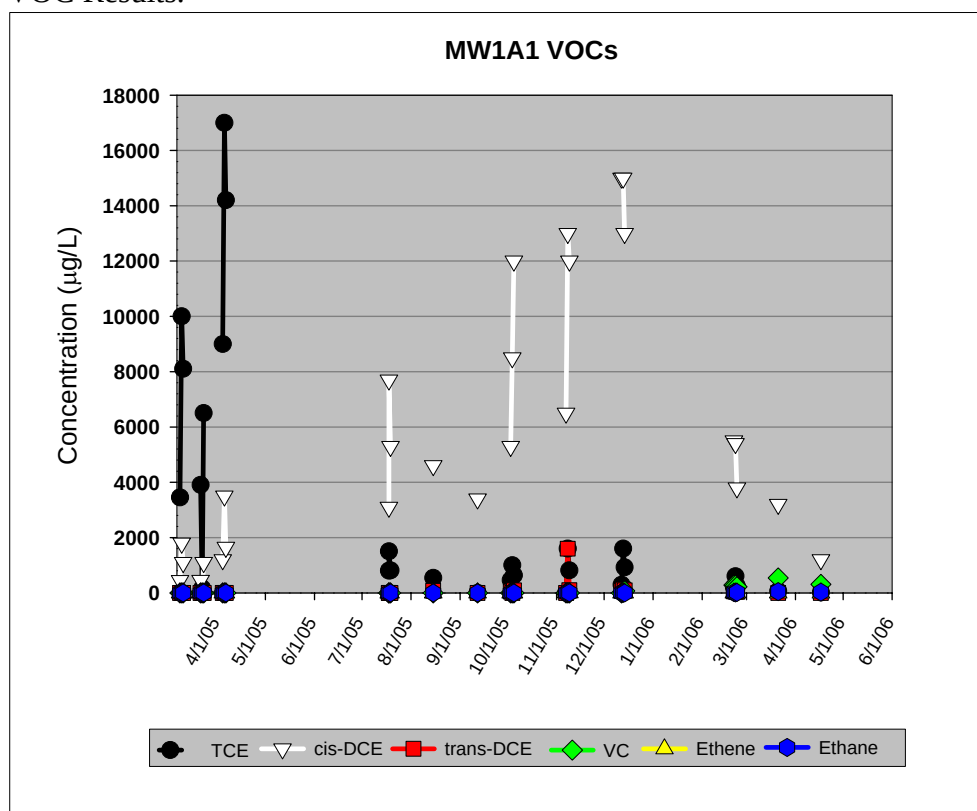
Redox Results. (continued).



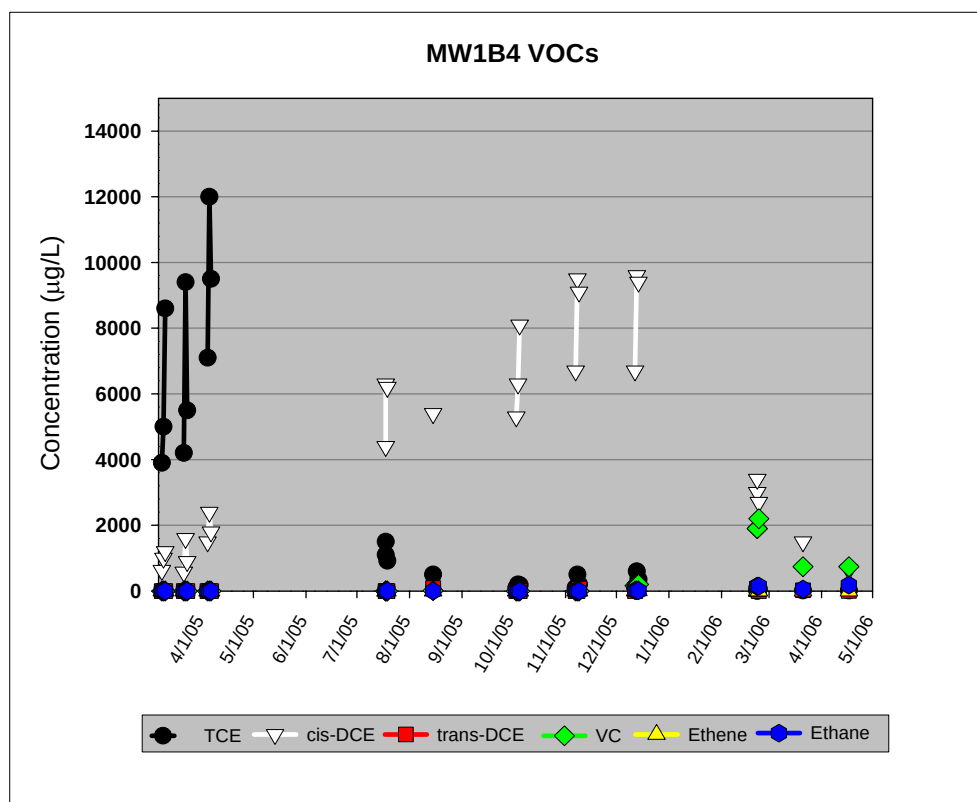
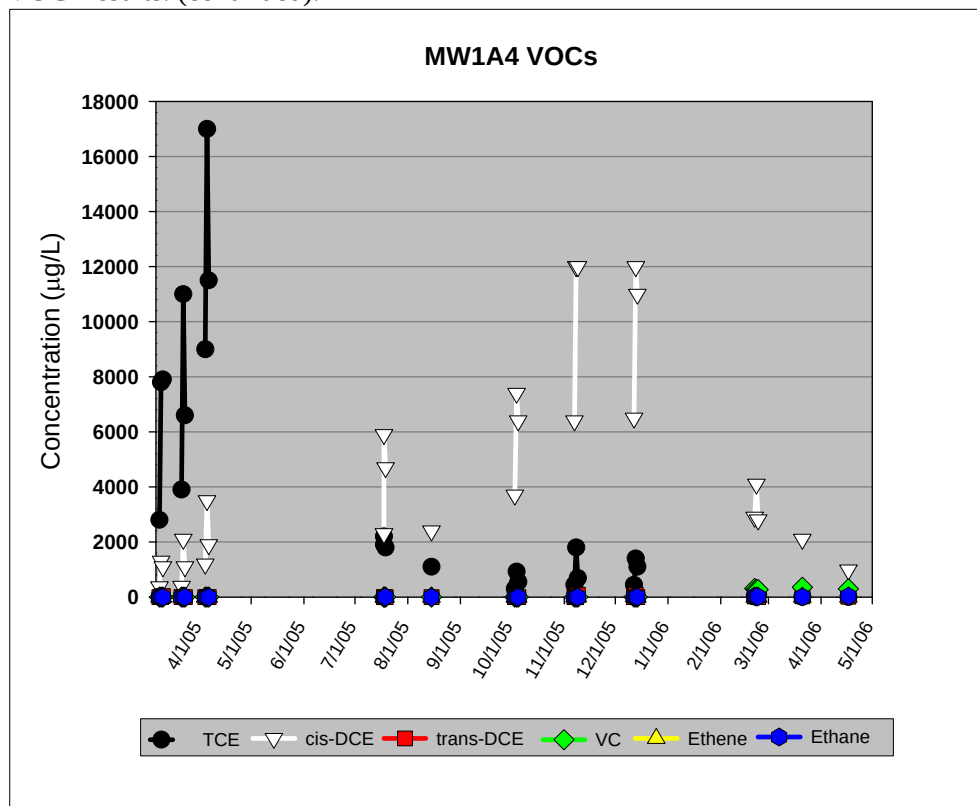
Redox Results. (continued).



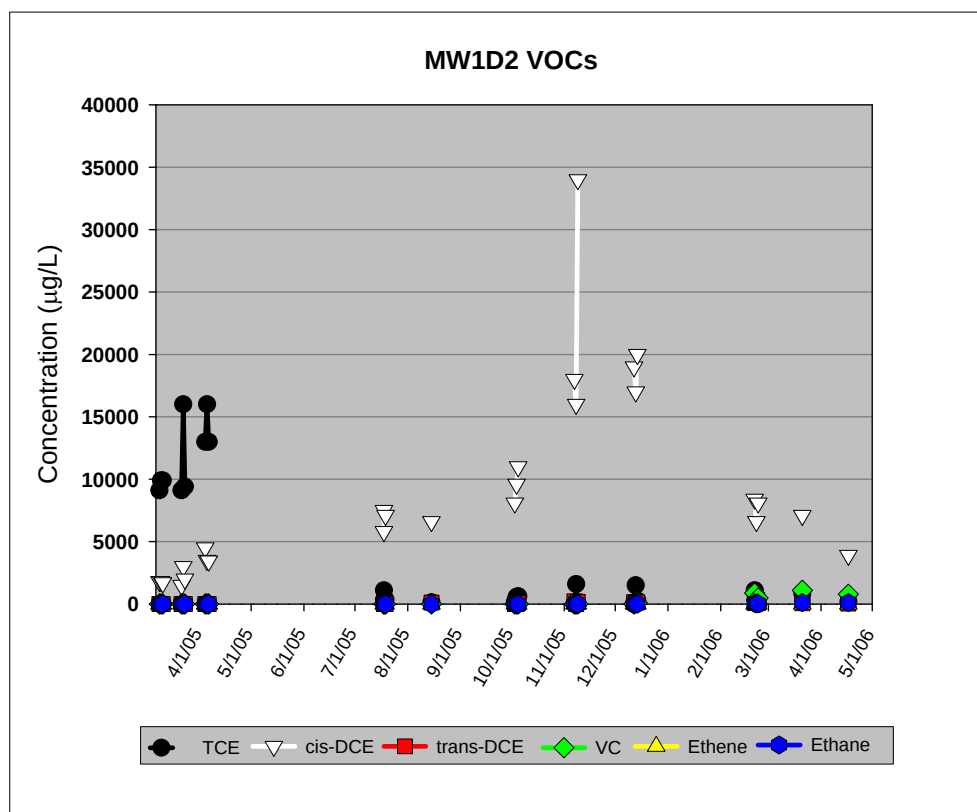
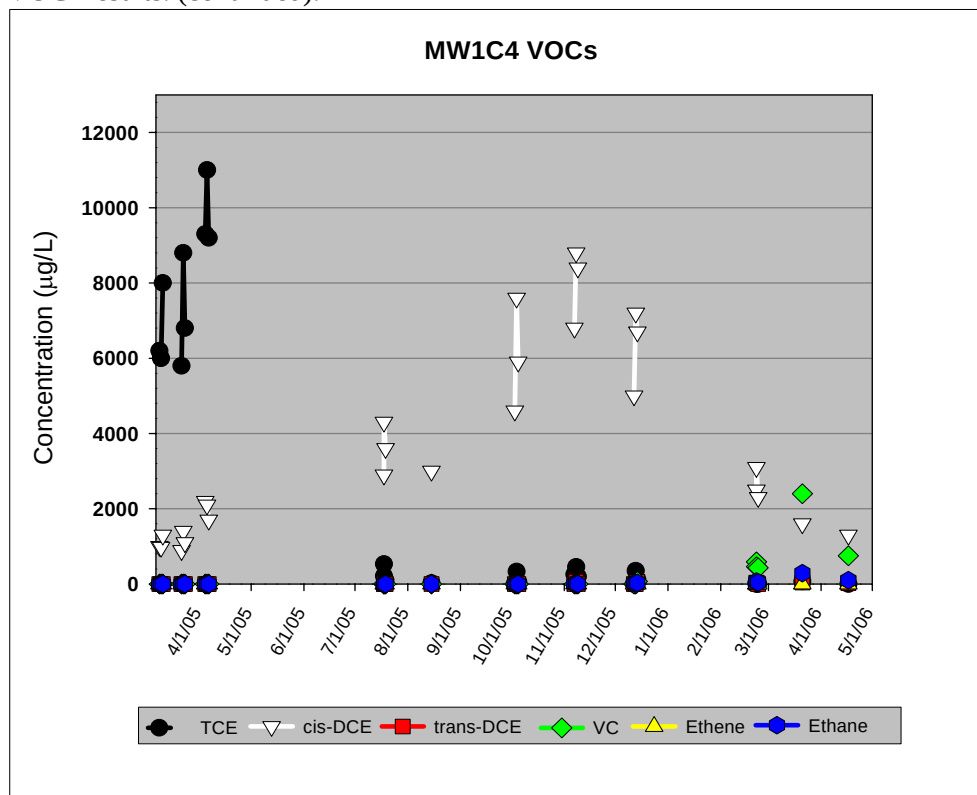
VOC Results.



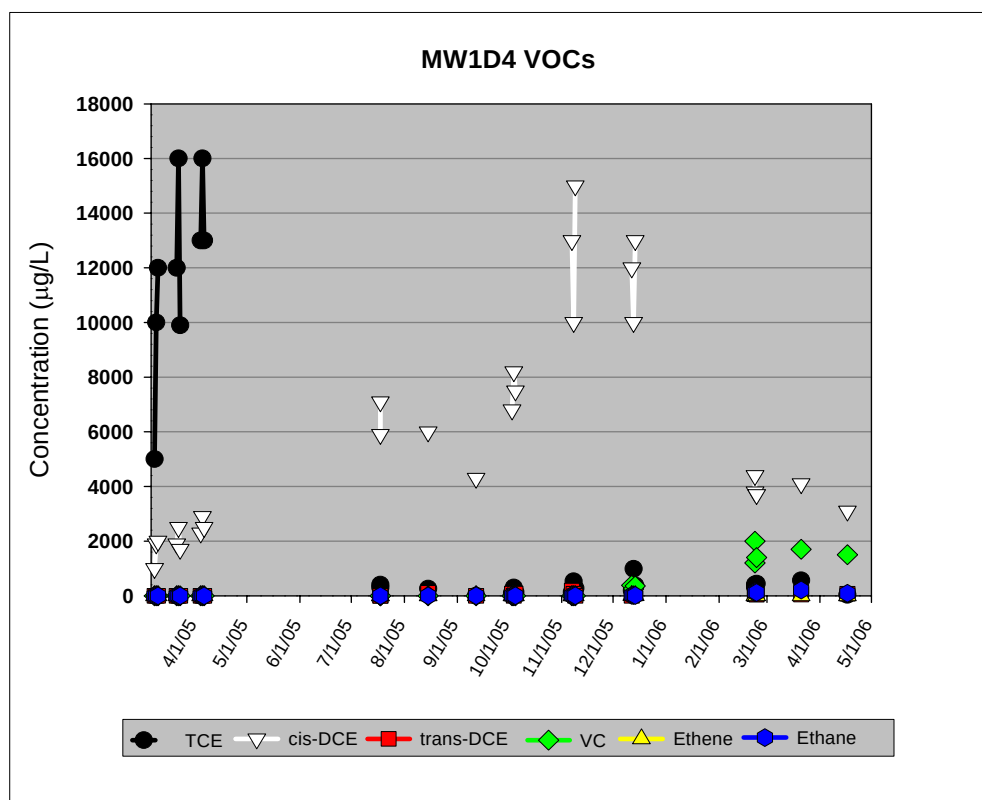
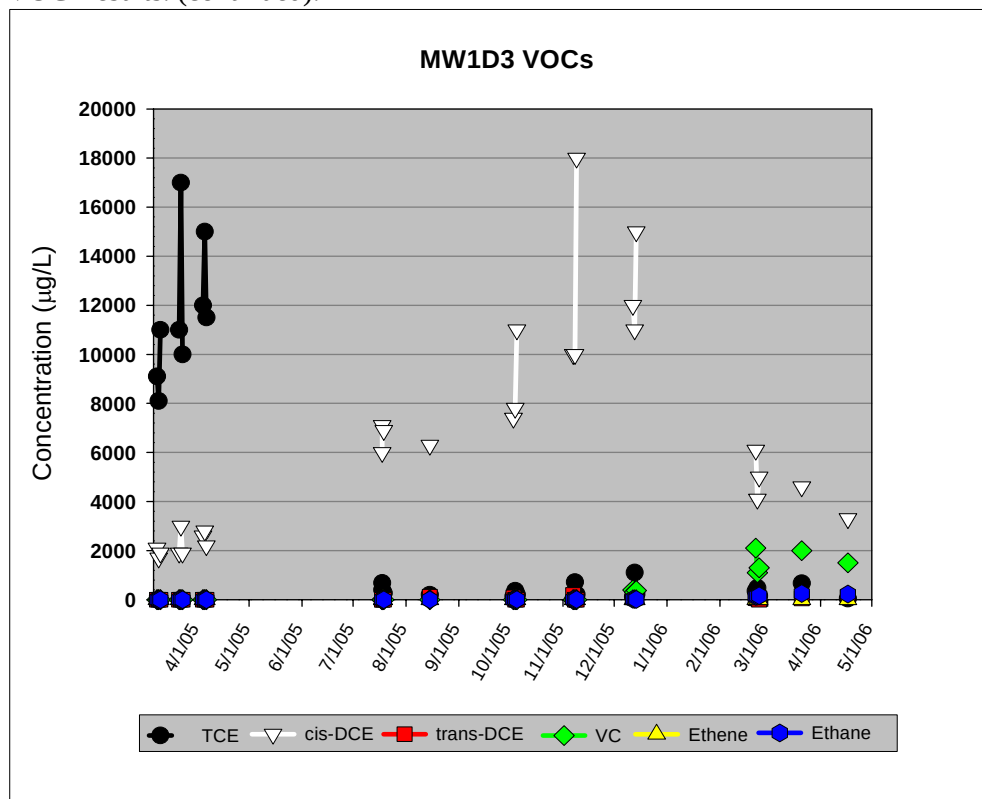
VOC Results. (continued).



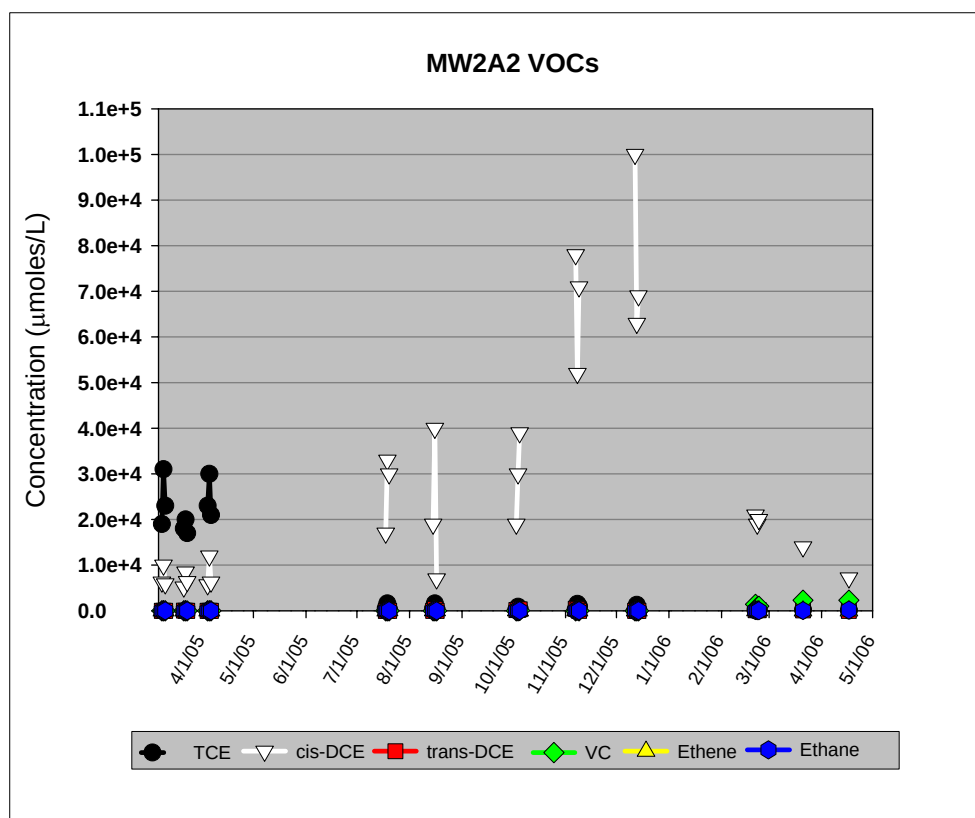
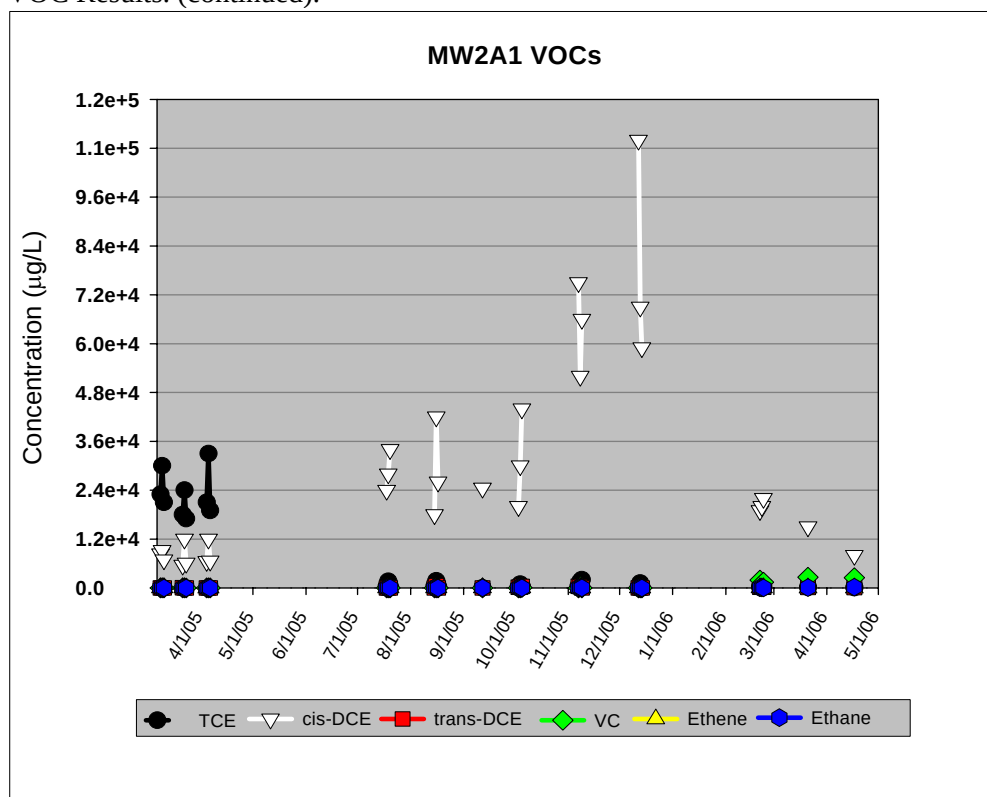
VOC Results. (continued).



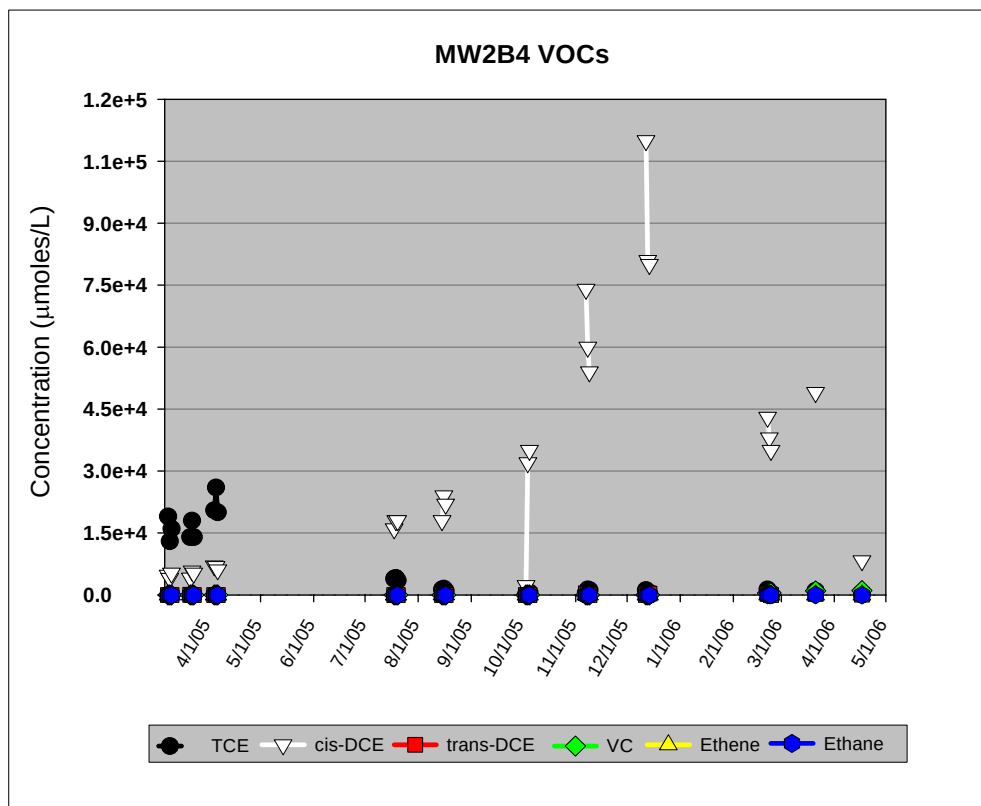
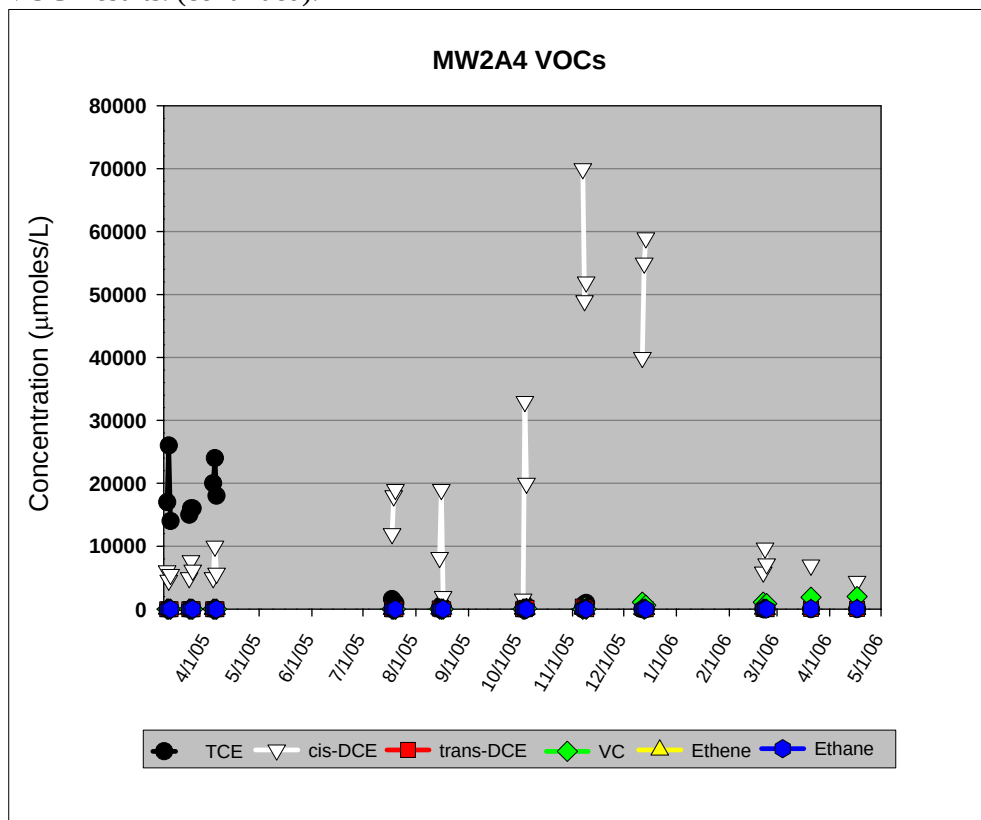
VOC Results. (continued).



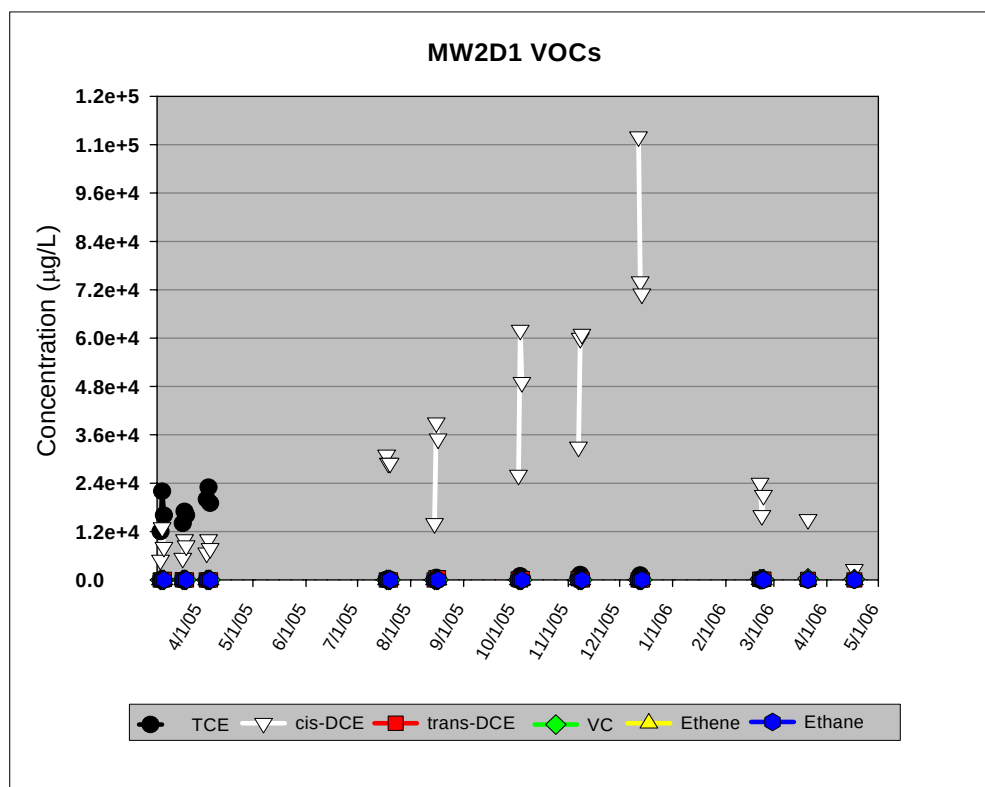
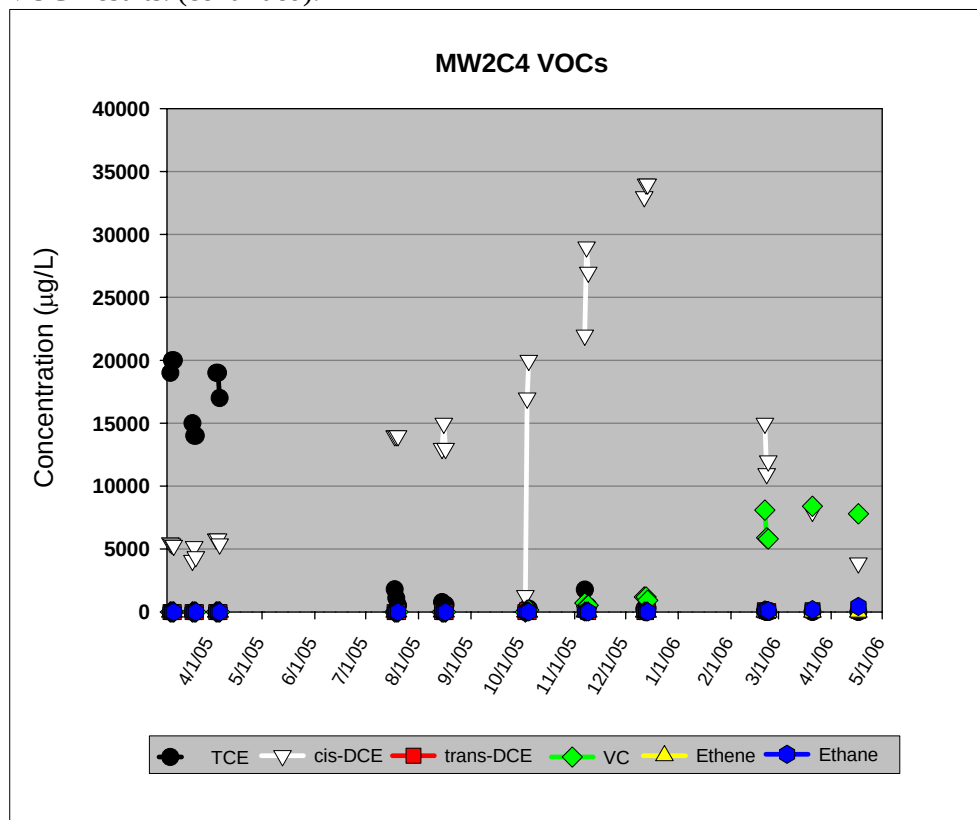
VOC Results. (continued).



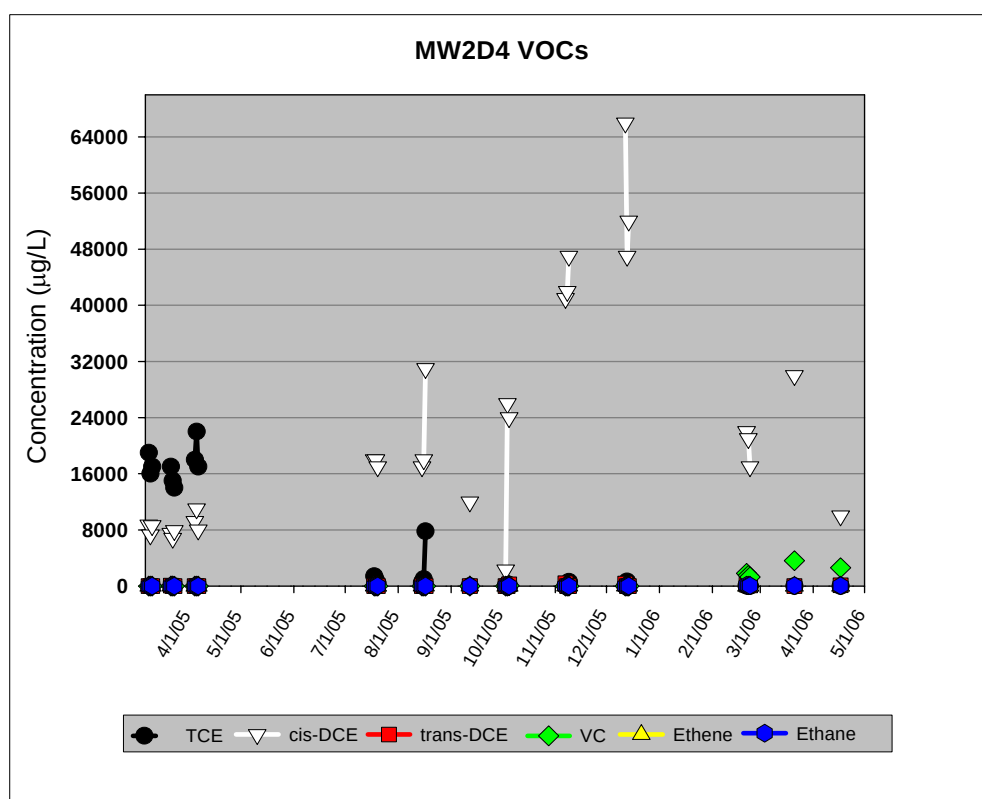
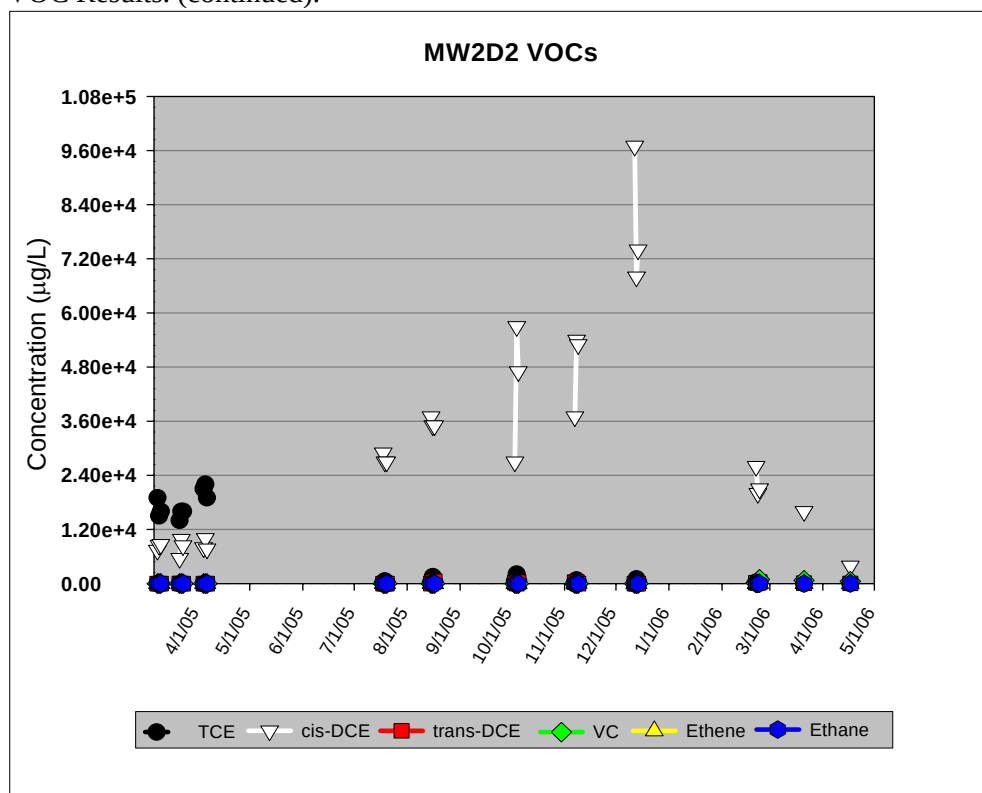
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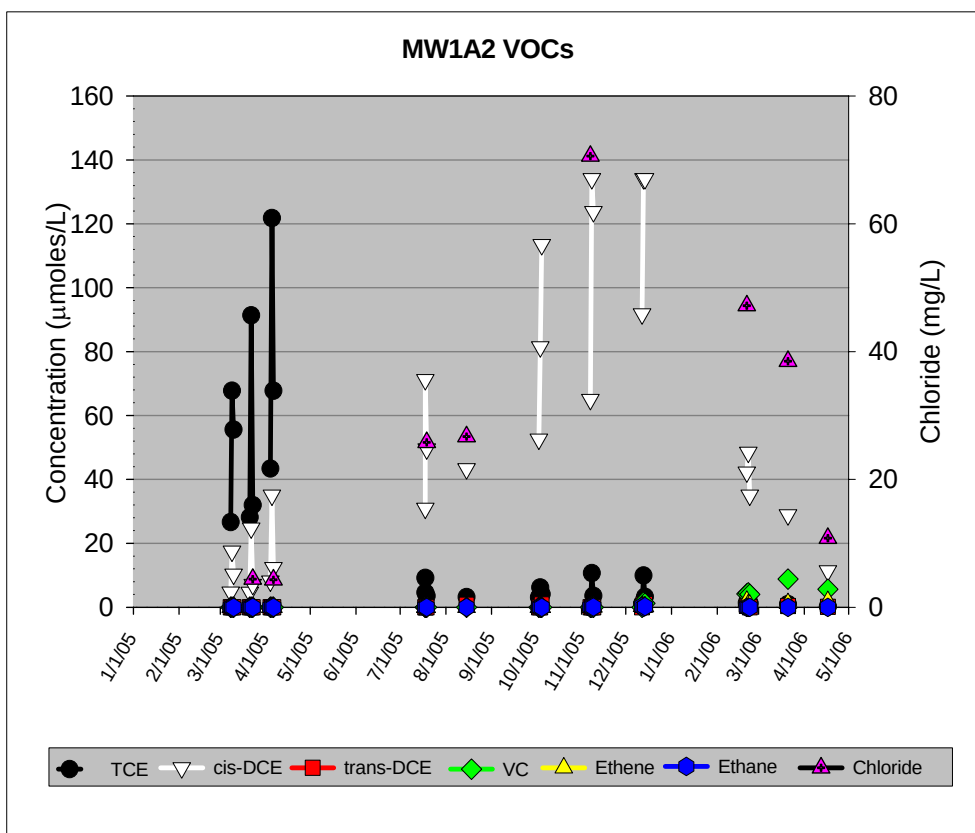
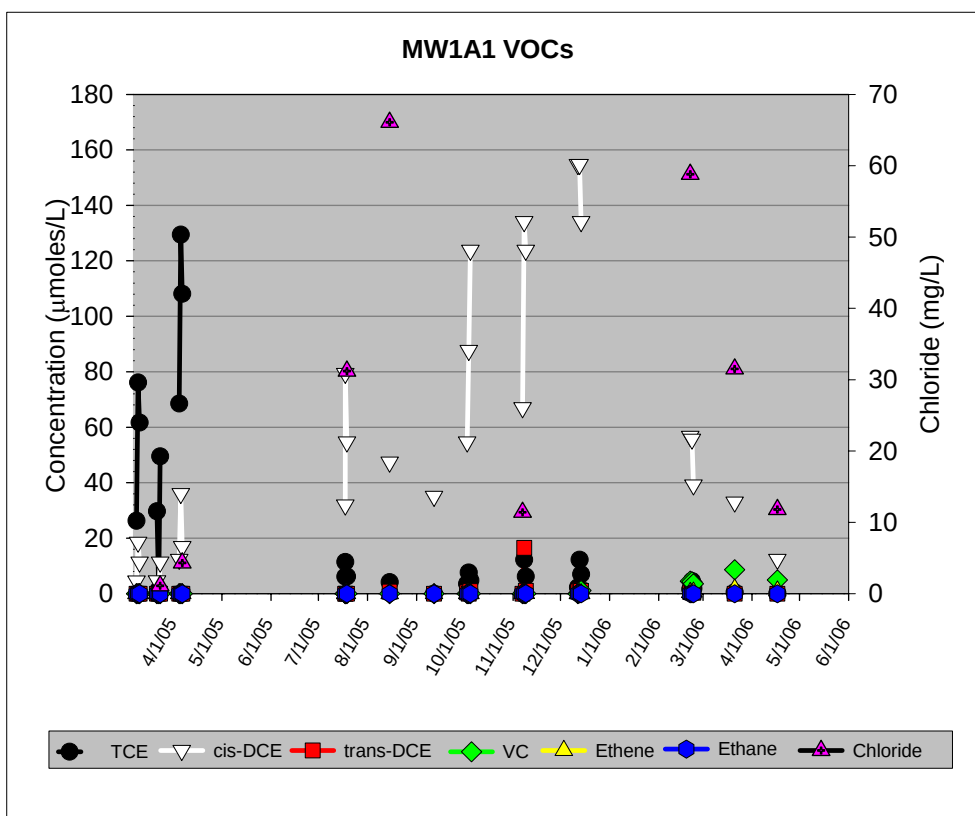
VOC Results. (continued).



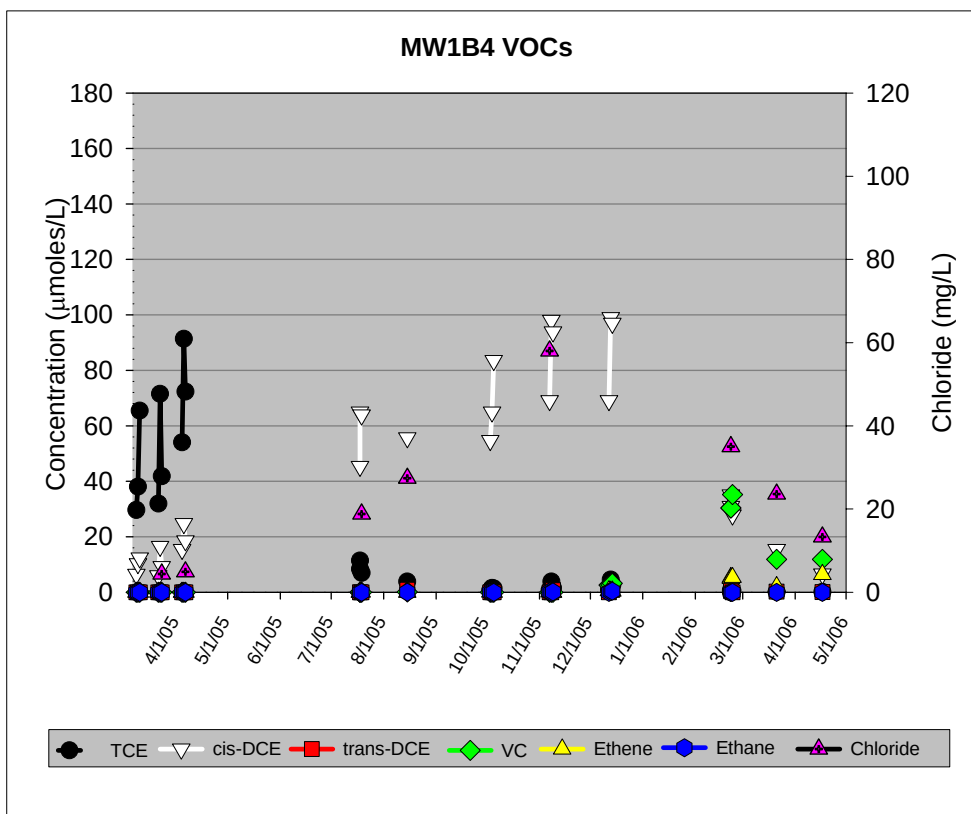
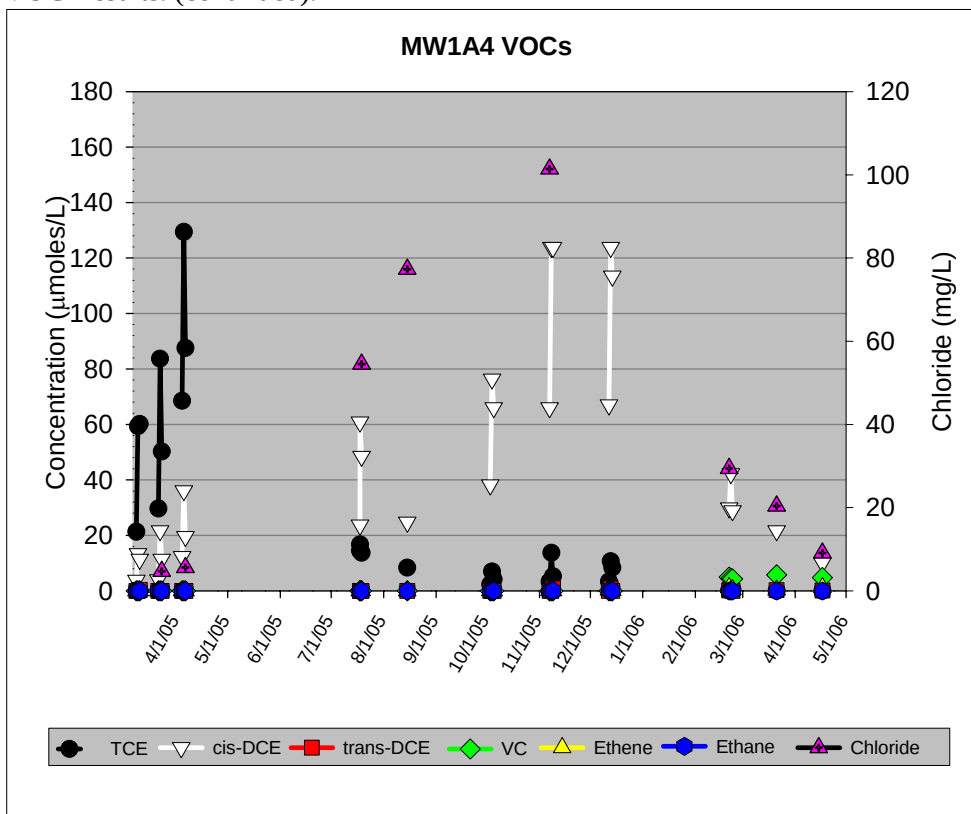
VOC Results. (continued).



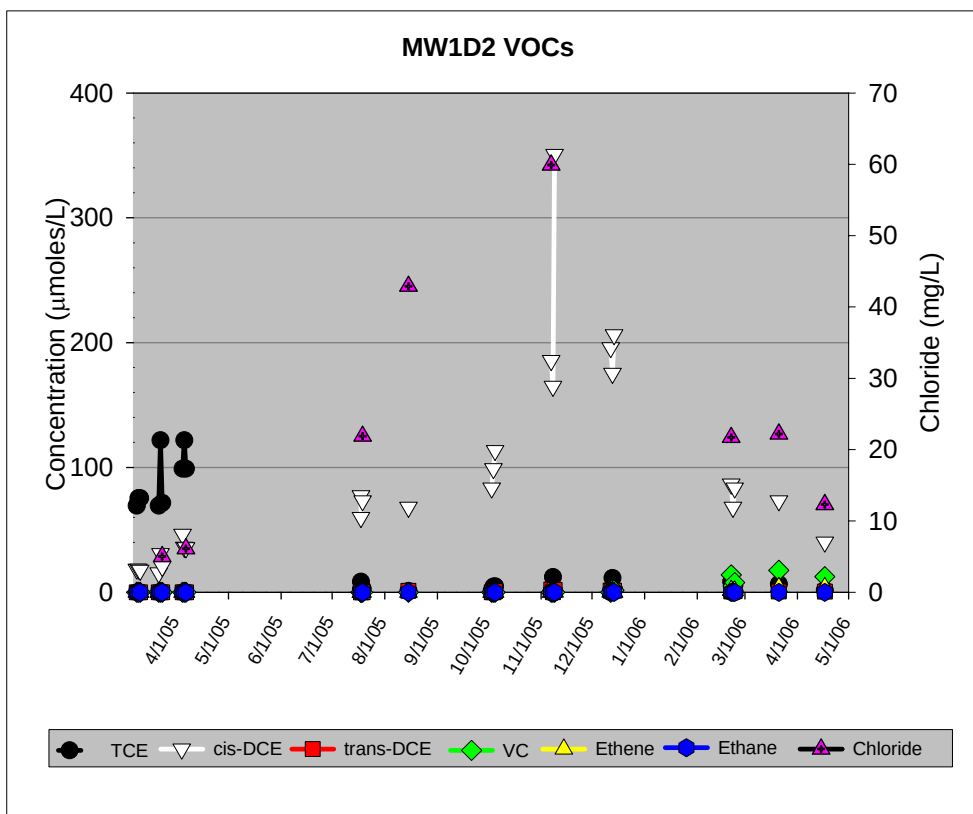
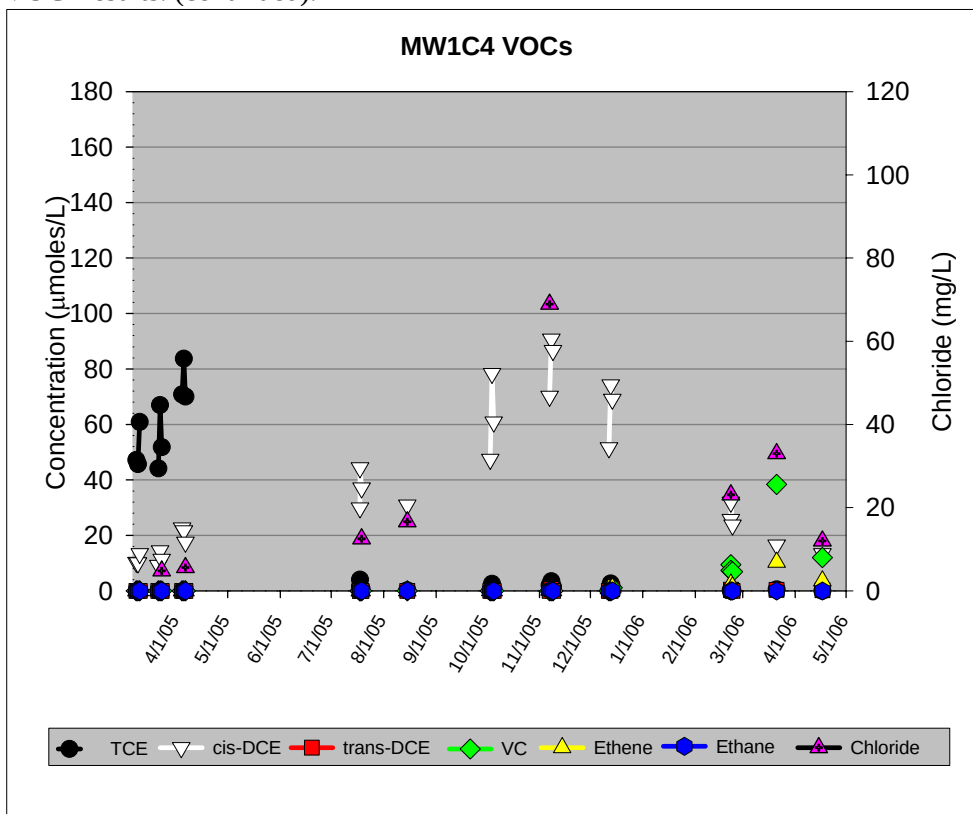
VOC Results. (continued).



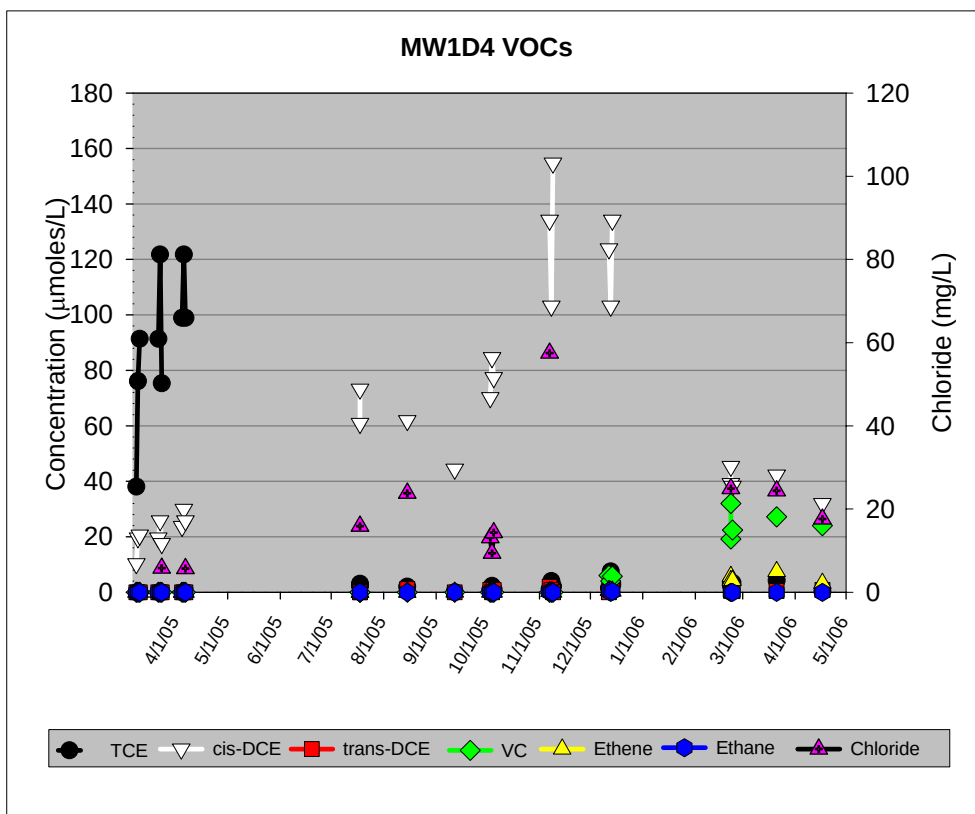
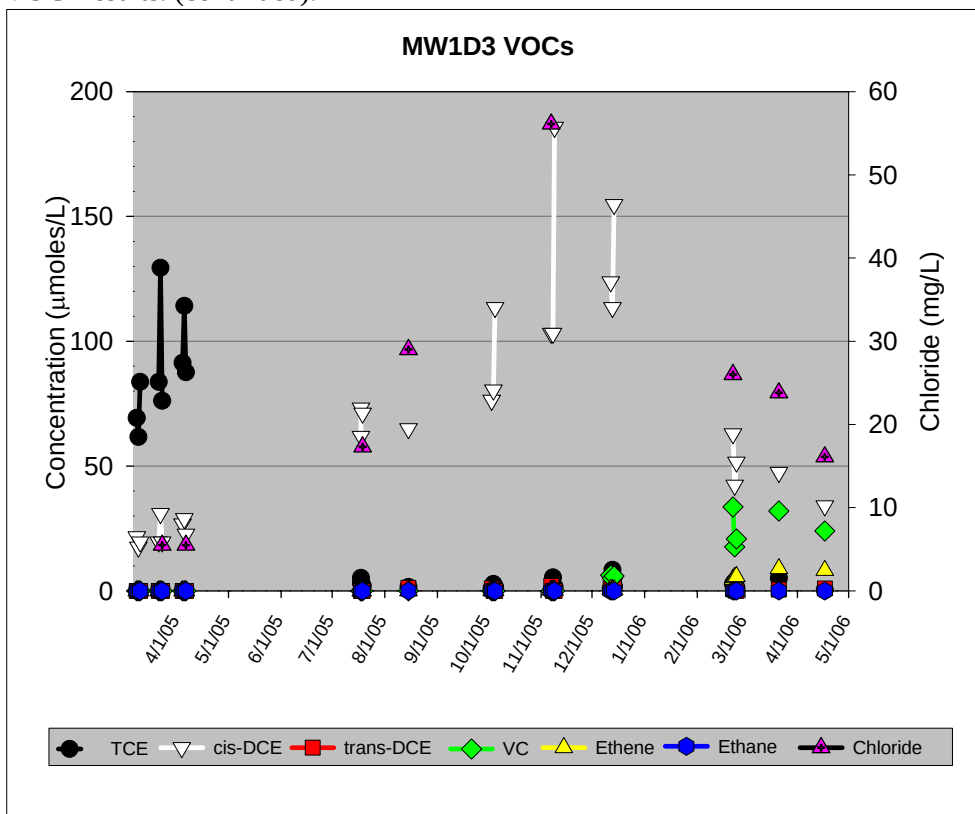
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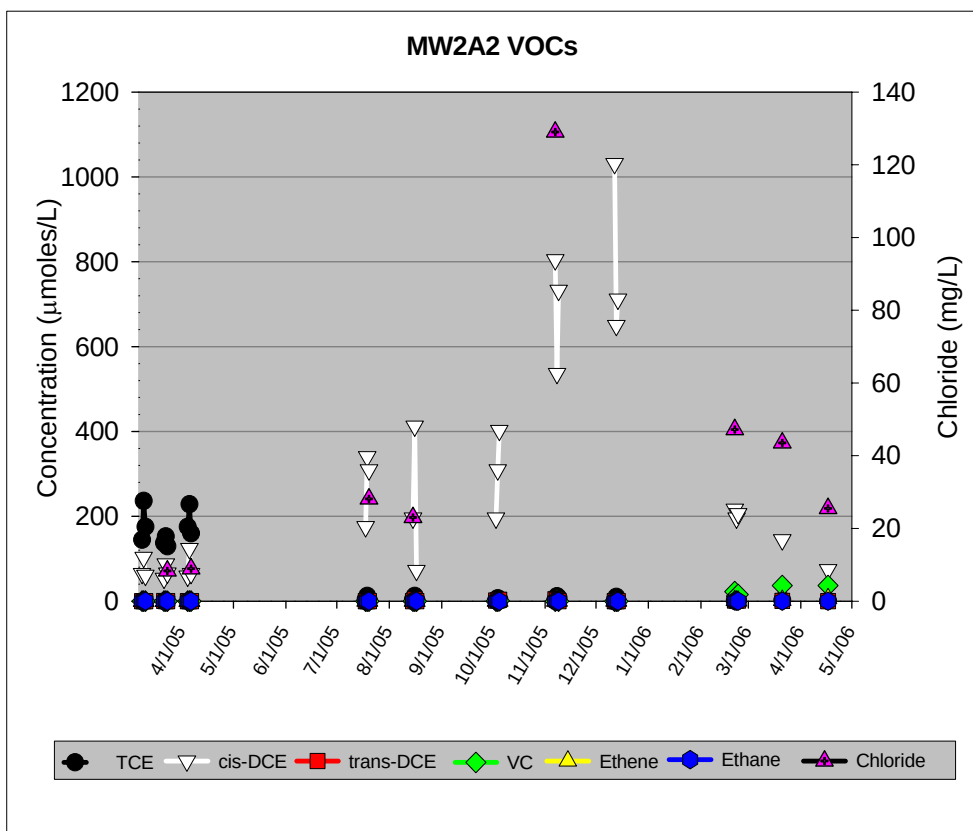
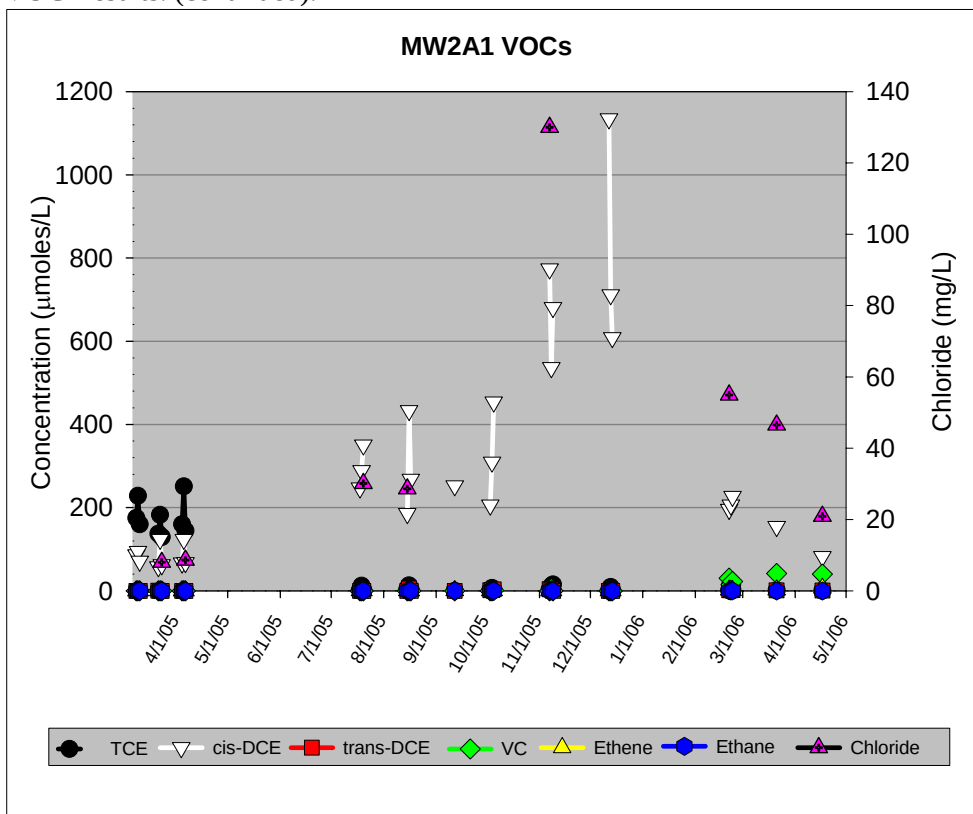
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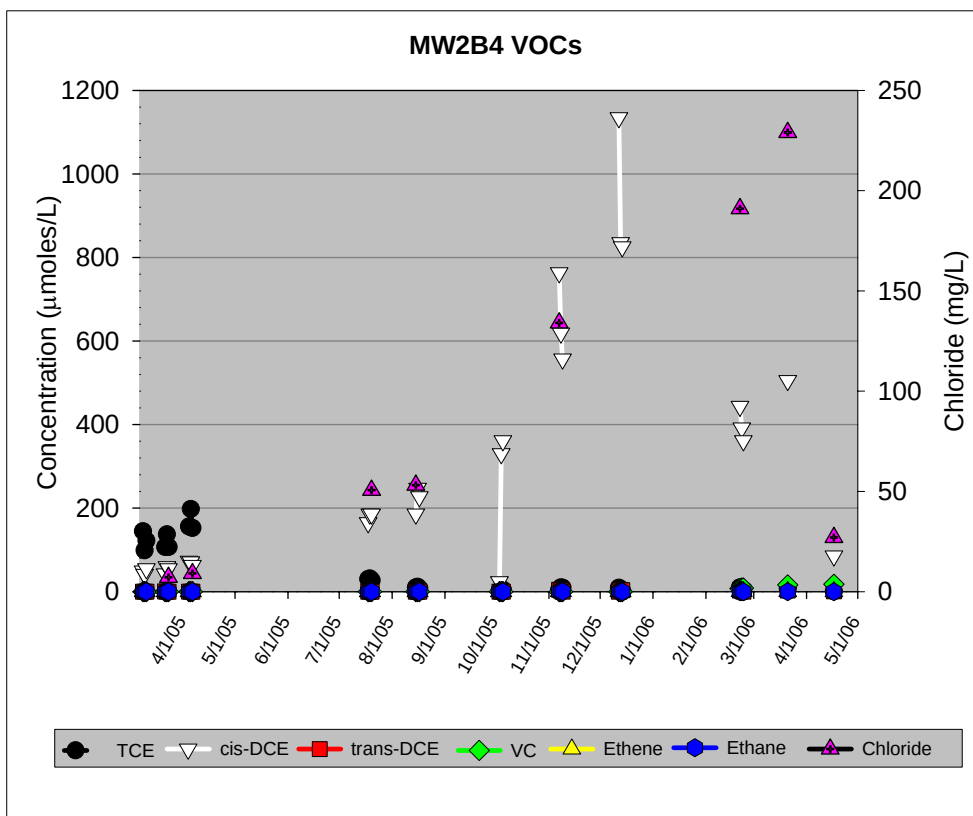
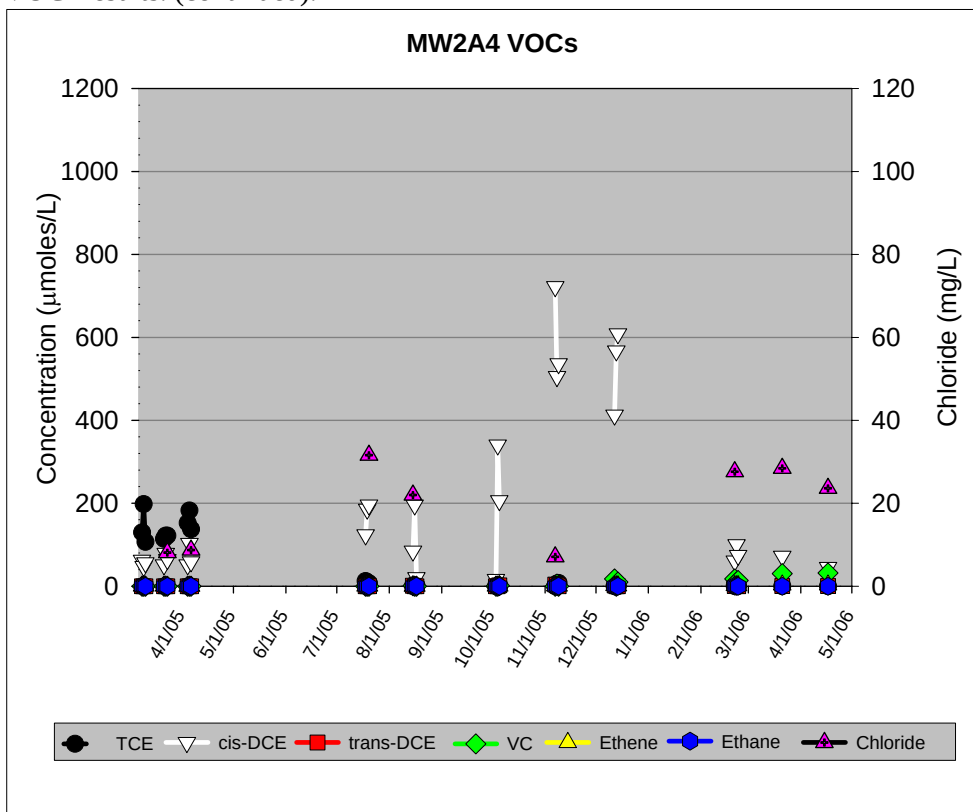
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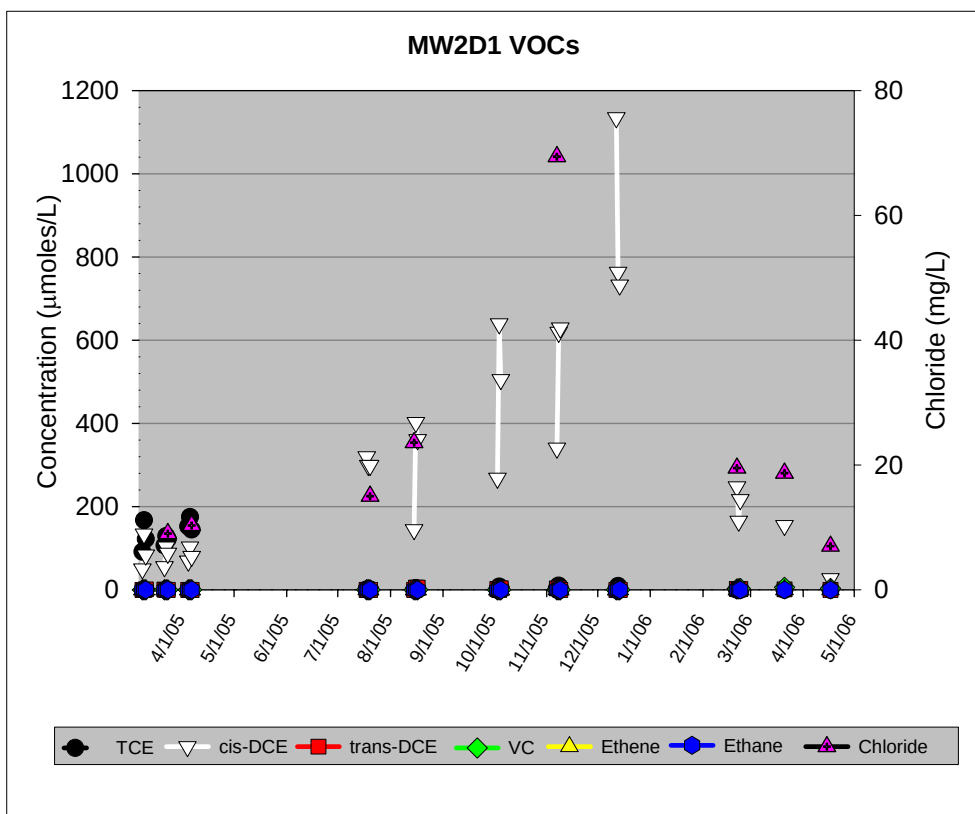
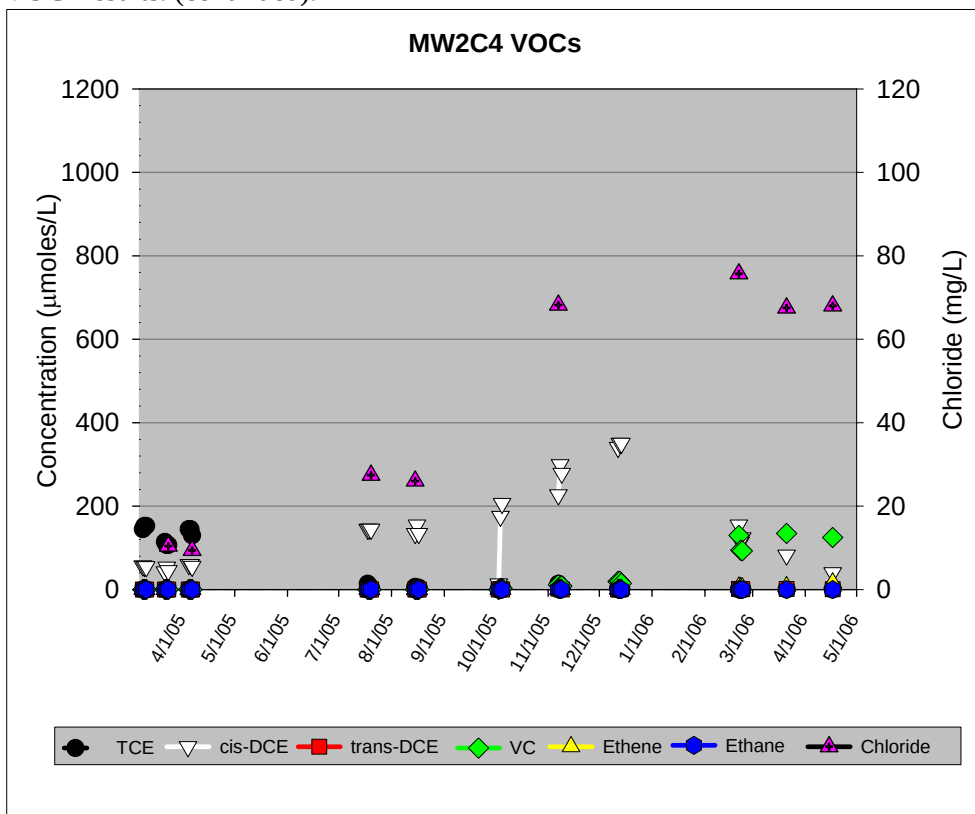
VOC Results. (continued).



VOC Results. (continued).



VOC Results. (continued).



VOC Results. (continued).

